The Future of Drylands

International Scientific Conference on
Desertification and Drylands Research
Tunis, Tunisia, 19-21 June 2006

Cathy Lee • Thomas Schaaf
Editors

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Preface

The year 2006 was declared "International Year of Deserts and Desertification" by the United Nations General Assembly. Concerned by the exacerbation of desertification and its far-reaching implications for the implementation of the Millennium Development Goals, in particular on poverty eradication, the year aimed at raising public awareness as well as protecting indigenous and local communities and the traditional knowledge of those affected by this phenomenon. The Year also aimed to protect the unique biological diversity of deserts. Home to an estimated two billion people and widespread poverty, the world's drylands also host a surprising wealth of biodiversity – many of the plant, animal and fungal species are remarkable in their adaptation to the harsh climatic conditions prevailing in the drylands. Nomadic and pastoral groups have developed a wealth of indigenous knowledge acquired over centuries in managing limited water resources sustainably, which is seen today as an example of an adaptive strategy that combines both scientific research and tested traditional practices. The International Year was therefore also a celebration of this dynamic and harmonious existence, which is at the heart of sustainable development.

Arid zones were at the centre of UNESCO's earliest efforts at international scientific cooperation in the study of natural resources. UNESCO's first international research programme dealing with arid zones was launched back in 1951. It was continued until 1964, after being raised to the status of a Major Project of the Organization in 1957 as a direct outcome of the International Arid Lands Meetings in New Mexico (USA). This Major Project was a pioneering effort in many respects. Not the least of merits was that it blazed a trail in its interdisciplinary approach to the study of natural resources and its holistic approach to the problems of arid and semi-arid zones. It was then followed by a series of other intergovernmental programmes having significant components relating to drylands, such as the UNESCO Programme on Man and the Biosphere (MAB), and the UNESCO International Hydrological Programme (IHP).

To commemorate 50 years of drylands research in the UN System, UNESCO organised one of the leading events of the International Year – the international scientific conference on "The Future of Drylands" held from 19 to 21 June 2006 in Tunis, Tunisia. The conference mobilised twenty international partners such as UN specialised agencies and bodies, international organizations, governmental scientific and environmental agencies, agricultural research institutes, and private donor organizations as well as more than 400 participants from over 50 countries. One of the main objectives of the conference was to take stock of the current scientific and indigenous knowledge of dryland ecosystems so as to effectively implement national action programmes of the United Nations Convention to Combat Desertification. It was also an occasion to identify important knowledge gaps for defining future drylands research priorities that will help attain the Millennium Development Goals. The conference papers assembled in this publication, prepared by leading dryland experts from all continents, provide an excellent overview of the current state of knowledge of dryland ecosystems and their sustainable management.

One of the major outcomes of the conference was the *Tunis Declaration* – a declaration on research priorities to promote sustainable development in drylands – that saw participants join forces to formulate an appeal to the scientific, policy and decision making community and civil society to place greater importance on the global issue of desertification and land degradation, using a holistic approach that leads to development that is sustainable as the principle tenet to combat desertification. Conference participants called upon governments and multilateral environmental agreements to use sound scientific knowledge to formulate and implement policies, laws, regulations and action programmes vis-à-vis environmental issues stressing integrated management of natural resources and conservation practices. Moreover, conference participants requested the scientific community to ensure its findings are made available and comprehensible to decision-makers and local dryland communities so that research can help shape sound policies and good governance as well as education on an interactive basis for sustainable dryland management and improved livelihoods.

I wish to thank all the conference partners that assisted in elaborating the main working themes of the conference. I warmly thank the donor agencies, the Sahara and Sahel Observatory and our colleagues of the UN System who generously contributed in ensuring the participation of the key people involved in drylands research and who work to serve their communities. I am particularly grateful to the Tunisian Government for its tremendous work in helping organize such a successful conference and for its warm hospitality. A special mention must go to the contributing authors who are not simply drylands experts but who have dedicated their lives to ensure a better world for those living in drylands. These proceedings are an important summation of their work and prove that their combined knowledge can provide hope for the *future of drylands*.

Professor Walter Erdelen
Assistant Director-General for Natural Sciences
UNESCO

Acknowledgements

Under the leadership of UNESCO, and with support from the many conference partners, the international scientific conference on *The Future of Drylands* was held in Tunis (Tunisia) from 19 to 21 June 2006 and was placed under the high auspices of H.E. Zine El Abidine Ben Ali, President of Tunisia. UNESCO wishes to thank the main national organizers of the conference, the Tunisian Ministry of Environment and Sustainable Development and The Sahara and Sahel Observatory (OSS) for their scientific input as well as their valuable logistic and technical support. UNESCO also wishes to acknowledge gratitude to the generous financial contributions made by the conference sponsors namely Oasis, a system-wide program of the Consultative Group on International Agricultural Research (CGIAR) jointly convened by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Flemish Government of Belgium, The Christensen Fund, and the Global Environment Facility (GEF).

UNESCO also wishes to warmly thank members of the Scientific Committee who contributed their time to review paper abstracts for selection as well as for their excellent chairing of the conference sessions, as well as members of the Conference Organizing Committee who contributed enormously to the conference's preparation and success and included representatives from the following organizations: Convention on the Conservation of Migratory Species of Wild Animals (CMS), Global Environment Facility (GEF), Food and Agriculture Organization of the United Nations (FAO), International Centre for Agricultural Research in the Dry Areas (ICARDA), The Sahara and Sahel Observatory (OSS), International Council for Science (ICSU), International Fund for Agricultural Development (IFAD), United Nations International Strategy for Disaster Reduction (UN-ISDR), United Nations Convention to Combat Desertification (UNCCD), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations University Institute for Water, Environment and Health (UNU-INWEH), United Nations University Institute for Environment and Human Security (UNU-EHS), World Meteorological Organization (WMO), the University of Arizona, as well as representatives of the Sustainable Management of Marginal Drylands (SUMAMAD) project.

Finally, UNESCO wishes to express special thanks to all those who presented their research findings and shared their experiences with conference participants during the conference sessions and poster sessions, and particularly to the contributing authors of this publication.

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Opening Session

Chapter 1
Ministry of the Environment and Sustainable Development, Republic of Tunisia

Nadhir Hamada

In the name of God, the clement and merciful,

Ladies and gentlemen,

I am happy to welcome our honourable hosts, world-renowned individuals, presidents of regional and international institutions, experts, researchers, and representatives of NGOs to this international conference. I also wish to express my warm thanks to the international organizations that have contributed to the preparation of this conference, particularly to UNESCO and to the scientific and technical committees for managing and organizing our work. It gives me great pride that this important meeting should take place on Tunisian soil, a country of solidarity, encounters and dialogue between civilizations.

Following on the resounding success of the World Summit on the Information Society, which took place in November 2005 in Tunisia, with the aim to reduce the digital divide between peoples, my country has today the honour to welcome the world's elite to discuss a subject of international importance, namely the appraisal of achievements in combating desertification over the last 50 years and the discussion of future work to be carried out on behalf of future generations, particularly those living in the drylands.

The organization of this conference, held under the high auspices of H. E. President Zine El Abidine Ben Ali, is an expression of the President's conviction of the importance and interest in the role of scientific research to find solutions capable of promoting the rise of drylands and strengthening of their economic and social development so as to ensure an honourable existence for the populations living there.

Ladies and gentlemen,

This conference is held within the framework of the International Year of Deserts and Desertification and provides unequivocal confirmation of the importance of scientific research and experience in the consolidation of efforts being carried out

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Minister of the Environment and Sustainable Development, Republic of Tunisia

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

within the framework of combating desertification, both at the national and the international level.

The choice that drawn from the study of the results obtained over 50 years of research, under the aegis of the United Nations, on dryland development reflects the importance of and the interest in the subject, just like the slogan 'Don't desert drylands' adopted for World Environment Day.

The fact that the international community dedicated 2006 to the question of deserts and desertification is a direct invitation to appreciate the strategic importance of dryland development and combating desertification. It is also an equally direct invitation to call for serious and effective action to contribute concretely to the treatment of desertification issues and dryland development.

Serious work is required to improve scientific cooperation for the benefit of important research programmes that aim to limit the impact of climate change and to combat desertification efficiently which affects more than two-thirds of the world's population and 40% of the total land surface, particularly in Africa. This situation has created almost insurmountable difficulties that reveal all the economic and social progress and developments agreed on by our countries.

In the same vein, I wish to emphasize the importance of agreeing to combine efforts by research centres, international institutes, regional specialists, and treatment observatories to mitigate the effects of desertification and climate change by developing scientific procedures of observation and to diminish the effects of drought in arid and semi-arid zones by monitoring indicators.

In addition, I seize this opportunity, in my role as President of the Sahara and Sahel Observatory, an important regional institution that serves African countries combating desertification, to invite you to continue to support such cooperative efforts and offer mutual assistance to this observatory, which is considered a unique regional instrument and a beacon of dissemination in its regional and international scope. I call for the adoption of an effective approach to deepen the understanding of the phenomenon of desertification and especially for the mobilization of greater scientific and financial means to mitigate the effects of drought and climate change.

Ladies and gentlemen,

In its approach to consolidate its action with respect to sustainable development, Tunisia has recognized that scientific research is an absolute priority; moreover, Tunisia commits 1% of its GDP in the domain of knowledge, with the ambition to increase this rate to 1.25% for 2009.

Scientific and technological research has undergone significant development thanks to the support of structures, programmes and objectives and the strengthening of research institutes in the field of natural resource conservation, such as the Institute of the Arid Regions in Medenine in southern Tunisia. This institute is today considered a point of regional dissemination in the domain of applied scientific research and practice for combating desertification. Furthermore, this scientific institute houses an international master's programme on natural dryland resource management as proof of its ambition to improve the evaluation of applied research with the objective of demonstrating exemplary investment in the traditional intellectual potential gleaned from dryland communities.

Ladies and gentlemen,

We firmly believe that the call by the President of the Republic, H. E. Zine El Abidine Ben Ali, to recycle debt, in part or in full, for use in environmental conservation and natural resource preservation projects stands at the forefront of scientific solutions and is even capable of resulting in an effective international effort to assure a better future for the drylands threatened by the scourge of desertification. On the occasion of this meeting, if I may, I renew this call on behalf of Tunisia.

Tunisia has already called for the creation of an international fund of solidarity for the eradication of causes of poverty in the drylands, where communities live on the socio-economic margins. Tunisia reiterates this invitation today to the international arena through regional and international institutions present among you to increase the level of solidarity with dryland inhabitants in order to alleviate their distress, the degradation of their immediate environment and the erosion of their natural resources. Let us not forget that in many regions these peoples have afforded to humanity the foundation of the world's civilizations.

Ladies and gentlemen,

We are convinced that this conference will increase awareness in the international community, as well as in international organizations, of the importance of making provisions for more efficient ways and international means to combat this scourge, particularly through better collaboration among experts, researchers and decision-makers.

The outcome of this conference will be an unquestionable contribution to scientific research that aims to limit soil erosion, the degradation of resources and the decrease of poverty and therefore to contribute to the realization, by 2015, of objectives set for the new millennium. Governments the world over have committed to work towards a better future and greater security and stability.

Finally, I would like to express once again my gratitude to the participants in this conference. May it yield results that ensure a dignified life to our peoples and the right to sustainable development for future generations.

May God guide you and bring you peace.

Chapter 2
The Arab Maghreb Union (AMU)

Habib Ben Yahia

Your Excellency, Mr. Nadhir Hamada, Minister of Environment and Sustainable Development, Tunisia,

Mr. Walter Erdelen, Assistant Director-General for Natural Sciences, UNESCO,

Mr. Hama Arba Diallo, Executive Secretary, UNCCD,

Ms. Claudia Cardinale, UNESCO Goodwill ambassador,

Distinguished delegates,

Ladies and gentlemen,

I am honoured to be among you today on the occasion of the international conference on the *Future of Drylands*, organized by UNESCO in collaboration with the Tunisian Government and its many institutional partners.

This conference is one of the many events taking place within the framework of the International Year of Deserts and Desertification and that brings together eminent scientists, field experts, practitioners and policy-makers. This event consolidates the accomplishments of the United Nations Convention to Combat Desertification and recognizes the scourge of desertification by the international community as a problem of worldwide proportions that affects all regions of the world.

To the Tunisian authorities, I wish to express my sincere gratitude for the warm welcome given to us since our arrival in Maghreb. I wish to express my warm thanks to the Sahara and Sahel Observatory, on behalf of the organizational committee, for their generous invitation to attend this important meeting.

Ladies and gentlemen,

The organization of this illustrious conference, under the high auspices of the President of Tunisia, His Excellency, Zine El Abidine Ben Ali, bears witness to the interest of His Excellency, and other Maghreb Heads of States, in environmental protection, and in particular in combatting desertification, and sustainable development at regional and international levels.

Secretary General, Arab Maghreb Union, Morocco

The choice of Tunisia as the venue for this meeting constitutes a sign of recognition of this country's tireless efforts to lead the fight against desertification, to mitigate the effects of drought through the use of effective traditional techniques that mobilize surface waters, and to promote dryland culture.

The numerous vestiges found throughout the Mahgreb drylands illustrate the success of the Mahgreb people throughout their history to adapt the arid environment to their own vital needs and to construct great civilizations despite climatic risks and natural disasters.

Chairman,

The requirements of the dryland communities, their legitimate aspirations for a better world and their responsibility towards present and future generations are at the heart of the debate on environmental protection in general. This will require a number of measures to meet the needs of the population and master the constraints, or the devastating errors, of unbridled development.

Sustainable development, particularly in the drylands, is a process. The many international instruments, notably Agenda 21 and the Convention on Climate Change, the Convention on Biological Diversity and the Convention to Combat Desertification, have underlined the need to plan development that is progressive and efficient and that does not burden the environment.

Chairman,

Given the similarities of environmental problems in the countries of the AMU, the sub-region I represent, which is heavily affected by the devastating effects of drought, the AMU states felt the pressing need to have an institutional instrument that supports a united action for environmental protection and combat against desertification.

Their desire for such an instrument was realized at the 5th Session of the Council of the AMU Presidency, in Nouakchott, November 1992, by the adoption of the *Magreban Charter for Environment Protection and Sustainable Development*, which gives priority to the promotion of drylands. The Member States are thus engaged to:

- Establish efficient policies of land rehabilitation, exploitation and use so as to ensure soil conservation and their specificities, and respond to the requirements of food security.
- Work towards defeating land degradation due to desertification.
- Reconcile development projects and environmental protection in the Saharan zones.
- Acknowledge a special interest in forests and reforestation and the preservation of the ecological balance.
- Consolidate regional projects to combat desertification in the AMU states.
- Ensure the protection of threatened water resources from the dangers of overexploitation in all its forms.
- Preserve non-renewable aquifers by ensuring the rational use of these reservoirs within the framework of collaboration between the AMU states.

This institutional instrument has just been strengthened by another charter that treats the problems of desertification individually within a vision that complements other themes, such as biodiversity and climate change.

With a view to implementing the provisions outlined in these charters, the Secretary General of the AMU has intensified contacts with its sub-regional and international partners. He has engaged in all activities concerned with the environment and sustainable development and in the drylands in particular while remaining convinced that success in this field requires intense and synergetic international cooperation that ultimately works so that humanity can thrive.

Chairman,

Today the AMU is highly determined to honour our commitments vis-à-vis the conventions and international agreements so as to instill an atmosphere of trust with our partners and to alleviate eventual problems with others. The AMU and its Member States are equally resolute in their will to lead the reforms in development strategies that integrate environmental concerns while conforming with national requirements, international commitments and, increasingly, a better sense of citizenship and philanthropy with regard to our future generations.

However, the AMU is fully conscious that combating desertification cannot be limited to intermittent actions must occur over time and with perseverance. The synergy of efforts and the mobilization of human, technological and financial means are as such major challenges that the majority of countries affected cannot face the challenge alone and obtain sustainable results.

It is in this context that international solidarity for the effective support of countries and regional organizations must be expressed. It must be firmly translated into a commitment that is as visible as it is efficient. Industrialized countries – due to their human, technological and financial means – are especially solicited in this respect to support national and sub-regional efforts.

Without a doubt, this will consolidate the momentum of international solidarity in this domain. Only by doing so will we be able to face the major threats that weigh on the future of the drylands, and even humanity itself.

Thank you for your attention.

Chapter 3
United Nations Educational, Scientific and Cultural Organization (UNESCO)

Walter Erdelen

Your Excellencies,

Honourable participants,

Ladies and gentlemen,

On behalf of Mr. Koïchiro Matsuura, Director-General of UNESCO, it is my great pleasure to welcome you all to this international scientific conference.

Drylands are often considered fragile ecosystems, yet they have a remarkable resilience to stress. They are home to unique and well-adapted plant and animal species that we need to conserve. Some of the world's greatest cultures and belief systems have originated in drylands. On the other hand, desertification and land degradation in drylands often result in poverty and cause environmental refugees to abandon their homes. These problems can only be addressed in a holistic manner, based on sound scientific research and findings. Solutions to the problems of dryland degradation need to be communicated as widely as possible through education at all levels.

These are many reasons why UNESCO – within its mandate of science, education, culture and communication – took the intiative to organize this conference. And we are glad that so many partners have responded to our call. UNESCO considers this conference as its main contribution to the observance of the International Year of Deserts and Desertification in 2006. We have deliberately chosen the title 'The Future of Drylands' as we feel it is time to redefine our priorities for science, education and governance in the drylands based on 50 years of scientific research in arid and semi-arid zones.

In fact UNESCO has one of the longest traditions, within the UN system, of addressing dryland problems from an interdisciplinary, scientific point of view. In 1955, the 'International Arid Land Meetings' were held in Socorro, New Mexico (USA). They were organized by the American Association for the Advancement of Science (AAAS), sponsored by UNESCO and supported by the Rockefeller Foundation. One important output of the International Arid Land Meetings was a book entitled *The Future of Drylands*, edited by Gilbert F. White and published in

Assistant Director-General for Natural Sciences, UNESCO

1956 by AAAS. In your conference folder, you will find a background paper commissioned by UNESCO and prepared by Professor Charles Hutchinson that compares the state of knowledge of drylands back in the 1950s with the state of knowledge today. UNESCO will launch Professor Hutchinson's book in the course of 2007.

Arid zones were at the centre of UNESCO's earliest efforts at international scientific cooperation in the study of natural resources. UNESCO's first international study programme dealing with arid zones was launched in 1951. It was continued until 1964, after being raised to the status of a Major Project of the Organization in 1957 as a direct outcome of the International Arid Lands Meetings in New Mexico. This Major Project was a pioneer programme in many respects. One of its merits, and it had many, was that it blazed a trail in its interdisciplinary approach to the study of natural resources and its holistic approach to the problems of arid and semi-arid zones. It was then followed by a series of other intergovernmental programmes that had significant components relating to drylands, such as UNESCO's programme on Man and the Biosphere (MAB) and its International Hydrological Programme (IHP).

Back in the mid-1950s, there were many uncertainties about dryland research and land degradation due to the inadequate availability of reliable data and the temporal and spatial variability of dryland climates. Some of these uncertainties prevail to this day. However, since 1955, national and international efforts have helped to fill some of the knowledge gaps in dryland research, conservation and management. We hope that our conference today will help to review progress achieved in drylands research over the past 50 years. We also hope that it will determine the scientific path for future operations – such as the interdependence of dryland degradation and climate change – to promote sustainable development in countries affected by desertification.

UNESCO also considers this conference an important contribution to the UN Decade of Education for Sustainable Development (2005–2014) for which UNESCO has been designated the lead agency. As the world's drylands are among the most poverty-stricken regions of our planet, and in line with the UN-wide joint effort to achieve the Millennium Development Goals, we need to mobilize our collective efforts to ensure sustainable development in the world's marginal areas that are deserts.

I wish to thank all our partner organizations from the UN system, international and regional organizations, national governments and private foundations that have helped us to make this conference a reality. In particular, I wish to thank His Excellency, the President of Tunisia, for having placed this conference under his high auspices. Itself having extensive drylands, Tunisia testifies to the fact that scientific research, such as that carried out by the Institut des Régions arides, coupled with an 'enabling environment' provided by the Ministry of the Environment, can lead to sustainable development in the drylands.

Thank you.

Chapter 4
United Nations Convention to Combat Desertification (UNCCD)

Hama Arba Diallo

Your Excellency, Mr. Nadhir Hamada, Minister of the Environment and Sustainable Development,

Representatives of the diplomatic corps and regional and international institutions,

Ladies and gentlemen,

I would like to begin by expressing my sincere gratitude to the Tunisian authorities for their invitation, addressed to the Secretariat of the United Nations Convention to Combat Desertification (UNCCD), to take part in this important meeting on the future of drylands. My thanks also go to the organizers of the conference and in particular UNESCO and OSS, and for all the provisions taken to facilitate our work.

Chairman,
Ladies and gentlemen,

The Secretariat of the UNCCD is particularly pleased that this initiative comes from the scientific community concerned with issues of sustainable development in drylands and at the same time as events are taking place in all the world's regions to celebrate the International Year of Deserts and Desertification in different and varied ways.

Experts in dryland issues do not wish to remain on the margins of these meetings aimed at combating desertification because *they* are the privileged partners of the countries affected by desertification and the recurrent effects of drought.

I would like to seize the occasion of today's conference to reiterate to the experts present here our sincere gratitude for their excellent cooperation with the institutions that come under the Convention to Combat Desertification, notably the Committee on Science and Technology (CST) of the UNCCD.

Executive Secretary, United Nations Convention to Combat Desertification (UNCCD)

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

Chairman,
Ladies and gentlemen,

After almost ten years since the Convention to Combat Desertification came into force we expected the future of drylands to have been better dealt with by the actors and decision-makers concerned. However, recent national reports submitted by affected countries as well as the Millennium evaluation report have shown that many challenges to the maintenance of the productivity of ecosystems in the arid, semi-arid and sub-humid zones and to taking advantage of all the economic opportunities in these ecosystems, have yet to be addressed.

As we know, the valorization of arid zones occurs through integrated and sustainable land management. From this point of view, the scientific community has shown the importance of such an approach through numerous studies.

Chairman,

I must add that the majority of cases have shown that technical solutions exist and knowledge is available for the benefit of a great number of people. However, it is the transmission of research to its application in the field which is often slow.

As a consequence, scientists, but also political decision-makers who provide instruction, remain confronted with the obligation to produce results for the populations living in arid zones.

When we talk about the future of drylands, how can we not listen to requests from populations living in these zones? These communities would like to see accumulated scientific knowledge and the latest technologies materialize in their daily lives whose aim is to improve the productivity of their land, the only assured source of wealth.

Chairman,

Here I must recall that the United Nations Convention to Combat Desertification offers scientists and political leaders, through its subsidiary body, the CST, an excellent context in which to define and establish the axes of a scientific and technological policy that meets the expectations of countries affected by desertification.

The CST is an instrument established by the Parties to the Convention. It regroups a great number of scientists from diverse horizons at its core and as a consequence it has even risen to the challenge of interdisciplinarity and the development of effective partners. Its programme of work, agreed upon by 191 Parties to the Convention, is examined at regular intervals. It rests on priority issues that face countries affected by desertification. In other words, the CST also aims to bring to national decision-makers responses of a scientific and technological order in the context of the implementation of the programme of action to combat desertification.

Chairman,

Presently when many countries enter the implementation phase of their national action plans, the network of scientists in this domain, in my view, should more than ever make themselves available to these countries to provide any assistance they may require.

In conformity with the applicable provisions of the Convention, a network of institutions, bodies and agencies working on desertification is being set up under the supervision of the Conference of the Parties.

The effective establishment of this network has been delayed for financial reasons. However, we continue to work to identify the partners interested in supporting the functioning of this network, whose ultimate goal is to serve as a scientific reference on issues such as information-sharing, evaluation and follow-up, and research and technology transfer in the context of the implementation of the Convention.

I believe that all scientific institutions involved in combating desertification and land degradation play a distinguished role in this network. This network will effectively contribute to the work carried out by the group of experts and scientific correspondents as well as improve the quality of the work by the CST. In fact, sound scientific foundations are essential for the harmonious development of an instrument such as the Convention. The preamble of the Convention rightly stresses that strategies to combat desertification will be most effective if they lean on rigorous scientific knowledge that is consistently updated.

At present the objective is to provide the necessary information to effectively combat desertification and implement appropriate scientific policies but also to clarify and accompany the decision-making process. In other words, to enable scientific expertise worldwide to play a full role by putting forward solutions to the pressing questions related to desertification. Let's hope that the International Year of Deserts and Desertification will also be the occasion to strengthen the work in science and technology in the context of the UNCCD.

The conference opened here in Tunis today is without doubt an important event of the year, but others will follow, and I invite you to participate actively and offer your irreplaceable knowledge and know-how. Towards the end of the year, a conference in Algiers to be attended by Heads of States and government leaders will provide an occasion to consider the summation of conclusions and recommendations in the different fora that contributed to promoting the International Year of Deserts and Desertification.

I invite the scientific community to frame its proposals in terms of the direction to be taken and the means required that it considers appropriate for the successful implementation of projects and programmes to combat desertification and the valorization of opportunities existing in the drylands.

Finally, I hope this conference will have all the success it deserves considering the quality of its organization and the debates proposed. The interest generated by the organization of such an event is in itself a positive sign for the future of drylands.

Chairman,
Ladies and gentlemen,

To conclude, allow me to reaffirm here the commitment of the Secretariat of the Convention to accompany the activities of the scientific community. We are convinced that beyond the manifest resolve of each and every one of you, there is today sufficient knowledge, and means, to accomplish this noble ambition of development that reconciles the environment and the economy.

If we succeed in working together in the spirit of good will, I believe that we can give good reasons for the one billion people confronted daily with the effects of desertification and poverty to stay on their land and to bring prosperity to their cultures and civilizations.

I thank you for your kind attention and wish you success in your work.

Chapter 5
Convention on Biological Diversity (CBD)

Ahmed Djoghlaf

The Convention on Biological Diversity (CBD) is very pleased to be celebrating the International Year of Deserts and Desertification (IYDD).

Deserts and other drylands present some of the harshest conditions on Earth. In the Kalahari Basin, temperatures regularly fluctuate 40°C between day and night while some areas of the Atacama Desert in Chile receive rainfall only once in every hundred years.

Despite these challenges, drylands host some of the most spectacular life on Earth. The Serengeti grasslands in sub-Saharan Africa support an annual migration of more than two million ungulates, while the Mediterranean Basin contains no less than 11,700 endemic plant species.

Unfortunately drylands are under threat. Desertification and biodiversity loss are threatening the ability of dryland ecosystems to support life and livelihoods. In fact, 2,311 species are threatened or endangered in dry and sub-humid lands and 15 known species have disappeared entirely from the wild. The CBD Programme of Work on the biological diversity of dry and sub-humid lands and the joint work programme with the UNCCD seek to address these threats and preserve the value of deserts and other drylands.

At the eighth meeting of the Conference of the Parties to the CBD, a set of provisional goals and targets, within the framework of the 2010 Biodiversity Targets, were applied to dry and sub-humid lands. These goals and targets complement the Millennium Development Goals (MDGs), recognizing the link between biodiversity conservation and the achievement of adequate and equitable development. Perhaps nowhere is this link stronger than in drylands.

Approximately 90% of the inhabitants of drylands live in developing countries, where biodiversity resources play a key role in supporting livelihoods. In Senegal, for example, wild resources and non-timber forest products provide more than 50% of rural household incomes. Promoting the sustainable use of biodiversity resources is the second Focal Area of the 2010 Biodiversity Targets and a key prerequisite to the achievement of MDG 1 – reducing extreme poverty and hunger – in drylands areas.

Executive Secretary, Convention on Biological Diversity (CBD), Canada

Infant mortality rates, the focus of MDG 4, are also a particular challenge for drylands, where the rate is twice as high as it is in non-dryland areas in developing countries. The ecosystem goods and services provided by drylands biodiversity, including the maintenance of water quality and increasing resistance to natural disasters, can contribute to improved health and reduced infant mortality rates. This is recognized by Focal Area 4 of the 2010 Targets which calls for the maintenance of goods and services from biodiversity to support human well-being.

Likewise in drylands the achievement of MDG 6 – combating HIV/AIDS, malaria, and other diseases – is closely linked to Focal Area 1 of the 2010 Targets: the protection of the components of biodiversity, including economically and culturally valuable species. In Ghana, the first line of treatment for 60% of children with high fever resulting from malaria is the use of plant-based medicines. Drylands genetic resources are also the source of one-third of all plant-based drugs in the United States. Overexploitation of these medicinal plants is a serious threat in drylands and many vital species, however, and the health benefits they provide may be lost if conservation efforts are not strengthened.

The achievement of global targets in dry and sub-humid lands will benefit from awareness raised through the IYDD. As such, in support of the IYDD, the CBD named drylands biodiversity as the theme for International Biodiversity Day held on 22 May 2006. In 2006, the CBD will also hold a regional workshop to promote synergies between the three Rio conventions and a consultative workshop on joint actions to achieve the 2010 Targets in dry and sub-humid lands.

The CBD activities launched during the IYDD comprise some of the first steps towards a new focus on implementation, steps that represent the strengthened commitment of the CBD to the preservation of life and livelihoods in the unique and vulnerable drylands of the world.

For more information on the activities of the CBD please contact the CBD Secretariat at: the following website: http://www.biodiv.org/default.shtml.

Chapter 6
The CGIAR (Consultative Group on International Agricultural Research) System

William Dar

It is an honour to represent the Consultative Group on International Agricultural Research (CGIAR) in this major global conference. The CGIAR would like to express its gratitude to Tunisia for hosting this conference on behalf of the world community.

We are also grateful to UNESCO for leading the planning and organization of this major event, along with the Sahara and Sahel Observatory, as well as to the many institutions involved in the organizing activities and those who have contributed to funding conference. Finally, I wish to thank all of you who have come here to share your knowledge and expertise.

The CGIAR fully shares the world's vision of a better future for the drylands, safe from the scourge of desertification, to be achieved in accordance with the United Nations Convention to Combat Desertification. As a non-profit international organization, we in the CGIAR work in close partnership with national and regional research organizations across the developing world.

We appreciate that this conference focuses on the role of science in combating desertification. It is too easy for misunderstandings about desertification to grow and become 'conventional wisdom'. When that happens, we exhaust our energy working on the wrong problems. We also confuse the public and lose their support. The role of science is to help us to find the facts and stick to them, to go after the real problems, and to target the right interventions.

We also have to be on guard against the impressions about drylands that we get from the media. Disaster, suffering and crisis make headlines. But they do not tell the whole story.

Mr. Chairman, we believe that managing misery is not enough. There is quiet progress in many dryland areas, driven by the wisdom and sense of responsibility that the people living there hold for their lands. Like us, they too dream of a better future. If we focus only on the chaos and suffering, we think too small. We have to think of the possibilities and potentials, and they are great.

Director-General of ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), India

This is where science and research come in. Research is powerful because it creates new possibilities that can change the equation of development. My organization, the CGIAR, focuses on stimulating a global network of research organizations.

Together with our partners, we have developed a number of innovations that build livelihoods while protecting the drylands. Here are just a few:

- Leading-edge technologies to map and measure land degradation.
- Ways to protect dryland plants and animals.
- More drought-resistant varieties of staple food crops.
- More productive livestock and fish breeds, and ways to manage them.
- Soil-enriching technologies that the poor can afford.
- New farming systems that integrate trees, crops, livestock and fish, reducing risk through diversity.
- Higher-value agricultural products to raise incomes in drylands.
- Ways to care better for rangelands, forests and watersheds in the drylands.
- An understanding of the decision-making processes of poor land users and how those decisions affect desertification.
- Ways to bring communities and governments together to manage lands better in order to combat desertification.
- Policy options for more sustainable dryland management.

The CGIAR consists of 15 centres that work in hundreds of countries across the developing world. Their work to combat desertification is united under the banner of a programme called ‘Oasis’. We chose the name Oasis to reflect our belief that a much brighter future lies ahead for the drylands through the concerted efforts of all of us in partnership with land users. By combining forces, our partnerships can take the holistic approach that the problem demands.

Mr. Chairman and distinguished colleagues, we hope that this conference carries forward the message that all is not doom and gloom in the drylands, that, on the contrary, the possibilities are enormous if science is harnessed, through research, to change the equation fundamentally. Let us go beyond managing misery to a future where we build livelihoods while saving lands.

We look forward to learning from all of you – and to making new friends in this wonderful country.

Thank you.

Chapter 7
The Food and Agriculture Organization (FAO)

Mustapha Sinaceur

Your Excellency, Mr. Nadir Hamada, Minister of the Environment and Sustainable Development,

Your Excellency, Mr. Habib Benyahia, Secretary General of the AMU,

Mr. Walter Erdelen, Assistant Director-General for Natural Sciences, UNESCO,

Mr. Hama Arba Diallo, Executive Secretary of the United Nations Convention to Combat Desertification,

Mr. Ahmed Djoghlaf, Executive Secretary of the Convention on Biological Diversity,
Excellences, ambassadors and diplomats in Tunisia,

Dear colleagues from United Nations agencies and programmes,

Ladies and gentlemen,

It is a great honour for me to address you at the opening of this conference in my dual capacity as representative of the FAO and as resident interim coordinator of the United Nations agencies in Tunisia, and to express my great satisfaction in being able to participate with you today at this international conference organized by UNESCO on the theme of *The Future of Drylands*.

Allow me to salute this initiative enthusiastically as one of the flagship events in 2006, which the United Nations has declared the International Year of Deserts and Desertification.

The subject is *the future of drylands*! It is in fact a crucial issue that concerns the future of not only these zones but also the world in general. Why is that so? First, because the so-called drylands cover 40% of the Earth's surface and are spread throughout the continents; they are home to a wealth and diversity of ecosystems in over 100 countries; and they fulfill environmental functions that affect the entire planet. Secondly, because they are home to two billion people, who for the most part live under conditions of poverty. And, finally, because of their fragility linked to the rarity of its water resources, they are also subject to degradation, which has increased in recent years, reaching proportions that have become a major concern

Resident Interim Coordinator, Agencies of the United Nations System

today. In fact, it has been estimated that globally close to an average 20% of soil resources, water, pastures, forests, agriculture and biodiversity are seriously degraded in the drylands today, representing an economic loss of US$ 150–200 billion annually, and this accounts for the loss only from a productivity perspective. This situation is, for the most part, due to the forced over-exploitation of land by an increasingly large rural population that does not have the means to invest, conserve, renew and improve the resources they use.

Furthermore, a large number of these fragile zones are subject to all sorts of other pressures, such as the development of activities related to irrational tourism, the construction of big-scale infrastructures such as dams, the sites of petrol, gas and mineral exploitation, and military installations, that engender damage, which is often wrongly considered as denuded of interest in these desert zones.

It is crucial at this stage to identify the viable solutions of sustainable development in drylands, to elaborate a strategy for a global solution exclusively focused on the issues in these zones and so to prevent a mass exodus from them. I cite Mr. Kofi Annan during his message on the occasion of the 'World Day to Combat Desertification and Drought', 17 June 2006:

> current trends suggest that by 2020 an estimated 60 million people could move from desertified areas of sub-Saharan Africa towards North Africa and Europe, and that worldwide, 135 million people could be placed at risk of being uprooted.

Fortunately, however, the future of drylands is not only conditioned by the prevention of catastrophes linked to land degradation; the future is also about constructing a better world that responds to the needs of rural and urban populations, around a positive project, that mobilizes and creates solidarity, equitable wealth and well-being.

So what can be done in the face of such stakes? And in what way can this conference bring added value? The first avenue we suggest is linked to the reinforcement and sharing of knowledge in a way that is consensual as well as to a better appreciation of the true nature of the stakes at hand, the benefits, difficulties and possible responses in the drylands. This conference is likely to shed light on the dimensions of knowledge-sharing.

Among the fundamental questions requiring clarity, we recall the need to understand the degradation processes with their causes and effects for each ecological zone, and their system of production, and the need to understand clearly the policies, approaches and practices of resource management in order to correct those that are damaging and to encourage those that valorize productivity over the long term. The work of identification and the promotion of best practices should be carried out within the reality in the field, and they should integrate the rural populations affected in a participative way. It is also increasingly accepted that this knowledge must be multi- and trans-sectorial and evolutive; it must also be holistic and integrate the dynamic between ecosystems, rural societies and production systems. Finally, this knowledge should not be gathered into new virtual ivory towers in the form of specialist Internet sites but must above all be generated, exchanged understood and used in an operational manner by all the actors that affect natural resources, including the populations, politicians, public and private investors and non-governmental organizations working in these regions.

Success stories about projects that have integrated methods from cooperation agencies are numerous. The United Nations Development Program (UNDP) as well as the Food and Agriculture Organization (FAO), with help from other development partners, have already carried out work in this direction. The emphasis is actually on the creation of an international pole of excellence in knowledge management regarding rural development, agriculture and the environment.

The second point of action concerns the implementation of multi-actor and multi-level partners on the development of drylands, particularly in the rural milieu. In fact all studies today reveal that the principal obstacle to development in fragile areas, particularly in the drylands, is linked to the absence of harmonized and coordinated programmes between development partners coming from sectors at different levels. These partners are representatives of local populations, different ministries, the private sector, the non-governmental sector, donors and development agencies. This multi-partner, multi-level approach remains a veritable challenge, and methods are being elaborated to achieve concrete, immediate action. These are based on the implementation of multi-sectorial and multi-partner executive committees that possess power and important financial means, and that are coordinated at the highest political levels. They are responsible for conceiving and coordinating investment programmes that influence renewable resources management and are implemented within a harmonized framework, with direct support from national development strategies, notably in the fight against poverty.

Tunisia, marked by rampant desertification and one of the first countries to ratify the Convention to Combat Desertification in 1995, developed very early on, and over the last 30 years, national programmes based on techniques and knowledge concerning soil and water conservation, for example, encouraged community participation and called for the protection of catchment reservoirs, and dunes and for sylvo-pastoral planning.

Several United Nations agencies have been involved in this vast domain through specific programmes of intervention to combat desertification.

In this connection the United National Environment Programme (UNEP), taking into consideration problem-solving as well as the multiplicity of actors, has made it a primary objective to provide support in terms of coordination. It places particular emphasis on the establishment of institutional mechanisms at the regional level that bring about better dialogue between the different actors and a better coordination of efforts among the different Tunisian partners in this field, such as the GTZ and the Global Mechanism of the UNCCD.

To this day, with the support of the UNDP's Dryland Development Centre and funding from Finland, seven regional action programmes to combat desertification have been elaborated, and are being incorporated into the next national plan for economic and social development for the period 2007–2011. Moreover, the UNDP regional project, financed by the Global Environment Facility (GEF), on the participative management of phytogenetic resources of date palms in the Maghreb oasis ended with success. In addition to increasing the involved parties' awareness of the importance of biodiversity conservation of the date palms, it also underscored for the governments of the three countries concerned (Algeria, Morocco, Tunisia) the importance of valorizing the oasis ecosystems and the necessity of developing national strategies of development in the oasis, such as is currently underway in Tunisia.

The International Fund for Agricultural Development is also involved, with funding from the GEF, in combating land degradation in the region of Siliana and in the domain of agro-pastoralism in Douz and Tataouine.

The International Center for Agricultural Research in the Dry Areas, through research support projects on genetic resources, is involved in integrated management of natural resources (notably in projects to combat desertification), provides support to local development and human resource capacities, and receives the support of all the donors.

As for the FAO, which I represent here in Tunisia and in North Africa, the organization is involved in two domains through two projects of forest development: strategic studies of the Intergovernmental Group on Forests financed by Japan and the on-going elaboration of the National Forestry Programme with support from the Mechanism, and a project on soil and water conservation, which is in fact a vast participative programme covering governates of central Tunis and which is co-financed by Italy and Tunisia.

Here as everywhere, several efforts have been initiated in the direction of multi-partnership, but they still remain limited and insufficiently integrated within the multi-dimensionality of the issues just highlighted.

Excellencies, colleagues and friends,

All the presentations you will listen to this morning point to one and the same thing: let's work together beyond institutional or national differences, let us harmonize our means to achieve a common goal – to make the drylands into a better place so as to heighten the well-being of their populations, their ecosystems and those of the entire world. This conference will not only remind us of the crucial importance of the dryland issues but will also bring together all the research and development actors and thereby will promote exchanges and partnerships that will truly benefit from possible synergies between the different conventions and the agencies of United Nations agencies.

In conclusion, I would like to thank the Tunisian government for its commitment and capable support of the causes of human sustainable development. The warm welcome reminds us of one of the great cultural qualities of the dryland countries: their spirit of generosity and humanity. May this spirit inspire us and help us to construct the future during discussions in the coming days.

Thank you for your kind attention.

Chapter 8
International Strategy for Disaster Reduction

Sálvano Briceno

Mr. Chairman, distinguished participants, ladies and gentlemen,

It is a great honour and pleasure for me to address the Future of Drylands conference, within the context of the International Year of Deserts and Desertification and commemorating 50 years of drylands research. I would like to express my appreciation to the President of Tunisia, His Excellency, Zine El Abidine Ben Ali, and the Tunisian Government for hosting this important conference in collaboration with UNESCO.

This conference is an opportunity to share experiences and knowledge and to identify ways to cooperate on drylands research, conservation, policy and sustainable drylands development. Above all, it is a valuable contribution to the Millennium Development Goals (MDGs). However, this contribution will be significant only if governments can address, in a substantive manner, the need to reduce risk and vulnerability to drought and its terrible consequence, famine.

Disaster reduction is one of the crucial areas requiring our collective efforts to achieve the MDGs and to ensure sustainable development. Over the last ten years, disasters due to vulnerability to natural hazards claimed over 600,000 lives and affected over two billion people. The direct economic loss is estimated at USD 700 billion. In 2005 alone, losses were at USD 220 billion after 150 disasters claimed 97,000 lives.

At the second World Conference on Disaster Reduction, which was last held in January 2005 in Kobe, Japan, 168 governments adopted the Hyogo Framework for Action (HFA) to build resilience of nations and communities to disasters by 2015. Its five priorities for action are to: (1) ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation; (2) identify, assess and monitor disaster risks and enhance early warning; (3) use knowledge, innovation, research and education to build a culture of safety and resilience at all levels; (4) reduce the underlying risk factors; and (5) strengthen disaster preparedness for effective response at all levels. The challenge is to turn these goals into

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Director, United Nations Secretariat of the International Strategy for Disaster Reduction

specific national and local strategies, with practical measures and tangible activities by which progress in disaster reduction can be measured.

It is important to stress that the five priorities mentioned must be addressed together to enable local communities and governments to reduce disasters, risks and negative impacts. This means that all five areas – governance and organizational issues; risk identification and early warning; knowledge management, research and education, reducing risk factors; and preparedness for effective response and recovery – should be integrated in risk reduction strategies with a view to building the resilience of nations and communities to disasters.

Following the Kobe conference, we have witnessed a progressive trend in follow-up and implementation of the HFA. At the national level, 35 countries have established national platforms for disaster risk reduction; several other countries are in the process of establishing them; and gradually disaster risk reduction is being given higher priority in national planning processes. Moreover, there is evidence that recognizing risk reduction as a multi-sectoral and crosscutting issue has led to closer and more harmonized cooperation among responsible sectors in several countries. One of the key messages of the Kobe conference was the importance of developing people-centred risk reduction mechanisms. The implementation of the HFA and the establishment of national platforms contribute to a more systematic and organized participation of public and civil society in local and national disaster risk reduction.

Expansion of regional cooperation and mechanisms for disaster risk reduction has been another important trend following the Kobe conference. Collaboration of all stakeholders at regional and international levels plays a key role in achieving the expected outcomes of disaster risk reduction, as wisely considered in the HFA. Treatment of trans-boundary risks and disasters, commonalities in risks and vulnerabilities, complementarities in resources and capacities, and the need for shared early warnings and information management and harmonized actions, all require effective regional and international cooperation on risk reduction. Today numerous initiatives on regional and international cooperation for disaster risk reduction are being developed in different parts of the world. In Africa, the African Union has been facilitating political will to implement the HFA in Africa, and in December 2005 the first African Union Ministerial Conference adopted the Programme of Action for the Implementation of the African Regional Strategy for Disaster Reduction as the regional implementation of the HFA. African environment ministers underlined the urgency for action in the African Strategy for Disaster Reduction at the African Ministerial Conference on the Environment (AMCEN) in Brazzaville in May 2006.

Mr. Chairman, ladies and gentlemen,

Drought is one of the most common and recurrent natural risks that, if not dealt with effectively, turns into a disaster such as famine with long-term negative impacts on nations and communities. The available statistics show that the number of drought impacts increased from 15 in 2004 to 22 in 2005. In 2005, some 22,788,083 people were affected by drought, as compared with 11,541,000 people in 2004. A recent International Strategy for Disaster Reduction (ISDR) survey concludes that droughts are a natural, recurrent component of the climate system and also that drought-related hazards are expected to increase in the future as society places ever growing pressure on the natural resource base. This increase in the drought hazard may result from an increased frequency and severity of meteorological drought, increased societal vulnerability to drought, or a combination of both. More than other natural hazards, the risk of drought depends on the effectiveness of governance and the management of responsible national and local mechanisms, as well as on the degree of the vulnerability. To prevent drought from becoming a disaster as in the case of famine, the involvement of all stakeholders with a strategic vision that involves empowering communities should be developed by governments.

Although mechanisms to cope with drought have been developed over recent years, challenges still remain that require our collective attention. Appropriate policies, information management and monitoring, prediction models, science, technical and technological development, methodologies for early assessment and impact analysis, the relationship of vulnerability and impact on communities are only some of the areas that must be better addressed to cope with drought.

Drought is one of the most serious transboundary and regional natural risks. Often several countries are at risk of drought and famine when hit by severe climate variability. The threat of larger climate change only increases the need to reduce risk and vulnerability as rapidly as possible. There is need for close regional and international collaboration on various aspects and phases of reducing the risk of drought and better preparedness to face its negative impacts.

Under the auspices of the ISDR, the establishment of a Drought Risk Reduction Center is being planned in China and a first preparatory expert meeting on drought risk reduction will be held next week in Beijing. The establishment of this regional centre focusing on drought risk reduction and management is a remarkable step towards fruitful international cooperation on preventing and reducing risk and the negative impacts of drought at all levels.

Mr. Chairman, ladies and gentlemen,

I would like to take this opportunity to stress the single most important action in the field of reducing risk of disasters, the importance of education, which is one of priority areas of the HFA. Education, including formal, non-formal and informal methods, plays a crucial role in developing a culture of prevention.

In June 2006, UNESCO and the ISDR secretariat launched a campaign for promoting disaster risk education and school safety. During 2006–2007, the campaign will promote the protection of schools as a high priority everywhere and will include risk reduction in school curricula. I encourage you all to contribute, use and support this initiative.

The HFA provides an opportunity to join efforts in reducing risk to drought and famine. It clearly spells out the responsibilities of governments, regional and international organizations, including the UN system and the ISDR's overall facilitating role. The challenge remains how we can each translate these responsibilities into concrete actions with tangible results in our respective areas of authority and professional capacities at local, national, regional and international levels.

I sincerely hope that the deliberations at this conference will result in tangible outcomes for planning and implementing collaborative efforts, in particular for reducing risk and vulnerability to drought and famine, and I very much look forward to staying in touch on its follow-up.

Once again I would like to express my appreciation and thanks to the Tunisian Government and UNESCO, and I look forward to a very productive meeting.

Thank you for listening.

Chapter 9
United Nations University

Adeel Zafar on behalf of Mr. Hans van Ginkel, Rector of the United Nations University

Your Excellency, Mr. Nadhir Hamada, Minister of the Environment and Sustainable Development, Tunisia,

Your Excellency, Mr. Chérif Rahmani, Minister for Land Management and Environment, Algeria,

Mr. Walter Erdelen, Assistant Director-General for Natural Sciences, UNESCO,

Ambassador Hama Arba Diallo, Executive Secretary, UNCCD,

Mr. Ahmed Djoghlaf, Executive Secretary, CBD,

Mr. Alexander Müller, Assistant Director-General for Sustainable Development Department, FAO,
Dr. William Dar, Director-General, ICRISAT,

Distinguished speakers and participants,

Let me express my very warm welcome to all of you on behalf of the United Nations University (UNU). Please accept my sincere apologies for not being able to join this event due to other, prior commitments. It is my great pleasure to share some thoughts at this auspicious gathering, which celebrates half a century of research on drylands and marks the apex of the International Year of Deserts and Desertification (IYDD).

I am very appreciative of the leadership demonstrated by UNESCO in bringing together a team of UN and international agencies to organize this conference. It is indeed a timely exercise to take stock of where we are, and where we should be going. A number of years have passed since the global leaders made commitments in the form of the Millennium Development Goals and reiterated them as the Johannesburg Plan of Implementation in 2002. Today we already know that it will be very difficult, if not impossible, to meet many of those goals. This year we will also reach the ten-year mark since the United Nations Convention to Combat Desertification (UNCCD) came into force. This is, therefore, a critical turning point where we can reflect on the achievements of the scientific and research community as well as the international development community, particularly the United Nations system.

Director, UNU-INWEH, Canada

This is also an occasion to reflect on the future and what we can do to improve the situation for those living in drylands. As you probably know well, of the two billion people who live in drylands, a large fraction is vulnerable to desertification and loss of the benefits and services they derive from their environment. It is imperative for us to act and urgently so. And my plea to you is that we join forces to make a difference on the ground.

In this context I would like to draw your attention to four joint initiatives in which UNU is taking the lead together with our partners to help to mitigate the situation for dryland dwellers.

First, UNU in partnership with many UN and international agencies, and with the generous support of the Algerian Government, will hold in mid-December a conference in Algiers to discuss desertification and the international policy imperative. That policy conference will directly link with and build upon this conference and provide an opportunity to summarize other policy-relevant dialogues taking place during the IYDD. It will primarily highlight the policy underpinnings that are necessary to enable successful strategies in dryland communities. We are hopeful that it will enable implementation of new initiatives to mainstream desertification issues into national and international policy processes.

Second, we are concluding a two-year International Master's Degree Programme in collaboration with the Institut des Régions Arides, the Institut National Agronomique de Tunisie and the Chinese Academy of Sciences. Focused on integrated management of dryland resources, it is specifically designed to enhance and mobilize the existing expertise in the region. I am pleased to inform you that the first cohort of graduate students will receive their Master's degrees at a special graduation ceremony tomorrow night.

Third, UNU joined hands with ICARDA and a number of other international partners to launch earlier this year an international drylands research network called CWANA + (Central and West Asia and North Africa). It focuses on the region spreading from North Africa to West Asia, Central Asia and China, and is intended to foster South-South cooperation on sharing experts and facilities, training scientists and promoting the best practices among centres of excellence in sustainable dryland development. This new initiative builds on UNU's longstanding engagement in collaborative partnerships with ICARDA and UNESCO in dryland research activities, including promotion of traditional water management technologies and the implementation of the joint project called Sustainable Management of Marginal Drylands (SUMAMAD).

Fourth, in collaboration with six UN agencies and support from the Global Environment Facility (GEF), UNU is executing a major initiative to support the evaluation of global environmental benefits achieved through sustainable land management. The initiative, called Knowledge Management from Land or KM:Land for short, will entail a broad range of regional and global consultations, bringing together project managers as well as sustainable land management experts. KM: Land will aim to collaborate with other global initiatives on land degradation and be beneficial to the UNCCD processes; particularly by actively contributing to the work of the Committee for Science and Technology (CET), including that on benchmarks and indicators, best practices and assessment.

I reiterate to you that these international partnerships are critical for overcoming one of the most threatening environmental challenge of our times – desertification. I am hopeful that this conference will pay due attention to scientific priorities and knowledge gaps, and motivate the international community to step forward and fill these gaps immediately.

In conclusion, I would like to express my warm gratitude to the Tunisian hosts for the excellent arrangements for this conference and wish you all a very successful meeting.

Thank you very much for your attention.

Chapter 10
United Nations Environment Programme (UNEP)

Gemma Shepherd on behalf of Mr. Achin Steiner, Executive Director of the United Nations Environment Programme

Your Excellency, Mr. Nathir Hamada, Minister of the Environment and Sustainable Development, Tunisia,

Your Excellency, Mr. Habib Ben Yahia, Secretary-General the Union du Maghreb Arabe,

Mr. Walter Erdelen, Assistant Director-General for Natural Sciences, UNESCO,
Excellencies, distinguished delegates, ladies and gentlemen,
Dear friends and colleagues,

On behalf of the Executive Director of the United Nations Environment Programme (UNEP), Mr. Achim Steiner, I warmly welcome you to the Future of Drylands Conference.

The sustainable management of the world's dryland environments is perhaps one of the most challenging and pressing development problems of today. The drylands represent a nexus between extreme environmental and development problems – where the world's ecosystems are most sensitive and people most vulnerable to environmental and global change.

UNEP has been fully engaged in dryland environmental management for over 30 years, through its partnerships with other UN agencies, governments and a wide array of stakeholders. UNEP was primarily responsible for preparing the United Nations Conference on Desertification, which was held in Nairobi in 1977, and subsequently played a major role in the negotiating process leading to the United Nations Convention to Combat Desertification (UNCCD). UNEP has supported, and continues to support, the implementation of the Convention through global environmental assessments, the development and implementation of projects, especially through the Global Environment Facility (GEF), and policy support to regional, sub-regional and national action plans for combating desertification.

One of UNEP's recent activities to commemorate the International Year of Deserts and Desertification was the dedication of this year's World Environment Day to desertification, with the catchy slogan 'Don't Desert Drylands'. UNEP celebrated the day with the launch of its Global Environmental Outlook for Deserts

Dryland Management Officer, United Nations Environment Programme (UNEP)

report. Deserts are biologically unique in terms of variation in origin, evolutionary history and climatic patterns, and yet they are vulnerable to biological extinction and environmental degradation. The outlook report brings to wide public attention the deep challenges deserts present for sustainable development, but also the opportunities, such as solar power, tourism and development of innovative and globally-relevant water-use technologies and policies.

UNEP also launched on World Environment Day its *Guide on Tourism and Deserts* – a practical guide on managing social and environmental impacts in the desert recreation sector. The guide seeks to promote desert tourism as a leading source of sustainable development in the countries concerned.

Excellencies, ladies and gentlemen,

UNEP participated in the Executive Board and the consortia of the Millennium Ecosystem Assessment (MA), which assessed and subsequently developed response measures for multi-scale ecosystem approaches relevant to drylands. The report *Ecosystems and Human Well-being: Desertification Synthesis* integrates findings related to current state and future trends of desertification and its impacts on ecosystems and human well-being, and is organized around a set of key information needs identified by the UNCCD.

A key finding of the Millennium Ecosystem Assessment is that 60% of the world's ecosystems are in decline or even degraded to an extent that we can no longer rely on their services. Desertification is projected to increase under any likely development scenario, especially in semi-arid areas, due to intensifying use of rangeland and cropland.

It is clear that improving the well-being of dryland peoples in vulnerable countries will require that future decisions take into account the true value of nature – the value of natural resources and ecosystem services on which dryland peoples depend for their livelihoods.

However, the process of developing empirical knowledge, by trial and error, is failing in drylands because change is happening faster than experience can accumulate, and because policy impacts take time to have detectable effects across large isolated areas and against the background of climatic variability. This is where science-based approaches can contribute – by helping to speed up reliable learning processes in dryland countries.

Excellencies, ladies and gentlemen,

It is clear that there are no simple or universal solutions to desertification, and integrated responses are required at multiple scales. There is growing consensus that improved desertification science should be focused on resolving remaining uncertainties impeding policy action and on integrating latest science and technology with local knowledge to improve scientific rigour in assessment, monitoring and adaptive learning. A major implication is the need to give top priority to building science and technological capacity of developing dryland countries.

Therefore, we welcome this conference, which will review the current state- of-knowledge of dryland ecosystems and the socio-economics of dryland development, to identify important knowledge gaps for defining future paths of research into drylands.

Today we celebrate the achievements of dryland research of the past 50 years. We wish every success to the Future of Drylands conference to point the way forward for science over the next 50 years, to ensure that we indeed *Don't Desert Drylands*, but rather conserve their environment for the future well-being of dryland peoples.

Chapter 11
UNESCO Goodwill Ambassador

Claudia Cardinale

Ladies and gentlemen,

In my country of my birth – Tunisia – it gives me great pleasure to be have the opportunity to address such a priority issue as the *future of drylands*. The beauty of our deserts is threatened and the future of its populations uncertain. We need an ecological revolution, which should be increasingly felt and occupy our conscience.

Many countries have already begun to construct a more sustainable future. Alarm bells have started to ring at the doors of other states and multinational companies. Scientists have opened the path and continue to show the way. The media grant increasing coverage of environmental themes, and thanks to those areas of culture, education and art that follow and support this issue, we can establish a 'natural' and healthy relationship with nature.

Water plays a key role in deserts. However, we talk about water as a potential element of conflict. Instead, let's talk about water as an element of peace, of exchange! The vital access to water sources, the respect for ancient and functional techniques used by populations, the understanding of the different relationships that people, in many different parts of the world, maintain with their habitat are as much a part of the inexhaustible and essential discussion and should be considered and acted upon as such.

Respect for the environment is a step towards a world without borders. It opens the way towards a more complete perception of our role on Earth and the relationships we maintain with our surroundings. It is a discussion that reunites people, regardless of their colour, race or religion. The spirit of interdependance among peoples is necessary in order to prevent Earth from declaring war on itself – not because of how we manage our resources but because we plunder these same resources.

How can we ensure peace with the Earth that nourishes us? First, by managing our resources wisely; arid and semi-arid zones benefit from an abundance of sun and wind. Let's therefore use these inexpensive and inexhaustible resources! Rather than waste fossil fuels and increase the deforestation of the savannah, let's help desert peoples use renewable energies. Today the issue of solar and wind energy is at the heart of our concerns and, although it is still too early to depend exclusively on renewable energies, we should not hinder the process towards its development.

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

The use of renewable energies in the deserts is only one example. I wish to support and further promote this issue with UNESCO by creating projects that take into consideration the moves necessary to construct a sustainable future. Good actions and wise choices lead to better options and open other avenues because they are embarked upon with love, and once love is awakened, it cannot be hampered – it consumes everything.

We need clarity, precision and access to these issues in order to transform the alarm bells into dialogue and action. I ask that all the scientists among us today reveal to us the good practices required for man to live in harmony with nature. And when I say *man,* my first thought is of *women*. As a UNESCO Goodwill Ambassador for women, I wish to stress the role of women in transmitting these practices for the conservation and sustainable development of the drylands for the benefit of future generations.

Keynote Presentations

Chapter 1
The Future of Arid Lands – Revisited: Executive Summary

Charles F. Hutchinson, Stefanie M. Herrmann and Wiebke Förch

1 Drylands Research – Past and Present

In 1956 the American Association for the Advancement of Science (AAAS) published *The Future of Arid Lands*, edited by Gilbert F. White. It contains a collection of papers that were presented at the International Arid Lands Meetings in New Mexico, in 1955. Organized by the AAAS sponsored by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and supported by the Rockefeller Foundation, these meetings convened a panel of experts with the aim of considering the issues that confronted arid lands and developing a research agenda to address them. They heralded the opening of a period of sustained interest in the drylands.

Papers contained in *The Future of Arid Lands* we are organized into four broad categories: (1) variability and predictability of water supply, (2) better use of present resources, (3) prospects for additional water resources, and (4) better adaptation of plants and animals to arid conditions. The choice of topical areas reflects what were then considered the most critical issues pertaining to arid lands. The assumption on which the book is based is that arid lands represent a resource to be utilized in some way. Thus, the thrust of the 1956 book was not necessarily about better understanding the nature of arid lands, but about defining the limits of knowledge to making more productive use of them, and to chart out a course to address those limits.

Fifty years later a team from the Office of Arid Land Studies (OALS) at the University of Arizona in Tucson is revisiting *The Future of Arid Lands* on the premise that we are now living and working in the future that was the topic of White's volume.

The Future of Arid Lands – Revisited (2008) affords us the unique opportunity to look back in time and assess where we are now relative to then. We are able to

Office of Arid Land Studies, University of Arizona,

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

consider not only changes in science and technology but also the political and socio-economic contexts that framed them and, perhaps most important, an understanding of what were considered the critical issues of the day. A reflection on the past state of knowledge on drylands, as well as the general attitudes and scientific paradigms that shaped it, provides us with valuable lessons for today and the future (Figs. 1, 2). Particularly the critical consideration of the unintended consequences of past thinking, which often are obvious in drylands today, as well as policy alternatives, will be useful to an audience of decision-makers. While decision-makers are our primary audience, we also intend to provide value for the informed and interested lay person, or for students who wish to identify some of the major issues that confront the use and management of drylands today.

The list of relevant topical areas included in *The Future of Arid Lands – Revisited* is considerably different from that of 50 years ago. Most of the differences are due to our improved knowledge of drylands, the processes that govern their ecological behaviour, and the economic, political and social issues that shape their use. Taking into account the developments that happened in the past 50 years, *The Future of Arid Lands – Revisited* is organized into the following six topical chapters, each of which is divided into a Then and a Now section:

- Water development
- Climate variability and weather modification
- Ecosystem behaviour
- Plant and animal alternatives
- Land management alternatives
- Policy alternatives: sustainability debate

While concrete examples underpinning the developments in several topical areas will be considered in more detail in the individual chapters, the following points emerge as key:

- Although there are broad statements about trends of development in the preface to *The Future of Arid Lands*, the papers it contains are not so much about the future as they are about the state of knowledge in the mid-1950s.
- *The Future of Arid Lands* is testimony to a belief in the beneficial use of science and technology.
- *The Future of Arid Lands* is also testimony to an unshakable belief that much more of the drylands could be brought into productive use through the mere application of technology.
- An important constraint acknowledged in *The Future of Arid Lands* is that there was very little data available 50 years ago to allow an understanding of processes, particularly at regional or global scales.
- Among the many lessons that might be learned from comparing what is found in *The Future of Arid Lands* with what we know today is a better appreciation of the “law of unintended consequences”.

Fig. 1 Map of the extent of arid lands by Peveril Meigs (1953). (Redrawn from inside cover of *The Future of Arid Lands* [1956])

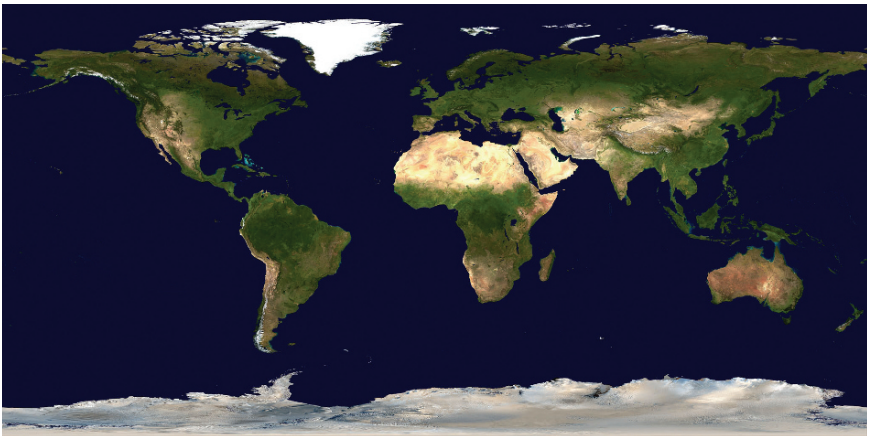


Fig. 2 Distribution of drylands (light brown) as observed by NASA MODIS (Courtesy of NASA Goddard Space Flight Center)

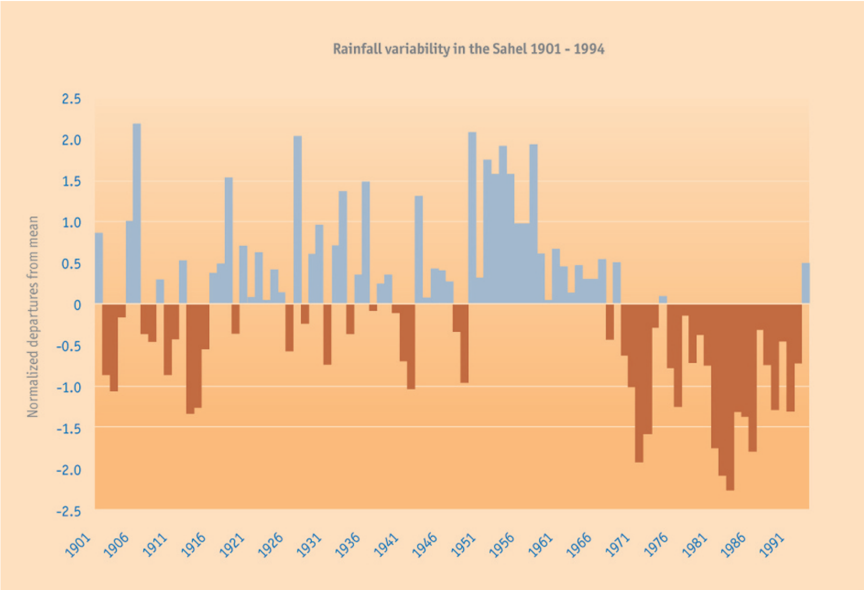


Fig. 3 Rainfall index showing standardized departures from mean annual rainfall compiled from meteorological stations in the West African Sahel (Data courtesy of Sharon E. Nicholson)

2 Water Development

Water – or rather its absence – defines drylands. Paradoxically, the dryland climate in the low latitudes has much to recommend it as a place to live and a place to grow crops: clear skies, warm temperatures, long growing seasons. The key to making the desert bloom has always been finding water. With water at such a premium, the pursuit of new sources of water for drylands has been intense and unrelenting.

Then, water was to come from existing surface sources, augmentation of existing sources (e.g., cloud seeding), or "new" water from untapped sources (e.g., desalinization of brackish and seawater). There was a great belief in what future technology might deliver. The 1950s were the dawning of the era of large dam-building for the world, whereas not much attention was paid to groundwater as a major water resource.

The intervening years have seen much of what was discussed then play out. Inevitably, though, many things happened that were not foreseen. The 1950s marked the beginning of a period of growth in water consumption (Figs. 4, 5), particularly in the agricultural sector, that was not anticipated but has continued until today. Perhaps as a consequence of this rapid growth in consumption, there have also been some fundamental changes in the general perception of water development. While cost–benefit analysis was and is done for most water development projects, the scope of what is included among both costs and benefits has been broadened significantly since then from strictly economic to incorporate environmental and social costs as well.

Despite the fact that groundwater largely was dismissed as a major option in 1956, exploitation of groundwater resources developed rapidly from the 1950s onward, with most development taking place between 1960 and 1980. This development was mostly concerned with immediate returns on investment and not sustainability. Now, as the value of water is increasingly realized, markets have emerged as a mechanism to address inequities in the distribution of water both through its direct sale and also through the trade of commodities that represent water, or "virtual water".

In considering water development and water use as a whole, the most fundamental difference between 1956 and today is that focus has shifted from developing new water supplies to a more comprehensive effort to manage all water from an integrated perspective, on both the supply and the demand sides, and from a quality point of view.

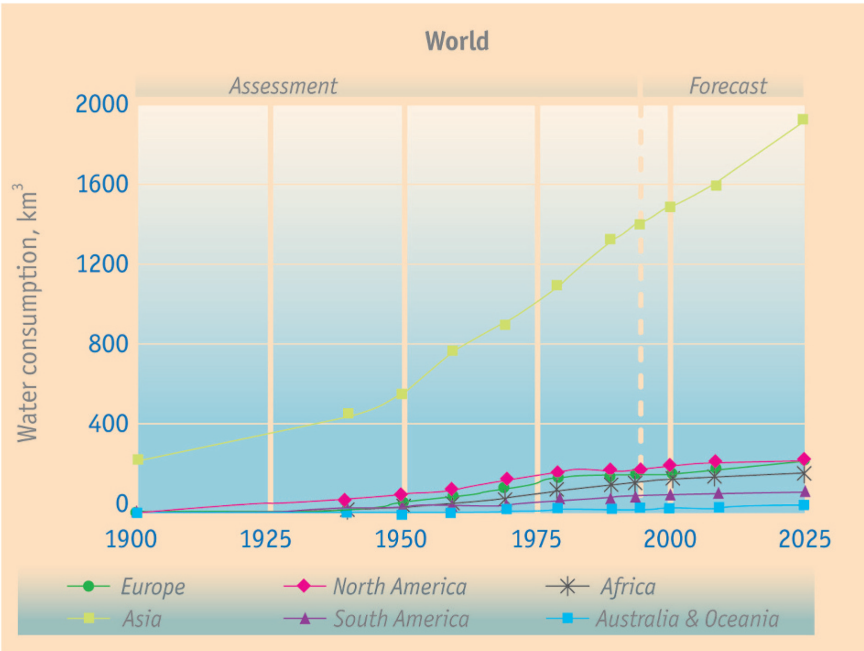


Fig. 4 Global water consumption by region (Courtesy of UNESCO)

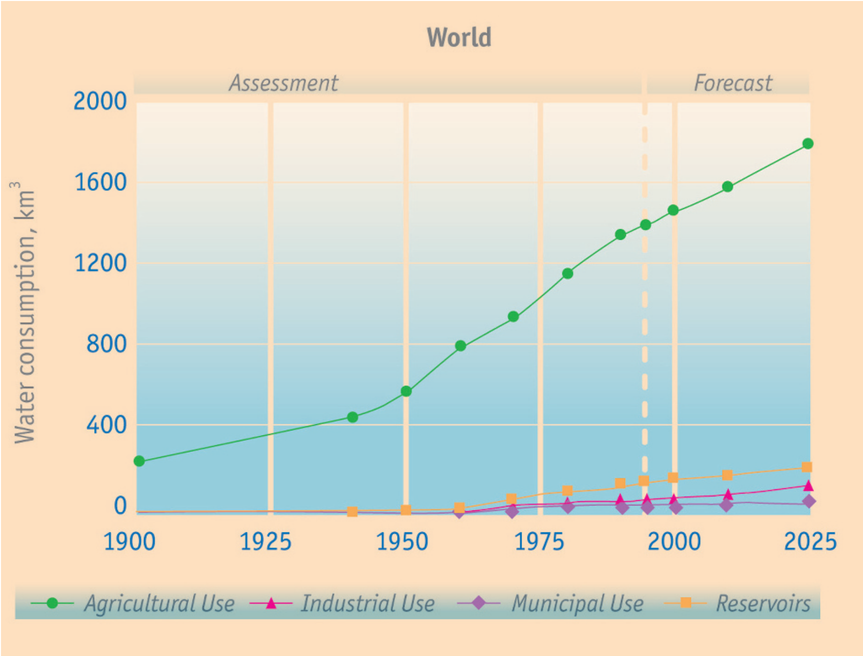


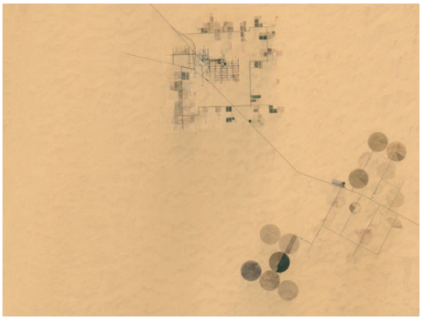
Fig. 5 Global water consumption by sector (Courtesy of UNESCO)

3 Weather Modification and Climate Change

In the drylands, where rainfall is often scarce but always variable (Fig. 3), there has been a keen interest in understanding and being able to predict this variability and in finding ways to "make it rain" when natural rainfall is inadequate. By the time of the publication of *The Future of Arid Lands*, techniques for weather modification, such as cloud seeding, were just emerging (Photo 1). Significantly, these were paralleled by the beginnings of numerical weather modeling using computers. The general view held that modifying weather and climate was a promising and appropriate means of furthering societal and even military goals. It proved to be possible to induce rainfall in very restricted situations over small areas, but this technique was of such limited and often unpredictable value that it was largely sidelined after a good deal of research. However, it is still routinely pursued in some areas with the hope of marginally increasing water supplies (e.g., Colorado River Basin).

Now, some 50 years later, the optimism that once surrounded our emerging ability to control climate and create more favorable weather in the drylands has largely given way to concern about undesired human impact on global climate, such as global warming. Scientific and political discourse that once focused on purposeful weather modification has been replaced by debate over strategies for mitigating the impact of inadvertent climate change and adapting to its consequences.

With the growing awareness of the connectedness of large-scale atmospheric, oceanic and terrestrial systems, the focus of scientific interest has shifted from local and regional impact to changes at a global scale. Increases in temperatures threaten the modest water resources of drylands in several ways. Clearly, increases in evaporation rates as a function of higher temperatures not only threaten reserves stored in reservoirs and soils but also increase water demand by plants. A more ominous threat for many regions may be that, as minimum temperatures rise, decreased amounts of water will be stored in snowpack in the mountains surrounding many of the world's drylands (Fig. 7, Photos 2 and 3).



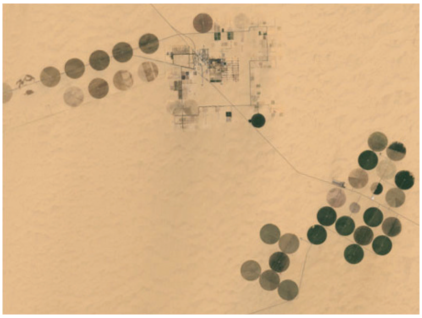


Fig. 6.1 and 6.2 Fossil groundwater resources are mined in the Saharan Desert to support irrigated farming projects. The images (1999, 2001) show the expansion of center pivot irrigation systems just north of the border between Egypt and Sudan (Courtesy of USGS EROS Data Center)

Photo 1 Cloud seeding activities in New Mexico undertaken by *Project Cirrus* (1947–1952)

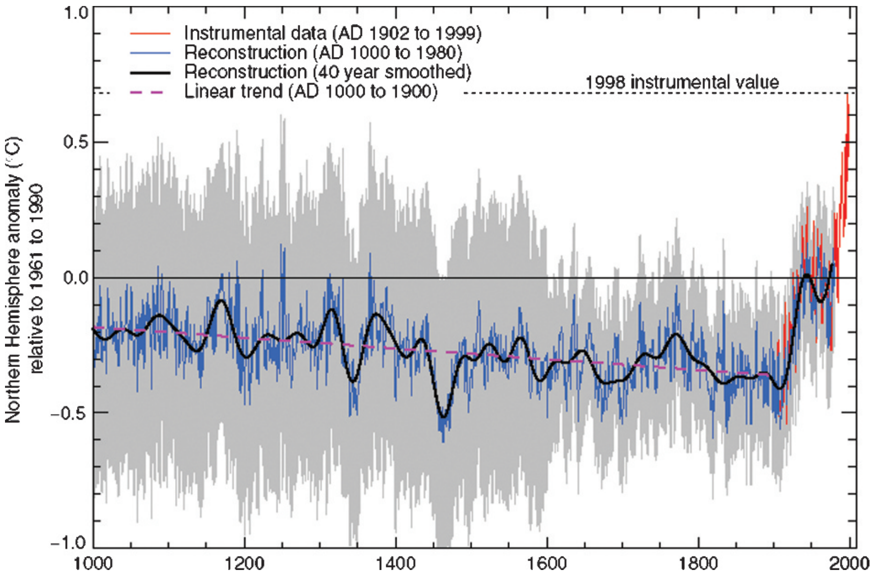


Fig. 7 Millennial northern hemisphere temperature reconstructions and instrumental data from 1000 to 1999 (Adapted from Mann et al., 1999; courtesy of IPCC, 2001)

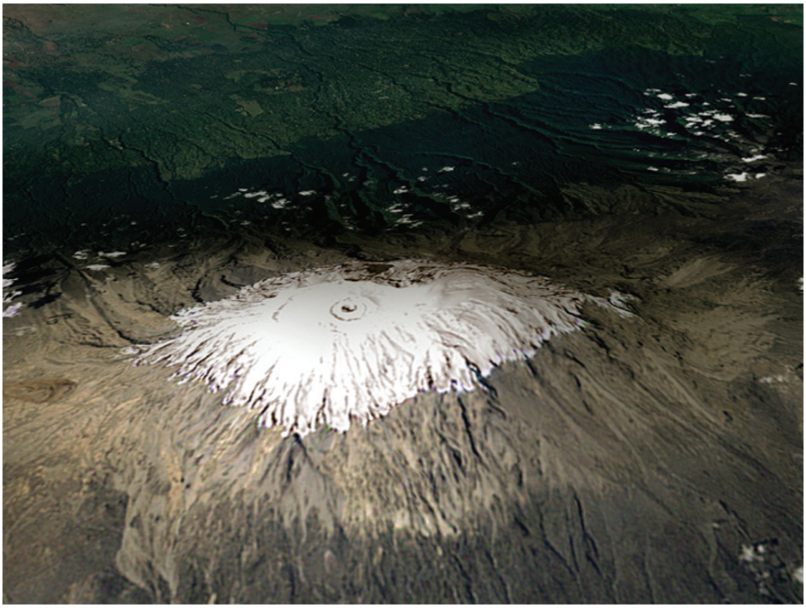


Photo 2 Repeat satellite images show glacier retreat on Mount Kilimanjaro in 1993 (Courtesy of NASA and USGS)

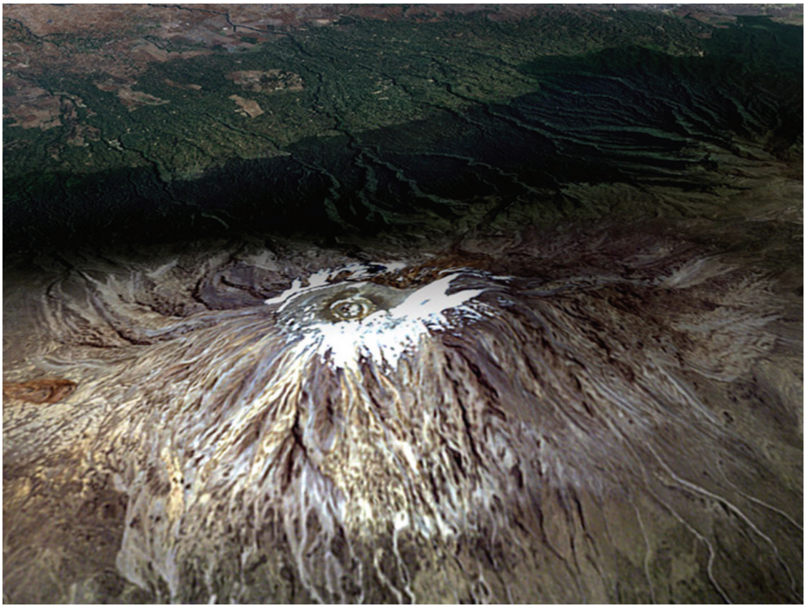


Photo 3 Repeat satellite images show glacier retreat on Mount Kilimanjaro in 2000 (Courtesy of NASA and USGS)

4 Ecosystem Behaviour

Ecology did not receive much explicit attention in *The Future of Arid Lands*. However, the underlying assumption of an ecological balance is implicit throughout the book. The fundamental question of ecological relevance posed in the 1950s was whether and how it is possible to increase production without inadvertently damaging the environment by changing vegetation composition or accelerating soil erosion.

Ecology, maybe more than any other discipline, can be taken as an example of how paradigms develop. The process is not necessarily chronological with a new paradigm replacing an older one; rather, schools of thought, or paradigms, fall into and out of favour with communities of practice. In ecology, the two most prominent paradigms are represented by the equilibrium ("balance of nature") and the non-equilibrium ("flux of nature") models of ecosystem behaviour.

Ecological thinking in *The Future of Arid Lands* was dominated by the equilibrium paradigm – a model of ecological dynamics based on assumptions conceived in the context of northern temperate zones that emerged early in the preceding century. Its validity as a framework for thinking about dryland environments was challenged almost from the very beginning, yet it came to dominate policy thinking for most of the 20th century. Today, though, dryland ecosystems are better described by non-equilibrium models, with disturbance, variability and unpredictability as accepted drivers. However, the equilibrium model persists institutionally, and management in many drylands still follows an equilibrium approach.

The development of dryland ecology has further benefited from the emergence of and advances in complex systems science. Focus has now shifted from the study of individual components of dryland ecosystems – such as soil, water, vegetation and herbivores – to relationships and interactions among them.

5 Plant and Animal Alternatives

The primary focus of *The Future of Arid Lands* was agricultural production, both plant and animal (a focus that many critics, even in 1956, saw as too restricted). Only a handful of strategies were envisioned for improving drylands agriculture: (1) exploit the plant and animal resources that were already there; (2) introduce crops and/or animals from other similar regions that might perform better than natives; or (3) create "better" crops or animals through breeding or more advanced forms of genetic manipulation. The larger part of the book is devoted to the latter two strategies.

The challenge of finding "better" animals was not directly resolved. There was speculation about general strategies for improving returns, such as selecting for smaller breeds that might more efficiently harvest widely dispersed plant resources. Some argued that larger animals were inherently more efficient, and especially favoured the camel as "ideal"; but the difficulty of expanding the market for camel products outside their traditional range was not discussed. Aside from arguing for careful site-specific selection and reliance on local breeds for certain situations, it was generally agreed that more and better forage was the most critical element for livestock production. Thus, plant production became the primary focus both for rangelands and in agricultural fields.

Exotic plant species were seen as having great potential. A century or so of unwitting introductions had established that many plant species performed much better when introduced to areas outside their native range, particularly in areas with homologous climates. By 1956, there were programs to reseed burned or degraded rangelands with exotic grasses.

Since then, exotic species use has been very controversial. In many areas, such as the Sonoran Desert of northern Mexico, large areas of native vegetation have been cleared and reseeded with exotic grasses. Many ranchers like their ability to colonize disturbed areas, outcompete native species, and survive drought; they feel their land can now support more cattle. However, these very characteristics make these exotics undesirable in other parts of the region, where they are seen as a distinct hazard because they replace native species and introduce fire where it was previously unknown.

Many conventional crops are prodigious water users, and there is a long history of seeking "new" crops better adapted to arid conditions. Two different approaches to this search were discussed in 1956. One was to exploit native drylands plants with unique properties – like jojoba, a source of high-quality wax. The other was to selectively breed or engineer conventional crops for specific features, such as improved yield, drought tolerance, or disease resistance. By 1956, CIMMYT's work in this area led to Mexico's self-sufficiency in wheat production; this success spurred even greater interest in the genetic approach to increasing crop production.

Both these approaches have their limitations. During photosynthesis, plants take up carbon dioxide from, and give up water to, the atmosphere. This presents two constraints. First, while plants can be engineered to be more water efficient, there are fundamental limits to what can be achieved. Second, the adaptations many dryland plants have to reduce water loss also restrict their ability to take up carbon dioxide: many desert plants are not particularly water efficient. Furthermore, some dryland plants, such as jojoba, will not produce fruit during droughts; if a crop is desired every year – something that farmers expect – the plants must often be irrigated, thus negating some of their presumed drought-adapted advantage.

A third approach to using dryland plants was discussed in 1956 but has only really emerged over the past few decades. As noted then, dryland plants produce unique chemical compounds to deal with competition, heat, drought stress and predation. There are now programmes to discover and characterize compounds produced by dryland plants and associated microbes, and determine whether they have value for treating diseases such as cancer and HIV/AIDS.

Discussion in 1956 was focused on identifying one crop, or some small suite of crops, that might transform dryland agriculture. Since then, attention has broadened dramatically to include not just plants but all elements of agricultural production. Thus, both research and development now focus not just on improving the plant and its environment through irrigation, fertilization and pest management, but also on improving rural livelihoods and the physical, social and economic well-being of households and communities. Just as in research on water and on climate, this is a transformative shift from characterizing individual elements to seeking to understand processes and systems that govern the behaviour of elements.

6 Land Management Alternatives

In drylands, land values have always been inextricably linked to water availability. Without water – whether rainfall, surface or groundwater – land will be "underutilized". As water availability increases, land can be brought into increasingly "higher" (i.e., more valuable) uses, ranging from "forestry", to grazing, to rainfed agriculture, to irrigated agriculture (Figs. 6.1 and 6.2). In 1956, these were the primary land uses proposed for drylands and they were treated as separate and distinct activities.

Then, the primary strategy was "greening the desert" by developing primarily surface water resources and extending large-scale irrigation systems to all lands that could be economically included. There was little concern with environmental and social impact, or water use efficiency. Maximizing the area under rainfed agricultural production was also a priority. However, it was understood that, because of climate variability, extending rainfed cropping into lands that had been previously devoted to grazing was risky.

A great deal of concern existed in 1956 over the possible negative impact of traditional land use systems on drylands, particularly in developing countries. Livestock production, especially pastoralism, was clearly considered less desirable than cultivation and needed to be made more productive through the use of modern range management techniques. This, however, might involve "improvement" by removing undesirable vegetation through mechanical or chemical means, and/or a reduction in stocking rates so that vegetation might recover. Either alternative was and is expensive and probably not suited to developing countries.

Since then, strict distinctions among agricultural land uses have blurred, and attention has instead focused on land use systems within a region or household. Land use or livelihood systems may include one or a number of economic land uses. Thus, agricultural research and development has focused increasingly on each such use as one part of a larger system, thus exploiting synergies among them (e.g., agro-silvo-pastoralism). In addition, the value of land has come to be determined by other considerations, including environmental, historical, social, cultural and spiritual values.

Now, attention has also been drawn to the negative consequences of some of the modern methods put in place then. The potential of salt accumulation in the soil was well recognized then as a problem, and the basic concepts of salinity management were known, but solutions, such as drainage systems, were expensive. It was also believed that the process was easily reversed. Salinity management continues to be the main challenge to irrigated agriculture. Furthermore, as concern grows over land degradation and desertification, large irrigation schemes are often viewed skeptically for their high financial, social and environmental costs and their potential to damage other sectors (e.g., fisheries of the Aral Sea), particularly in developing countries.

Because of the value of water, considerable progress has been made in increasing water use efficiency. Centre-pivot irrigation technology spread quickly beginning in the 1960s. It allowed comparatively inexpensive irrigation virtually anywhere that water was available. It also allowed irrigation of a wide variety of terrains. Other advances have been made in conventional irrigation. On large scales, land levelling has greatly increased water use efficiency. On small scales, the development of small portable pumps has allowed many farmers to insure production during dry spells and to increase the number of cropping seasons per year. Development of drip irrigation has also increased water use efficiency, particularly in developed countries. More recently, micro-irrigation techniques (i.e., drip irrigation using buckets and inexpensive tubing) have multiple potential benefits for small farmers in developing countries by increasing yields while decreasing water, fertilizer and labor requirements.

In developing countries, water harvesting through hand-constructed water control structures is also receiving renewed attention as a means of promoting local self-sufficiency, reducing poverty and increasing food security where irrigated agriculture is not feasible. Such solutions are seen as potentially more sustainable, since they are based on local technologies and materials and generally require little cash investment.

While agricultural land uses were the only management options seriously considered in 1956, over the last 50 years a much broader range of potential options for drylands has emerged. Some drylands have competitive advantages in terms of the production of cash crops in controlled environments for off-season markets. Other drylands are increasingly sought out for amenities in terms of lifestyles and recreation, as illustrated by high rates of growth in dryland metropolitan areas in developed countries. Moreover, there is increased interest in their use for power generation and non-renewable natural resources.

7 Policy Alternatives

In terms of policy, the primary objective in 1956 was to do "better". What this meant was not explicitly stated, but implicitly, "better" meant more water and more agricultural production. The stated need to find 'the consequences of utilizing arid lands beyond their capabilities' might be considered as touching on sustainability, but many development threads pursued after 1956 were clearly unsustainable. For example, the exploitation of fossil groundwater in North America, North Africa and the Arabian Peninsula is acknowledged to have finite limits. Since these resources were developed, more comprehensive tools for evaluating development impact have been put in place. We should expect that, just as the concept of sustainability has been elaborated upon since it was first outlined by the Brundtland Commission, there will be further discussion of how sustainability is defined and how it will be assessed in the future.

Population is as much a concern today as it was in 1956. World population is expected to peak at about 9 billion by 2050 – more than three times as many people as 100 years earlier. Most of the growth will occur in developing countries, much of that in drylands, and the bulk in urban areas. This growth offers challenges and opportunities to drylands. The challenge is to develop safe, secure urban water supplies without causing undue harm to the agricultural sector (thus further encouraging urban migration) or damaging the ability of the environment to provide goods and services for future generations. One opportunity is the reclamation and use of urban wastewater streams. Policy must acknowledge wastewater and stormwater as increasingly important resources.

Climatic variability is the defining feature of drylands. This was acknowledged in 1956 but, both then and now, it is difficult to craft policy that acknowledges and accommodates this variability. Policy can take one of two general paths. One approach is to minimize the risk of agricultural producers. This might involve incentives to change the basic nature of production by (1) encouraging irrigation where suitable, (2) implementing on-farm water and soil conservation programmes through the use of appropriate technologies, (3) moving from rainfed cropping systems to free-ranging livestock production systems, or (4) abandoning agricultural production in the riskiest settings. Another option would be to provide some type of insurance or underwriting for farmers and livestock operators to help spread the risk across the general population. As all elements of the global economy become increasingly intertwined, this latter approach may prove to be the most effective.

As our skill in near-future weather prediction improves, more adaptive management policies will probably be required to allow some sort of optimization. For example, if we can predict good or bad growing seasons six months into the future, mechanisms must be in place to advise and allow farmers and livestock operators to adjust their cropping or stocking strategies accordingly. Similarly, others who manage critical resources, such as water, must be able to coordinate the flow of their resources, often at regional (i.e., multinational) levels.

Climate change appears to be inevitable and could add severe stress to the other challenges noted here. Again, some form of adaptive management policy that is regional to global in scope would allow response to changes as they arose.

It was argued in 1956 that agriculture in drylands was not a very good use of water. Some felt that crops could be better grown in other regions and that drylands should focus more on "industry" in which they might have some advantage. This reasoning foreshadowed a global economy in which each region might capitalize on some competitive advantage in the global marketplace. Moreover, as technological innovation continues to change how business is conducted, opportunities will appear and develop more and more quickly, and will increasingly transcend national boundaries. As a result, policy must be agile and compliant enough to allow advantages to be pursued when and where they arise.

Gilbert White stated in 1980 that the lines of development discussed in 1956 were far too sectoral and should be more "integrated". In particular, he noted that watersheds were treated as a collection of sectoral interests (i.e., irrigated agriculture, hydro-power, municipal) rather than as a set of often competing interests that occupied a contiguous space as part of an integrated whole. Over time, the intricate network of connections among and within sectors has become increasingly evident. Development policy at a macro-scale now routinely considers all sectoral interests. Similarly, research within sectors now considers a far more comprehensive set of factors that affect development at the lowest levels. For example, agricultural research in the 1950s tended to focus on individual elements of farming, seeking to improve varieties through plant breeding, or efficiency through new irrigation technologies. Since then, these lines of research continue, but the agricultural enterprise has increasingly been placed in a much larger and more complex framework as part of a larger set of systems. Thus, research now focuses on issues that range in scale from plants, to fields, to households, to regions, and addresses linkages between and within topical areas (e.g., plant breeding, irrigation, household allocations of land, labor and capital, post-harvest storage processing, markets, credit, transportation), and scales of operation from farm to national levels. The degree to which all things are tied together has become both increasingly obvious and necessary to accommodate, and the task of development has come to be more about achieving marginal improvements in the function of the system at each level. Much of the improvement in system performance may be technical (e.g., improved crop varieties), but a great deal may also be related to policy (e.g., trade, subsidies, tariffs).

Just as there was little appreciation for the interconnectedness of sectors in 1956, there was little if any understanding of the chaotic nature of most natural systems. Dryland climate was understood to be variable, but it was expected that this variability could be captured, understood and ultimately predicted. Moreover, it was assumed that the variability might even be controlled – to a limited degree – in the case of weather modification. Ecological systems (e.g., grassland ecosystem) were assumed to be fairly stable and to operate in an "equilibrium" sense: if perturbed, a system would return to its initial state if the perturbing factor was removed. With such models as the foundation, management policies can be quite simple and prescriptive: if the system appears to be changing, stop what you are doing. However, non-equilibrium models of natural systems have emerged, particularly in drylands. In these, a number of stable equilibrium states might exist, and a system might move between them if a perturbation forces them across some threshold. In this case, management policy must be adaptive and anticipate and respond to changes as they occur.

In 1956 the responsibility for conducting research and dealing with dryland development challenges was assumed to reside with government – national, bilateral, multilateral and international. In fact, there was little if any discussion of how change might actually be achieved and who, specifically, might effect it.

The notion that government could supply both the answers and the means to address these challenges has changed over the last 50 years. Certainly business, both national and multinational has become a much greater force for change as its power and influence has grown. Equally important, non-governmental organizations (NGOs), unmentioned in 1956, are ubiquitous and powerful agents nationally and internationally. In considering development, all three must now be included.

In 1956 science was seen as the cornerstone on which drylands development would build. This was the entire premise of *The Future of Arid Lands*. That belief persists today and there is little doubt among scientists that much of their output will and should have a direct impact on these issues. However, it has become increasingly obvious that the movement of knowledge from research to practice does not happen as quickly or reliably as it must. In this, both scientists and policy-makers have often failed to make the necessary linkages between what is known about the nature of the world and how the policies that guide human actions are developed.

8 The Case for Drylands

Although *The Future of Arid Lands* suggested that the drylands would receive renewed and sustained interest, since 1956 they have instead been plagued by "underinvestment". There are several reasons to reverse this situation.

First, the problem described by Malthus 200 years ago has not disappeared. Over the next 40 years, the world's population will increase by 50%. As in 1956, there will be major challenges in feeding and sheltering that population while trying to maintain the climate and biological systems that make the Earth habitable. Over the long term, the drylands must play a larger role in meeting these growing demands.

Second, from a more immediate, environmental perspective, it can be argued that significant parts of the world's drylands are the source of potentially serious global problems. Dust from the Saharo-Sahelian region of Africa and the drylands of central Asia is transported over continental scales and is of global concern. Dust from central Asia causes health concerns not only in China and Japan but also in North America. Dust from Africa may be a contributing factor to the decline of coral reefs in the Caribbean. There is growing concern among researchers about potential effects of dryland dust on global climate as a result of reflection, scattering and absorption of solar radiation, and on cloud formation and precipitation.

Third, from a global economic perspective, drylands have largely been marginalized. This is partly due to their physical isolation, but it is also a function of their lack of economic, political and social leverage within their respective countries. In some drylands that possess energy or other mineral resources necessary for global industry, this is not the case. In the future, due to their favourable location, climate, lack of competing land uses and correspondingly low land prices, drylands may also play a central role on the renewable energy stage as solar technology improves and costs decline. It is conceivable that drylands may enjoy other increasingly competitive advantages as suppliers of specialty crops or tourist destinations. Perhaps most important, it has been shown now that potential returns on investment in drylands are higher than in more humid areas.

Finally, it has been argued that globalization is about more than just economics. There are issues of equity. Currently, 20% of the world's population consumes 85% of the world's resources. More broadly, a central challenge today is to ensure that globalization becomes a positive force for all the world's people. Eradicating extreme poverty and hunger and ensuring environmental sustainability are primary international goals. Moreover, many of the problems enumerated here are rooted, at least partially, in poverty.

Fifty years ago, speaking for his colleagues in the Preface to *The Future of Arid Lands*, Gilbert F. White challenged us to look for solutions that included technology but were not proscribed by it. He urged us to look beyond solutions that were tied to a single sector, and to frame them in an international context. Finally, he pointed to perhaps the greatest challenge, which was to translate our knowledge into action at the level of individual farmers, herders and resource managers. These challenges remain. What has changed, though, is that as science has advanced, our understanding of the scale and complexity of the systems we are attempting to manage has expanded exponentially. Where White encouraged us to think regionally rather than locally, we now understand that the challenge is global: we need to develop global partnerships for development in line with the Millennium Development Goals.

Chapter 2
Policy Requirements to Combat Desertification

Wafa Essahli and Youba Sokona

1 Desertification, a Multidimensional Issue

Combating desertification remains one of the major challenges of the 21st century, and nowhere more so than in Africa where the vulnerability of populations and the ecosystems of the arid, semi-arid and dry sub-humid zones are particularly apparent. Desertification, or land degradation, in these zones is a complex multi-dimensional phenomenon with diverse political, social and economic implications that are in perpetual mutation. The controversy that has long surrounded the definition of the phenomenon and divided politicians and scientists indicates its complexity, as well as the difficulty of grasping its multiple facets, which are inextricably linked and are multi-thematic and multidisciplinary. Furthermore, desertification is at the heart of development concerns of the majority of the poorest nations.

Insidious and treacherous, desertification does not even make the news headlines, unlike a tsunami, a civil war or even immigration. Yet there are 480 million people worldwide who are affected and one billion who are threatened; 3,600 million hectares, or 70% of the world's arid lands, are degraded, and 10 million hectares of arable land deteriorates every year. The vicious cycle of desertification and poverty results in causes becoming effects, as highlighted in Article 1 of the Convention to Combat Desertification: the combined effect of anthropogenic activities and climatic conditions that causes the degradation of land and vegetation cover, leading to clearing and overgrazing with the result, for example, of sand encroachment and erosion seriously compromising development efforts and initiating, in extreme situations, populations to migrate.

In countries where natural resources are the principal sources of income, essentially based on an agricultural economy that is largely extensive, and where the inputs for the most part are limited to the strict minimum, the overexploitation of natural resources brings about increased poverty among the population, causing immigration to become the only option for survival. The interaction between

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desertification and poverty is as great as the level of development is low, and natural resources make up the principal capital of the local populations. Because the poverty of these populations greatly limits their investment capacity to improve their living conditions, they are forced to borrow from their meagre savings and/or fall into debt so as to satisfy their most urgent needs and far from the concern to maintain natural resources. The overexploitation of resources that results makes them vulnerable and diminishes their resilience to the increasingly frequent climatic extremes resulting in further poverty and inevitably further misfortunes associated with extreme poverty, migration and humanitarian disaster. This interaction between desertification and poverty reveals the global dimension of this catastrophe.

2 Desertification and Development

Aridity is not inevitable, however. Examples of arid zones in the United States and in Australia reveal that development programmes supported by political resolve can succeed by diversifying sources of income and creating wealth to maintain the population while preserving the equilibrium of the ecological systems (World Bank, 1999). The tradition of transhumance and temporary migration were already adaptative practices to drought. In a recent study, Chris Reij and D_Steeds (2003) report on other examples of local development action in certain Sahel countries which could be extended to include other contexts. There are numerous examples of situations in which appropriate initiatory measures have proven productive and capable of generating alternative income activities in arid, semi-arid and dry sub-humid zones (ACDI, 2006). On the other hand, development programmes strongly influence the state of natural resources, and the sectorial approaches to development favoured in the last decades have had deleterious effects on the ecosystems by inciting changes in land use that have led to irreversible ecosystem degradation (Medaction, 2004). Structural development policies – though necessary to drive the development of certain countries and to take advantage of foreign direct investment – have not impacted positively on the preservation of natural resources because they have not always been accompanied by the institutional changes necessary to deal with the socio-economic changes they bring about, such as the break-up and disorganization of agriculture, absence of agricultural planning, irregular itineraries and a rise in cattle herds (FAO, 1997).

3 The Globalization of the Problem

The problems of land use changes and land use are not the sad prerogative of our era, as Antoine Cornet (OSS, 2006) indicates, the phenomenon of land degradation is as old as the world. Plato already cited it when he noted the harmful effect of agriculture on forested land, and there are further references from the beginning of the nineteenth century. The term "desertification" was first coined in 1927 by Louis Lavauden, but it only became familiar on a worldwide scale following the terrible droughts that affected the Sahel in the 1970s. It took the Rio Summit and pressure exerted by the African nations to achieve adoption of the United Nations Convention to Combat Desertification (UNCCD) in Paris in 1994, an event that marked the mobilization of the international community and explicitly recognized the global reach of the phenomenon.

From the United Nations conference held in Nairobi in 1977 to the adoption of the UNCCD in 1994, the concepts evolved greatly, from the notion of an advancing desert to a desert that is created. In fact, in the 1970s there existed a pervasive image of dunes that inexorably advanced from the Sahara to finally submerge the oases, arable lands and human infrastructures under sterile sand. Combating desertification was carried out within the framework of intermittent projects, in space and time, with actions geared towards reforestation and programmes involving shelter belts, barriers, green belts, dune fixation, as well as water and soil conservation. New institutions were created in response to the perverse effects of the loss of soil productivity. However, no effective instrument or action framework was implemented at the international level.

The UNCCD brought a new acceptance of desertification: we know today that deserts do not advance but are created and grow wherever resources are overexploited, overcoming manmade barriers, no matter how high or large (MEDACTION, 2004). In addition to the agreed definition, which sees desertification as land degradation in arid, semi-arid and dry, sub-humid areas due to the combined effects of human activities and climatic variables, the UNCCD also introduced innovative ways to combat desertification which henceforth were to be integrated in development programmes using a less technical approach while taking into consideration the socio-economic issues and aiming at poverty elimination. It would also involve a bottom-up approach, associating local populations, civil society and the private sector. Improving scientific knowledge of the phenomenon and its impact on the population and environment was also highlighted.

In 2006, the International Year of Deserts and Desertification, ten years after the adoption of the Convention and its ratification by 190 countries, the arose over debate on the UNCCD's impact and the progress of its efforts to combat desertification – in the first instance, at the local level but also at the national level, where development, social and economic plans continue to be elaborated, and at the regional and international levels, which are important forces in the elaboration of these plans (globalization of exchanges, global environmental governance and so on).

4 Combating Desertification: The Achievements

Many achievements have been made at the governance level. Internationally, the frameworks for sustainable development for have multiplied since Agenda 21 and the other conventions emanating from the Rio Summit process, including the

Millennium Development Goals, the Johannesburg Action Plan, and the New Partnership for Africa's Development (NEPAD). The resultant frameworks offer many opportunities to modify development paradigms and to ensure the integration of the environment into development policies so as to achieve greater sustainability.

On the national level, huge efforts have been made by affected countries both to elaborate strategies and development plans to reduce poverty and to adopt legislation on natural resource management. As recommended by the UNCCD, countries have endeavoured to elaborate their national action programmes to combat desertification according to the new participatory and multisectorial approach and have established national centres of coordination intended to ensure a concerted and integrated vision within the programme to combat desertification throughout all sectors of development. One of the principal advantages of these instruments is that they contribute to the improvement of knowledge on desertification and poverty as phenomena (causes, evolutionary processes, impacts, etc.) instead of the interactions between them. The national actors, often with the inclusion of civil society, have characterized and analyzed these phenomena.

At the regional level, there also have been significant achievements. Sub-regional bodies have been organized and are equipped with competent agencies to ensure that combating desertification counts among the action priorities of social and economic agendas. Sub-regional action programmes to combat desertification also have been developed that, far from being condensed versions of national programmes, have brought about a new transboundary vision of integrated and concerted management of common resources that allows for the harmonization of methodologies, strategies and political intervention by and for the exchange of experiences, knowledge and know-how between countries. The thematic networks put in place within the framework of regional action programmes are appreciable initiatives, they promise to contribute greatly to the mobilization of scientific and technical institutions on these issues.

The UNCCD has also enabled the greater mobilization of scientific and technical organizations at every level. Today significant progress has been made in scientific knowledge about the phenomena, their causes and their effects on populations and natural resources. Coordinated natural observation and monitoring networks are beginning to be implemented. Attempts are being made to define harmonized and shared methodologies, as well as to define and produce monitoring indicators of natural resources and guidelines to follow the implementation of action programmes and assure that they lead to significant outcomes.

5 Persistent Gaps

As important as these achievements may be, they cannot mask the gaps that persist and the difficulties that prevent an adequate integration of the objective to combat desertification in development programmes; the differences are great between the political discourse that considers environmental problems and the actions taken in the field to combat desertification. The latter has almost become a sector in its own right – instead of being a factor integrated in different sectors of development. The decision-makers have little relevant information that allows them to assign to combating desertification the priority it needs over other development issues that appear more pressing (food security, health, education). Moreover, environment ministries national coordination centres often feel that should neither giving priority to the fight against desertification nor act as true coordinating bodies. Deprived of the role of "chief coordinator", which would be capable of bringing about synergy between the different actors, the national coordination centres are charged with overseeing support projects and the implementation of action programmes and other associated bi- or multi-lateral funding sources.

However, the sub-regional organizations, created to respond to crisis situations brought about by drought of catastrophic proportions, have not been able to make the changes needed to free themselves from dependence of international funds; they have been unable to become instruments for the implementation of environmental policy in their member countries, which ideally would recognize their value would have agreed to the efforts the centres were undertaking and ensured the funds necessary to support those efforts.

Nor have the sub-regional organizations been effective at the scientific and technical level. Despite the efforts agreed on by several international or regional organizations, the work on references and indicators are situated at the global level; due to a lack of established traditions of long-term data collection in individual countries, few indicators are calculated in a systematic and periodic manner at national and local levels that would be more useful for decision-making and the prioritization of actions to combat desertification. Affected countries still do not have the necessary means for establishing an environmental monitoring and observation network. Data collection carried out exclusively in the framework of projects that are limited in space and time is often fragmented, poorly documented, and conducted according to such diverse and varied methodologies that they cannot contribute to synchronic or diachronic studies that would apprehend the changes that have occurred or predict possible trends. Furthermore, the use of teledetection techniques, despite their proven contribution as a complement to local observations for a more synoptic vision of the phenomena of land degradation, has remained at a demonstrative stage and has not led to operational processes of information production useful for decision-making. Institutional segmentation still remains a constraint on the circulation of information between the different actors, thus, the sharing of data that abounds remains little known and under-utilized and not at all valorized in the decision-making processes.

However, without precise data and without appropriate information it is impossible to predict, adjust or reinforce actions to combat land degradation and rise to the challenge of food security through efficient water resources management. As for North–South relations, the UNCCD has not kept all its promises. Differences are growing at each conference of the Parties between the expectations of affected countries, which propose a catalogue of projects in their National Action Plans that would be enough to drain their respective resources, and industrialized countries, which do not increase their development aid and only slightly modify their procedures of cooperation. As for countries of the South, we can reproach their sectoral development aid policies insofar as they do not always sufficiently integrate environmental issues.

Furthermore, the South–South partnership has not evolved in the recommended direction and has stalled, remaining strongly dependant on multilateral support instead of being driven by the countries themselves, where divergence persists between the three principal group of actors: politicians, populations and researchers.

Despite these gaps, the UNCCD has continued to rally Parties, whether they are affected by desertification or industrialized nations; over the last ten years, the political resolve has continually been reaffirmed; and despite its limitations, the Convention has never been placed in doubt.

6 The Challenge of Combating Desertification for Sustainable Development

Poverty and desertification continue to gain ground, particularly in Africa, diminishing the few economic gains that certain African countries have managed to obtain. The implementation of environmental and sustainable development initiatives and strategies continues to be held back by the shortage of inter-institutional consultations on the one hand and the lack of synergy between the different instruments and actors on the other hand. Attempts to integrate environmental issues into development strategies for poverty reduction remain negligible. The precariousness and the heavy financial dependence of African countries on their cooperation partners constitute further important obstacles to the execution of strategies and initiatives aimed at sustainable development in general and combating desertification in particular.

To rise to the challenge and surmount the constraints to the implementation of effective actions to combat desertification requires, it is especially necessary for countries to assume responsibility that fully accepts and understands the problem translated into more concrete actions than speeches and official declarations of intent. Links with actions to combat desertification must be established at the defining stage when strategies and development plans are first elaborated. This is necessary if they are to grasp fully the role and impact of sectoral policies on the state of natural resources and to envisage alternative sources of income in order to ease the pressure on populations and thus ensure, from the outset, the link between combating desertification and poverty eradication.

7 Policies Necessary to Combat Desertification Successfully

It is clearly time to break the vicious circle of the marginalization of the arid, semiarid and dry, sub-humid zones, which has made it the poor parent of development programmes in affected countries; 'these zones have always been perceived as areas of high risk investment by the public sector and donor agencies, in the context of Millennium Development Goals (MDGs)' (ACDI, 2006). The measures to be taken are numerous and of political, legislative, judicial, institutional and financial importance. On the political level, there is a need to reinforce actions of decentralization and integration from the local to the national and from the national to the international level. To ensure success, these political measures must have appropriate frameworks, and legal and judicial instruments to regulate the system of land tenure, mobilize common resources, dynamize credit institutions, and valorize public awareness services, research products and so on. Private investment can be stimulated in these areas thanks to powerful economic and financial instruments capable of supporting bank loans through the implementation of specials funds, taxes and financial incentives for the development of these areas. On the institutional front, national coordination bodies should be reinforced and equipped with a concerted action programme that is shared with all the actors involved so that they renounce the temptation to become "operators" of the desertification combat and become "facilitators" that reunite the actors: technical departments, research institutions, civil society, community representatives, etc. The participation of *all* actors at *all* stages of policy identification in combating desertification is essential in order to appreciate the preventative nature of sectoral development policies. Another essential element is the development of the knowledge base on which combating desertification should be founded; its effective implementation depends on information collection and management, and its public character. There is a need to set up monitoring and observation systems of the natural resources. Countries must make the necessary efforts to equip themselves with devices to observe and monitor natural resources and engage the process of data access, treatment, sharing and valorization, as well as financing this data in the long term (IDDRI, 2005). However, the absence of such data and information should not delay the implementation of actions to combat desertification; on the contrary, this should be the occasion to reinforce existing instruments and facilitate the setting up of efficient data collection and treatment procedures that ensure information transparency. This is precisely the work of the OSS within the framework of its 2010 Strategy: to master environmental information so that it is useful for the implementation of the UNCCD and other conventions emanating from the Rio process.

At the regional level, sub-regional action programmes to combat desertification should be translated into programmes that mobilize and encourage the sharing of experiences and expertise that borrow from useful past lessons, such as the initiative recently adopted by the Community of Sahel-Saharan States CEN-SAD – to re-examine the concept of green shelterbelts and establish a programme that combats desertification by integrating aspects of afforestation into development actions that combats both desertification and poverty (Reij and Steeds, 2003). On the institutional front, change in the existing organizations should be encouraged while reinforcing their action capabilities for a better understanding of the evolving needs of their country and member organizations.

These measures on the national and regional levels can achieve these objectives only if they are reinforced and supported by a more unified international

North–South–South cooperation that grasps and valorizes all existing opportunities together instead of taking them separately and differentiating the implementation frameworks (Reij and Steeds, 2003). The prevailing logic of compromise is moving towards a logic of unified partnership in countries whose capacities and scientific thinking allows them to negotiate global environmental governance.

Finally, it is important to recall that to succeed in combating desertification, firm political resolve is required. Such resolve alone makes it possible to integrate concerted action into development priorities between the different actors, including development partners, and into a programmed long-term vision based on knowledge management of the phenomenon, its evolution and its impact on the population and the environment.

References

ACDI, PNUD. 2006. *Réalisation des objectifs de développement pour le millénaire dans les zones arides du Monde*. Groupe de réflexion 'Impératifs de développement pour les zones arides', version provisoire pour discussion. Programme des Nations Unies pour le Développement (PNUD). (In French.)

Commission européenne. La stratégie européenne de protection des sols. 2004. The EU Soil Protection Strategy: a New Framework. *Étude et Gestion des Sols*, Vol. 11, 3, pp. 349–352. CE, Bruxelles.

FAO. 1997. *La sécurité alimentaire des villes africaines: Le rôle des SADA, Collection 'Aliments dans les villes'. Programmes d'ajustement structurels et de stabilisation et sécurité alimentaire, Rome, FAO. Food and Agriculture Organization,* http://www.fao.org/DOCREP/003/AB788F/ab788f08.htm. accessed 11 April 2007 (In French.)

IDDRI. 2005. Rapport d'activités 2004. Institut de développement durable et des relations internationales, Paris.

MEDACTION. 2004. *Module 4: Design of a desertification policy support framework. General Part, Final report*. Retrieved September 15, 2003, from (Accessed 11 April 2007: http://www.icis.unimaas.nl/MEDACTION)

OSS. 2006. Note d'orientation et d'analyse de l'Initiative Grande Muraille Verte de l'espace CEN-SAD. (Accessed 11 April 2007: http://www.mediaterre.org/afrique/actu,20070906170846.html

Reij, C. and Steeds, D. 2003. Success Stories in Africa's Drylands: Supporting Advocates and Answering Sceptics. Paper commissioned by the Global Mechanism of the Convention to Combat Desertification. CIS/Centre for International Cooperation Vrije Universiteit Amsterdam, The Netherlands. http://www.csf-desertification.org/catalogue/2001_CSFD_Cornet.pdf (Accessed 20 August 2006). Responses to the impacts of land and environmental degradation and desertification, FAO. http://www.fao.org/docrep/x5318e/x5318e03.htm (Accessed 20 August 2006).

World Bank. 1999. Drylands, poverty and development. *Proceedings of the June 15–16, World Bank Round Table*, Washington, DC, World Bank, pp.

Chapter 3
Interventions and Implementation Needs for Sustainable Dryland Development

William D. Dar

1 Introduction

The CGIAR Future Harvest Centres carry out agricultural research to support development that combats desertification. With a wide array of partners around the world, we have been studying the problem for three decades. I want to share with you some of our observations on ways to improve the success of interventions and their implementation.

Desertification is a downward spiral, with a dead-end outcome. Towns are abandoned, livelihoods are lost. People become refugees or are driven to crime and violence as they fight over dwindling resources. The world must help these people to find a better future.

2 Loss of Land Cover: The Direct Cause of Desertification

To implement the right solutions, we need to be clear on the causes. Dryland degradation breaks out in patches where droughts, overgrazing and overtillage strip away the vegetation. This loss of land cover is the central cause of desertification.

Agriculture is the biggest user of land, and the largest employer of people in the drylands – most of them poor. Without vegetation, these rural poor have no means of making a living. Restore the vegetation, and life blooms once again.

When vegetation is lost, the topsoil blows or washes away, leaving impoverished soils that make it much more difficult for vegetation to recover. If the pressures persist, degradation can become a permanent feature of the land.

The poverty-stricken communities suffer the most, and sometimes they cause dryland degradation by growing crops year after year without restoring the fertility of the land, simply because they cannot afford to do so. We call this "soil mining"

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because it is like taking from the bank but never replenishing it. Eventually, the land becomes bankrupt and has to be abandoned. But who can begrudge them when they are just struggling to survive? The land is all they have. Once its productive capacity is lost, they're lost too. They know this, and they would like to sustain the land for their children. It is our job to help them find practical ways to do that.

However, it is not just the poverty-stricken who cause land degradation. Wealthier land users also overgraze these fragile areas, and often more rapidly. Government policies also inadvertently reward land degradation.

Large-scale development subsidies in the fragile drylands have sometimes unintentionally caused a lot of harm; for example, those that encouraged the draining of the Aral Sea for irrigation and large-scale mechanized tillage of these fragile soils, which created a desertification dustbowl nightmare in Asia. Moreover, when disaster aid compensates herders in the Middle East for losses of sheep following droughts, it unintentionally encourages larger herds, since the risks have been assumed by the government.

3 The Integrated Ecosystems Approach

We need a better way. In the past, most interventions have been sectoral, addressing either agriculture or environmental issues, but not both. Yet this is an artificial divide. Agriculture and the environment are interdependent. We cannot simply strip the land bare and then hope for the best. We need to respect and maintain the balance between natural ecosystems and agricultural ecosystems.

Natural ecosystems sustain agricultural ecosystems by providing goods and services like biodiversity, traditional foods, feeds and fiber, fuelwood and construction material, restoring the fertility of the soil, controlling weeds, and pollinating crops. And agro-ecosystems provide people with the incomes they need to be able to re-invest in protecting the land instead of mining and stripping it into oblivion. Both of course are affected by human and social factors, such as policies and markets, which influence the decisions that land users make.

Sustainability in the drylands will depend on learning to manage these interdependencies to keep both natural and agricultural ecosystems healthy. We call this taking an *integrated ecosystem approach*.

The integrated ecosystem approach implies that we need to find win-win solutions that both "save lands" and "build livelihoods". Without the reward of better livelihoods, land users will not invest in protecting their lands. And if we don't protect natural ecosystems, agricultural ecosystems will degrade until they become barren.

4 Putting the Integrated Ecosystems Approach into Action

To achieve this dual benefit to both lands and people, we have to change our ways of thinking. I want to highlight five changes in mindset we need to achieve in order to succeed.

1. To go beyond thinking of natural ecosystems as a bottomless well, there for the taking to drive our agricultural systems, we have to pay close attention to the balances, flows and interactions that sustain these systems.
2. We have to recognize that natural ecosystems produce valuable goods and services; so it makes good sense to "pay" for them by taking better care of the environment.
3. We have to think differently about the domain we work in. Ecosystems cross political boundaries. For example, changes in water and nutrient supplies upstream affect the water catchments downstream in a different country. In a similar way, our technical and scientific institutions cannot artificially separate themselves from the policy environment that will largely determine whether their technologies have any impact or not. We have to take a holistic, systems approach.
4. We have to change the tendency to think only about the limitations and risks of the drylands. We need to remember that the drylands also have advantages, such as plenty of sunshine and warm temperatures that favour the growth of a wide range of crops, and are less prone to livestock and human diseases. Some of the most productive agriculture in the world is in dryland areas. We need to envision the potential of these lands and peoples, and then work towards that vision rather than just managing misery.
5. We have to change how we think about diversity. For too long, agriculture has tried to reduce diversity, preferring monoculture on vast areas to supply just a few food commodities. A lack of diversity is especially risky in the drylands, where drought can wipe out a crop and cause famine. We have to use diversity to reduce risk and increase sustainability.

5 Diversification

By intermixing tree, crop and livestock operations, farmers can increase their incomes, provide more gainful employment for youth, and reduce their overall risk. But how can we implement diversity in a world that demands simple, uniform, high-volume solutions? I want to spend a little time on this issue, because I think this is a key dimension.

Diversity creates complexity, which is good for the environment but sounds difficult to manage. How do we scale up solutions when they have to be different in every situation to meet the needs and characteristics of local lands and communities?

We can do it by involving those who live on the land. We must provide a wide range of options for land users to choose from, not just single magic-bullet solutions, and these should not be inflexible, finished options – they should be prototypes that can be customized by communities to fit local conditions and needs.

This is a different way of doing business from what we are used to, so it requires major changes in our thinking and our approach. Since we need to involve land users in order to implement diversity, we need to spend more effort on understanding how land users adopt new technologies.

6 Sustainable Development Pathways

Poor land users do not just jump from simple to complex systems in one big leap. Instead, it is a series of small steps, adapting and fine-tuning along the way. As they adopt a new practice, if it is profitable or good for them in some way they will be motivated to adopt the next practice and so on, climbing the stepladder to prosperity.

So in implementing solutions, we need to be clear on how those solutions will start land users moving along such "*sustainable development pathways*".

An example of a sustainable development pathway that combats desertification is a technique we call fertilizer microdosing. By reducing the fertilizer rate to a very small microdose dropped in the cavity where the millet seed is sown in the Sahel, fertilizer use becomes more affordable and profitable. By overcoming the fundamental constraint of nutrient deficiency, microdosing causes yields to rise 50–100%. Because it is profitable, this first step gives farmers an incentive to take a second step, namely to work together to buy fertilizer in bulk at cheaper rates the following year, further increasing their profits and their motivation.

Once they are working together, they will take the third step of using their group as a means to share knowledge and obtain improved seed varieties that respond better to fertilizer, and to grow different crops. This adds still more to their profits. This development pathway increases the amount of vegetation protecting the land while at the same time improving livelihoods.

7 Profiting from Diversity

For better or worse, money makes the world go around. Diversified farming systems have to earn farmers an income or else they won't adopt them. Today's supermarket culture demands that farmers focus on a few highly uniform commodities rather than a diverse basket of products. And most environmental services are treated as free public goods. So how can a land user make a living from diversity?

This is a tough issue with many aspects. We know it is difficult to change people's eating habits or to rewire the global economy to start paying for environmental services, though many important efforts are underway to achieve this.

There are many dryland products that already have local and global demand, but producers have not been well organized and most of the profits are gained by intermediates or retailers. We can help rural communities capture a larger portion of the profit pie by assisting them in carrying out some processing and marketing steps themselves.

Non-governmental organizations in the developed world can assist by reducing the red tape to provide access to their lucrative markets, and sharing the knowledge needed to give underprivileged communities a competitive edge. They can also educate foreign consumers on the benefits of supporting sustainable agriculture through fair-trade mechanisms. Also, urban centres in the developing world are rapidly growing and will pay for diverse indigenous products because they are familiar.

Technical interventions and policies are critical because these determine the market competitiveness of agricultural products. We need to help land users in the transition from costly, artisanal production to more cost-efficient practices that are well integrated within market chains.

And policies should not embrace foreign subsidized imports that put local producers at a great disadvantage. They should establish a level playing field.

Through efforts like these, we can help impoverished land users capture the dollar value of diversity so they will be motivated to implement such actions on their farms.

8 Enhancing Knowledge-Sharing

Clearly diversity demands much greater sharing of knowledge. Sustainable development pathways, for example, require knowing when and where fertilizer can be bought at the best price, new crop varieties, new crops and ways to grow them, markets and daily price swings, export opportunities and so on.

This is where the underprivileged are at a real disadvantage, because of illiteracy, isolation and neglect by society. As we implement solutions to combat desertification, we must place major emphasis on closing the knowledge gap. Fortunately the information technology revolution gives us fantastic new tools, if we adapt them for the rural communities.

We should not think that they cannot join the ICT (information and communication technology) revolution. The spread of satellite dishes, cellphones and radios in remote villages demonstrates that they readily absorb new technology when it is affordable and manageable. Farmers need not become computer experts. For example, information from the Internet can reach these communities by using ‘old technology’, namely notices on a blackboard or announcements by bullhorn.

Though farmers may not be able to use computers themselves, village moderators can help them find the information they need. These moderators become bridges, brokers and catalysts for sustainable development and their role goes beyond just an information pipeline. They are also key actors in bringing communities together to work for the common good. For example, to manage rangelands in ways that are sustainable for everybody in the long term instead of a free-for-all exploitation for short-term gain.

We, as implementing agencies, must focus on ways to get land users involved and working together. We need to provide options that give them tangible rewards in the short term as well as in the long term. Rural knowledge brokers will be key players in the successful implementation of more sustainable land management.

9 Beyond Managing Misery

I want to close by emphasizing that the potential of drylands is great, much greater than we are usually led to believe by the stories of suffering that dominate our media. Better and more sustainable livelihoods *can* become a reality if we provide our assistance in different ways than in the past. The interventions and implementation must be holistic, diverse and knowledge-based and include social, economic and environmental considerations as well as technology. Simple magic bullets won't work.

Session I
Conservation of Biodiversity, Cultural and Natural Heritage in Drylands

Session I
Conservation of Biodiversity, Cultural and Natural Heritage in Drylands

Session Chair: Prof. Ricardo Valentini
Rapporteur: Prof. Charles Hutchinson

Synthesis of Presentations

A. Prof. Iwao Kobori, United Nations University, reported on 50 years of extensive and intensive study of traditional hydro-technology (foggaras in northern Africa and qanats in Asia) which demonstrated their value as efficient groundwater development and delivery systems. The spread of tube wells has destroyed many of these once viable traditional systems. However, over the past ten years, there has been a growing recognition of the value of foggara technology as an energy-efficient and sustainable alternative to pump wells. Unfortunately, displacement of foggara technology has resulted in the erosion of trad itional knowledge required to build and maintain them. Several steps are suggested: (1) translate documents that describe foggara technology into appropriate languages to facilitate dissemination; (2) conduct a global inventory of foggara resources that identifies local expertise and the cultural context in which the systems operate; (3) assemble kits that might be used for training; (4) prepare educational videos on foggara technology; and (5) support on-going foggara research.

B. Ms. Beate Scherf, FAO, described the important roles that livestock play in the agricultural economies of most, if not all, countries in the world's drylands. For example, some dryland human settlements in the Asian highlands are totally dependent upon livestock (i.e., yaks). Livestock genetic diversity is a critical asset for ensuring the continued productivity of breeds worldwide. Dry rangelands of the Near East, Central Asia, selected areas of east and south Asia, South and Central America and, Africa were found to hold considerable livestock genetic diversity. Existing data suggest that erosion of genetic diversity in drylands is low, but data are likely underreported and often of low quality and erosion rates may be much higher. This is a critical concern that needs attention. Mobility of herders is imperative for diversity maintenance and rangeland condition: keep borders open. In the end, it is management of humans that is the problem, not livestock.

C. Dr. Roseline C. Beudels-Jamar, Royal Belgian Institute of Natural Sciences, Belgium, showed that many large mammals in drylands of northern Africa and western Asia are threatened with extinction. Yet many are keystone species and critical to maintenance of biodiversity (e.g., oryx and gazelle in the Sahel). However, the focus of many efforts of biological diversity conservation is on areas of species richness, which tends to place these dryland species at a disadvantage. Thus, it is critical to identify alternative methods by which to mobilize conservation efforts for the large, distinctive megafauna of the drylands. Because of their charisma, these animals are also closely linked to local and regional cultures, and thus are well represented in their art, often becoming emblematic of them. Linking major archaeological and historic sites, in which the region is exceptionally rich, with natural sites of unique quality, through the theme of the great mammals, is a particularly promising approach to enhance the value of dryland resources.

D. Mr. Mohammed Al-Qawaba'a, The Royal Society for Nature Conservation, Jordan, described a dynamic "business ecosystems" approach that was employed to manage a Biosphere Reserve in Jordan. The model was based on understanding the nature of (a) the physical ecosystem, (b) the management organization, (c) the ecosystem users (i.e., nomads), (d) the relationships among these components, (e) how they change seasonally and through time, and (f) how the players and their relationships evolve in the face of those changes. In addition to this basic model of behaviour and evolution, the nature of the relationship with users will change over time in response to the management plan. User changes will be encouraged and supported through providing alternatives to herding, such as olive product development, and incentives to adopt these changes.

E. Dr. Pietro Laureano, Ipogea, Research Centre on Traditional and Local Knowledge, Italy, argued that traditional knowledge for water and soil management, protection of natural areas, and architecture (urban and rural) has considerable value. They are technically and scientifically sound and offer a foundation on which to build modern technology. They can facilitate adoption because they are understood and valued locally. To capture, organize and disseminate traditional knowledge, an inventory of indigenous knowledge is being built in a geo-referenced, web-enabled database in order share this technology and cultural heritage globally. "Use the revolutionary strength of tradition."

F. Dr. I. Hartmann, Ethiopean Cultural Heritage Project, Ethiopia, explained how development of the craft industry, based on the use of local materials, is an opportunity to foster community development. This can take two paths. One is focused on developing the national and international crafts market for art objects. A second is focused on developing crafts for the local and regional markets for functional, aesthetic and symbolic objects. The former focuses on developing the most talented artisans, benefits a relatively small number in the community, and may threaten local biodiversity. The latter focuses on developing the community, thus serving a broader spectrum of community members and local interests. Because there is a direct linkage between the crafts and their relationship to the local environment, this approach may foster attitudes that are more conservative of local biodiversity. Each approach has desirable elements that might be incorporated in some hybrid.

G. Prof. Durgadas Mukhopadhyay, Delhi University, India, used the Bishnoi tribe as an example of a unique dryland community in the Thar Desert of India that uses traditions and traditional knowledge to create sustainable productions systems and conserve local biodiversity. Sacred groves of trees or forest – Orans – are protected as a reserve for grazing animals and birds and the promotion of biodiversity. A Bishnoi woman, Amrita Devi, and 366 others died saving trees in 1730, and inspired the famous Chipko movement. The Khejari or *Prosopis cineraria* is a "wonder tree" that provides food, fuel, fodder, medicinal products, and also serves as a windbreak and sand stabilizing plant. Traditional techniques of water harvesting are used to produce highly valued winter crops. Pitcher irrigation is selectively used to conserve water. The Bishnoi have persisted and conserved their environment through "ecological sense and religious sensibility".

H. Dr. Mohamed Neffati, Institut des Régions Arides, Tunisia, described a programme that is underway to develop agricultural alternatives in southern Tunisia. It is based on production of plants for their unique medicinal and aromatic products selected from a large regional flora. Many of these are "spontaneous" plants that have become part of the rural pharmacopeia. The rural population in southern Tunisia has grown and the pressure of humans and animals on the land has caused degradation. The intent of the programme is to provide alternatives to farmers that are both more profitable and less water consumptive than their current cropping systems. Studies and field trials are underway to understand the cultural requirements of the plants and the quality of the products that they yield under different cultural practices.

Discussion

The bulk of the discussion during the session revolved around the use of traditional knowledge in general, and the rights to traditional pharmacopeia specifically. Discussion focused on trying to find the answers to two related questions:

(a) Who "owns" traditional technology?
(b) How can local farmers benefit most and best: from the production of the crops and medicinal plants for sale, and/or some form of licensing of intellectual property?

There was no resolution to either of these very pressing issues, and it is clear that there must be further debate before they can be resolved.

Chapter 1
Fifty Years of Personal Experience in Arid Land Studies

Iwao Kobori

Abstract Since my first field surveys in Western Asia (1956) I have been involved in many missions to Asia, Africa and the Americas which were organized by national or international academic institutions. During these missions I have found my life work: the comparative study of the foggara oasis of the arid zone of the old continent. The main case studies outlined in this paper were carried out in North Africa, Western Asia and China. In 1962, at the UNESCO Crete Symposium, I had an excellent opportunity to receive critical advice for my topics from distinguished dryland scientists.

Although the foggara system is globally distributed, we recognize the imbalance of quality through these case studies. For example in Iran, several case studies were carried out by western scholars in the 1950s but the subject was given little attention from Iranian authorities. Because of the rapid growth of the urban population, Iranians began to change their water system from traditional hydro-technology, such as the qanat system, to modern pumping wells. However, in the last ten years, they have recognized the positive contribution of traditional technology from the point of energy-saving aspects and sustainability of the system. The main topics for combating desertification designated by UNCCD include the usefulness of traditional technology. UNESCO together with the Iranian government supported the establishment of the International Qanat Research Center in Yazd in 2005, and in 2004 the European Commission started a three-year project on foggara in North Africa. This paper explains the changes occurring in foggara oases in the last fifty years based on my field studies.

Keywords Foggara, qanat, underground water systems, arid lands research studies

1 Introduction

Men against the Desert, published in 1953 by Ritchie Calder, is one of the most stimulating books I have ever read and its good suggestions have paved the way for my lifework. Calder conducted a preliminary study leading to the development of the

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United Nations University, Japan

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

UNESCO Arid Land Programme, which was launched in 1951 and was elevated to a Major Project of the Organization in 1957. His reports on various problems in arid lands were striking to readers. The book was later translated into Japanese by Mr. Kai. I found the descriptions fascinating, and it inspired me to travel to places mentioned in the book. Fortunately in 1956, I achieved the dream of visiting them as a member of the Tokyo University Iran-Iraq Archaeological Expedition. During that mission, I became interested in traditional underground water systems in arid lands, especially the qanat system in Iran and its adjacent regions. In this sense, the year 1956 was an unforgettable milestone to begin comparative studies of the qanat system.

Since then, I have devoted 50 years to scientific research on arid lands covering Asia, Africa and North and South America, and it delights me to find the year's chronological coincidences with the start of UNESCO's Arid Land Programme and the Office of Arid Land Studies at the University of Arizona.

2 Early Interest in Arid Lands

My first visit to arid lands was to a region of northeast China, formerly known as Manchuria. It was during the Pacific War in 1944. As a geography student at Tokyo Imperial University (now the University of Tokyo), I could observe various arid landscapes such as Yardang, Balkhan, and microliths that were not found in Japan and I was able to study the livelihoods of the Mongols on the steppes. Following Japan's defeat in 1945, there were no opportunities for me to travel abroad to study arid lands. I was obliged to conduct library research such as reading many classical reports of expeditions to China, Central Asia or the Middle East. From 1956 onwards, I started to participate in three important missions sponsored by the University of Tokyo to Iran–Iraq (1956), the Andes (1958), and West Asia (1961, 1964, 1967 and 1970). Although these missions were for an archeological or anthropological purpose, I was still able to pursue my interest in arid lands during field work. In 1981, I visited China by the invitation of the Chinese Academy of Sciences and met with leading scientists of arid land studies. I also visited important institutions in China, especially the North Western regions such as Xinjiang and Kansu provinces.

In addition to these academic missions, I was asked to become a member of the Board of Trustees of ICRISAT (1976–1982) and later became a member of the Board of Trustees of ICARDA (1996–2002). During my affiliation with Japanese universities, such as the University of Tokyo (1949–1985), Mie University (1985–1987) and Meiji University (1987–1995), I organized special missions for comparative studies of oases and qanat systems (1977–1990) and for the study of technology transfer in the Sahara oases (1990–2000). These missions were sponsored by the Japanese Ministry of Education and the Toyota Foundation. Needless to say, we owe very much to the generous academic and logistical collaboration of academic and scientific institutions and individuals in the host countries such as China, Syria and Algeria.

3 Early Work and Research

Following my first involvement with the University of Tokyo missions, I had opportunities to participate in several desert programmes: Pakistan (1979–1980, feasibility studies of the utilization of an asphalt moisture barrier in arid lands), Egypt (the New Valley project in 1962, 1963 and 1969), and Tunisia (Middle East Peace Initiative in 1994; Waste Water Use and Zero Emission feasibility study by United Nations University in 1998). These experiences allowed me to become better acquainted with sustainable development in arid lands. Among the international conferences and workshops I attended, the first was the UNESCO symposium on 'Land use in semi-arid Mediterranean climates' held in Crete, Greece in 1962 where I presented a paper entitled 'Human geography of irrigation in the central Andes'. At that time, I met with leading researchers in arid land studies who gave me friendly comments to my approach to research. In 1980, on the occasion of the 24th International Geographical Congress (IGU) held in Japan, we organized the first symposium on desertification called 'Desertification in and around arid lands' at the foot of Mount Fuji, which was supported by UNESCO–MAB and the United Nations University (UNU). A report by a Chinese delegate, Professor Chao Sung Jao, who demonstrated excellent maps of Chinese deserts, gave me a remarkable perspective, which I was able to use in my research activities on deserts and desertification in China. The IGU Commission on arid lands continued well after the Mount Fuji meeting, and I was able to attend several symposiums in Germany, France and the United States as a member of the Advisory Committee of the Natural Resources Program, UNU (1976–1982). Although most of the participants were geographers, extensive information on the progress of arid land studies was helpful for my research.

4 Later Involvement with Arid Land Studies

I gradually developed my worldwide network of arid land institutions and specialists. In 1993, I first became involved with the International Desert Development Commission (IDDC) at the Mexico meeting; there I forged contacts with scientists from various academic disciplines. In Japan, a group of scientists who were interested in arid lands established the Japanese Association for Arid Land Studies. The inaugural meeting was held at Meiji University on 18 May 1990 in Tokyo. I was nominated as the first president of the association (1990–2000), and my inaugural speech was 'Learning from Deserts'. In the speech, I stressed the importance of future international cooperation in arid land studies. In the early days, many people asked how it was possible to sustain this organization in a country with no deserts in her territory. My answer was always very simple: Although we have no deserts in Japan, arid lands occupy around 40% of the terrestrial surface of our planet and there are many important problems to be analyzed for the future benefit of humankind. This association has just celebrated its sixteenth anniversary in 2006, and it has over 500 members from diverse disciplines, including natural sciences, engineering, social sciences and humanities. Those members cover almost all the institutions and universities concerned with arid land studies.

Following the UN International Conference on Combating Desertification (1997, Nairobi), and especially after the UN Conference on Environment and Development (Rio Summit) in 1992, Japanese companies began to show interest in combating desertification and to improve desert conditions. Several leading Japanese corporations joined this organization and became interested in the development of new technological strategies for finding solutions to the problems faced in desert areas. The Japanese Government has also shown interest in multi-lateral programmes, such as Mechanism of Desertification and Dust Storm in Eastern Asia by the Science and Technical Agency. Field research connected with arid land studies in Africa and Asia has been developed by several universities, funded by the Ministry of Education, while JICA (Japanese International Cooperation Agency) has sent several project teams concerning arid land development. UNU has also launched a new arid land programme in collaboration with UNESCO and ICARDA in 1998, concentrating on sustainable management of marginal drylands and traditional hydro-technology.

5 Case Studies

5.1 Algerian Sahara (Tidikelt)

I have worked in arid lands for many years but I have stayed nowhere as often as in the oases of Tidikelt in the Algerian Sahara. The main purpose of my research was, firstly, to conduct comparative studies of the oasis with the qanat system on the old continent and, secondly, to record the evolution of society in the oasis after the introduction of new technology. In 1962 – at the UNESCO Symposium on Land Use in Semi-arid Mediterranean Climates in Crete – I happened to meet excellent academic advisors and colleagues such as Michel Batisse (father of UNESCO's Arid Land Program), R. Capot-Rey, J. Dresch, P. Rognon, K. Troll, X. de Planhol and I. P. Gerasimov. In the Algerian Sahara, I have closely collaborated with the Centre National des Recherches sur les Zones Arides (CNRZA) and found a wonderful local counterpart, Mr. Ahmed El-Hadj. Following almost 16 years of preparation, I chose In-Belbel, Tideket, as an ideal place for continuous research. It takes four days by camel or four to five hours by car (distance 120 km) to reach In-Belbel from Aoulf (Wilaya Adrar). Aoulf can be reached by plane from Adrar or Salah. From Tokyo, I flew to Adrar from Algiers and traveled to Aoulef by car. I was struck by the warm hospitality of the people upon my arrival at In-Belbel.

In 1977 the population in the oasis was almost 300 and consisted of traditional date palm gardens fed by foggara and one school with one teacher and seven pupils. There was no electricity or telephone and only one or two pick-up trucks. Nevertheless, villagers welcomed us with great hospitality and they allowed us to stay as guests of the village. Between the first visit in 1977 and the last in 2005, I visited the oasis several times either with my colleagues or alone but always with Ahmed El-Hadj. We lived in a local house, a *zaouia*, a kind of guest house for travelers that was originally a religious building. We ate local food and made a cadastral map of 1:5000 scale including all the resources in the village. Due to a lack of documents, the origin of this village was not clear. According to oral tradition, a marabout came to this area and discovered a fountain and dug the foggara by himself. From the top of the surrounding hills, one can easily observe three evolving stages of habitat: the abandoned old Kasbah, the modern ksar and the newly developed housing zone subsidized by the government. The main sources of income for the villagers were agricultural products from the garden as well as small ruminants (sheep and goat). The life of the villagers was totally dependant on the foggaras, which provided them with water for drinking, washing and irrigation. Before the first Sahel drought (1968–1972), Tuareg caravans from Mali or Niger came to this oasis to exchange products like dried meat, tobacco and dried dates. Surrounding the oasis there is an area of grassland and a small group of livestock. The caravan from Mali would come to feed their camels. However, following the drought the vegetation changed; the grass cover decreased and today caravans are no longer seen in the area. In the village, there used to be a shaduf (now abandoned), a shallow well and an old pumping well with a diesel engine. Today, they have rehabilitated the size of the pumping well to obtain enough water from a depth of 150 m. When we began our first survey in 1978, the population was very busy with moving from the old habitat to the new housing area. They were also working to dig the second foggara because of the diminishing water quantity of the first foggara. Compared to other Arab regions, women in the village also work in the gardens. Their sense of distance is unique and they travel by night from oasis to oasis watching the stars and the shape of the mountains. In 1980, the government installed houses with solar batteries on deserted roads, but these collapsed during severe winds. I visited and stayed at this village nine times (in 1977, 1979, 1980, 1981, 1992, 1993, 1999, 2000 and 2005). After a quarter century, I noticed that the quality of life in the oasis has slowly improved for the inhabitants, and agricultural production increased as the water supply improved. Commercial business with other oases also significantly improved. For example, in 1961 (even in 1977) it was difficult to find food products from areas other than the oasis. Today, there are legumes from local merchants in neighbouring oases. In other words, the infrastructure of the oasis has been modified by central government policy in order to develop the south from the 1980s.

Some 15 km east of In-Belbel, there is an oasis called Matriounne. Even today the population is small with one primary school and one foggara for water. In the late 1980s, they had begun to build a new garden and greenhouses around the oasis using water from the pumping wells. In the Sahara, greenhouses are made from vinyl sheets and the doors of the greenhouse are left open. The mode of irrigation is the drip method. Concerning education, there were seven teachers and 140 pupils including girls in In-Belbel in 2005. Between 1977 and 2005, however, I observed the changes that were taking place in the Sahara Desert. In 1977, the children did not have proper clothes to wear, they did not even have pencils to write with, so on my next visit I bought them some. The living conditions in the deserts improved as people moved from their homes to search for better jobs. I noted that the jobs were in the oil and petrochemical industry, and this brought wealth. Although this was the general trend in the Saharan desert, things remained practically unchanged in In Belbel (except for the level of education) as they relied on aid from the government. Thus, the major requirement for the people of In-Belbel are good asphalted roads to the nearest big city, an ambulance and a good electric power supply.

Hadj is a good Muslim (he carries out five daily prayers) and our friendship has lasted more than 40 years. I met Hadj for the first time in 1961; he was recommended by the chief of Aoulef. His grandfather came from Mali as an agricultural worker; Hadj is married to an Arab woman and has five children. He owns a small house and a homestead garden. Following the independence of Algeria in 1962, he tried to obtain a French language certificate to work as a primary and secondary teacher. Whenever I went to the Sahara, his house was always my base camp, and we often talked about world events. In doing so, I studied contemporary world political events from desert areas, especially from the Sahara. The Sahara runs through the southern part of Algeria and has been very peaceful compared to the northern part of Algeria. About ten years ago, I returned my gratitude to Hadj for his help over the years by inviting him to Japan. He arrived with my old jacket and camera that I had presented to him during my stay in In-Belbel. He showed great dignity and pride.

During my field research in Tideket, I witnessed several natural hazards such as sandstorms, one of which buried a villager alive near the oasis, and the invasion of locusts, which damaged and destroyed crops. I was surprised to see children eating the locusts.

5.2 Syria

In Syria we carried out research on qanawat Romani (Roman qanat) in an oasis called Taibe, 80 km north-east of Palmyra. It is situated in the central steppe area and had a population in 1977 of about 300. The population has begun to move from the hill tops to the plains and use water from the qanat for their home and gardens. The main income derives from commerce or trade, and in some cases from smuggling, crossing borders to Kuwait, Saudi Arabia or Jordan. The income based on agriculture, mainly olive trees, makes up approximately one-fifth of the total income; the remainder comes from animal husbandry and commerce, although the major source of income for the villagers is animal husbandry. We discovered the name of this village on a Byzantine map and also found prehistoric remains on the surface, which have not been studied archeologically. We conducted field observations starting in 1978, 1980 and 1987 and saw a slow change in livelihoods. Improvements in the transport system, such as asphalted roads, increased the villagers' chances to contact other oases. Nowadays, they have their own small clinic, which was donated by Japan. I visited this place several times from 1977 to 2006, and started the construction of a new primary school, which has several teachers, including female teachers, today. A large mosque has been built with donations from villagers. The main source of water used to come from qanawat Romani, but this system has been almost completely abandoned today – villagers use the same underground water source, albeit through a new open canal. Although I have never been to Mecca, I draw similarities between Mecca and Taibe, as they are both oases at commercial and trade crossroads. Once I saw the village elders call Azzan (the call for indicating the time of sarat or prayer) from the minaret and people assembling in the small mosque. It seems likely that Taibe began as a small tel[1] along the Roman roads, and nomads came to settle there over generations. Even today, the biggest animal owners live in big cities like Aleppo, yet they breed their animals in the villages. The animals are brought by large trucks to sell at the city market – the villagers are paid in cash or with animals. The government subsidizes cereals for animals based on the number of animals.

The central government supports nomads by constructing wells for the animals and providing an itinerant school for children. Recently, natural gas was discovered in the Syrian central steppe area. As a result, frequent traffic of gas and oil transportation from Iraq and the development of tourism may alter the social environment of the Taibe area. The Syrian central government started the Badiya ("steppe" in Arabic) programme to support nomads and oasis dwellers in the steppe.

5.3 China

China is an important area for comparative studies of the qanat system. In I981, I started surveys of Chinese karez[2] with kind support from the Xinjiang Institute of Biology, Pedology and Desert Research, Chinese Academy of Sciences. The mission was funded by a research grant from the Japanese Ministry of Education. The few studies on karez that exist have been carried out mainly by archaeological historians and geographers in China and abroad and provide a general descriptive introduction. However, I have found excellent traditional engineers called kung chang, which are equivalent to the Muqqani in Iraq. Muqqani have the

[1] An artificial mound consisting of the accumulated remains of one or more ancient settlements (often used in Egypt and the Middle East as part of a place name).

[2] A water management system reliably providing water in hot, arid and semi-arid climates. This technology was first developed in ancient Persia and then spread to other cultures, especially along the Silk Road as far east as China.

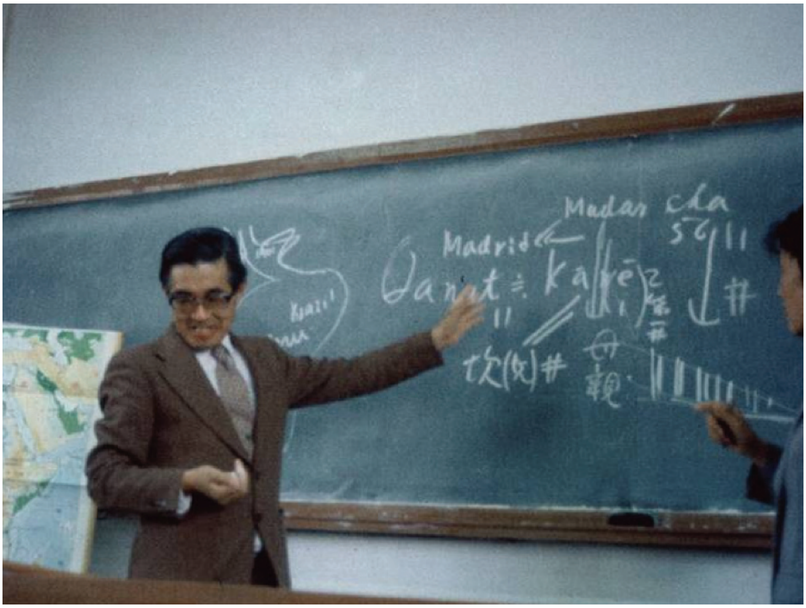

Fig. 1 Lecture in Xinjiang university-1981

Fig. 2 Panoramic View of In Belbel (2002)

Fig. 3 UNESCO Crete Symposium-1962

technological know-how for digging karez and are acquainted with the custom of water rights or the division of water. It is almost impossible for foreigners to conduct socio-economic field surveys or use topographic maps or aerial photos, which are strictly limited. Of course, nowadays we may use satellite imagery, but the necessary land survey is not so easy under these circumstances. Our mission to China attempted to obtain general information on karez in the Turpan Basin, as well as to conduct small scale mapping of selected karez (results of our survey were published in Japanese).

In 1990 an international conference on karez irrigation was organized in collaboration with the MAB National Committee of China, UNESCO and the Xinjiang Institute of Biology, Pedology and Desert Research (Kobori, 1993). The conference was supported by the Chinese Academy of Sciences, Xinjiang Uigur Autonomous regions and Meiji University, and included contributions by Chinese and Uigur authors on to the past, present and future of karez in China.

Karez irrigation was introduced from Persia in the eighteenth century during the Qing Dynasty. Technology transfer from inland China (Shensi province) began in the first century A.D. following the invention of the technique by Uigur shepherds. There have been many debates over the origin of karez irrigation, but the matter has yet to be settled. The present and future of karez in the Turpan Basin is also problematic. Generally speaking, karez systems are now in decline because of rapid rural development. Under these circumstances, it is important to balance water use among karez, pumping wells and open canals. The Xinjiang Karez Research Society was established following the international conference, and as a consequence, the budget for the conservation of the karez system increased. The Sino-Japan Karez Study Group (1988–1990) has helped to demonstrate the importance of this traditional system to the administration concerned.

In 2006 the Society published a monumental book, *Karez in Xinjiang* (two volumes totalling 1,143 pages in three languages, Chinese, Uigur and English: Xinjiang People's Publishing House, Urmuqi). This inventory covers all karez sites in Xinjiang and describes physical settings and hydrological data. Other qanat countries do not have such a thorough data book.

6 Conclusion

In addition to the aforementioned case studies, I have learned many lessons through my qanat studies and from arid land research around the world. As there are no arid lands in Japan, I have had intensive contact with international and local institutions and individual researchers, as well as desert peoples. I had to master local languages at least for everyday conversation.

Bibliographical works in libraries outside Japan were quite costly and difficult to obtain. In the 1950s and 1960s, research grants from the Japanese Ministry of Education were quite modest and occasionally my participation at important academic gatherings such as the UNESCO Crete meeting (1962) and the International Geographical Union (IGU) Moscow meeting in Ashkhabad, Turkmenistan, would have been impossible without the hearty support of my family and friends. From the 1980s on, financial grants for oversees research have steadily improved and young researchers now have the opportunity to conduct arid land field studies abroad.

Based on my past experiences, I would like to make two observations about the future of arid lands. Firstly, I have witnessed a huge technological evolution in arid lands research. I began my research in the field using my own drawings and topographical maps that were available at the time. We are now able to use aerial photos and even sophisticated technology such as remote sensing and geographic information system (GIS), which enable us to pinpoint research locations. Furthermore, bibliographical surveys, interlibrary services and Internet communication allow for more prompt access to sources of information. And due to technological advances in transport, we can travel to areas that previously were difficult to reach.

Secondly, the number of local researchers focused on arid lands has notably increased. For example, at the Nairobi conference (1977), many African and Middle Eastern national reports on desertification were written by non-native scholars and consultants. Today there are a good many local researchers. However, inter-linkages between institutions have yet to be reinforced, especially communication between francophone and anglophone scientists. For example, multilateral collaboration of qanat studies was made possible at the International Conference on Qanats in 2000 on the initiative of the Iranian Government and UNESCO, where the participants were able to exchange expertise with scientists from various linguistic and cultural backgrounds. Following the conference, the Iranian Government established the International Centre on Qanats and Historic Hydraulic Structures (ICQHS) and the European Commission set up an important project on foggara and shaduf in the Mediterranean Basin. The new trends in qanat studies not only include historical perspectives but are also geared more towards sustainable development by means of appropriate technology.

References

Kobori, I. 1962. Human geography of irrigation in the Central Andes. *Land Use in Semi-Arid Mediterranean Climates*, *UNESCO Arid Zone Research* XXVI, UNESCO, Paris, pp. 135–137.

———. 1964. Some considerations on the origin of Qanat system. *Memorial Collected Papers Dedicated to Professor E. Ishida*. Tokyo, pp. 157–163.

———. 1969. Le système d'irrigation dans le Sahara central – Tidikelt. *Bulletin of the Department of Geography*, *University of Tokyo*, No. 1, pp. 1–32. (In French.)

———. 1973. Some notes of diffusion of Qanats. *Orient*, Vol. 9, pp. 43–66.

———. 1976. Notes on Foggara in the Algerian Sahara. *Bulletin of the Department of Geography*, *University of Tokyo*, No. 8, pp. 1–32.

———. 1979. *Qanawat Romani of Taibe Oasis*. The Tokyo University Scientific Mission for the Comparative Study of the Foggara Oasis in the Arid Zone of the Old Continent, Report No. 1.

———. (ed.). 1982. *Case Studies of Foggara Oases in the Algerian Sahara and Syria*. The Tokyo University Scientific Mission for the Comparative Study of the Foggara Oasis in the Arid Zone of the Old Continent, Report No. 2.

———. 1987. *Mambo Qanat in Japan*. Mieji University, Tokyo. (In Japanese.)

———. 1993. *Proceedings of the International Conference on Karez Irrigation*. Urumgi, Xinjing, China. (In Chinese and English.)

———. 1995. *Water System in Arid and Semi-Arid Lands* (Kansoo-chiiki no Suiri-taikei). Taimei-do, Tokyo. (In Japanese and English.)

———. 1996. *Water System in Arid Lands: Formation and Diffusion of Qanat*. Taimei-do, Tokyo. (In Japanese and English.)

———. 1999. How to cooperate with international activities for research and development in deserts: A Japanese view point. *Proceedings of the Fifth International Conference on Desert Development: The Endless Frontier*, I. R. Taylor, Jr., H. Dregne and K. Mathis (eds.). International Center for Arid and Semiarid Land Studies, Office of International Affairs, Texas Tech University, Lubbock, TX, pp. 6–14.

———. 2000. Urgent need for international cooperation for comparative studies. *Proceedings of the First International Conference on Qanat*, Yazd, Iran, Vol. VI, pp. 161–162. (In Persian and English.)

———. 2002. *Le japonais de In-Belbel*. Documentary film by Procom International (45 min). (In French.)

———. 2005. Lessons learned from qanat studies: A proposal for international cooperation. *A History of Water Issues: Lessons to Learn*. United Nations University, Tokyo, pp. 187–194.

UNU Desertification Series. 1998. New technologies to combat desertification. *Proceedings of the International Symposium*, Teheran, Iran, 12–15 October 1998. Environment and Sustainable Development, UNU, Tokyo.

———. 1999. Water management in arid lands. *Proceedings of the International Workshop*, Medenine, Tunisia, 18–22 October 1999. Environment and Sustainable Development, UNU, Tokyo.

Chapter 2
Livestock Genetic Diversity in Dry Rangelands

Beate Scherf[1], Barbara Rischkowsky[1], Irene Hoffmann[1], Mateusz Wieczorek[1], Alberto Montironi[2] and Ricardo Cardellino[1]

Abstract The paper explores the significance of livestock genetic diversity in the dry rangelands of the Near East, Central Asia, and selected countries in East and South Asia, South and Central America and Africa. The selection of rangeland *versus* non-rangeland countries is based on the production system maps developed by the International Livestock Research Institute (ILRI). The analysis includes cattle, sheep, goats, camelids, horses and asses. Data on breed distribution and risk status are obtained from the global database of the Domestic Animal Diversity Information System (DAD-IS), which contains information on 37 species of domestic animals used in food and agriculture from 180 countries.

The contribution of the rangelands to the overall livestock production is used to provide an indicator of the economic importance of rangeland livestock breeds within each geographical region. The share of rangeland breeds in overall breed diversity within the respective regions or countries is assessed. The magnitude of the risks of erosion and breed extinction faced by livestock genetic resources in the rangelands is then contrasted with the overall risk status of breeds for each geographical area. Rangeland breeds are usually raised by specific ethnic groups and have developed over a long period of time. Examples of specifically adapted species and breeds are highlighted for better understanding of their contribution to human food security. An appropriate utilization and maintenance of this genetic diversity will help to ensure human food security in these harsh environments in the future.

Keywords Livestock genetic diversity, breed distribution and risk-status, pastoralism, transboundary breeds

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1 Introduction

The domestic animals important today for food and agriculture production are a consequence of processes of domestication that have existed for almost 12,000 years. As human societies evolved, migrated or extended over the area under their control, animals were domesticated and breeds were developed so as to provide for human needs in the new environments. The result was the development of genetically distinct breeds as these animal populations responded to two interacting forces: the selection pressures imposed by human communities, identifying and making greater use of preferred genetic types amongst the available animals, and the selection pressures imposed by environmental stress factors. The 40+ domesticated species contribute directly and indirectly to 30–40% of the total value of food and agricultural production.

Animal genetic diversity allows farmers to select stocks or develop new breeds in response to environmental change, threats of disease, new knowledge of human nutrition requirements, changing market conditions, and societal needs – all of which are largely unpredictable. What is predictable is the future human demand for food. This demand will be felt most acutely in developing countries, where 85% of the increased food demand is expected. Given the above facts, domestic animal diversity is critical for food security (FAO/UNEP, 2000).

In many agro-ecosystems, livestock is an important element. This is particularly true for arid and semi-arid areas, where extensive grazing frequently is the only means to produce (high-value) agricultural products under the given eco-climatic conditions (Scoones, 1994). Pastoralism and agro-pastoralism are the key agricultural production systems in many drylands. In these systems, animals have become an essential aspect of the cultural, social and religious life of the people who depend upon them (FAO, 2000), and specific breeds adapted to the needs of the people and the environmental stressors have been developed. In many countries, livestock waste products are highly important sources of fuel and are widely used for cooking and heating. This is particularly true for dryland systems and particular dryland species such as cattle, camel and yak (FAO, 2000). In sub-Saharan Africa, drylands constitute nearly half of the land area, and in some countries pastoralists represent the majority of the population. Nevertheless, most governments of countries with pastoral populations are reluctant to invest in pastoral production systems, since pastoralism is regarded as backward and possessing little potential for improvement (Rass, 2006). This attitude, interlinked with other pressures, has led to the situation that pastoralism worldwide is threatened as a livestock production and livelihood system (Blench, 2001). Pressures on pastoralists include increased human densities, inappropriate government policies on land tenure leading to the encroachment of cultivation onto rangelands, private ranching and protected areas, failure to develop appropriate livestock and human services, recurrent drought and armed conflict (Devendra et al., 2005). Consequently, animal genetic resources (AnGR) kept in these systems are potentially threatened.

The objective of this paper is to assess the share and the importance of livestock genetic diversity maintained by dry rangelands as compared to the global situation.

2 Material and Methods

The analysis commenced by selecting and including countries with drylands. The North American and European regions were completely excluded from the analysis. The countries to be included in the other regions were selected by visual appraisal of the livestock production systems maps published by Thornton et al. (2002). These maps use similar production system categories to those used by Seré and Steinfeld (1996). In addition, FAO country profile maps showing the length of growing period were consulted (http://www.fao.org/countryprofiles). For the purpose of this paper, drylands were defined as lands with a growing period of less than 120 days (FAO, 1993).

As a result, the following geographic regions were considered: all countries of the Near East, selected countries in Latin America, Africa and Asia, while the Southwest Pacific, Southeast Asia and the Caribbean were excluded from the analysis. In total, 34 countries were included in the analysis with the following regional distribution: Africa – 16 countries; Asia – 5 countries; Near East – 7 countries; and Latin America – 6 countries.

The assessment of the contribution of drylands to the global supply of animal products and overall production of the share of drylands of the populations of the selected species was based on FAO statistics for the selected countries. The assignment of country-level information from FAO statistics to dryland livestock production systems (Groenewold, 2004) followed the method developed by Seré and Steinfeld (1996) for livestock production systems. Seré and Steinfeld distinguished grassland-based systems (LG[1]), mixed-rainfed systems (MR), mixed irrigated systems (MI) and landless systems (LL). A further distinction within these three systems is based on their occurrence in temperate zones and tropical highlands (e.g., LGT), humid and subhumid tropics and subtropics, and arid and semi-arid tropics and subtropics. The statistics presented in this paper were calculated for grassland-based systems in semi-arid tropics and subtropics (LGA), and mixed rainfed (MRA) or mixed irrigated systems (MIA) in the arid and semi-arid tropics, and subtropics with a considerable proportion of pastureland were included. Human population figures are presented in relation to the resource base (land and livestock numbers). Livestock production and productivity as well as density indicators were also calculated.

Assessment and reporting on the state of livestock genetic diversity and on the state of management of animal genetic resources in general is one element of FAO's Global Strategy for the Management of Farm Animal Genetic Resources. To assess the current situation and encourage country-level actions, the FAO coordinated a first country-driven State of the World's AnGR reporting process. The FAO also maintains the Domestic Animal Diversity Information System – DAD-IS (http://dad.fao.org). The information system includes a global inventory of animal genetic resources, containing national data reported by more than 180 countries. It covers

[1] Grassland-based systems are livestock systems in which more than 90% of dry matter fed to animals comes from rangelands, pastures, annual forages and purchased feeds, and less than 10% of the total value of production comes from non-livestock farming activities. Annual stocking rates are less than 10 livestock units per hectare of agricultural land.

more than 30 species used for food and agriculture. In 2005, the databank was updated and further developed based on 169 country reports on management of animal genetic resources received by the FAO during 2002–2005. The number of within-country breed populations reported to the FAO increased to nearly 14,000 for all mammalian and avian species recorded. However, it has to be noted that even though data has been collected for more than ten years, there are still large gaps in the information on population sizes and structures.

This database was used to assess breed diversity and risk status. The analysis was restricted to mammalian species that are sustained by dry rangelands, namely camelids (Bactrian camel, dromedary, llama and alpaca), cattle and yaks, goats and sheep, as well as asses and horses. Breed entries for these species were classified into two categories: breeds that occur in drylands or were developed in drylands, and all other breeds of the species in the analysis. Once the lists of breeds for the selected countries had been prepared, a number of experts were consulted to assist in the classification of the breeds of a particular country or sub-region in the two categories.

3 Results and Discussion

3.1 Resource Base, Production and Productivity

Table 1 provides an overview of general data on human population, the resource base in terms of land, the numbers of cattle, and sheep and goats, major outputs for these species, and several productivity and density indicators. For these parameters, the table presents data for the drylands of the selected regions and compares them to the world totals. In terms of area, Asia contains most of the drylands of the world, followed by Africa, the Near East and Latin America. Thirty percent of the world's grazing lands are classified as drylands, which maintain 6% of the world's human population, 9% of the world's cattle and 18% of the world's sheep and goats. Density of the human population per hectare of land is, particularly for grazing land, significantly lower than the world's average. However, only 5% of the world's beef meat, 14% of the sheep and goat meat and 5% of the milk is produced in dryland systems. These figures originate from official governmental statistics reported to FAOSTAT and probably mainly include marketed products. Based on those estimates, output per head of animal is 50–70% of the world's average, depending on the product. Our calculation for selected countries based on the Seré and Steinfeld classification covers 24% of the Earth's land surface, whereas the total land area covered by drylands according to IUCN (http://www.iucn.org/wisp – The World Initiative for Sustainable Pastoralism) stretches over 41%.

The importance of drylands becomes more obvious when looking at countries that are classified entirely as drylands, such as Djibouti, Somalia, Eritrea, Sudan, Niger, Mauritania, Benin, Chad, Guinea-Bissau, Guinea and Mali. The pastoralists in these countries not only own a major proportion of the national herd, but they also contribute a significant share to national meat production – 41% for East Africa and 33% in West Africa (Rass, 2006). But it needs to be noted that

Table 1 General data, production of main products and productivity of dryland systems in selected countries (based on Groenewold, 2004; Seré and Steinfeld, 1996).

Parameters	Africa	Asia	Latin America	Near East	Drylands Total	World	%
Human populations (millions)	120	96	80	67	364	6,135	6
Resource base							
Permanent pasture (millions ha)	346	414	72	253	1,085	3,591	30
Arable land (million ha)	32	48	16	17	114	1,474	8
Irrigated land (million ha)	2	14	4	6	26	227	9
Livestock numbers							
Cattle (million head)	54	17	29	19	119	1,360	9
Dairy cows (million head)	9	7	5	3	24	231	11
Sheep and goats (million head)	117	116	22	71	327	1,780	18
Major outputs (million kg)							
Beef meat	963	754	1,148	228	3,093	57,769	5
Sheep & Goat meat	432	717	81	417	1,647	11,917	14
Dairy milk	3,615	11,690	6,813	3,371	25,489	503,417	5
Other milk	2,329	1,194	30	1,707	5,260	91,828	6
Total milk production	5,944	12,884	6,843	5,078	30,749	595,245	5
Productivity and density indicators							
Beef meat (kg/head)	18	44	40	12	26	42	61
Sheep & goat meat (kg/head)	4	6	4	6	5	7	68
Milk yield/cow (kg)	399	1,650	1,363	1,006	1,041	2,176	48
Rum meat/inhabitant (kg)	12	15	15	10	13	11	115
Grazing land/inhabitant (ha)	3	4	1	4	3	1	510
Arable land/inhabitant (ha)	0.3	0.5	0.2	0.3	0.3	0.2	130

sub-Saharan Africa is home not only to the greatest share of the world's pastoralists (50 million), but also to the majority of the world's extremely poor pastoralists (54%). Poverty incidence among pastoralists within the different countries in sub-Saharan Africa ranges from 25% to 55% (Rass, 2006).

3.2 Breed Diversity

As expected, livestock diversity in the Near East is mostly maintained in the drylands: 90% of all the region's breeds are bred and kept in the drylands (Table 2). In Africa, 56% of its total diversity is adapted to drylands; in Asia, 42%; and in Latin

Table 2 Number of local breeds (including extinct breeds) reported per region

	Africa		Asia		Latin America		Near East		Total	
Species	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land
Cattle	176	76	257	55	148	17	44	34	625	182
Yak	0	0	26	26	0	0	0	0	26	26
Goat	86	45	184	81	26	17	34	31	330	174
Sheep	114	68	276	149	74	12	51	46	488	275
Ass	18	17	39	27	21	7	17	17	95	68
Horse	42	17	142	43	65	4	14	14	263	78
Alpaca	1	1	0	0	2	1	0	0	3	2
Bactrian camel	0	0	8	7	0	0	0	0	8	7
Dromedary	44	43	13	13	0	0	23	23	80	79
Llama	0	0	0	0	3	2	0	0	3	2
Σ	481	267	945	401	312	60	183	162	1,921	893

(Selected countries)

America, only 19%. On average, 46% of the breeds in the four regions are adapted to drylands.

The distribution of some domesticated species is completely or mainly restricted to specific parts of the drylands. Camelids are hardly found outside of drylands; the species differ in their adaptation to altitude and climatic zones. Yaks are specialized to high altitudes in the Asian drylands and are raised only in these areas. At lower altitudes, they are either crossed with or replaced by cattle; for example, in many parts of the Himalaya, yak crosses with cattle are extremely important. The total number of yaks is estimated at 14 million, of which 13 million are found in China and 0.5 million in Mongolia. Small numbers are also present in the Russian Federation, Nepal, Bhutan, Afghanistan, Pakistan, Kyrgyzstan and India. The unique genetics of the yak, which enable it to tolerate the low atmospheric oxygen levels of the Asian highlands, enable human communities to live in these otherwise inhospitable ecosystems by supplying most of their daily needs (FAO/UNEP, 2000). Yaks produce fat- and protein-rich milk in very harsh high-altitude environments and are used as a beast of burden. In addition to contributing to agricultural production, the yak is valued as a cultural, religious and social asset.

More than 70% of the breeds of asses reported are adapted to drylands. The number of asses is high in the Near East and in Asia, where they are used as work and pack animals. The country with the largest population is China, where Mao Zedong popularized the animal to decrease the drudgery faced by rural women. It is believed that fewer breeds have been developed than in other species, but it is likely that many breeds have never been recorded, as asses have not been the subject of much research. As in the case of yaks, where agro-ecological conditions allow, horses or their crosses with asses are often preferred and a smaller number of ass breeds are found in more favourable areas. Nevertheless, 30% of horse breeds are also particularly adapted to drylands. Around half of sheep and goat breeds are particularly adapted to drylands, while this is the case for a third of cattle breeds.

Due to the mobile lifestyle of many livestock keepers in the drylands, the same breed often occurs in more than one country. These "transboundary" breeds were classified as regional transboundary breeds if they are restricted to a single region, or as international transboundary breeds if their distribution also crosses regional borders.

Sixty percent of the world's regional transboundary breeds can be found in the drylands. The proportion differs greatly between species, ranging from 41% in horses and 48% in cattle to 70–100% of the other species listed in Table 3. Probably an even larger proportion of national breed populations are in fact genetically connected, and there has always been exchange of breeding material across country borders. Interestingly, no regional transboundary breeds have been reported for yaks or Bactrian camels.

In Africa and Asia, dryland breeds represent a relatively high proportion of all regional transboundary breeds (69% and 58%, respectively), while in Latin America the percentage is much smaller (27%). A surprisingly small number of regional transboundary breeds (4 breeds of sheep) were counted in the Near East. This is probably due to the fact that many of the region's transboundary breeds are also found in neighbouring countries of Africa and Asia, which leads to their being classified as international transboundary breeds.

Twenty-three percent of the international breeds are adapted to drylands (Table 4). This is a surprisingly high proportion, which results from the fact that there has always been exchange and trading across the borders between neighbouring countries in Africa, the Near East and Asia. However, commercial trade in the international transboundary dryland breeds is probably much less common than in the international breeds of temperate origin.

Table 3 Number of regional transboundary breeds (including extinct breeds) reported per region

	Africa		Asia		Latin America		Near East		Total	
Species	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land
Cattle	36	21	19	7	8	2	0	0	63	30
Goat	15	14	11	8	2	0	0	0	28	22
Sheep	27	21	13	7	2	0	4	3	46	31
Ass	4	3	3	3	1	0	0	0	8	6
Horse	7	2	10	7	5	0	0	0	22	9
Alpaca	0	0	0	0	2	2	0	0	2	2
Dromedary	2	2	1	1	0	0	0	0	3	3
Llama	0	0	0	0	2	2	0	0	2	2
Σ	91	63	57	33	22	6	4	3	174	105

(Selected countries)

Table 4 Number of international transboundary breeds (including extinct breeds reported per species

Species	Number of breeds within species Σ	drylands
Cattle	113	17
Goat	40	18
Sheep	100	21
Ass	6	5
Horse	66	11
Bactrian Camel	2	2
Dromedary	2	2
Σ	329	76

Nevertheless, some international dryland breeds are well known and commercially marketed in large parts of the world. The Boran cattle breed was developed by Borana pastoralists in Ethiopia and improved by ranchers in Kenya (Valle Zárate et al., 2006). The Boran is an East African Shorthorned Zebu type, raised primarily for meat production, and shows high resistance to heat, ticks and eye diseases. It has been reported from 11 countries: nine in East, Central and Southern Africa; two in Australia and Mexico.

The Karakul sheep is probably the oldest breed of domesticated sheep. It is native to Central Asia and named after a village called Karakul, which lies in the valley of the Amu Darja River in the former emirate of Bukhara, in today's Uzbekistan. This is a high altitude region and one with scant desert vegetation and a limited water supply. Archaeological evidence indicates the existence of the Persian lambskin as early as 1400 B.C. and carvings of a distinct Karakul type have been found on ancient Babylonian temples. Although known as the "fur" sheep, the Karakul provides more than the beautifully patterned silky pelts of the young lambs. They are also a source of milk, meat, tallow and wool, a strong fibre which was felted into fabric or woven into carpeting (http://www.ansi.okstate.edu/breeds/sheep). The Karakul is nowadays found in substantial numbers in southern Africa, and has also spread to India, Australia, Brazil, Europe and the USA.

The Awassi, a dairy sheep breed of the Near Eastern Fat-tailed type, has spread to 15 countries in southern and eastern Europe, Central Asia, Australia and the Middle East. Over several thousand years, the Awassi had become fully adapted to the harsh conditions of its extensive breeding area in the semi-arid or arid regions of southwest Asia. Over centuries of natural and selective breeding, it evolved as a nomadic sheep breed to become the highest milk-producing breed in the Middle East (FAO, 1985).

The Arabian horse is the most successful among the world's horses. It has had an unique influence on horse breeds throughout Europe and has spread to 52 countries.

The Damascus (also called Shami) goat has a more limited distribution. It originates from Syria and is raised primarily for milk production. It has recently been

Table 5 Risk status of dryland *versus* all mammalian breeds reported per region

	Local and regional transboundary breeds								Internat. breeds		Total breeds	
	Africa		Asia		Latin America		Near East				Dry-lands total	World
Risk status	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	Σ
at risk	43	19	80	15	43	1	6	2	29	2	39	881
extinct	35	10	45	12	21	5	5	3	1	1	31	643
not at risk	187	65	776	228	81	19	85	62	312	59	433	2135
unknown	384	173	469	147	304	35	107	98	58	14	467	1940
Σ	649	267	1370	402	449	60	203	165	400	76	970	5599

(selected countries)

improved in Cyprus and has gained international recognition as an outstanding dairy breed for tropical and sub-tropical regions. While population numbers have remained small, the breed has spread around the Mediterranean basin (Alandia Robles et al., 2006).

3.3 Risk Status of Breeds in Drylands

To assess the threat of erosion, the risk status of the dryland breeds was examined and compared to the global situation. Breeds were classified as at risk when the total number of breeding females was equal or lower to 1,000 or the total number of breeding males was less than or equal to 20. It was found that the proportion of dryland breeds at risk is highest in Africa (44%), followed by the Near East (33%) and Asia (19%). In Latin America, only 2% of the dryland breed diversity is classified as at risk. In comparison to the global situation, the proportion of dryland breeds at risk is higher than for non-dryland breeds in Africa and lower in Asia, Latin America and the Near East. In total, however, only 4% of the world's breeds classified as at risk are found in the drylands. So far only 3% of the dryland breeds have been reported as extinct. This is much lower than the world's total of 11%.

Table 6 summarizes the status of dryland versus that of all breeds by species. A quarter of the breeds reported for the species included in this analysis are found in the drylands of the world. Only a small percentage of these breeds are classified as at risk (7%).

These figures have to be treated with caution, since for more than half of all reported dryland breeds no risk status could be defined due to missing population data. This lack of data is even more pronounced in camelids and asses. The proportion of missing data, particularly on the size and structure of dryland breed populations, is much higher than for the other agro-ecological zones. In Africa, 65% of

Table 6 Risk status of breeds by species

	at risk		extinct		not at risk		unknown		World	
Species	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land	Σ	dry-land
Cattle	210	6	209	17	499	120	393	92	1311	235
Yak	0	0	0	0	18	18	9	9	27	27
Goat	84	6	19	2	306	113	209	95	618	216
Sheep	179	13	180	11	633	172	417	141	1409	337
Ass	27	5	6	2	34	18	95	54	162	79
Horse	181	10	87	1	246	39	272	50	786	100
Alpaca	0	0	0	0	5	3	1	1	6	4
Bactrian Camel	2	2	0	0	7	6	3	1	12	9
Dromedary	4	4	0	0	33	32	51	48	88	84
Llama	0	0	0	0	5	4	0	0	5	4
Σ	687	46	501	33	1786	525	1450	491	4424	1095

the dryland breeds could not be assigned to any category; the number was close to 60% in the Near East and Latin America. In Asia, data were more complete, information unavailable was for only 37% of the breeds. The lack of information for dryland breeds can be explained by the mobile lifestyle of many people living in the drylands, which means that they are less linked to the organizational structures of their countries.

4 Conclusions

Human settlement would not be possible in many drylands of the world without well adapted livestock breeds. On the other hand, livestock production is also associated with dryland degradation through overgrazing. Land degradation may be evident around permanent settlements and water points where livestock mobility is reduced, and it is much less extensive in open rangelands where mobility is unrestricted. Where mobility continues unhampered, it has resulted in biodiversity conservation and sustainable land management. Where it has been constrained, it has led to serious over-grazing and land degradation (http://www.iucn.org/wisp/drylands.html).

A quarter of the world's livestock diversity has been developed in and is adapted to drylands. A surprisingly high proportion of this livestock diversity consists of regional and international transboundary breeds. Exchange and trading of breeding stocks, particularly of dryland breeds, among countries and regions is very important and should be supported by appropriate policy and legal frameworks.

Erosion of the livestock genetic diversity of the drylands currently seems to be lower than for other production systems. The reasons are that in these harsh environments people depend more on adapted breeds. In addition, government policies directly or indirectly promoting high-producing exotic breeds do not reach communities in drylands to the same degree as in more intensive production systems. But this relatively favourable situation may not last much longer, for the livelihoods of many mobile livestock keepers have been deteriorating in recent decades leading to changes in production strategies and out-migration to more favourable agro-ecological conditions or to urban areas (Lokhit Pashu-Palak Sansthan, 2005).

The data quality related to livestock genetic diversity is much lower for drylands than for other production systems. Thus, it is probable that the number of dryland breeds is underestimated, since some breeds have never been officially reported. This may be the case particularly for goats, asses and camelids. Policy-makers are faced with the challenge of better connecting pastoral communities to services and organizational structures, which would enable better data collection. This would also foster better recognition of the values and manifold roles of dryland livestock diversity. To date, dry grassland-based systems have been associated mainly with low productivity, a perception arising from the fact that productivity in terms of output per animal is indeed much lower than the world average. This evaluation, however, neglects the fact that the production systems are characterized by very low levels of external inputs. Thus, if productivity were defined in terms of unit output per unit input, it might be even higher for the drylands than for other more intensive production systems.

In particular, local breeds, notably those that have been developed in harsh environments in developing countries, have not been sufficiently characterized. In the case of their extinction, the value lost to humankind is not known. The lack of information hinders proper decision-making with respect to what to conserve and how to allocate the limited funds available for conservation. A certain loss of local breeds will be inevitable and acceptable given the current dynamics in production systems, and the limited availability of resources for conservation in the public sector.

However, it is certainly time for action to safeguard the world's animal genetic resources for food and agriculture, in particular those with specific adaptive traits, many of which are to be found in the drylands. Animal genetic diversity is our common heritage and contributes to food security at present and will help to secure future food security by allowing the supply of a wide range of products under diverse environmental conditions.

References

Alandia Robles, E., Gall, C. and Valle Zárate, A. 2006. Global gene flow in goats. Valle Zárate A., Musavaya K. and Schäfer C. (eds.), *Gene Flow in Animal Genetic Resources: A Study on Status, Impact and Trends*, pp. 229–240. GTZ, BMZ, Eschborn (also available in: FAO. 2007.

Annex to *The State of the World's Animal Genetic Resources for Food and Agriculture*. Rome, FAO.)

Blench, R. 2001. *Pastoralism in the New Millennium*. FAO Animal Production and Health Paper No. 150. Rome, FAO.

Devendra, C., Morton, J. F. and Rischkowsky, B. 2005. Livestock systems. Owen, E., Kitalyi, A., Jayasuriya, N. and Smith, T. (eds.), *Livestock and Wealth Creation: Improving the Husbandry of Animals Kept by Resource-poor People in Developing Countries*. Nottingham University Press, Nottingham, pp. 29–52.

FAO. 1985. *The Awassi Sheep, with Special Reference to the Improved Dairy Type*. FAO Animal Production and Health Papers No. 57. Rome, FAO.

_________. 1993. *Key Aspects of Strategies for the Sustainable Development of Drylands*. Rome, FAO. (See http://www.fao.org/documents/show_cdr.asp?url_file = /docrep/T0752E/T0752E05.htm)

_________. 2000. *Briefing Kit: The Global Strategy for the Management of Farm Animal Genetic Resources*. Rome, FAO.

FAOSTAT data, 2006 at http://faostat.fao.org/faostat/collections?version = int&hasbulk = 1&subset = agriculture (Accessed 8 September 2006).

FAO/UNEP. 2000. *World Watch List for Domestic Animal Diversity*, 3rd edition, Scherf, B. (ed.). FAO/UNEP, Rome. (See http://dad.fao.org/en/refer/library/wwl/wwl3.pdf) (Accessed 8 September 2006).

Groenewold, J. 2004. *Classification and Characterization of World Livestock Production Systems*. Update of the 1994 livestock production systems dataset with recent data. Unpublished FAO report. (See http://www.fao.org/documents/) (Accessed 8 September 2006).

Lokhit Pashu-Palak Sansthan. 2005. Saving the camel and peoples' livelihoods. Building a multi-stakeholder platform for the conservation of the camel in Rajasthan. International Conference, 23–25 November 2004, Sadri, India.

Rass, N. 2006. *Policies and Strategies to Address the Vulnerability of Pastoralists in Sub-Saharan Africa*. PPLPI Working Paper No. 37. Rome, FAO, p. 93 www.fao.org/AG/AGAInfo/projects/en/pplpi/docarc/wp37.pdf.

Scoones, I. 1994. New directions in pastoral development in Africa. Scoones I. (ed.), *Living with Uncertainty, New Directions in Pastoral Development in Africa*. Intermediate Technology Publications, London, pp. 1–36.

Seré, C. and Steinfeld, H. 1996. *World Livestock Production Systems: Current Status, Issues and Trends*. FAO Animal Production and Health Paper No. 127. Rome, FAO.

Thornton P. K., Kruska R. L., Henninger N., Kristjanson P. M., Reid R. S., Atieno F., Odero A. and Ndegwa T. 2002. *Mapping Poverty and Livestock in Developing Countries*. ILRI (International Livestock Research Institute), Nairobi.

Valle Zárate, A., Musavaya, K. and Schäfer, C. (eds.). 2006. *Gene Flow in Animal Genetic Resources. A Study on Status, Impact and Trends*, pp. 229–240. GTZ, BMZ, Eschborn (also available in: FAO. 2007. Annex to *The State of the World's Animal Genetic Resources for Food and Agriculture*. Rome, FAO.)

Chapter 3
The Role of Megafauna Restoration in Dryland, Natural and Cultural Heritage Conservation

Pierre Devillers and Roseline C. Beudels-Jamar

Abstract Eurasia and North Africa are traversed by the world's largest continuous belt of drylands. It has harboured the earliest manifestation of many endeavours of mankind and most major domestication events. Deserts and the challenges they provide have generated extraordinarily elaborate responses by biological evolution and by human technological and cultural development. The achievements of these processes can still be admired today in species of unique emblematic value and in manifestations of cultural know-how. This inestimable cultural and natural heritage is gravely threatened, in part by ignorance of its significance. Deserts have a negative image in dominant socio-economic models. The value of their biological diversity resides in beta-diversity, so that they escape the attention of many actors of conservation, focused on centres of species richness. Identifying conservation processes for their distinctive species and communities is thus urgent. The megafauna is a determinant factor of these efforts. Its constitutive species are key components of dryland ecosystems. They are an essential source of inspiration for cultural traditions, extensively represented since earliest times in art and myths of the region. They have an unparalleled attraction potential, extending well beyond the generation of tourism as a source of cultural, scientific and recreational interest in the land. They can be flagship species, guaranteeing sustainability of conservation efforts. Linking major archaeological and historical sites, in which the region is exceptionally rich, with natural sites of unique quality, through the theme of the great mammals, is a particularly promising approach to the revalorisation of the resources of drylands.

Keywords Megafaunal restoration, cultural heritage, Arid Lands Concerted Actions, migration

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1 Introduction

Eurasia and North Africa are traversed by the largest and most complex continuous belt of arid lands on earth, comprising an entirely interconnected ensemble of hot deserts, cold deserts, semi-deserts, sub-desert steppes, temperate steppes and cold steppes. Such arid lands tend to have a negative image in dominant socio-economic models, even among organizations concerned with environment and sustainable development. Yet these extraordinary biomes and their associated rivers and mountains have seen the earliest manifestation of many endeavours of mankind, the birth of great civilizations, urban life, writing and alphabets. They are the cradle of most major animal and plant domestication events. They harbour an inestimable cultural and natural heritage, unique cultural landscapes, prestigious architectural and artistic legacies of civilizations going back over ten millennia, striking signs of past climate changes, impressive testimonies of ingenious, imaginative and ambitious ways to cope with challenging environments as well as catastrophic examples of misuse provoked by irresponsible economic and social models, a fauna and flora of prodigious beauty and fascinating adaptations. More than any other ecosystem, the desert has, by the very nature of the challenges it provides, generated extraordinarily elaborate responses both by the process of biological evolution and by that of human technological and cultural development. The achievements of these processes can still be admired today in animal and plant species of unique emblematic value, as well as in manifestations of traditional cultural know-how. This exceptional heritage is gravely threatened, in part by ignorance of its significance. Identifying conservation processes for their distinctive species and communities is urgent. The megafauna may be a determinant factor of these efforts.

2 Material and Methods

A survey of the present and past distribution of the megafauna of the arid lands of Eurasia and North Africa has been conducted using recent faunal inventories and programme results, archeo-zoological data, as well as archaeological and art history analyses and syntheses. Published sources, reliable on-line information and databases held by conservation and research institutions have been perused. An inventory of fauna and ecosystem conservation and restoration programmes and projects presently operating within the area has also been compiled, and their motivations, both biological and cultural, analyzed.

3 Megafaunal Restoration as a Tool for Biodiversity and Ecosystems Rehabilitation

The biosphere is undergoing a period of massive extinction characterized by extinction rates on the order of 0.001/year, which extrapolated to the level of resolution available for previous episodes (0.1–1 MY) leads to a loss at least comparable to that of the most severe extinction crises of the past (Simberloff, 1984; Wilson, 1992; Ramade, 1993). Periods of diversity growth are governed by the stochastic frequencies of speciation and extinction phenomena, largely controlled by local abiotic factors (Cracraft, 1982; Eldredge, 1989), and by the Darwinian determinism that underpins the evolution of populations. During periods of wholesale extinction, species that disappear and species that survive are selected according to rules that differ fundamentally from those that prevail during periods of growth (Gould, 1989, 1993). Large space requirements, dependence on matrices of complementary habitats and K-selected reproductive strategies are among the main factors of vulnerability. These are common characteristics of large mammals, and, logically, large mammal communities are the component of biological diversity that has suffered and is suffering the most in the course of the extinction crisis we are living. Reasonably complete arrays of species are now found only in sub-Saharan Africa and in peninsula India. Most temperate and sub-tropical areas of the world, and in particular the large arid land belts, are severely impoverished.

The loss of the large mammal assemblies has serious ecological consequences, for they often include keystone species capable of shaping the evolution of ecosystems, their vegetation and the communities of smaller animals they support. These keystone species, both large grazers and top predators, are essential, particularly in the open habitats characteristic of the arid belts, in preserving or promoting overall richness and diversity and preventing take-over by successful, exogenous or endogenous, invasive species, the “pests and weeds” (Primack, 1993; Fletcher and Robbie, 2004; Donlan et al., 2005).

Large mammals are an essential part of the cultural heritage of humankind, entirely comparable to the greatest monuments and the most important repositories of knowledge. Their disappearance leads to a considerable impoverishment and loss of originality of local patrimonial values. They are the organisms whose affective and cultural perception is the most vivid, as exemplified by the place they take in the world of toys, decorations, objects, films and literature, and their pivotal importance in the attraction of tourism. National parks and nature reserves that hold large mammals have a much higher frequentation and generate much greater benefits from distant visitors than those devoid of them. On a world scale, such parks rank among the major attractions, irrespective of the continent on which are located. Large mammals have an unparalleled attraction potential, extending well beyond the generation of tourism as a source of cultural, scientific and recreational interest in the land. They are particularly adequate as flagship species whose presence in an area guarantees a high level and continuity of conservation efforts.

Humankind’s special relationship with other species of large mammals has existed during all periods of human cultural and social evolution. As a result, mammals are by far the animal group most closely linked to the cultural heritage. They have been an essential source of inspiration for traditions, myths and artistic expression in many cultures, particularly of the steppes and semi-deserts, and their prominence in artistic testimonies is totally out of proportion with their representation in local faunas (Fig. 1).

Fig. 1 Przewalski horse, the national symbol of Mongolia, in Houstai NP. Roseline Beudels-Jamar. IRScNB. With permission

4 Principles of Megafaunal Reconstruction

The ecological and cultural significance of large mammals has incited several actors of biodiversity conservation to regard megafaunal restoration as an essential tool in the promotion of ecosystem conservation and rehabilitation over large tracts of land. The reconstruction of the severely depleted South African fauna was probably, historically, the first large-scale effort in this direction, and it was highly successful. Programmes, some very ambitious, have now been proposed or have already been implemented in other parts of the world that suffer from severe megafaunal depletion, in particular Europe (Bunzel-Drüke et al., 1994, 1999; Capt et al., 1998; Yalden, 1999; Cromsigt, 2000; Kampf, 2000; Vera and Buissink, 2001; Devillers, 2003), and North America (Donlan et al., 2005). In order to succeed, however, megafaunal restoration must be founded on sound ecological evaluation and a sense of ownership among the local actors. The animals restored must have a record of past occupation of the area, but this occupation must have taken place in biogeographical and ecological conditions that are not too distant from those of today. If components of the past fauna are lost everywhere, so that no adequate material can be translocated, any substitutes proposed must be reasonable counterparts – both in their ecological role and in their overall appearance – of lost fauna, so that the emotional content, the distinctness and the uniqueness of the restored heritage are preserved (Bunzel-Drüke, 2001). Authenticity is a key to cultural identification, and cultural identification is essential to public support for what are space-consuming and potentially high-impact efforts.

Fig. 2 Scimitar-horned oryx in Bou-Hedma NP, Tunisia. Tim Woodfine-Marwell Zoo. With permission

5 The Megafauna of the Arid Lands of Eurasia and North Africa

Though their species richness is comparatively low, the arid zones harbour a number of highly emblematic, uniquely adapted species (Fig. 2). The high value of their biological diversity is thus mostly that of beta-diversity (reflecting differential diversity), not that of alpha-diversity (measuring local richness), so that they escape the attention of many actors of biodiversity conservation, who are increasingly focused on centres of species richness, or biodiversity "hotspots". Their array of large mammals is particularly remarkable, not least because they have been forced by the very nature of the resources they exploit to undertake migrations, often of a complex and atypical kind. Indeed, migration – seasonal, opportunistic, multi-annual – has always been a strategy quite characteristic of arid lands, developed by many organisms, particularly large mammals, including man. This makes continental, transborder approaches and network thinking indispensable to the preservation or reconstitution of characteristic processes.

6 The Area

From the point of view of megafaunal conservation and promotion, biogeographically meaningful outer geographical limits can be drawn by including all lands with a phytomass of less than 50 t per ha (Walter and Breckle, 1999). Thus defined, the zone includes all cold, cool and hot steppes, deserts and semi-deserts, of Eurasia and northern Africa and engulfs isolated islands of temperate, Mediterranean and sub-Sudanian, usually montane or sub-montane, non-desert biomes. These are either entirely surrounded by deserts or are enclaved between them and the seas of southern temperate Eurasia and sub-tropical Western Asia. They must be included within the area of concern, as their mammalian fauna is either related to that of the surrounding arid land, or has been strongly influenced by the progression of the deserts and the resulting fragmentation and isolation of the enclaves. This vast area can be divided into three major sub-zones with contrasting climates and histories (Zohary, 1973; Walter, 1974; Walter and Breckle, 1999). A first zone includes the Sahara, the Sahel and Mediterranean enclaves of the Maghreb. A second zone includes the steppes and the cold and temperate deserts of Asia and Europe, which include all arid lands of China, Mongolia, Russia, Ukraine, Kazakhstan, Turkmenistan, Uzbekistan, Tajikistan, Kyrgyzstan, Azerbaijan, Nepal, Afghanistan, Georgia, Armenia and Turkey. Enclaved Mediterranean and montane areas are principally those of Anatolia, the Caucasus, the Zagros, the Elburz and the Central Asian mountains. A third zone encompasses the hot deserts of the Arabian Peninsula and western Asia, with Mediterranean enclaves of the Levant and sub-Sudanian enclaves of the southwestern Arabian Peninsula. In the southwest the line of demarcation between cool deserts, semi-deserts and steppes of the Irano-Turanian zone and hot deserts of the Saharo-Arabian zone leaves all of Syria and northern Iraq in the northern region, most of Jordan and southern Iraq in the southern region (Zohary, 1973).

7 Baselines

Cultural and biogeographical authenticity provide a strong frame of reference for the choice of time-baselines, a prerequisite for any restoration project and yet one of the most difficult, controversial and debated aspects, often expressed in terms of biological integrity and environmental health, notions that are difficult to define. Megafaunal richness and diversity should be maximized, in keeping with the basic objectives of the scheme, but within limits set by eco-ethological and biogeographical plausibility on the one hand and by the relevance of cultural identification and the likelihood of patrimonial appropriation on the other.

In Western Europe, artistic testimonies to the megafauna go back to 20,000 BCE and are very much a part of the European heritage. However, these extraordinary achievements of Palaeolithic populations were created within a biogeographical and ecological environment that had nothing to do with today's landscapes. The effect on the land of the glaciations were profound and fundamental. Even the early post-glacial sequences, in which a megafauna of high-northern affinities lingered, were totally foreign to present-day habitats. Later, the return of nemoral forests culminated around 2000 BCE in a highly diverse, thermophile forest that is practically parallel to what is found in present-day Europe. It was only around 1000 BCE that environments broadly comparable to present-day ones became established. Choosing earlier baselines for European re-wilding projects would be entirely artificial.

In the arid lands of western Asia, the Iranian Plateau, southwestern Central Asia and northwestern India, a baseline extending back to 11,000 BCE is legitimate. Subsequent climate changes have been relatively minor, successive drought crises provoked shifts in isohyets that had profound local effects, both on human occupants and, surely, on faunal composition, but little impact on the region as a whole (Vila, 1998; Weiss, 2000; Weiss and Bradley, 2001; Wilkinson, 2003). Steppe and dry woodland types, still present today, occupied varying but contiguous surfaces, with little qualitative modification. Marine transgressions provoked minor rearrangements of coastlines. No connection with major faunas external to the region opened at any moment as a consequence of these climatic vicissitudes. A profusion of artistic and cultural testimonies to the megafauna, generated by past human populations that continuously occupied the area, provides an ample foundation for cultural identification and appropriation throughout the period.

Rich cultural material is also available for the Sahara, the Sahel and Mediterranean North Africa, in particular rock art spanning at least six millennia. However, between about 8000 and 2000 BCE, humid episodes in the Sahara favoured its invasion by Sudanian and wooded savannas and opened wide connections between Mediterranean and sub-Saharan Africa (Jelínek, 2004). These connections no longer exist. Re-establishing a fauna that existed prior to 2000 BCE and depended on these connections for its viability would be meaningless.

8 Current Status

With a baseline of 11,000 BCE for Eurasia and 2000 BCE for North Africa, the combined megafauna of the arid belt comprises about 108 species (Table 1). Of these, about 80, or three-quarters, survive in some part of the region, though more than half of them are now represented by relict populations restricted to a minute fraction of the historic range, with very small populations (Table 1). Of the missing 28 species, four have already been reintroduced to one or another part of the range, completely adequate extra-regional material exists for a further ten, slightly less adequate for two, and feral populations very similar to ancestral ones exist within the region for another two.

A number of taxonomic groups have their main centre of occurrence in the old world arid lands and their associated enclaves, others are represented within the area by highly specialised species. However, their representative species are not often distributed over the entire belt of arid lands.

Table 1 Baseline composition and current status of Eurasian and North African megafauna

Eurasia	North Africa
Felidae *Acinonyx venaticus*, *Felis lynx, Felis caracal, Panthera persica*, *Panthera pardus*, *Panthera tigris*, *Uncia uncia*	**Felidae** *Acinonyx jubatus*, *Felis caracal*, *Felis ser val*, *Panthera leo*, *Panthera pardus*
Hyaenidae *Hyaena hyaena*	**Hyaenidae** *Hyaena hyaena*
Canidae *Cuon alpinus*, *Canis lupus*, *Canis laniger*, *Canis pallipes*, *Canis aureus*	**Canidae** *Canis aureus*, *Lycaon pictus*
Ursidae *Ursus arctos*, *Ursus gobiensis*, *Ursus thibetanus*	**Ursidae** *Ursus arctos*
Suidae *Sus scrofa*	**Suidae** *Sus scrofa*, *Phacochoerus africanus*
Hippopotamidae *Hippopotamus amphibius*	**Hippopotamidae** *Hippopotamus amphibius*
Camelidae *Camelus ferus*, *Camelus dromedarius*	
Cervidae *Cervus albirostris*, *Cervus maral*, *Cervus bactrianus*, *Cervus yarkandensis*, *Cervus wallichi*, *Cervus hanglu*, *Cervus canadensis, Dama dama*, *Dama mesopotamica*, *Capreolus capreolus, Capreolus pygargus*	**Cervidae** *Cervus barbarus*
Bovidae *Alcelaphus buselaphus* *Antilope cervicapra*, *Gazella subgutturosa*, *Gazella marica*, *Gazella gazella*, *Gazella gazella cora*, *Gazella muscatensis*, *Gazella erlangeri* , *Gazella bennettii*, *Gazella soemmerringii*, *Gazella saudiya*, *Gazella arabica*, *Procapra gutturosa*, *Procapra picticaudata*, *Procapra przewalskii*, *Pantholops hodgsoni*, *Saiga tatarica* *Bison bonasus, Bos mutus*, *Bos primigenius*, *Bos indicus*, *Bos gaurus* *Bubalus arnee*, *Boselaphus tragocamelus*, *Tragelaphus imberbis* *Capra caucasica*, *Capra cylindricornis*, *Capra falconeri*, *Capra aegagrus*, *Capra nubiana*, *Capra sibirica*, *Hemitragus jayakari*, *Hemitragus jemlahicus*, *Naemorhedus goral*, *Ovis ammon*, *Ovis orientalis*, *Ovis vignei*, *Pseudois nayaur*, *Rupicapra rupicapra* *Oryx leucoryx*	**Bovidae** *Alcelaphus buselaphus* *Gazella rufifrons*, *Gazella leptoceros*, *Gazella cuvieri*, *Gazella rufina dorcas*, *Gazella mhorr*, *Gazella dama Bos primigenius, Ammotragus lervia*, *Capra nubiana, Oryx dammah, Addax nasomaculatus*

(continued)

Table 1 (continued)

Equidae *Equus ferus*, *Equus przewalskii*, *Equus kiang*, *Equus hemionus*, *Equus onager*, *Equus khur*, *Equus syriacus*, *Equus africanus*	**Equidae** *Equus africanus*
Rhinocertidae *Rhinoceros unicornis*	
Elephantidae *Elephas maximus*	**Elephantidae** *Loxodonta (africana) pharaoensis*

9 Cultural Heritage and Megafauna in Eurasian and North African Aridlands

The arid belt of Eurasia and northern Africa has one of the greatest cultural heritages in the world, testimony to events that have uniquely shaped the history of humankind. The sites that hold the first signs of sedentary village life and use of domesticated plants are in Syria and neighbouring areas (Hillman et al., 2001; Akkermans and Schwartz, 2003; Huot, 2004). Urban life and writing were born in Iraq and neighbouring Iran. The first archaeological traces of sheep, goat, cow, and horse domestication are in Syria, Iran, Anatolia or Ukraine (Bradley et al., 1996; Jansen et al., 2002; Luikart et al., 2001; Götherström et al., 2005). Most of these processes were intimately tied to the megafauna, and its significance is superbly illustrated by Mesopotamian and Iranian monumental sculpture, Mesopotamian, Iranian and Indus glyptic, Saharan rock art, the vivid animal art of the great steppe cultures of Central Eurasia, and the rich Roman mosaics of Syria and Tunisia (Strommenger, 1964; Wheeler, 1968; Behm-Blancke, 1979; Collon, 1987; Perrot, 2003; Lebedynsky, 2003; Jelínek, 2004; Ascalone, 2006). Many archaeological sites at which a direct experience of these processes can be obtained, with its potent emotional and intellectual content, are scattered within areas of great natural beauty, in unique habitats where the megafauna that inspired them once roamed, in cultural landscapes where unparalleled techniques of coping with the arid environment were successfully developed millennia ago. These sites are scattered over great distances and, except for a very few in or close to major urban concentrations, they are very little visited. Knowledge of them outside of specialist groups is so slight that some have been obliterated with little world outcry. A tenth-millennium village where one of the earliest manifestations of domestic plants was discovered, with a potential to become a cultural attraction of world magnitude, was sacrificed to a dam (Huot, 2004) that yielded little local return but bare the mainstream economic label of “development”.

National parks holding large mammals are a major source of revenue for east and southern African countries, through tourism and the side-activities it generates but also because of media interest, potential for emblematic and commercial promotion and exploitation, image-building and notoriety for the country that holds them. They constitute a magnet that can be combined with historical and indigenous people's values to makeup packages of much higher attraction potential.

Particularly in an area of scattered distribution of sites, as the arid zone is, the combination of several poles of attraction is indispensable to reach a sufficient threshold of socio-economic visibility. The fabulous cultural heritage of the arid zone is probably too sparsely distributed to be a major source of revenue. Linking its main archaeological and historical sites with natural sites of unique quality, through the theme of the great mammals, is a particularly promising approach to the revalorization of dryland resources, first through quality tourism and its immediate by-products, then by the longer-term notoriety effects it generates. It is a particularly appropriate association, as the cultural and natural heritages of arid lands are similarly – and critically – not least by enterprises that, with a stupefying blindness to history, regard the desert only as a general nuisance, waiting to be transformed into a productive wasteland amenable to the rules of the market.

Desirable development, beyond subsistence, can only rest on access to and promotion of resources that enhance the local quality of life or whose benefits can be traded with other people. The natural, historical, artistic and cultural heritages represent a large part of those resources. They can be increasingly enjoyed by developing communities as their living standard and awareness increase, and they constitute a powerful factor of exchanges based on an attraction potential that goes well beyond the generation of tourism and its by-products as a source of cultural, scientific and recreational interest in the land. This exchange potential is dependant, however, on the intrinsic cultural appeal of the heritage and the degree to which it differs from that of other areas. Large mammal fauna are prime examples of both cultural visibility and distinctness. Migratory behaviour adds an element of mystery and time renewal to their other values.

10 Concrete Schemes: CMS Arid Lands Concerted Actions

The conservation and restoration of the megafauna of arid lands has been a major and ambitious endeavour of the United Nations Convention on Migratory Species since 1991, having been translated into two major Concerted Actions, the Sahelo-Saharan Antelope Concerted Action and the Central EurAsian Aridland Concerted Action. The Convention's approach is based on admiration, praise, respect and passion for a heritage painted, carved, sculpted, used, hunted and worshiped by millennia of brilliant civilizations, a desire not to change the nature of the arid zones but to conserve and enhance their value, and a will to considerably raise the world awareness of their significance. Its actions proceed from the conviction that very practical, in-the-field actions are what is needed. The development of its Concerted Actions has shown that the arid lands are a privileged domain of activity for CMS. Over the years, the Convention has acquired a considerable experience in addressing the highly specific requirements of their environment and their fauna. Moreover, it has held a unique position in that field, as most other organizations and funding agencies have preferred to focus on biomes of higher biological diversity, such as tropical forests. The Convention's goals, however, require the co-operation of many actors. It wishes to join forces and develop partnerships with like-minded conservation organizations to rise to the level of its grand objectives.

The Sahelo-Saharan Antelope Concerted Action, initiated in 1991, is a conservation and restoration programme that originally targeted six ungulates of arid and semi-arid habitats of northern Africa: the Scimitar Oryx (*Oryx dammah*), the Addax (*Addax nasomaculatus*) (Fig. 3), the Dama Gazelle (*Gazella dama s.l.,*), Cuvier's Gazelle (*Gazella cuvieri*), the Rhim or Sand Gazelle (*Gazella leptoceros*), and the Dorcas Gazelle (*Gazella dorcas*), which represent the most significant surviving element of North African large mammalian fauna. Still reasonably abundant in the middle of the 20th century, they collapsed with extraordinary rapidity, through the combined effects of several human pressures, to reach the status of threatened to critically endangered and, for one of them, unfortunately, extinction in the wild. Other species are considered in present developments. An Action Plan, supported by status reports, was drafted in 1997–1998 and adopted by the 14 Range States at a regional seminar, held in Tunisia in February 1998 (Beudels-Jamar et al., 1999). Its objectives are the reconstitution of free roaming populations of all species, the development of networks of effective protection systems, including protected areas and community-based stewardship, the affirmation of the importance of common natural and cultural resources of Sahelo-Saharan deserts and semi-deserts, and a considerable reinforcement of the awareness of local stakeholders. With continued support by the Conference of the Parties, the programme has now entered a phase of implementation, with the preparation and execution of medium-sized local or regional projects. One of these, centred on the central-western parts of the range, is supported by the Fond Français pour l'Environnement Mondial (FFEM) and is now in its third year of operation.

The Central EurAsian Arid Land Concerted Action, initiated in 2003, aims at restoring the entire megafauna of the deserts, semi-deserts, steppes and associated mountains of Central Asia, the Northern Indian subcontinent, Western Asia, the

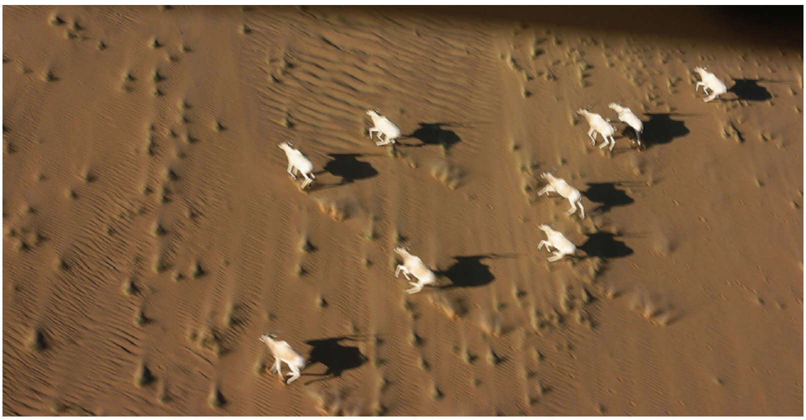

Fig. 3 One of the last remaining group of free-ranging addax, Chad (Nov. 2005). Roseline Beudels-Jamar. IRScNB. With permission

Caucasus and Eastern Europe. Formally adopted by the Conference of the Parties at Nairobi in December 2005, it requires an Action Plan by 2007. The Concerted Action aims at federating the many initiatives already operating in the area and at constructing a coherent network of protected areas and migration corridors closely linked to the major anchor points of the cultural heritage.

References

Akkermans, P. M. M. G. and Schwartz, G. M. 2003. *The Archaeology of Syria from Complex Hunter–Gatherers to Early Urban Societies* (*ca. 16000–300 BC*). Cambridge, Cambridge University Press.

Ascalone, E. 2006. *La Mésopotamie*. Paris, Hazan. (In French.)

Behm-Blancke, M. R. 1979. *Das Tierbild in der Altmesopotamischen Rundplastik*. Mainz am Rhein, Ph. von Zabern. (In German.)

Beudels-Jamar, R. C., Devillers, P. and Lafontaine, R. M. 1999. Conservation measures for Sahelo-Saharan antelopes. Action plan. *CMS Technical Series Publication*, Vol. 4, pp. 7–87.

Bradley, D. G., MacHugh, D. E., Cunningham, P. and Loftus, R. T. 1996. Mitochondrial diversity and the origins of African and European cattle. *Proceedimgs of the National Academy of Sciences*, USA, Vol. 93, pp. 5131–5135.

Capt, S., Breitenmoser, U. and Breitenmoser-Würsten, C. 1998. Monitoring the lynx population in Switzerland. C. Breitenmoser-Würsten, C. Rohner, and U. Breitenmoser (eds.), *The Re-introduction of Lynx into the Alps*. Environmental encounters 38. Strasbourg, France, Council of Europe Publishing, pp. 105–108.

Bunzel-Drüke, M. 2001. Ecological substitutes for Wild horse (Equus ferus Boddaert, 1785 = E. przewalskii Poljakov, 1881) and Aurochs (Bos primigenius Bojanus, 1827). *Natur- und Kulturlandschaft* 4 (Höxter/ Jena), 9 pp.

Bunzel-Drüke, M., Drüke, J. and Vierhaus, H. 1994. Quaternary Park – Überlegungen zu Wald, Mensch und Megafauna. *ABU info* 17/18 (4/93 and 1/94), pp. 4–38.

Bunzel-Drüke, M., Drüke, J., Hauswirth, L. and Vierhaus, H. 1999. Grosstiere und Landschaft – Von der Praxis zur Theorie. *Natur- und Kulturlandschaft* 3 (Höxter/Jena), pp. 210–229.

Collon, D. 1987. *First Impressions: Cylinder Seals in the Ancient Near East*. London, British Museum Publications.

Cracraft, J. 1982. A non-equilibrium theory for the rate-control of speciation and extinction and the origin of macroevolutionary patterns. *Systematic Zoology*, Vol. 31, 348–365.

Cromsigt, J. P. G. M. 2000. *The Large Herbivores of the Eurasian Continent. A Reference Guide for the Large Herbivore Initiative (LHI)*. Geneva, Large Herbivore Initiative.

Devillers, P. 2003. Grands mammifères de Belgique. Historique et perspectives. *Bulletin du Centre d'Écologie appliquée du Hainaut*, Vol. 46, pp. 2–21.

Donlan, J., Greene, H. W., Berger, J., Bock, C. E., Bock, J. H., Burney, D. A., Estes, J. A., Foreman, D., Martin, P. S., Roemer, G. W., Smith, F. A. and Soulé, M. E. 2005. Re-wilding North America. *Nature*, Vol. 436, pp. 913–914.

Eldredge, N. 1989. *Macroevolutionary Dynamics*. New York, McGraw-Hill.

Fletcher, R. and Robbie, W. A. 2004. Historic and current conditions of Southwestern grasslands. Finch, D. M. (ed.), *Assessment of Grassland Ecosystem Conditions in the Southwestern United States*. Vol. 1. Gen. Tech. Rep. RMRS-GTR-135-vol. 1. Fort Collins, CO., U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 120–129.

Götherström, A., Anderung, C., Hellborg, L., Elburg, R., Smith, C., Bradley, D. G. and Ellegren, H. 2005. Cattle domestication in the Near East was followed by hybridization with orochs bulls in Europe. *Proceedings of the Royal Society*, Vol. 272, pp. 2345–2350.

Gould, S. J. 1989. *Wonderful Life: The Burgess Shale and the Nature of History*. Harmondsworth, UK, Penguin.

Gould, S. J. (ed.). 1993. *The Book of Life*. London, Ebury-Hutchinson.

Hillman, G. C., Hedges, R., Moore, A. M. T., Colledge, S. M. and Pettitt, P. 2001. New evidence for Late Glacial cereal cultivation at Abu Hureyra on the Euphrates. *The Holocene*, Vol. 11, pp. 383–393.

Huot, J.-L. 2004. *Une archéologie des peuples du Proche-Orient. I. Des premiers villageois aux peuples des cités-états (X*[e]*–III*[e] *millénaire av. J.-C.)*. Paris. (In French.)

Jansen, T., Forster, P., Levine, M. A., Oelke, H., Hurles, M., Renfrew, C., Weber, J. and Olek, K. 2002. Mitochondrial DNA and the origins of the domestic horse. *Proceedings of the National Academy Sciences*, Vol. 99, pp. 10905–10910.

Jelínek, J. 2004. *Sahara, histoire d l'art rupestre libyen*. Grenoble, Million. (In French.)

Kampf, H. 2000. Beweidung in den Niederlanden. *ABU info* 24, 2, pp. 2–19.

Lebedynsky, I. 2003. *Les nomades*. Paris, Errance, 271 pp. (In French.)

Luikart, G., Gielly, L., Excoffier, L., Vigne, J.-D., Bouvet, J. and Taberlet, P. 2001. Multiple maternal origins and weak phylogeographic structure in domestic goats. *Proceedings of the National Academy Sciences*, USA 98, pp. 5927–5932.

Perrot, J. 2003. L'iconographie de Jiroft. *Dossiers d'Archeologie*, Vol. 287, pp. 96–113. (In French.)

Primack, R. B. 1993. *Essentials of Conservation Biology*. Sunderland, MA, Sinauer Associates.

Ramade, F. 1993. *Dictionnaire encyclopédique de l'écologie et des sciences de l'environnement*. Paris, Ediscience International. (In French.)

Simberloff, D. 1984. Mass extinction and the destruction of moist tropical forests. Th. Obschch. *Biology*, Vol. 45, pp. 767–778.

Strommenger, E. 1964. *The Art of Mesopotamia*. London, Thames & Hudson.

Vera, F. and Buissink, F. 2001. *Wildernis in Nederland, bossen en beesten*. Baarn, The Netherlands, Tirion.

Vila, E. 1998. *L'exploitation des animaux en Mésopotamie aux IV*[e] *et III*[e] *millénaires avant J.-C.* Paris, CRA 21, CNRS (Centre National de Rechereche Scientfque). (In French.)

Walter, H. 1974. *Die Vegetation Osteuropas, Nord- und Zentralasiens*. Stuttgart, Fisher Verlag. (In German.)

Walter, H. and Breckle, S.-W. 1999. *Vegetation und Klimazonen*. Stuttgart, Eugen Ulmer. (In German.)

Wheeler, M. 1968. *The Indus Civilisation*. Cambridge, Cambridge University Press.

Weiss, H. 2000. Beyond the Younger Dryas: Collapse as adaptation to abrupt climate change in ancient West Asia and the Eastern Mediterranean. G. Bawden and R. M. Reycraft (eds.), *Environmental Disaster and the Archaeology of Human Response*, Anthropological Papers No. 7, Maxwell Museum of Anthropology, pp. 75–98.

Weiss, H. and Bradley, R. S. 2001. What drives societal collapse? *Science*, Vol. 291, pp. 609–610.

Wilkinson, T. J. 2003. *Archaelogical Landscapes of the Near East*. Tucson, AZ, University of Arizona.

Wilson, E. O. 1992. *The diversity of Life*. Harmondsworth, UK, Penguin.

Yalden, D. 1999. *The History of British Mammals*. London, T & AD Poyser.

Zohary, M. 1973. *Geobotanical Foundations of the Middle East*, Vol. 1. Stuttgart, Gustav Fischer Verlag.

Chapter 4
Learning from Nature and Culture to Manage Nature Reserves: Experience from Dana Biosphere Reserve, Jordan

Mohammed Al-Qawaba'a

Abstract In the context of global efforts to introduce new people-centred approaches to biodiversity conservation and dry land management in developing countries, this paper applies various transformation theories to the management of an internationally important nature reserve in the Hashemite Kingdom of Jordan. The objectives of the paper are as follows:

- To develop an overall (holistic) approach to the biosphere reserve's development and dryland management.
- To introduce a new management strategy (the integrated ecosystem management approach) to guide the biosphere reserve's management and dryland areas management towards a new approach to management, and to inform how this approach is integrated within the Sustainable Management of Marginal Drylands (SUMAMAD) project.

The following management theories and approaches were studied and assessed in relation to the management issues of the biosphere reserve and dryland management: (1) the stages of organizational and management bodies development (Lessem, 1998), which categorized the management's current development stage and identified the attributes needed for the new order; (2) the concepts of strategy and strategic planning (various authors), which guided the selection of a new strategic approach to the management of the biosphere reserve, appropriate to the current development stage; and (3) the Ecosystem Approach to Business Management (Moore, 1996) because of its obvious relevance to natural systems and its emphasis on accommodating the whole ecosystem in interrelating all members of the ecosystem in management development.

Keywords Biosphere reserve management, strategic planning, the Ecosystem Approach, Crafting the New Strategy

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Royal Society for the Conservation of Nature, Jordan

1 Introduction

The Dana Biosphere Reserve is a system of wadis and mountains that extend from the top of the Rift Valley down to the desert lowlands of Wadi Araba. Dana is truly a world of natural treasures. Visitors to Dana will experience the beauty of Rummana Mountain, the mystery of the ancient archaeological ruins of Feynan Eco-lodge, the timeless tranquility of Dana Village, and the grandeur of the red and white sandstone cliffs of Wadi Dana.

The Dana Village area, overlooking the scenic Wadi Dana, has been occupied since 4000 BCE. Archaeological evidence indicates that Paleolithic, Egyptian, Nabatean and Roman civilizations have been drawn to the area by its fertile soil, water springs and strategic location. Dana Village is inhabited mostly by tribes that settled in the area during the Ottoman period, about 400 years ago. The villagers abandoned it in search of a better livelihood. Today, the village is coming back to life. The people have rebuilt many of their traditional stone houses and restored their beautiful terraced gardens.

2 Study the Strategic Planning in the Reserve

The existing management planning approach is closer to "the analytical approach" because it concentrates on the analysis of internal ecological processes and ignores the "big picture" in terms of interrelationships with external players.

The biosphere reserve needs dynamic strategic planning due to the unpredictability of most ecological processes and because the dynamic strategy gives flexibility to respond to ever changing situations.

3 Ecosystem Approach

3.1 Definition of Ecosystem

An "ecosystem is a system formed by the interaction of a community of organisms with their physical environment".

3.2 Definition of Business Ecosystem

"A business ecosystem is an economic community supported by a foundation of interacting organisations and individuals – the organisms of the business world. This economic community produces goods and services of the value to customers, who are themselves members of the ecosystem".

3.3 Principles for Guiding Strategy Development

- What you do is not as important as how your capabilities relate to what others are doing.
- Strategy-making involves having an awareness of the big picture and finding ways to play a role in it.

3.4 The New Paradigm Requires Thinking in Terms of the Whole System

Successful strategy helps us to co-evolve with others.

4 Crafting the New Strategy

- The biosphere reserve becomes the centre of the ecosystem, where conservation of natural resources is the priority.
- The biosphere reserve seeks to co-evolve with other users within the system.
- The biosphere reserve becomes the centre of regeneration of productivity by applying social innovation to replace direct reliance on unsustainable uses of natural resources.
- The renewal of Islamic values aims to strengthen bonds between all players who share the reserve's ecosystem.
- The main engine of social innovation should be the further development of ecotourism.

5 The Stages for Crafting the New Strategy

1. Know your ecosystem (Fig. 1).
2. Know yourself and your age.

   One cannot develop a strategy for the future without looking back in time from the present and define patterns of past actions.
   Stages of development:

   a) Entrepreneurial stage
   b) The youthful stage
   c) Adulthood stage
   d) Midlife age (age of the renewal)
   e) The maturity stage (age of innovation)

Table 1

Stage of development	Description of each phase and needed attributes
Entrepreneurial stage	• Operations management • Capacity to work hard and play hard • Human resource management • Enthusiasm and ability to motivate others • Information management • Mental agility and quick wittedness • Competitive strategy • Wilful risk-taking and emotional resilience • Accounting and finance • Financial acumen and the capacity to improve • Marketing management • Intuition and an eye for opportunities • Research and development • Imagination – enough to see around the corner • Business ethics • Faith in oneself, and what one stands for • Cooperative renewal
Midlife age (age of the renewal)	• Process re-engineering • Service management
The youthful stage	• Organizational learning • Hard work • Raw enthusiasm • Mental agility • Emotional resilience • Financial acumen • Market instinct • Basic inventiveness • Faith in oneself • Strategic dynamics • Measuring performance • Crises and renewal • Social innovation • Total quality
The Maturity stage (age of innovation)	• Organizational knowledge-creation • High energy level • Organizational culture • Intelligent enterprise • Visionary leadership • Knowledge creation • Business ecosystem • Global business sphere • Spirit and transformation

3. Know your ecosystem members (Fig. 1).
4. Know the relations within the ecosystem (Fig. 2).

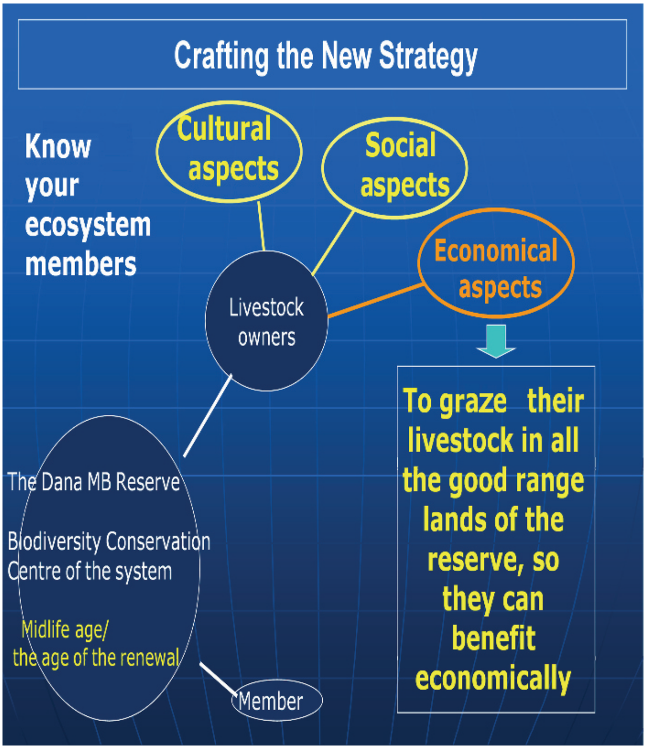

Fig. 1 Crafting the new strategy: know your ecosystem members

1. The achievement of the new outputs.
2. A summary of Islamic religious principles that support biodiversity:

- God has granted human beings the right to utilize natural resources, with an obligation to conserve them both quantitatively and qualitatively and maintain sustainable utilization.
- Humans have no right to cause the degradation of the environment and distort its intrinsic suitability for human life and settlement. Nor have they the right to exploit or use natural resources unwisely.
- Man's annihilation of any species of animals or plant can in no way be justified.
- The establishment of a nature reserve (*Hima*) has a strong support in Islam, as the role of the governing authorities is to establish these reserves.

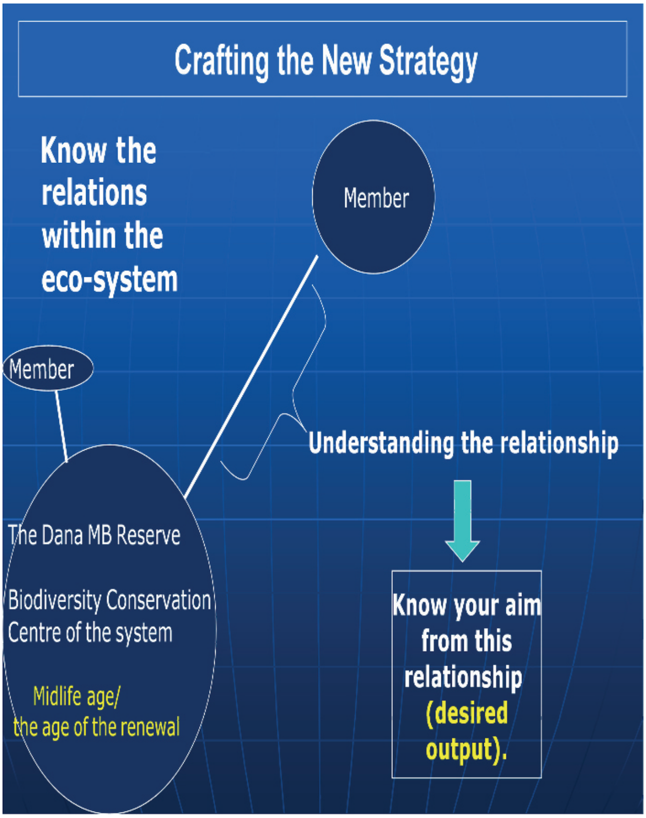

Fig. 2 Crafting the new strategy: know the relations within the ecosystem

3. Future follow-up:
   - Further develop the ecosystem analogy and translate it into other management situations.
   - Application of other attributes of renewal: process re-engineering; service management; organizational learning; measuring performance; crises and renewal; social innovation and total quality.
   - Develop a monitoring programme to assess whether the new approach is achieving conservation objectives.
4. The SUMAMAD project contribution to the new strategy.

Table 2

Know your ecosystem members	– Carrying socio-economic studies for the new settlements in the southern part of the reserve (Al-Rashaidah and Al-Azazmah villages)
Know the relationships within the ecosystem	
The final step, Provide alternatives & incentives (Fig. 3)	– Start income-generating projects (the olive oil soap work shop at the Dana Centre)

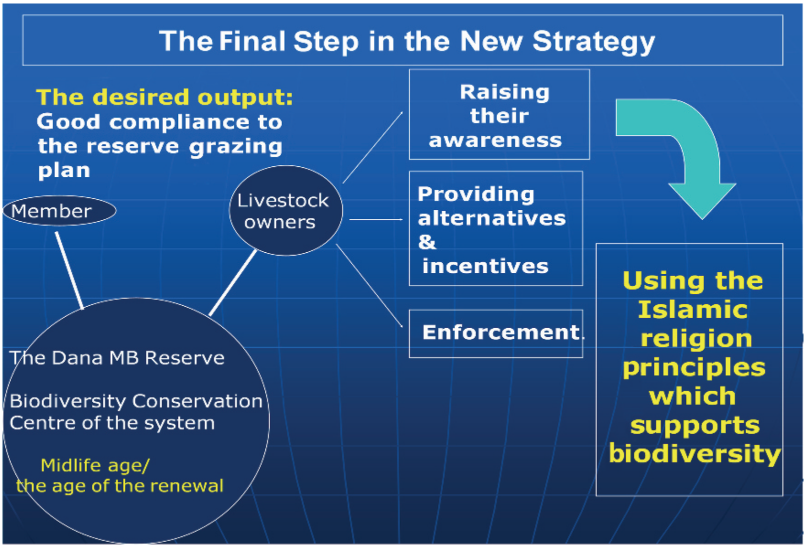

Fig. 3 The final step: providing alternatives and incetives

References

Moore, J. 1996. *The Death of Competition: Leadership and Strategy in the Age of Business Ecosystems*. New York, Harper Business.
Lessem, R. 1998. *Management Development through Cultural Diversity*. London, Routledge.

Chapter 5
Traditional Knowledge and the World Databank for Safeguarding Ecosystems

Pietro Laureano

Abstract Traditional knowledge is a sum of ancient techniques and practices, which is specific to a territory and passed on over generations, for water harvesting, soil management, the use and protection of natural areas, rural architecture and for organizing urban centres. They are the historical knowledge of humanity that enabled people to build architecture and landscapes with a universal value and are today protected by UNESCO under the category of cultural landscapes. An appropriate use of natural resources such as water, soil and energy is made possible by using traditional knowledge that establishes the harmony of architecture with the environment, the symbiosis of the techniques of organization of space with the traditions, the social habits, the spiritual values and the fusion between practical aspects and beauty.

Today, traditional knowledge is in danger and its disappearance would cause the loss not only of people's capability to keep and pass on the artistic and natural heritage, but also of an extraordinary source of knowledge and cultural diversity from which appropriate innovative solutions can be derived today and in the future.

UNESCO launched a global programme for an inventory assigned to IPOGEA – Research Centre on Traditional and Local Knowledge. The project gathers and protects historical knowledge and promotes and certifies innovative practices based on the modern reappropriation of tradition. The main targets are the firms, natural areas and historical centres that will be assigned quality trademarks and acknowledgements of international excellence in production or use of good practices and innovative solutions. Each technology, proposition and achievement will provide a spin-off on an international scale and each good practice will contribute to safeguarding the whole planet.

Keywords Traditional knowledge, water harvesting techniques, Sassi of Matera, urban ecosystems, natural resource management

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IPOGEA – Research Centre on Traditional and Local Knowledge, Matera, Italy

1 Water Harvesting Techniques in the Mediterranean Arid Zones

Three sides of the Mediterranean Basin are connected with areas where humankind had to cope with dryland areas; its islands are completely lacking in underground or groundwater where complex civilizations developed, and even in its more northern areas, it undergoes a changing and catastrophic environment. Therefore, most traditional techniques relative to the water organization for water harvesting, conservation and diversion are widespread as well as the systems of slope protection and the creation of soil that have different characteristics according to the environment. In southern Italy and in Spain there are also water systems, such as the underground drainage tunnels common in oasis towns, in North Africa and in the Eastern World that have been handed down by Islamic civilization or more ancient civilizations (Figs. 1–6).

The several water saving techniques used in Nabatean agriculture (condensation caves and pits, stone arrangement for rainfall harvesting, underground dams) are widespread not only in the Negev Desert but also in the whole Mediterranean region. In Petra (Jordan) they represent a synthesis of their urban ecosystem, but they can be also found in Tunisia, Libya and in southern Italy, and particularly on the Mediterranean islands thanks to the influence of prehistoric or widespread traditions imported by exchanges. The techniques used in Andalusia agriculture in Spain are widely represented because of the influence of the Islamic civilization. On the island of Ibiza, there is a similar irrigation practice called *feixes*, which uses an ingenious hydraulic system. The fields are divided into long and narrow rectangular plots by means of a network of canals having the twofold function of draining excess water and collecting and saving it for use later to irrigate the fields during drought seasons. In fact, if these works had not been undertaken, the fields would be swampy during certain seasons and arid or flooded by seawater in others. This system functions as a self-regulating process that supports the practice of intensive cropping of both marshlands and arid lands. Open canals are about one-metre deep, and flow at a lower level than the plots of land, thus keeping them dry. The land excavated for building the canals is used to raise the level of the cultivated land. During hot seasons, when the land undergoes high evaporation, the plots absorb the necessary quantity of moisture directly from the subsoil and from the walls of the canals by osmosis and capillarity. The process is then fostered by further underground canalisation in the plots. These underground canals are built with porous stones and pine-tree branches covered with a layer of Posidonia algae collected along the coast. This method ensures good running water piping and at the same time obtains a certain level of permeability so that the land receives enough water to keep it moist. The irrigation runs from the subsoil directly to the plant roots. This technique helps to save water that would be lost to evaporation were open irrigation methods used.

Traditional techniques can be found not only on southern Mediterranean shores and in southern areas of Europe but also in northern France and even in the Swiss mountains, where specific geomorphologic conditions cause aridity. This situation depends on the position of the mountain slopes compared relative to the direction of the dominant winds, which release their moisture as they rise upwards. Once they have reached the top, they lash against the slopes below with high pressure dry wind currents, which dissolve the clouds. This phenomenon of the foothill deserts creates dry, arid conditions in the valleys of Switzerland. Conversely, in the region of Valais and the province of Sion, there are green pastures and plentiful vineyards. The landscape is the result not of natural conditions but of the skilful use of a traditional local technique called *bisse*. This consists of a series of channels made of wood or carved out of the rock that extend up into the mountains as far as the sources of the brooks and the perennial glaciers, running for many kilometres. They slope very gently down the steep edges, remaining at a high altitude to convey the water along above the natural course of the river bed and use the force of gravity alone to irrigate distant valleys; otherwise, they would completely lack water. This system is supported by social cohesion, by water boards and companies similar to those that manage Andalusian agriculture or the Saharan drainage tunnels. Just as in northern Africa and in Spain, this system generates a landscape in which the location of the settlements is determined by the layout and the outlets of the *bisses*.

The most widespread system and thus a typical feature of the Mediterranean Basin is the terracing that can be found from the Middle East to Greece and from Italy to Portugal. Terracing associated with olive and wine growing actually contributes to shaping the landscape. The slopes and hills in the northern Mediterranean have withstood erosion over time and their present shape is the result of long-standing action. Along with the dry stone walls, the stone barrows (*specchie*) and the *tholos* constructions (*trulli*), terracing is typical of the Apulian region in southern Italy. Here the terraced slopes of Amalfi and in the north, the Cinque Terre in Liguria, create fascinating and traditional urban ecosystems. In Sardinia and Ibiza, there are systems of fields surrounded by dry stone walls called *tanka*, which is a term deriving from an ancient Mediterranean toponym.

The majority of the ancient Mediterranean sites follow the layout of the terracing and the water systems network. These sites adopt the techniques of rainfall harvesting, protected vegetable gardens, the use of organic waste for the creation of humus, methods of passive architecture, and climate control for food storage and energy saving, as well as the practices of recycling productive and food residues. The aesthetic qualities, the beauty of natural materials, the comfort of architecture and spaces, and the organic relationship with the landscape that these ancient towns boast stem especially from the intrinsic qualities of traditional techniques and the search for symbiosis and harmony intrinsic to local knowledge. The survival of poor archaic societies throughout the Mediterranean depends on the accurate and economical management of natural resources. The close link between traditional farming techniques and settlements make the traditional historic centres a fundamental element for environmental preservation. In the Mediterranean region, which is characterized by intensive historical settlements, each part of the environment is not only the result of natural processes but also represents a cultural landscape where historical centres are the crystallization of knowledge appropriate to correct environmental management and maintenance.

2 The Case Study of Matera, Southern Italy

The Sassi of Matera provides a typical example of traditional use of water resources in the Mediterranean. The local knowledge system adopted is found in a wide variety of situations ranging from the troglodyte dwellings of the Loire Valley in France, to Petra in Jordan, to the towns carved out of the calcareous rock in Cappadocia in Turkey, to the underground settlements of Matmata in Tunisia, to the villages along the canyons in Algeria, and in Morocco up to Andalusia and Nabatean water farming techniques. The towns are built along the borders of deep valleys, the Gravine, that have a small water carrying capacity or none at all. The settlements are not placed on the bottom of the canyon like one might expect if it were to provide water, but on the upper part, along the plateau and its steep slopes. In fact, the resources of the maze-like troglodyte dwellings of the Sassi of Matera and of the other stone towns of the Gravine are the rain and the dew that are harvested in drains and in cave dwellings (Laureano, 1995). The time stratification of traditional knowledge according to social groupings “hunter-gatherers”, “farmer-breeders”, “agro-pastoralists” shows the progressive determination of a complex system of knowledge and appropriate use of resources until the creation of the stone oasis and of the urban ecosystem.

2.1 Hunter-Gatherers (Water Harvesting in the Cave Dwellings by Dripping and Percolation)

Human beings have settled Matera from the Palaeolithic onwards, as proven by a number of stone findings in the Grotta dei Pipistrelli (The Cave of Bats) and by an intact skeleton of a hominoid found in a karst pit near Altamura which has been dated at about 250,000 years old. The Grotta dei Pipistrelli is a natural formation but its structure is made up of a passageway, the entrance of which gives out onto the slope, and the other end of which emerges through a karst sink hole onto the plain and is a model for later artificial constructions.

2.2 Farmer-Breeders (Rainwater Harvesting in Wells and Cisterns; Villages with Large Ditches to Drain the Soil and Harvest Water; Multipurpose System)

During the Neolithic, a number of techniques were developed for digging the calcareous highland and for harvesting water. Bell-shaped cisterns, huts and small canals were enclosed in deep ditches, forming circles and ellipses and were therefore called entrenched villages. It is nonetheless likely that the ditches were used not for defensive purposes but for animal husbandry and farming. An analysis of aerial photographs that show where vegetation grew more thickly, also show drainage systems that were used for water harvesting or humus collection, and the maze-like systems called *corral* that were necessary for agricultural and animal grazing. The recent excavation of the Neolithic complex of Casale del Dolce near Anagni underpins this hypothesis.

2.3 Agro-Pastoralists (Cave Excavation for Worship and for Intercepting Water; Pit Courtyards; Terracing for Soil Conservation and Plants; Dry Walls; Megalithic Monuments; Moisture Condensers; Barrows and Stone Arrangement)

The Metal Age provided new tools that made it easier to excavate caves and pits. As the environment deteriorated, these caves became ever more attractive as human dwellings. In fact, the progressive loss of vegetation cover left the surface villages without shelter and the land unprotected, thus causing a shortage of wood for building and heating purposes. The climate ranged from freezing winters to scorching summers.

The absolute lack of water in rivers or on slopes made it necessary to harvest meteoric water in underground cisterns. An increasing popular form of dwelling was the pit courtyard, which had been developed during the Neolithic subsequent to the development of excavation techniques where tunnels radiated out from a central shaft.

This dwelling model also arose in remote areas, such as Matmata in Tunisia and on the dry plains of China, and was the origin of the courtyard dwelling used by the Sumerians both in antiquity and during the Islamic era. An excavated house near the Neolithic site of Murgia Timone, across from the Sassi of Matera, proves just how effective this type of construction is. The house is rectangular in shape, like the megaron of Crete, and is divided into three spaces made up of two open rooms and a third underground room. The courtyard is used as a water reservoir; it is an open, sunny space that is protected by its walls and can be used for food preparation. At the opposite end is a garden that is used for waste and as a compost heap that is carved out of the rock. The garden is absolutely necessary given the poor soil and the need to protect plants. The caves keep a constant temperature throughout the year and are ideal as shelters for humans and animals, for the storage of grains and water conservation.

It is interesting to note that after the structure was discovered and freed of sediments, the underground part of the cistern soon filled up with water, even though there had been no rainfall. Therefore, the system started working again using capillary infiltration and condensation.

Even the barrows of the Bronze Age took their shape from water harvesting practices, both functionally and ritually. The barrows consisted of a double circle through which ran a corridor with a room excavated down the centre. What is interesting is that these structures were introduced along the excavation of the archaic Neolithic walls which had been abandoned when the buildings were constructed but still can be used as moisture diversion systems.

What has been found in Matera is quite similar to prehistoric structures made up of barrows and underground rooms in the Sahara Desert. Actually, these are solar tombs made up of concentric rings around the barrow. They could also be ancient methods for the collection of moisture and dew and could belong to cults devoted to the practice of water harvesting.

Similar interpretations could be made of the dry stone structures spread throughout the drylands of Apulia, where stone mounds harvest the night dew, thus replenishing the soil with moisture. Indeed, the roots of centuries-old olive trees all point to the low walls that are a staple of the farmland. The walls, the barrows, the trulli and the mounds of calcareous rock called *specchie* are all structures of water condensation and conservation. These structures carry out their tasks during the day and at night. In the scorching sun, the wind carries traces of moisture which seeps into the interstices of the stone mounds, whose internal temperature is lower than the outside temperature because it is not exposed to the sun and has an underground chamber. The decrease in temperature causes the condensation of the drops that fall into the cavity. That same water accumulates and provides further moisture and coolness by amplifying the efficiency of the condensation chamber. Overnight, the process is reversed and condensation occurs externally so that dew settles on the surface; the dew slides into the interstices and is harvested in the underground chamber.

2.4 Stone Oases (Canyon and Gravina Settlement: Vertical Integration of the Systems; Terracing, Realization of Ecosystems; Dwellings Built in Traditional Materials for Energy Saving, Water Harvesting and Recycling)

By developing the original prehistoric techniques, an adapted habitat system that uses the combination of different water production techniques (catchment, distillation and condensation) is in use in the Sassi of Matera. During torrential rainfalls, the terracing and the water collection systems protect the slopes from erosion, and gravity pulls the water down towards the cisterns in the caves. During dry spells, the dug out caves suck out the moisture in the air at night: the moisture condenses in the final underground cistern, which is always full, even if it is not connected to outside canals or ducts. The result is a multitude of underground storeys topped by long tunnels leading downward underground. Their slope allows the sun's rays to penetrate down to the bottom when heat is most necessary. In winter, the sun's rays are more oblique and can penetrate the underground areas. During the warm season, when the sun is at its zenith, it shines only on the entrance to the underground caves, which thus remain fresh and humid.

We know of up to ten storeys of caves, one atop the other, with dozens of bell-shaped cisterns all connected to each other by means of canals and water filter systems.

Like in the Sahara oasis, the system of local knowledge makes it possible, in a situation without water resources, to have good living conditions thanks to the appropriate use of techniques and to their perfect interaction with the environment.

2.5 Urban Ecosystem

Medieval monasticism contributed to this archaic texture. The hermitages, parish churches and farmhouses that are located in checkpoints of hydraulic works represent the poles of the urban growth process. The two main drainage systems called *grabiglioni* provide tillable land and humus by sewage collection and are surrounded by two urban sections, Sasso Caveoso and Sasso Barisano. In the middle is the Civita, the fortified acropolis that was an ancient shelter from danger, where the cathedral was built. Along the boundaries of the highland are large cisterns and ditches, as well as cave silos for grain storage and the craftsmen's workshops.

The vertical structure of the town allows the use of gravity for water distribution and protects against wind blowing on the plateau. Matera boasts hundreds of rock-hewn churches painted with beautiful Byzantine frescoes or built on the plateau and bearing monumental facades carved out of the *tufa* in the architectural style of the period of construction – medieval, classical or baroque. However, the maze of small streets, stairs and underground passageways continues to follow the ancient hydraulic structure. Therefore, it is still possible to understand the urban layout of the Sassi of Matera by starting from the original matrix of the underground spaces, the cisterns and the terraced gardens, as well as from that system of traditional knowledge that allowed a concentrated use of resources without depleting them.

2.6 Collapse and Rebirth

During the 1950s the Sassi of Matera were closed due to their neglected condition, and 20,000 inhabitants were moved to other neighbourhoods. The abandoned houses became state property, and a wall was erected to prevent their being occupied. The Sassi of Matera was transformed into a ghost town; the greatest troglodyte centre in all of Europe was completely abandoned. The dwellings were neither occupied nor ventilated, which led to their rapid degradation. The churches carved from the rock and decorated with beautiful medieval frescoes soon crumbled away as a result of theft and pillage.

In 1986, largely thanks to the motivation of individuals involved in cultural activities, the Italian Government allocated 100 billion Lire to restore the Sassi and undertake the work necessary to improve its sanitary conditions and urbanization, and to encourage private individuals to take up residence there. All the state properties were entrusted to the Mayor of Matera, who was responsible for financing the project.

The turning point in the management of the Sassi came with their inscription in 1993 as an UNESCO World Heritage Site. Matera became a destination for both national and international tourists, and individual requests to return and live in the Sassi multiplied. The Mayor of Matera equipped the Sassi with a network of water systems, drains, gas, electricity and telecommunications whose cables were buried in underground trenches so as not to disturb their architectural qualities or landscape. About 3,000 people now live in the typical cave-homes, half built, half hollowed out.

2.7 The Restoration of Traditional Systems of Water Collection

The Sassi of Matera illustrate the natural resource management capabilities (water, sun and energy) that were once perfectly employed but are so often neglected today.

The international debate on urban development makes this problem topical and relevant. It is necessary to maximize the potential of a town at the local level to assure its harmonious and sustainable development. It is for this reason that the Ministry of the Environment chose Matera as an urban rehabilitation model within the framework of the Rio Conference and the United Nations Convention to Combat Desertification (UNCCD), its directives and action plans.

The very encouraging experiment in Matera could be adopted in other urban centres, such as the inland region of Lucania and the dwelling systems of the Gravine (canyons). Indeed, these sites offer similar architectural and environmental characteristics but have yet to be renovated. Above all, this experiment is an exceptional example for those countries situated on the southern Mediterranean sea. In these countries, the progress of modernization has often destroyed traditional methods of managing space and threatened the ecological equilibrium of the whole region. Only by demonstrating the success of rich industrialized countries, like Italy, to restore traditional systems can countries that are less industrialized be persuaded to do the same.

3 Ancient Water Techniques for a Sustainable Future

Using traditional knowledge does not mean directly reapplying the techniques of the past but rather understanding the logic of this model of knowledge. It allowed societies in the past to manage ecosystems in balance, to carry out outstanding technical, artistic and architectural work, which is universally admired and has always been able to renew and adapt itself. Traditional knowledge is a dynamic system able to incorporate innovation and test it over the long term, thereby achieving local and environmental sustainability.

The Traditional Knowledge World Databank promotes traditional knowledge as advanced, innovative knowledge appropriate to elaborate a new technological paradigm based on the progressive values of tradition: the capacity for enhancing a society's internal resources and managing them at a local level, the versatility and the interpenetration of technical, ethical and aesthetic values, and production not *per se* but for the long-term benefit of the community. Activities are based on the principle of mutual support without waste; energy use is based on cycles in constant renewal; the purpose, including economic interest, is to protect the ecosystems, the cultural complexity and diversity of all living beings. The project aims to elaborate a new model of development and a technological dimension connected with historical memory.

Traditional knowledge consists of practical (instrumental) and normative knowledge concerning the ecological, socio-economic and cultural environment. Traditional knowledge originates from people and is transmitted to people by recognizable and experienced actors. It is systemic (inter-sectorial and holistic), experimental (empirical and practical), handed down from generation to generation and culturally enhanced. Such knowledge supports diversity and enhances and reproduces local resources. It is part of an extensive system that hands down and accumulates shared knowledge whose proficiency and evolution is appreciable over long long periods.

The functioning principle of the traditional systems is strong cohesion between society, culture and the economy. Their effectiveness depends on the interaction between several factors: aesthetic and ethical values complete the interaction between environmental, productive, technological and social aspects.

Traditional techniques, therefore, cannot be reduced to a list of mere isolated technical information that can be used to solve a specific problem. To grasp the full meaning and importance of traditional techniques, they must always be highly contextualized, not only within the local environmental situation but within a precise historical moment and the complex social construction that originated them.

An understanding of the logic of using traditional techniques, and of their success in terms of environmental sustainability and effectiveness over long periods, is fundamental not only to safeguard a vast cultural heritage but also as a new paradigm on which to found the modern reappropriation of traditional techniques.

3.1 Innovative Use of Ancient Water Techniques in Agriculture

Prehistoric techniques, which were used to form the Italian agricultural landscape, are today being proposed again in agriculture as the best practices for replenishing soils, saving water and combating hydrogeological instability and desertification.

The technique of drainage ditches spread in the Apulia district of Daunia 6,000 years ago when Neolithic communities built more than 3,000 villages surrounded by trenches in the shape of a crescent. The ditches met environmental needs by draining water and drying some areas to be tilled during the wet season and by working as drinking troughs for cattle, humus collection and water reserves during the dry season.

After this practice was replaced by mechanized agriculture, the area has suffered terrible floods in winter and extreme drought in summer. On the Ethiopian highlands, on the slopes of the Rift Valley ridges, many villages still use multipurpose ditch systems to store and manage water resources, gather sewage and produce fertilizers.

The atmospheric water condensed inside caves or mounds of stones and the dry limestone walls are used by all ancient societies in arid zones. Today, authentic aerial wells (atmospheric condensers producing water from vapour) are used in the desert. They produce water from atmospheric moisture using the principles and resources of very ancient techniques.

The practice of setting cistern-jars full of water or calcareous masses close to plants to provide irrigation is again being proposed today with innovative techniques that overcome constraints in ancient systems through modern drop irrigation. These traditional innovative techniques are used, for example, in the reforestation of arid areas; it allows each individual shrub to be supplied with the quantity of water it needs to grow so long as the plant has sufficient independent vegetative resources. Within the framework of this family of techniques, a large company has elaborated an enzymatically degradable product called “dry water” that, when set into the soil close to the roots, progressively transforms into the necessary water supply.

Drainage tunnels were used 3,000 years ago; they are underground tunnels spread over arid areas and are still working today in the Sahara Desert, in China and in Iran to supply oases with water (Figs. 7–10) – they absorb the right quantity of water for the replenishment of the environment itself. This solution could again be an alternative to the excavation of wells that lower the groundwater and deeply perforate the soil, causing pollution and surface salinisation.

In the Sahara, people are experimenting with the use of techniques to relieve hard excavation work by introducing small machines especially for this purpose. These include mechanical adapted tools, which range from mini-tractors for the excavation of lunettes for water harvesting to new machines for sustainable agriculture.

The reappropriation of such ancient techniques has been successful in combating erosion and soil degradation. In southern Italy, there has been successful experimentation with practices such as grassing and sowing on hard soil. The former involves making grass grow under orchards and in olive groves, thus forming a protective cover to avoid ploughing that causes erosion. The latter consists in sowing wheat over unploughed soil. This technique protects soil, reduces costs and achieves better results than ploughing. It is most advantageous during drought periods because ears of wheat grow to a lesser height and need a less water and chemical fertilizers.

3.2 Innovative Use of Ancient Water Techniques in Urban Settlement and Architecture

Several innovative traditional techniques are being explored in urban settings (Fig. 10). The building of most of the ancient centres followed the layout of the terracing and water systems network. As a matter of fact, rainwater harvesting techniques, walled gardens, the use of organic remains for the production of humus, passive architectural methods and climate control for food conservation and for energy saving, and recycling production and food residues were integrated and perpetuated in the very structure of the ancient centres. Such practices included all innovative techniques in the photovoltaic, sun warming, water catchment, composting and waste recycling fields. In some advanced contexts, for example in Tokyo, a number of industries are now employing by law, the roofed-garden technique in which new houses benefit from being covered by vegetation on the terraces of the modern buildings, bringing to mind the hanging-gardens of Babylon. This keeps optimal climatic conditions inside the houses, harvests water and becomes an area for entertainment and contemplation. The micro-solutions for city quarters and houses represent a large innovative sector in the waste recycling field. Several mini-compost machines have been placed inside gardens or in common areas of the quarters to directly absorb organic waste and supply the gardens with humus. A water compost machine is a device set beneath the toilet bowl which directly transforms waste into compost. Biomass mini-reactors, which transform waste into kitchen gases as well as greater plants for heating the whole house, have also been developed. Also small- and large-scale solutions for sewage water have been found. In Germany, modern houses have been equipped with a vertical marsh, a device that reproduces the processes of water decantation and filtration that exist naturally in marshlands. The process is reproduced along the wall of the building in glass interspaces where sewage waters seep into, infiltrate and constantly recycle themselves by gravity. In Calcutta, an innovative traditional technique used on a very large scale solved the serious problem of used waters. Sewage waters, traditionally re-used in rice-fields, are today turned into a resource for irrigating and fertilizing rice fields by using systems of sewage water filtration and sterilization.

A very large series of products, materials and know-how necessary in high-quality architecture form a further innovative sector. The aesthetic components we appreciate in ancient towns, the beauty of the natural materials, the comfort of the buildings and spaces, the organic relationship with the landscape are due to the intrinsic qualities of the traditional techniques and the search for the symbiosis and harmony embedded in local practices. In this field, experiences of companies reappropriating market materials and processes derived from tradition, such as lime, natural clay and pozzolana, both for renovation and new construction, are now widespread.

3.3 Production and Landscape

Local knowledge is a driving economic factor in several productive sectors. Tradition persists and plays a fundamental role precisely in those sectors and countries that are considered technologically advanced. The values existing in tradition, the work practices and the handicraft skills constitute added value for manufacturing practices in many modern countries. Where tradition persists, its role in society and economics is consolidated and stabilized and can be proved specifically in the more technologically advanced countries and sectors.

In particular, typical food production such as oils, cheese and wine, safeguards both the aesthetic and environmental quality of the landscape, since the old production systems are possible thanks to the use of traditional techniques of soil management. In this same field, the growing dissemination of organically controlled agricultural crop and meat production shows even greater interest in traditional techniques of husbandry and breeding.

These considerations are true even in other sectors ranging from quality articles and haute couture to real estate and the construction industry. The most refined production houses are proud to list the traditional techniques used in their manufacturing and the success of many companies is actually due to their capacity to incorporate tradition into their processes or to be located in traditional environments or historical town centres.

In the Valais in Switzerland, in the Loire Valley in France and in Tuscany in Italy, the maintenance of traditional techniques in agriculture has ensured the stability of high quality landscapes. The major difficulties and burdens due to the use of more expensive labour techniques can be overcome thanks to the great value of the product that can be obtained using these techniques, and this holds particularly in the case of wine.

In Valais the water catchment systems from springs and glaciers, through little surface canals called *bisse*, allow mountain slopes to be irrigated by gravity on a higher level than the stream's natural course. A similar technique is used today in Tibet with innovative methods to protect glaciers which are in danger because of global warming. In the Loire Valley, the traditional technique of cave dwelling and the excavation of subterranean caves is maintained in order to preserve every single metre of surface area, precious for high-quality wine production, and to maintain wine cellars with a microclimate perfect for its production. In Tuscany, wine production provides the economic resources necessary to preserve from destructive transformations one of the most wonderful agrarian landscapes, which has been consolidated and affirmed over the centuries.

Thus, it is wrong to consider traditional knowledge as marginal compared to the great economic and technological processes under way. Even from a quantitative point of view, their use still supports most of humankind in the less industrialized countries. Paradoxically, in these places, where traditional techniques are still used in a massive way, these are considered by modernist thought as a sign of "underdevelopment" or "backwardness", whereas in advanced countries, they create an image of desirability and provide added value.

What we recognize as tradition is not a static and immutable condition but a dynamic system that has evolved through innovation, that often is easily overlooked. For instance, nowadays everyone considers the Mediterranean region to be inseparable from olive and tomato cultivation; however, both were introduced: the olive in ancient times and the tomato after the sixteenth century. It is commonly thought that Native Americans always used horses. However, the latter appeared on the continent only after Europeans arrived. American nomadic people used them immediately and, during the period of colonization of the American Far West, the horse was already an essential component of the local tradition.

Medieval historical houses persisted in Europe because they were restored and adapted together with the hygienic facilities required for modern life. The more this is done with respect for tradition and authenticity, the more it requires advanced innovative and appropriate capacities and creates added value as well as economic effects.

The same consideration is true for entire historical centres and rural landscapes that are doomed to perish and be abandoned when they are unable to incorporate the innovations they need in order to function.

In Liguria in the Cinque Terre region of northern Italy, where there is one of the largest systems of terraced slopes in the Mediterranean, this traditional practice protects the soil, catches and channels waters, and has been perpetuated through innovative agricultural mechanization. Agricultural work on terraces is hard due to tiring transport systems that are operational only on foot. Traditionally, transport techniques consisted of sledges drawn up hill by ropes. Already at the beginning of the century, these were substituted with mechanical funicular systems on rails. The same technique has been proposed today using appropriate monorail systems that enable the ascent of the slope without disturbing the landscape or the ecosystem.

In Botswana the *motswelo* is a traditional form of cooperative and bank that usually gathers together between 15 and 20 people who join the group voluntarily and provide what they can: money, produce from the land, or labour. Thanks to this ancient system, it is possible to save money and obtain interest-free loans and funds to start important activities. For instance, it makes possible the organization and production and sale of traditional beer, the cultivation of new lands or the restoration of villages. Production and trade are considered equivalent to monetary deposits. All the profits are, in turn, given to the members of the *motswelo* who use them to fund one of their activities or other social needs, such as feasts, marriages or a house purchase. These practices are today reproduced by ethical banks and micro-loans, which are an innovative means to appropriate traditional social habits.

In Burkina Faso *zai* is a particular traditional technique capable of regenerating highly degraded soils. The soil is dug with holes that fill up with water in the wet season and are used as dumping-sites for rubbish and manure in the dry season. This practice attracts termites which digest rubbish, which is then absorbed by the plant roots. Furthermore, the tunnels dug by the termites increase the soil's porosity. Seeds are then sown in the holes, giving very high crop yields. Innovative practices that promote original forms of symbiosis between humankind and animals or micro-organisms are today proposed again to rehabilitate degraded soils or soils made suitable for human living in extreme areas. In the Balearic Islands, *feixes* are a traditional system of agricultural organization by which the plant roots are irrigated directly from underground without wasting water. The tilled fields are separated by superficial drainage channels into which water flows. From these a network of channels made of porous materials and covered with a layer of seaweed branches out under the crops. The channels release the quantity of water to the tilled soil according to seasonal and climatic needs. The technique is used in hydroponic cultivations and for spatial planning.

3.4 The Competitiveness of the Past

Thus, we must speak of an on-going construction of tradition. Guaranteeing its future does not mean to reduce or inhibit capacities of innovation, though this idea has been subjected over time to criticisms and biases as well as further weakened by the lack of communication and exchange of successful experiences.

With emigration and the dramatic transfer from traditional habitats into new urban agglomerations, the rapid abandonment of the agricultural sector by large segments of the population, and with the erroneous suggestion of the absolute superiority of modern technology, the process of conservation and dissemination of knowledge is being interrupted and lost. Conversely, the improved welfare conditions of people favours social cohesion, creates confidence within cultural identity, and safeguards traditional systems through the guarantee of a high remuneration of the work necessary to maintain them. It explains the apparent paradox of those rich countries that were able to maintain high levels of traditional techniques, and succeeded in paying for the necessary efforts with an important increase in product (added) value. Thus, tradition is a feature of "successful modernity", capable of drawing benefits and values from it. To reappropriate tradition by reviving its historical relationship with people's innovative and creative power is decisive for safeguarding the landscape and realizing sustainable futures.

Fig. 1 An artificial pyramid-shaped dune

Fig. 2 Creation of an oasis

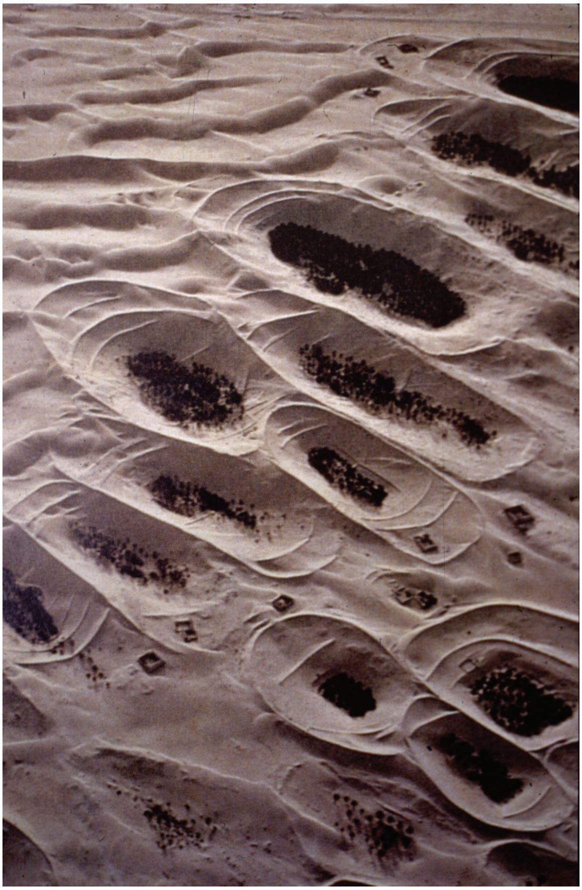

Fig. 3 Erg oases – the Algerian Souf region

Fig. 4 Oasis of Ihzer

Fig. 5 Oasis Oman

Fig. 6 The oasis of Tashit

Fig. 7 Fossara wells

Fig. 8 Khettara well

Fig. 9 Oasis of Timimoun-Kesria

Fig. 10 Water distribution in the oasis

Fig. 11 Cultivation oasis

Bibliography

Amiran, R. 1970. The beginnings of urbanization in Canaan. Sanders, J. A. (ed.), *Near Eastern Archaeology in Twentieth Century*, Essays in Honor of Nelson Glueck, Garden City, New York pp. 83–100.

Barker, G. 1981. *Landscape and Society: Prehistoric Central Italy.* London University and Academic Press, London.

Barrois, A. G. 1937. *Les Installations Hydrauliques de Megiddo. Revue Syria,* No. 3, Librairie Orientaliste Paul Geuthner, Paris.

Cantelli, C. 1994. Misconosciute funzioni dei muretti a secco. *Umanesimo della pietra*, No. 9, pp. — .

Cauvin, J. 1994. *Naissance des divinités Naissance de l'agriculture*. Centre national de la recherche scientifique (CNRS), Paris. *The Birth of the Gods and the Origins of Agriculture*, translated by Trevor Watkins. New Studies in Archaeology. Cambridge University Press, Cambridge, 2000. (In English.)

Childe, V. G., 1954. Prime forme di società. *A History of Technology*, Clarendon, Oxford, Vol. I.

Dentzer, M. et al. 1989. *Contribution Française à l'archéologie Jordanien*. IFAPO, Amman.

Di Lernia, S., Fiorentino, G. and Galiberti, A. 1990. Gargano prehistoric mines project: the state of research in the Neolithic mine of Defensola-Vieste (Italy). *Origini*, Vol. XV, pp. — .

Diamond, J. 1998. *Guns, Germs, and Steel: The Fates of Human Societies*. W.W. Norton, New York.

Drower, M. S. 1954. Fornitura di acqua, irrigazione e agricoltura. *A History of Technology*, Clarendon, Oxford, Vol. I, pp. — .

EC. 2000a. *Mediterranean Desertification: Research Results and Policy Implications*. Proceedings of the International Conference, 29 October to 1 November 1996, Crete, Greece, Vols. 1–2, Brussels, EC.

_________. 2000b. *Desertification in Europe: Mitigation Strategies, Land–use Planning.* Advanced Study Course, European Commission, Brussels.

Evenari, M., Shanan, L. and Tadmor, N. 1971. *The Negev: The Challenge of a Desert*, 1982 second edn., Harvard University Press, Cambridge, Mass.

Gruet, M. 1952. Amoncellement pyramidal de sphères calcaires dans une source fossile moustérienne à El Guettar (Sud tunisien). *Actes du II congrès panafricain de Préhistoire et de Protohistoire*. Alger. CNRS, Paris.

Laureano, P. 1988. *Sahara, giardino sconosciuto*, Giunti, Firenze. French edition: *Sahara jardin méconnu*, Larousse, Paris, 1991.

_________. 1993. *Giardini di Pietra, i Sassi di Matera e la civiltà mediterranea*. Bollati Boringhieri, Torino.

_________. 1995. *La Piramide Rovesciata, il modello dell'oasi per il pianeta Terra.* Bollati Boringhieri, Torino.

_________. 2001. *Atlante d'acqua, conoscenze tradizionali per la lotta alla desertificazione*, Bollati Boringhieri, Torino.

_________. 2005. *The Water Atlas: Traditional Knowledge to Combat Desertification*. Laia Libros, Barcelona.

Lourandos, H. 1980. Change or stability? Hydraulics, hunter-gatherers and population in temperate Australia. *World Archaeology*, Vol. II, No. 3, February, pp. — .

Nebbia, G. 1961. Il problema dell'acqua nelle zone aride: l'estrazione dell'acqua dall'atmosfera, *Annali della Facoltà di Economia e Commercio*, n.s., Vol. XVII, pp. — .

Peretto, C. (ed.). 1991. *Isernia La Pineta. Nuovi contributi scientifici*. Firenze.

Pirenne, J. 1977. *La Maîtrise de l'Eau En Arabie du sud Antique*, Geuthner, Paris.

_________. 1990. *Fouilles de Shabwa*. Geuthner, Paris

Tinè, S. 1967. Alcuni dati circa il sistema di raccolta idrica nei villaggi neolitici del foggiano. *Atti della XI e XII Riunione scientifica dell'Istituto Italiano di Preistoria e di Protostoria*, Firenze.

_________. 1983. *Passo di corvo e la civiltà neolitica del Tavoliere*. Genova.

UNCCD. 1998. *Traditional Knowledge and Practical Techniques for Combating Desertification in China*. United Nations Convention to Combat Desertification, Bonn. Online: www.unccd.int.

_________. 1999a. *Traditional Knowledge: Report of the Ad Hoc Panel*. ICCD/COP(3)/CST/3. United Nations Convention to Combat Desertification, Bonn. Online: www.unccd.int

_________. 1999b. *Building Linkage between Environmental Conventions and Initiatives.* United Nations Convention to Combat Desertification, Bonn. Online: www.unccd.int

_________. 1999c. *Synthesis on Important and Widely Applied Traditional Knowledge on a Sub-Regional and Regional Basis and on Traditional Scale*. ICCD/COP(3)/CST/3. United Nations Convention to Combat Desertification, Bonn. Online: www.unccd.int

_________. 1994a. Special issue: *Traditional Knowledge in Tropical Environments*. *Nature and Resources*, Vol. 30, No.1.

_________. 1994b. Special issue: *Traditional Knowledge into the Twenty-First Century*. *Nature and Resources*, Vol. 30, No. 2.

Wittfogel, K. A. 1957. *Oriental Despotism*. Yale University Press, New Haven, CT.

Zaydine, F. 1991. Le royaume des Nabatéens. *Les Dossiers d'Archéologie*, No. 163, pp. —.

Chapter 6
Cultural Diversity in Ethiopia and Its Impact on Local Economies and Biodiversity

Ingrid Hartmann

Abstract This paper shows examples of the cultural diversity of Ethiopia and its rootedness in biodiversity and history which is expressed in its crafts. Two main approaches for their preservation are illustrated, a subsistence-oriented and a market-based approach. Different kinds of products, like basketry, weaving, leather and cultural foods, are analyzed in respect to their natural and historical rootedness and the way in which current approaches for their promotion impact the rural economy and the natural environment and thus contribute to the creation of alternative livelihoods in drylands. A specific focus is on the socio-economic conditions of traditional Ethiopian craftworkers, who remain ostracized and impoverised.

Keywords Biocultural diversity, crafts, cultural value systems, cultural identity, biodiversity conservation

1 Introduction

1.1 Biocultural Diversity of Ethiopia

Ethiopia is considered the cradle of humankind, and its historical monuments belong to the world's most important reminders of Christianity. Ethiopia was the first and maybe the only country in the world where Christians and Muslims used to live in peaceful conviviality. The country is one of Nikolai Vavilov's centres of genetic resources due to the fact that Ethiopia is a tropical country with altitudes ranging from below sea level in the Dallol Depression to over 4,000 m on Ras Dashen. The Ethiopian Plateau, which comprises about 45% of the land mass, is dissected by the Great Rift Valley of Africa and deep river valleys.

Cultural Heritage Project Ethiopia, Addis Ababa, Ethiopia

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

Rainfall varies from an annual total of over 2,000 mm to virtually nil in the Dallol Depression (Million et al., 2005). There are various approaches to explain how this natural diversity evolved into the present cultural diversity patterns in Ethiopia, and it Donald N. Levine (1974) has related it to the ecological conditions by describing it as a process of holistic specialization. Holistic specialization assumes that small and relatively homogenous societies occupied the various ecological niches of the Ethiopian environment and thus created an overall pattern of a heterogenous society consisting of many different homogenous cultures, differentiated into separate small-scale societies with distinctive religions, social organizations and technologies, accompanied by the evolution of numerous languages, which consist of four generalized groups (the Ethio-Semitic, Cushitic, Omotic and East Sudanic languages families). Due to the presence of other kinds of cultures in a larger ecological setting, all members of each society developed a keen sense of their own identity and cultural expression. Nevertheless, many aspects of the culture–such as ways of living and thinking and ways of eating and clothing–cross the borders of religion and language, which establishes a *unity in diversity* that is a unique and distinct feature of Ethiopian identity (Aleme, 1982).

1.2 The Role of Crafts in Drylands

The intense relationship in societies between cultural and natural diversity is manifested in their products, mainly in their crafts, which have various functions in connecting culture and nature. And these functions are usually multipurpose: Crafts are historical documents, they give cultural identity, they are witnesses of cultural survival skills, and they are economic goods. In this broader sense, crafts can be considered here in relation to all that which that connect, culture and material.

For the future of drylands, this has a specific relevance, since it is the adverse conditions of drylands that require specific coping strategies and survival skills; it is the fragile environment that needs specific care and knowledge of conservation; and, finally, it is the fact that drylands are the ecosystems where poverty is most widespread which requires the development of alternative livelihoods (MEA, 2005), where crafts can play an important role (UNCCD, 2004).

2 Approaches for the Preservation and Promotion of Ethiopian Crafts

Various approaches are being implemented for the promotion of crafts and the preservation of cultural diversity, ranging from market- and export-oriented ones to community-based subsistence-oriented approaches. They all aim at the conservation and revitalization of traditional skills (World Bank, 2002).

Subsistence-oriented approaches, mainly pursued by NGOs, focus on strengthening the intimate relationship between humans and material. This perception of crafts also includes cultural food and house construction (Belay et al., 2005; Mitchell, 2001), emphasizing the biocultural values of crafts and their importance for agrobiodiversity and biodiversity protection by preserving farmers' knowledge of this diversity and its use. This discovery also survives in the elaborate folk taxonomy and system of nomenclature, as well as in the beliefs, value systems, cultural songs and aphorisms (Asfaw, 2000).

Poverty reduction targets are implemented through the direct contributions that the produced crafts give to the subsistence sector and to local markets, so that subsistence needs are satisfied in a non-monetary way, or income generation is achieved through the provision of crafts for local demands.

On the other hand, international marketing of crafts has created opportunities to gain high incomes within a short time in several countries. These approaches are currently considered very promising, since in some countries the rapid development of tourism, and particularly ecological and cultural tourism, has created very strong interest in cultural industries for "exotic" products in the developed world. Paradoxically, it has been globalization that has made traditional craft trade among the fastest growing industries, providing earnings of millions of dollars to some developing countries (Marc, 2005).

To promote this type of development in Ethiopia, training courses are conducted that mainly target craftspeople who are already successful. They aim to make of traditional crafts fit for the world market. While this international marketing approach has no direct component for poverty reduction, it implies that poverty reduction in general can be indirectly achieved through raising the level of the national economy.

3 Target Groups

There are different target groups for the various project approaches, with different social settings, historical backgrounds and environmental embedding.

3.1 Traditional Craftspeople

The evolution of a specialized craftsmen group occurred at a stage when small societies no longer relied solely on intermittent contact with outside groups to obtain goods and services (Fig. 1), but moved them into their own home society to secure a regular basis by finding a place for the suppliers through "mutual specialisation".

These groups have specific knowledge of certain elements of the environment, such as metal (blacksmiths), fire (blacksmiths and potters), soil (potters), fibres (weavers) and related techniques. Besides providing societies with their

Fig. 1 Woodcarvers in Adiet

specific material services, they play special roles in traditional customs and rituals, which are embedded in the specific belief systems. For instance, within certain groups like the Borana and Gurage, caste group members play distinctive and indispensable ritual roles, such as serving as functionaries in religious ceremonies (Pankhurst & Freeman, 2003), and thus support and preserve traditional belief systems both through their function in society as well as through their products. 'In societies where the gods are fully present and the spiritual life vivid, the role of images and sculptures as an inspiration for worship, or as the very expression of the divine, is as practical as any more "tangible" aspect of life' (Bidgood, 1999). This is true both for the natural religions in Ethiopia and for Muslim and Christian religion, who especially contribute to the preservation of biodiversity in their churchyards.

However, the reality that traditional craftspeople in Ethiopia face is far from being romantic. While the integration of alien crafts groups can be understood as a compromise due to a society's desire for certain products, the very activity of producing these is felt in some sense to be morally reprehensible. So, for example, 'the most conspicuous thing about the caste groups is not that they are indispensable, but that they are despised' (Levine, 1974).

Thus they are perceived as being polluted and bringing death due to their specific activity. Tanners are despised because they are said to be stingy; mana's (potters), because of the evil eye; falashas as demons and blacksmiths as sorcerers; weavers as bringing death because of the colour of their products. This results in prohibition of intermarriage, spatial exclusion during celebrations, and a general lower income status than the dominant – mostly farmers' –

groups. There is, however, no uniform expression of the rate or kind of exclusion that can be related to certain ethnic groups and different professions, and thus it varies within different areas among groups and professions (Pankhurst & Freeman, 2003).

Aside from some smaller efforts by some NGOs, none of the projects has really been able to target traditional craftspeople. To escape from their lower social status, they either emigrate, like certain Somali tanner groups, or, if possible, try to become farmers.

3.2 Household and Farm Crafts

There are also handcrafts, such as basketry, embroidery and spinning that are not related to professional groups but are conducted by women in almost every household to meet subsistence needs. Their designs and symbolic patterns testify to the rich biodiversity of the country (Ahmed, 1998).

Farmers also conduct craftwork especially to increase the family income during the dry season, like wood carving for churches, which is frequently conducted in shared labour with ecclesiastical painters and even priests themselves. These groups are targeted by almost all types of craft projects.

3.3 Elite Craftspeople

Following the formation of traditionally despised occupational castes, "elite" craft groups also developed by differentiation among the fully accredited members of society. A hallmark within this process has been the adoption of what has been termed "craft literacy", where written language is used for religious, magical and administrative purposes by a restricted group of literati, first occurring in ancient Aksum (Levine, 1974) (Fig. 2).

From here also the first professional families of gold and silversmiths originated, which spread all over the country. They were greatly respected by the society, as were ecclesiastical painters and woodcarvers (Pankhurst, 1990), who were found in large numbers in and around Aksum, but also in remote villages (Fig. 3). From among these products, current project approaches mainly try to introduce Ethiopian jewelleries into international markets.

3.4 Emerging Craft Industries

A few crafts were able to modernize within the last decades, especially weaving. Mid- to large-scale hand-weaving enterprises have been founded mostly in urban

Fig. 2 Ancient Koran, Harar

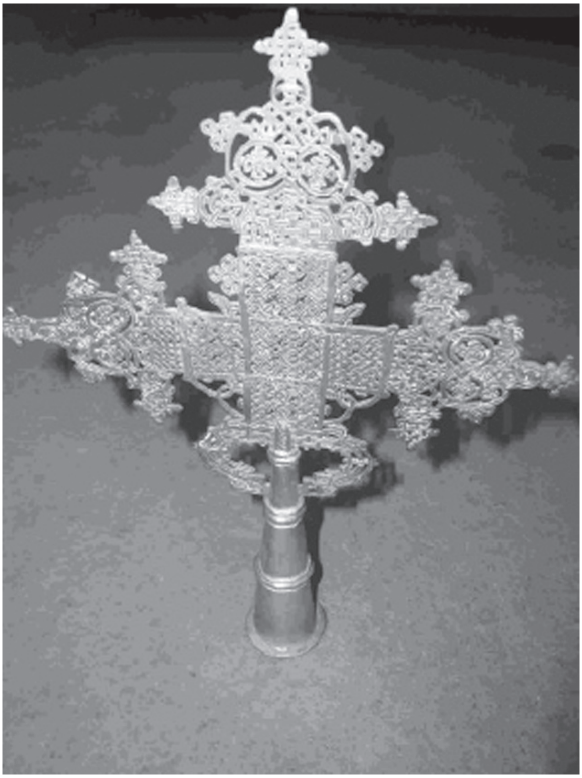

Fig. 3 Axum Handcross, silver

areas, which modernized designs and materials. Traditional *gabis*, for instance, made form cotton have been coloured, or traditional clothes transformed into curtains, table-runners or cushion covers. The main modern material is art silk (a natural material) and rayon (produced from cotton stalks) (Figs. 4, 5).

The process of manufacture, especially of spinning, however, is frequently still done in the traditional way, even in the most advanced craft industries.

Examples for modernized designs in pottery are water containers, which have been developed from a combination of old nomadic containers, where head rests are now used as a cover (Fig. 6).

The aim especially of projects that promote international marketing is to focus on these emerging craft industries, which are still small in number, and mainly found their markets through personal relationships.

Fig. 4 Traditional wear in the nineteenth century (Photo: University of Mainz)

Fig. 5 Modern weaving (Photo: Sara Abera)

Fig. 6 Modern water jug, composed from traditional head rest and container (Photo: Befekadu Terefe)

4 Goals and Problems of the Various Approaches

Subsistence-oriented approaches mainly try to strengthen the relationship between culture and nature, survival skills and the symbolic values of crafts, while marketing approaches mainly consider crafts as economic goods. Both approaches take into account the historical rootedness of crafts.

4.1 Strengthening the Relation between Natural Environment and Cultural Diversity

Cultural practices are often linked to the environment, as natural products are used for traditional activities. Thus, while cultural value systems contribute to biodiversity conservation, they are harmed if biodiversity is not conserved and cultural systems are not determined by the natural environment.

The enset plant or false banana, for instance, is central to the *Gurage* culture; it is important as both a staple food crop and a source of material for clothing and housing. It has social implications as a centre around which a number of communal activities are organized, including annual planting and harvesting ceremonies. It also permeates the ritual systems of *Gurage* culture. It is served in connection with all ceremonies that honour *Gurage* deities, and specific parts of the enset plant are applied in rituals connected with birth, puberty rites, marriage and death.

The *Afar*, for example, are closely tied to the nomadic herding of goats and camels in a parched region of desert, lava streams, volcanoes and salt depressions. The *Konso* have made specialized adaptation to stony highlands in the far south, stone walls are erected around their distinctively organized towns, stone is used for grinding corn, for sharpening knives, for building houses and constructing dams. Their use of stones gives a clarity and definition to their towns and homesteads which is extremely striking, it conveys a sense of order and harmony and is thus a true expression of their values (Levine, 1974).

The production of crafts is traditionally embedded into this cultural system in a harmonious way. Grasses used for basketry, such as *Eleusine jaegeri* (Figs. 7, 8) and *E. floccifolia* (locally known as *akirma*), are not palatable for livestock, and thus could become a weed if not harvested. *Pennisetum sphacelatum,* a slightly coarser grass, which is avoided by animals as well, is used for flat plates called *sefed*, used for winnowing grains and pulses (Hansorf, undated). If it is not imported, rayon, incorrectly called “art silk”, is made from cotton stalks and thus is a by-product. This resource efficiency proves the sustainability of crafts, which can conserve resources, if embedded in the social and ecological systems (Shiva, 2001).

4.2 Survival Skills

Crafts also conserve the survival skills developed through history which helped people to cope with harsh conditions of drylands and elsewhere. Taking a look,

Fig. 7 *Eleusine jaegeri* as weeds (Photo: FAO)

Fig. 8 Baskets cover from *Eleusine jaegeri* (Photo: ILRI)

for example, at the *Afar*, their knowledge of how to prepare famine food and build houses for migration are essential for survival under extreme conditions; thus their knowledge for survival is incorporated into the construction of their movable houses, which should not be lost (Fig. 9).

One of the central cultural features that can be ascribed to the preservation of survival skills is the preparation of traditional food, which is related to the knowledge and conservation of agrobiodiversity, since traditional dishes maintain the demands for traditional varieties, and thus protect genetic diversity through in-situ conservation (Vernooy, 2005; Belay et al., 2005).

Fig. 9 Afar mobile house (Photo: University of Mainz)

4.3 Crafts are Multipurpose and Have Symbolic Functions

Crafts mostly have multiple purposes and additional symbolic meanings. Traditional beehives, for instance, are hanged on trees in Ethiopia to mark the property rights of farmers on these respective trees deep in forest areas; thus they also have an important function for forest protection. Once replaced by modernized beehives, this demarcation of property rights is lost and also its nature conservation value. The preparation of crafts follows other criteria than the preparation of just economic goods (Hartmann, 2004). Colourful baskets, as prepared by Harari women, for instance, serve as presents for occasions such as weddings, as containers and as home decoration. So they are made not just for economic reasons. Because the preparation, for instance, of one fine-coiled basket, called *tihin*, can take more than one month, the economic efficiency of preparation only within this specific cultural system, where "time is not money".

4.4 History and Cultural Identity

Whether for utilitarian or artistic purposes, traditional crafts represent a very valuable form of cultural expression, a "capital of self-confidence", which is especially important for developing countries and thus serve as a reminder of the relationship between societies and the environment (Mitchell, 2004). They are rooted in age-old traditions that are renewed by each generation and stand at the threshold of cultural industries, captured in techniques and motifs–for instance, the motifs of the crafts by the Falasha, the Ethiopian Jews, who represent one of the main craftsmen groups, still tell their ancient migration history, based on the presumed love story between King Solomon and the Queen of Sheba (Fig. 10).

Ancient techniques like natural dyeing, however, have nearly been wiped out due to their replacement by chemical substitutes. Yet craftspeople do not simply conserve the cultural heritage but also enrich and adapt this heritage contemporary needs to meet a societies'.

Re-emphasizing the value of handmade works is also important for many developed countries can the quality of life is often threatened by excessive industrial standardization, Handmade works serve as a reminder of alternative production forms in an age that replaces well-made, durable and loved objects by industrial products clumsily put together and quick to fall apart, made of deadened materials with neither voice nor wholeness (Mitchell, 2004).

Jewellery, for example is frequently made for festivities and is important as a symbolic representation of the culture, which instills a sense of pride and helps in a collective recognition of identity. Without the richness of this creativity as expressed in the diversity of Ethiopian crafts and arts, it is said, the historical independence that Ethiopia has maintained over the last centuries, indeed millennia, would have been lost (Chojnacki, 1983).

Fig. 10 Falasha pottery, Queen of Sheba, King Solomon, and their son Menelik (Photo: Befekadu Terefe)

Integrating crafts into the global market economy, which is characterized by Western values and institutions, requires overcoming or mitigating strong cultural gaps and various trade-offs. This can be accompanied by disadvantages, mainly related to intellectual property and copy rights, when products become attractive on Western markets, so that they are produced everywhere, as has occurred with Navajo baskets, which now are produced in Pakistan (Marc, 2005).

4.5 *Crafts as Economic Goods*

Crafts have always been economic goods and have secured income or means of living for craftspeople for centuries. To assess the role that crafts could play as income resources, various criteria have to be considered, including the availability of raw materials, qualities and designs (Table 1). In general, environmental pressure on resources and the lack of rationalization of production prices of local

Table 1 Potential of product types

	Embroidery	Jewellery	Leather	Wood carving	Basketry
Potential quantity	++	++ Enough silversmiths in the town, but skills restricted to one group	+	Mostly restricted by CITES	+
Quality and design	+	++	++	++ Mostly for religious purposes	++
Costs (+ means low cost)	+	++	+++	Wood mostly forbidden for export	High labour input
Competition from other countries (+ means low competition)	+	++		++	
Raw material restriction (+ means low restriction)	Lack of fabrics in various colours	Cheap silver available (although Maria Teresias are more expensive)		Use of Wanza prohibited, may shift to other hardwood	Palm leaves far away
Potential employment effect	+++	+	++	++	+++

Ethiopian goods (whether raw material or manufactured goods) are perceived as being too great both within the country itself and abroad.

Furthermore, the availability of raw materials is declining due to environmental degradation, which also has contributed to the decline of the importance of crafts in subsistence production, increased the prices of raw materials and increased sales prices and decreased the revenues of craftspeople. Also silver, though not a natural material, is becoming increasingly scarce, since silver is recycled from Maria Theresia Thalers, the old African dollar, which the silversmiths usually buy from farmers, a resource that is slowly being exhausted.

No limitation of raw material exists for pottery and leather, since hides and skins, as well as soil, are available in abundance. Nevertheless, the constraint in the supply of raw materials for leather crafts is due to the low status of the tanning profession.

Leather is mainly used for books, paintings and bags; the importance of local shoe production is rather low, though demand is high. Due to the huge numbers of livestock, hides are generally abundant. Cotton for weaving is grown on a few large plantations and also by small-scale farmers; however, modern weaving industries also buy cotton in large quantities from India, which is cheaper than buying cotton from local markets in Ethiopia.

For all Ethiopian goods, competition from abroad is high whether it be raw cotton from India or colourful clothes from Indonesia, jewellery and leather articles from Dubai and Sudan. Especially basketry does not seem to be feasible in this economic sense, since prices for grasses rise and they require the most time to make.

5 Conclusion

Comparing the cost–benefit relations of both project approaches, international marketing requires high investment costs, which currently not provide adequate returns. Moreover, the tourism industry in Ethiopia hardly plays a role, since attempts to develop tourism (World Bank, 2002) have more or less failed up to now. However, very strong commercial pressure to adapt to the demands of a different culture and the need to sell cheaply could erode craftsmanship very rapidly, and also put an unsustainable pressure on natural resources.

These threats that do not exist in this way for the subsistence-oriented approaches, which pursue the promotion of freedom and democracy, generation and protection of livelihoods and conservation of the natural environment. When these human and ecological concerns are the primary ones for society, then society organizes itself to generate and promote technologies that are decentralized, make use of human hands and need fewer natural resources and little capita. Craft technologies allow the poorest of people to produce freely, have a livelihood and a meaning in life, and experience democracy in their everyday lives (Shiva, 2001).

Since, however, it is unaffordable to waste resources and to miss marketing chances which promise sustainable revenue, policy adjustments should be taken to mitigate both approaches so as:

- Not to lose the intimate relationship between craft and environment to ensure the sustainability of craft development
- To overcome current discrimination against professional craft groups and also of traders
- To preserve historical relations and cultural identity also during the process of expanding marketing for crafts

While strengthening the importance of crafts on the subsistence and local level currently addresses mainly household crafts and crafts performed by farmers, no larger initiatives exist which really support traditional craft groups in overcoming their marginal status due to discrimination, and the main interest of traditional craftspeople in the current situation is to escape their discrimination through becoming farmers (Pankhurst & Freeman, 2003).

A true strengthening of crafts on the local Ethiopian markets has hardly been achieved thus far, since this would require additionally national supporting policies to protect local producers and their prices, which face high competition from abroad. Currently it is mainly the middle class, that can afford local Ethiopian crafts. However, neglecting the local markets for Ethiopian crafts would mean neglecting the most important consumer group for Ethiopian crafts that exists – the Ethiopians.

References and Further Reading

Ahmed, Z. 1998. Harari basketry through the eyes of Amina Ismael Sherif. Silverman, R.A. (ed.), *Ethiopia: Traditions of Creativity*. Michigan State University Museum, pp. 47–64.

———. 2005. *Monthly Report*. Ethiopian Cultural Heritage Project. Unpublished.

Aleme, E, 1982. *The Cultural Situation in Socialist Ethiopia*. UNESCO, Paris.

Asfaw, Z. 2000. The barleys of Ethiopia. Brush, S. (ed.), *Genes in the Field*, International Plant Genetic Resources Institute, Rome, pp.—.

Belay, M., Edwards, S. and Gebeyehu, F. 2005. Culture as an expression of ecological diversity: integrating awareness of cultural heritage in Ethiopian schools. *Mountain Research and Development*, Vol. 25, No. 1, pp. 10–14.

Berhane, T. 2005. *Monthly Report*, Ethiopian Cultural Heritage Project. Unpublished.

Bidgood, S. 1999. Ethiopian artefacts made with plant materials: Vanishing wonders. I. Friis and O. Ryding (eds.), *Biodiversity Research in the Horn of Africa Region*. Proceedings of the Third International Symposium on the Flora of Ethiopia and Eritrea at the Carlsberg Academy, Copenhagen, 25–27 August.

Brush, S. (ed.) 2000. *Genes in the Field*: *On-Farm Conservation of Crop Diversity*. International Plant Genetic Resources Institute, Rome.

Chojnacki, S. 1983. *Major Themes in Ethiopian Painting: Indigenous Developments, The Influence of Foreign Models and Their Adaptation*. Franz Steiner Verlag, Wiesbaden.

Davies, R., Rahbek, C., Williams, P. and Balmford, A. 2002. The distribution of cultural and biological diversity in Africa. *Proceedings of the Royal Society, Biological Sciences,* Vol. 269, pp. 1645–1653.

Egziabher, T. B. G. 2002. *The Human Individual and Community in the Protection of Biological Resources*. Darwin Lecture, London (See http://www.ukabc.org/GeneticFutures/tewolde_darwin_lecture.pdf) (Accessed 20 August 2006).

Hansorf, J. n.d. *Beef, Bread and Baskets*. ILRI, Addis Ababa. http://www.ilri.cgiar.org/ILRIPubAware/Uploaded%20Files/2004811911510.02BR_FS_BeefBreadAndBaskets.htm

Hartmann, I. 2004. *No Tree, no Bee – no Honey, no Money. The Management of Resources and Marginalization in Beekeeping Societies in South West Ethiopia*. Millennium Assessment Conference: Bridging Scales and Epistemologies, Alexandria. http://www.maweb.org/documents/briding/papers/hartman.ingrid.pdf

Levine, D. N. 1974. *Greater Ethiopia: The Evolution of a Multiethnic Society*. 2nd edition, Chicago. University of Chicago Press.

Marc, A. 2005. *Cultural Diversity and Service Delivery: Where Do We Stand?* Conference Paper. Arusha Conference on New Frontiers of Social Policy, 12–15 December.

Millennium Ecosystem Assessment 2005. *Ecosystems and Human Well-Being: Desertification Synthesis*. World Resources Institute, Washington, DC.

Mitchell, M. K. 2004. Maker and matter: Our relationship with things. S. Brown and M. K. Mitchell. (eds.), *The Beauty of Crafts: A Resurgence Anthology*. Green Books, Vermont, US.

Pankhurst, A. and Freeman, D. (eds.) 2003. *Peripheral People: The Excluded Minorities of Ethiopia*. London, Hurst.

Pankhurst, R. 1990. *An Introduction to the Medical History of Ethiopia*, The Red Sea Press, INC, Trenton, New Jersey.

Shiva, V. 2001. The seed and the spinning wheel. *Resurgence magazine*, No. 209, Nov/Dec. (See http://www.resurgence.org/resurgence/issues/shiva209.htm) (Accessed 20 August 2006).

UNCCD. 2004. T*ext of the Convention: UNCCD, Part III, Action Programmes, Scientific and Technical Cooperation and Supporting Measures,* Article 10. (See http://www.unccd.int)

Vernooy, R. 2005. *Seeds that Give: Participatory Plant Breeding*. International Development Research Centre Publication, Ottawa.

Worede, M., Tesemma, T. and Feyissa, R. 2000. Keeping diversity alive: An Ethiopian perspective. Brush, S. (ed.), *Genes in the Field: On-Farm Conservation of Crop Diversity.* International Plant Genetic Resources Institute, Rome, pp.—.

World Bank 2002. *Ethiopian Cultural Heritage Project*. Working Document. Addis Ababa, Ethiopia.

Chapter 7
Indigenous Knowledge and Sustainable Natural Resource Management in the Indian Desert

Durgadas Mukhopadhyay

Abstract Indian local communities in the desert have often shown that they are good managers of their natural resource base through their traditional knowledge and wisdom. Efficient community strategies have exemplified their intelligent and sustainable use of land, water and soil without causing damage to the resilience and functioning of the surrounding ecosystem.

The Bishnoi tribe of the western Indian state of Rajasthan has over the centuries combined a unique blend of ecological sense and religious sensibility. The Thar desert in India is full of ironies – one of them being the Bishnoi community of Rajasthan. Here, peace is maintained with aggression, and robust health rubs shoulders with regular famine. Living amidst the barren wastelands interspersed with Khejri and Babool trees, the Bishnois are a proud race. Johra Ram, head of the Bishnoi community, says "Any change in the world has to begin within the society. All this talk about nature and wildlife protection would be more effective if each individual was to believe in the Earth as a living, breathing entity and fight for its survival the way we do." There is a story of Amrita Devi a Bishnoi woman who, along with more than 366 other Bishnois, died saving trees.

The Bishnois are an example of people living in harmony with nature where they maintain groves, locally known as *orans*, where animals graze and birds feed. Orans serve as important rechargers of rainwater in the desert aquifers, where every single drop of water is precious. It is estimated that *orans* account for about 9% of the desert area. Here, the tree species, *Prosopis cineraria* or *Khejari*, is worshipped for its immense ecological value.

Keywords Traditional ecological knowledge, Bishnoi community, scared groves, *Prosopis cinerari*

1 Introduction

Indian local communities in the desert have often shown that they are better managers of their natural resource base due to their traditional knowledge and wisdom. Efficient community strategies have exemplified intelligent and sustainable use of

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land, water and soil without causing damage to the resilience of the surrounding ecosystem.

One billion people live in dry regions of the world, which cover nearly 40% of the Earth's surface. Many live in rural areas and earn their living as farmers, pastoralists, herders and woodcutters. What they all have in common is a reliance on natural resources, as well as biodiversity, which is declining at a rate unprecedented in recorded history.

'Desertification is hard to reverse, but it can be prevented', says UN Secretary-General, Kofi Annan. 'It will also help to preserve landscapes and cultures that date back to the dawn of civilization and is part of our cultural heritage'. He added, 'The world's deserts are facing dramatic changes as a result of global climate change, high water deprivation and salt contamination of irrigated soils'.

According to an assessment by the United Nations Environment Programme (UNEP), not all the changes created by desertification are necessarily harmful. Some have concrete benefits for the indigenous peoples and other inhabitants of the deserts, and even for the entire world. Deserts also promise new sources of medicines derived from their plants and animals, which are uniquely adapted to the severe and unpredictable habitat. Deserts are threatened by unsustainable human activities, over-extraction of water and climate phenomena, all of which contribute to the extension of deserts into area previously green with vegetation – a process known as desertification.

2 The Desert

In India about 107.43 million ha, or 32.75% of the total geographical area, is affected by various forms and degrees of desertification, particularly the arid, semi-arid and sub-humid regions, commonly called drylands, which represent fragile ecosystems that are susceptible to desertification. These regions are also susceptible to frequent droughts that accelerate the process of desertification and increase its impact (GOI, 2001).

The Thar Desert, also known as the Great Indian Desert, straddles western India and south-eastern Pakistan (Fig. 3). It lies mostly in the Indian state of Rajasthan and extends into the southern portion of the Haryana and Punjab states and into northern Gujarat state. In Pakistan, the desert covers the eastern Sind province and the south-eastern portion of Pakistan's Punjab province. The Thar Desert covers 446,000 km^2 – extending 805 km^2 long and about 485 km^2 wide – with 208,110 km^2 in India, of which 61% falls within Rajasthan (Fig. 1).

The soils of the arid zone are generally sandy to sandy-loam in texture. Stretches of sand in the desert are interspersed by hillocks and sandy and gravel plains. Some wildlife species, which are fast vanishing in other parts of India, are found in the desert, such as the Great Indian Bustard (*Ardeotis nigriceps*), the Blackbuck (*Antilope cervicapra*), the Indian Gazelle (*Gazella bennettii*) and the Indian Wild Ass (*Equus hemionus khur*) in the Rann of Kutch (Gupta and Prakash, 1975). Due to the velocity of winds in these areas, the dust is blown away and deposited on

Fig. 1 Map of India

fertile lands, causing a problem of shifting sand dunes. The main occupation of the people in the desert is agriculture and animal husbandry. The Indian Desert is mainly inhabited by Hindus, Muslims and Sikhs.

3 Traditional Environmental Knowledge

Traditional knowledge and practices have their own importance, as they have stood the test of time and proved to be efficacious to the local people. Some of these traditional practices can be seen in the techniques of crop production, mixed farming, water harvesting, conservation of forage, combined production system, biodiversity conservation, forestry and domestic energy in the desert ecosystem.

The agricultural and natural resource management practices of indigenous people, perfected over a period of time, is called "traditional ecological knowledge" (TEK). Science should try to adopt traditional knowledge in contemporary situations and combine it appropriately with modern scientific inputs wherever possible. Recording and documentation of traditional knowledge requires close participatory interaction with communities, as they help in the identification and preservation of traditional knowledge in various ways (Ramakrishnan et al., 1998). One should look at it critically, scientifically validate it by conducting research at grassroots levels, and then start analyzing this knowledge to formulate strategies for better land utilization. A broad-based study should also be conducted to find out how traditional knowledge can be applicable in the contemporary world. Through a variety of approaches, traditional knowledge, wisdom and technology based on empirical knowledge accumulated over a long period of human evolution, traditional societies have learned to conserve and enhance biodiversity. Sacred groves maintained by traditional societies demonstrate spiritual values attached to biodiversity (Berkes, 1999). Ecological issues of sustainable development are connected with social, economic, anthropological and cultural dimensions.

4 The Bishnoi Community

Over centuries the Bishnoi community of the western Indian state of Rajasthan has developed a unique blend of ecological sense and religious sensibility. The Thar Desert in India is full of ironies – one being the Bishnoi community of Rajasthan. Here peace is aggressively maintained and robust health rubs shoulders with regular famine. The Bishnoi worship nature in all its manifestations. Here women suckle motherless deer, die to save trees, go hungry to provide food for animals, and live a strict life advocated by their guru, Jambaji. Living amid barren wastelands interspersed with *Khejri* and *babool* trees, the Bishnoi are a proud people. Johra Ram, head of a Bishnoi Village, says, 'Any change in the world has to begin within the society. All this talk about nature and wildlife protection would be more effective if each individual was to believe in the earth as a living, breathing entity and fight for its survival the way we do'. There is the story of Amrita Devi, a Bishnoi woman who, along with more than 366 other Bishnoi, died saving trees. In 1730 BCE, Maharaja Abhay Singh of Jodhpur required wood for his palace. So he sent his soldiers to fell green Khejri (*Prosopis cineraria*) trees at Khejarli village. Amrita Devi and other villagers hugged the branches while the soldiers chopped them down. This is still remembered as the great Khejarli sacrifice. The sect was founded by Guru Jambheshwar (b. 1451 BCE) after riots between Muslim invaders and the local Hindus. He had laid down 29 principles to be followed by the sect. *Bish* means twenty and *noi* means nine. Killing animals and felling trees were banned. Before his death, he stated that black was his manifestation after death and should be conserved. The Bishnoi are strong lovers of wild animals (Mukhopadhyay, 2004). It is because of their protection that in Bishnoi-dominated areas, deer, blue bulls and black bucks are seen grazing peacefully in their fields. The Bishnoi community launched strong campaigns against the killing of black bucks by Salman Khan, a film star, and Mansur Ali Khan of Pataudi, a former cricketer, and they were both duly prosecuted. The origin of the Chipko movement can be traced back to the Bishnoi.

The community abides by a set of laws, which includes a ban on killing animals and felling trees, especially their most sacred Khejri tree, which has numerous life-sustaining properties. Its fallen leaves can be used for fodder, its fallen branches for fuel, and its fruits for food. Khejri trees stabilize sand dunes and they are said to increase yields of crops that grow nearby. Groves, or *orans* as they are known locally, are maintained; they provide a protective habitat for the Indian gazelle and black buck. The Bishnoi are an example of people living in harmony with nature (Gadgil et al., 1993). Among the 29 principles propounded by the founder of the sect, three concern nature conservation. Cutting and hacking green trees is strictly prohibited. *Orans* serve as important rechargers of rain water in the aquifers in the desert, where every single drop of water is precious. It is estimated that *orans* account for about 9% of the desert area. In most *orans*, particularly in western Rajasthan, the dominant tree, *Prosopis cineraria* or *khejri*, is worshipped for its immense ecological value. The Bishnoi will not cut *khejri* trees even from their agricultural fields. The tree enriches soil nitrogen, and during drought and famine, the bark of the tree is mixed with flour for consumption.

The community has shown itself to be a skilled manager of natural resources. In areas with sparse vegetation, scrubland and little water, they manage the ecosystem with a fervour that shows no sign of warning. Recently, tour operators have teamed up with local NGOs and started offering "eco-cultural tours" that provide cultural glimpses into the various communities of Rajasthan. Tourists come to live among them and are guests in their homes, which are situated in remote villages. Since Bishnoi settlements are known as havens for all birds and animals due to the protection accorded to all wild animals and vegetation, these settlements are now attracting tourists in large numbers. Due to the steadily increasing number of eco-cultural tourists and the consequent rise in income, the village communities have been able to switch to LPG (liquid petroleum gas) instead of fuel wood and have added incentives to conserve and sustainably manage their natural resources. This commitment to conservation gives the Bishnoi a unique appeal as far as tourism is concerned.

5 Sacred Groves

Sacred Groves (SGs), act as nurseries and storehouses of many of the Ayurvedic, tribal and folk medicines. Species not under any immediate risk of extinction, and preserved in SGs, may offer great potential for diverse uses in the future. The SGs may also preserve genotypes that may be useful in tree-breeding programmes. One of the important ecological roles of these groves is to provide a more dependable source of water for the organisms living in and around them. All of these factors indicate that the conservation of SGs is essential for maintaining local/regional biodiversity, the comprehensive health of a landscape, and preserving the socio-cultural integrity of local communities (Gadgil, 1985). There are several SGs dedicated to temples in the Thar Desert. Communities zealously protect these groves from interference of any kind. The SGs are excellent examples of biodiversity conservation: there was a religious prohibition against cutting any vegetation from the lands in the immediate vicinity of temples and religious places, known as *oran* (protected forest) lands; collection of dry wood only is allowed for fuel, and the use of an axe in the *orans* is severely punishable. In the Barmer, Nagaur, Jodhpur, Pali, Sikar, Jhunjhunu and Jalore districts of Rajasthan, there are still 420 *orans* covering a total area of 100,140 ha.

In Jaisalmer, in the Bhadaria temple complex, the community maintains an *oran* with a concentration of *Ziziphus nummularia* (Ber) trees, which are known for their large fruit. Solar energy is used to extract underground water to irrigate the *oran,* whose resources are meant only for the animals and avifauna so as to ensure their survival in the harsh desert conditions.

6 Khejri – The Wonder Tree

Prosopis cineraria is a small- to medium-sized tree found mainly in the Thar Desert of Rajasthan, India (Fig. 2). Common names include *khejri*, *jand* and *sangria* (Rajasthan). The *Prosopis cineraria* tree grows in dry and arid regions of India, namely in Rajasthan, Haryana, Punjab and Gujarat. The leaflets are dark green with a thin casting of light shade and coppices profusely. Historically, *Prosopis cineraria* played a significant role in the rural economy in the northwestern arid region of the Indian sub-continent. This tree is a legume, improves soil fertility and is an important constituent of the vegetation system. It is well-adapted to arid conditions and withstands the adverse vagaries of climate and browsing by animals, such as camels and goats. It is about the only indigenous tree species that has withstood the rigorous and exacting conditions of the Rajasthan desert. The root system of *Prosopis cineraria* is long and well-developed. Growth above the ground is slow, but below the ground the roots penetrate deep into the sub soil layers. The tree is able to withstand the hottest winds and the driest seasons and remains alive when other plants would succumb (Mann and Saxena, 1980). The tree is also frost resistant. Because of its economic value, the tree is left to stand in the arable land, and the farmers regulate its population by adapting suitable agroforestry management.

Prosopis cineraria provides wood for the construction of houses, chiefly as rafters, posts, doors and windows, Persian wheels, agricultural implements and shafts. It is also much valued as fodder tree. The trees are heavily lopped particularly during winter months when no other green fodder is available in the dry tracts. There is a popular saying that death will not visit a man, even at the time of famine, if he has *Prosopis cineraria*, a goat and a camel, as the three together are said to sustain a man even under the most difficult conditions. The leaves are of high nutritive value. Feeding off the leaves during winter, when no other green fodder is generally avail-

Fig. 2 *Prosopis cineraria*

Fig. 3 The Thar desert

able in rain-fed areas, is thus profitable (Mukhopadhyay, 2004). *Prosopis cineraria* is also a most important feed species, providing nutritious and highly palatable green as well as dry fodder, which is readily eaten by camels, cattle, sheep and goats, and therefore constitutes a major feed requirement of desert livestock.

The flowers of *Prosopis cineraria* are ground up, mixed with sugar and used during pregnancy to safeguard against miscarriage. The water-soluble extract of the residue from the methanal extract of the stem bark demonstrates anti-inflammatory properties. The *Prosopis cineraria* plant produces gum, obtained during May and June. The bark of the tree is dry, acrid and bitter, with a sharp taste; its cooling anthelmintic cures leprosy, dysentery, bronchitis, asthma, leucoderma and haemorrhoids. The bark is used as a remedy for rheumatism, cough colds, asthma and scorpion stings (Kaul, 1976), while the plant is recommended for the treatment of snake bites.

During Vedic times, Khejri wood was used to kindle the sacred fire for performing rituals. Hindu epics, the Ramayana and Mahabharata, mention the use and significance of this tree. Lord Rama worshipped Khejri trees, which represent the goddess of power, before he led his army to kill Ravana.

Prosopis cineraria has a very deep tap root system and hence does not generally compete with crops. Rural communities encourage the growth of *Prosopis cineraria* in their agricultural fields, pastures and village community lands. Because of its extensive root system, it stabilizes shifting sand dunes and is also useful as a windbreak shelterbelt and in the afforestation of dry areas (Mukhopadhyay, 2005). It fixes atmospheric nitrogen through microbial activities and adds organic matter through leaf litter decomposition, thus rejuvenating poor soils.

7 Gender Issues

Women in the desert are dependent on the forest for food, fuel, fodder, medicines and fibers. Moving in and out of forests, women have accumulated knowledge through the years on the sustainable use of natural resource and also numerous insights into the value of biodiversity. Though women can play a significant role in protecting biodiversity, it has not been recognized (Mukhopadhyay, 1989), nor has their role in conservation. The loss of habitats and biodiversity mostly affects the underprivileged, many of whom are women. A large number of women participated in mass movements, such as Chipko in the upper reaches of Himachal and Uttar Pradesh. They had a stake in protecting the local biodiversity and natural resources, such as wood and water, as additional burdens fell on them when these resources dried up.

Drylands pose different challenges to rural men and women because of their different roles, relations and responsibilities, opportunities and constraints, and uneven access to and control of resources. By incorporating a gender perspective in policy, projects and programmes, innovative ways of combating dryland degradation and food insecurity, can be promoted. The result is a more sustainable, relevant and equitable development based on women's and men's full and equal participation, on their respective local knowledge, and on ecological and socio-cultural factors (Inglis, 1993).

8 Sustainable Natural Resource Management in Desert

In the Thar Desert traditional systems of land and water use met environmental challenges in various ways. One group of indigenous cultivators (*Paliwals*) devised a rainwater-harvesting technique fully capable of growing winter crops. As early as the fifteenth century, the *Paliwal* cultivators followed a unique practice of water harvesting and moisture conservation in suitable deep-soil plots. The bulk of the natural resource base of the arid region is best suited to pasture-based livestock farming. The traditional wisdom of the dryland farmer is clearly manifest in the evolution of the system of mixed farming – including crop and animal husbandry – which matched the potential and limitations of the natural resource base (GOI, 2001). The pastoralist, based on centuries of experience, developed a unique method of water harvesting. With the commencement of rains, the population was divided into different caste groups and dispersed to their *tobas* (small dug out ponds), along with their livestock. The *Jagirdar* (feudal landlord) imposed animal-grazing taxes and granted periodic free gifts especially to owners of large flocks of sheep and goat, which acted as a strong deterrent against indiscriminate grazing. With the abolition of *Jagirdari*, the practice of grazing taxes was discontinued, resulting in free-ranging and the consequent degradation of rangelands.

A useful indigenous technique of water conservation is called “pitcher planting”. Earthen pitchers with holes on one side are embedded near the root zone of newly planted seedlings to provide them with the required amount of water. This technique prevents loss of water due to either evaporation or seepage and helps seedlings to establish themselves. This technique is still practiced by melon cultivators in the arid region of Rajasthan. Similarly, these farmers bury bushes in a chess board pattern to protect melon plants from being buried by shifting sands (Kaul, 1976). Dryland farmers raised windbreaks (matt) around their fields and homesteads to protect crops and their livestock against hot desert winds. Lopping of trees, such as *Prosopis cineraria*, *Azadirachta indica* and *Ailanthus excelsa,* during the winter for leaf fodder is still a common practice in arid and semi-arid regions of Rajasthan. This is scientifically sound, as it causes no damage to trees because they are dormant when cut and all the food has already been moved to the roots.

9 Conclusion

Since many of these traditional systems are environment-friendly and sustainable, efforts should be made to restore and support them with modern approaches to enable their effective mainstreaming to combat desertification. Some of the indigenous traditional technologies offer promising community-based dryland resource management. The participation of local communities would also lead to greater use of traditional practices. It is therefore necessary to document such a knowledge base through a properly designed research programme and to analyze their economic, technological and socio-cultural sustainability.

References

Berkes, F. 1999. *Sacred Ecology: Traditional Ecological Knowledge and Resource Management*. Taylor & Francis, Philadelphia, PA.

GOI. 2001. *National Action Programme to Combat Desertification*. Government of India, New Delhi.

Gadgil, M. 1985. Social restraints on resource utilization: The Indian experience. *Culture and Conservation: The Human Dimension in Environmental Planning*, McNeely, J.A. and Pitt, D. (eds). Croom Helm, Dublin, Ireland, pp. ___.

Gadgil, M., Berkes, F. and Folke, C. 1993. Indigenous knowledge for biodiversity conservation. *Ambio*, Vol. 22, pp. 151–156.

Gupta, R. K. and Prakash I. (eds.). 1975. *Environmental Analysis of the Thar Desert*. English Book, Dehradun.

Inglis, J. T. (ed). 1993. *Traditional Ecological Knowledge: Concepts and Cases*. International Program on Traditional Ecological Knowledge and International Development Research Centre (IDRC), Ottawa.

Kaul, R. N. 1976. Trees or grasslands in the Rajasthan: Old problems and new approaches. *Indian Forester*, Vol. 93, pp. 434–435.

Mann, H. S. and Saxena, S. K. 1980. *Khejri (Prosopis cineraria) in the Indian Desert: Its role in Agroforestry*. Central Arid Zone Research Institute (CAZRI) Monograph II, Jodhpur.

Mukhopadhyay, D. 1989. *Culture, Performance and Communication*. B. R. Publishing, New Delhi.

———. 2004. Traditional environment knowledge in Indian religion and tradition. *Sustainable Development in India and Canada*, Nair, K. R. G. (ed.). Kaveri Publications, New Delhi.

———. 2005. *Indigenous Knowledge, Water Management and Sustainable Development*. Paper and documentary film presented in United Nations Environment Programme (UNEP) sponsored 3rd World Environment Education Congress, 2–6 October 2005, Turin, Italy.

Ramakrishnan, P. S., Saxena K. G. and Chandrashekara U. M. (eds). 1998. *Conserving the Sacred for Biodiversity Management*. Oxford and IBH Publishing, New Delhi.

Bibliography

Borgerhoff-Mulder, M. 1988. Behavioural ecology in traditional societies. *Trends in Ecology and Evolution*, Vol. 3, pp. 260–264.

Brush, S. B. and Stabinsky, D. 1996. *Valuing Local Knowledge: Indigenous People and Intellectual Property Rights*. Island Press, Washington, DC.

Burdak, L. R. 1982. *Recent Advances in Desert Afforestation*. Dissertation submitted to Shri R. N. Kaul, Director, Forestry Research, F.R.I., Dehra Dun, India.

GOI/MoFA. 1965. *Soil Conservation in the Rajasthan Desert*. Government of India, Ministry of Food & Agriculture, Jodhpur, India.

Kaul, R. N. (ed). 1970. *Afforestation in Arid Zones*. W. Junk N.V. Publishers, The Hague.

McNeely, J. A. and Pitt, D. (eds). 1985. *Culture and Conservation: The Human Dimension in Environmental Planning*. Croom Helm, Dublin.

———. 2006. Folk arts for environment education. Paper presented at the UNESCO World Conference on ‘Education in Arts’, 6–9 March 2006, Lisbon, Portugal.

Ramakrishnan, P. S. 2002. *Coping with Uncertainties: Role of Traditional Ecological Knowledge in Socio-Ecological Landscape Management*. School of Environmental Sciences, Jawaharlal Nehru University, New Delhi.

UNDP. 2004. *Sharing Innovative Experiences: Examples of Successful Conservation and Sustainable Use of Dryland Biodiversity*. United Nations Development Programme, New York.

Chapter 8
The Medicinal and Aromatic Plants Sector in the Drylands: A Promising Alternative for Sustainable Development and Combating Desertification in Tunisia

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Abstract In spite of its small area, Tunisia has a large plant biodiversity. In fact, its flora accounts for more than 2,150 species growing on various bioclimatic zones from sub-humid to arid and Saharan, and providing particular landscapes and agro-ecosystems such as oases and *Jessours* in the southern part of the country. Nevertheless, the high human and animal pressure resulting from the increasing needs of the rural population has led to the degradation of this heritage. Many spontaneous plant species are considered as herbal, medicinal and aromatic plants (HMAP) and are used in traditional phytotherapy by mainly rural communities having developed broad local knowledge. However, despite the importance of the HMAP sector in generating income for many poor rural households, as well as its increasing contribution to the GNP, it still remains fragile characterized by a limited number of cultivated species generally harvested during similar or overlapping periods in small areas (1,030 ha in 2001). For the development of HMAP cultivation, instead of other water consuming crops, the promotion, organization and establishment of a national strategy for this sector was implemented by IRA-Tunisia, ICARDA and USDA-ARS during the period 2002–2004. This research development project aims to preserve biodiversity, promote the use of HMAP, and create business opportunities for Tunisians, mainly the poor rural population. To meet the project objectives a new multidisciplinary approach was developed based on the establishment of a national network of collaborators and more than 100 stakeholders (societies, research organizations, NGOs, individuals, etc.,) acting directly and indirectly in the HMAP sector. The results of the project showed that all fixed objectives were accomplished. The main project achievements are as follows:

- The main actors involved were identified and grouped together in order to assume a good complementarity according to their role in the chain.

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- A socioeconomic study at the local, national and international level was carried out. At the local level the study presented the cultural and socioeconomical importance of HMAP in the rural areas of the Matmata mountains – the target site. At the national level, the study covered several aspects including the importance of HMAP within several sectors. At the international level, a study on building an international marketing strategy for the Tunisian HMAP sector was accomplished.
- The establishment of a national database for indigenous, herbal, medicinal and aromatic plants. Technical brochures for some HMAP species have been also developed.
- The increase in awareness among institutions on the importance and potential of HMAP to create business opportunities in southern Tunisia, with the eventual creation of jobs.

The project was also welcomed by the general population, and regional participating institutions, who regard the project's continuation as a great contribution towards biodiversity, research and education as well as being a financial gain for Southern Tunisia. Finally, the major learned lessons generated by this project are also presented and discussed in this paper.

Keywords traditional phytotherapy, traditional knowledge and cultural heritage, HMAP database, Export marketing

1 Introduction

In spite of its small area, Tunisia has a large plant biodiversity (Le Houerou, 1995). In fact, its flora includes more than 2,150 species (Pottier-Alapetite, 1979/1981), which grow in various bioclimatic zones from sub-humid to arid and Saharan, and give rise to unique landscapes and agro-ecosystems, such as oases and Jessours, in the southern part of the country. Nevertheless, the intense human and animal pressure resulting from the increase in the rural population's needs has led to degradation of this patrimony (Floret and Pontanier, 1982). In fact, more than 26 species are actually qualified as endangered. Many spontaneous plants are considered to be multipurpose and can be used to produce valuable substances, essential oils and original aroma useful for the agro-food, pharmaceutical and cosmetic industries. There are 200 to 350 spontaneous species of herbal, medicinal and aromatic plants (HMAP), which are used in traditional phytotherapy mainly by rural communities having developed a large local knowledge (Le Floc'h, 1983; Boukef, 1986).

The majority of Tunisian herbal, aromatic and medicinal plants grow in rain-fed conditions and are highly dependent on environmental factors. About 800,000 ha of forestland in the north and 4,700,000 ha of rangeland in southern Tunisia are suitable for spontaneous HMAP production. Almost 80% of forest cover is rosemary and myrtle. However, only a small number of forest and rangelands are exploited annually for spontaneous HMAP harvesting.

Tunisian HMAP production is still traditional and is characterized by a limited species number generally harvested during similar or overlapping periods. The cultivated area was about 1,030 ha in 2001 mostly without use of chemicals or pesticides. Total HMAP production is estimated to about 8,000 tons, 23% of which are exported mainly to European countries. The majority is processed for essential oil distillation. HMAP marketing represents an important part of the annual income of many rural households. Total HMAP value represents 0.06% of GDP. The export value of HMAP essential oils and other manufactured products contribute significantly to the national economy. It was 44.6 million TND (Tunisian dinars) in 2003, 5% of the total value of exported agricultural products (Ghoudi, 2002).

Tunisian HMAP production has many advantages, such as low production costs, favourable climatic conditions, large areas of spontaneous HMAP, closeness to the biggest importing markets, availability of laboratories and supervision services. However, essential oil exportation is considerably decreasing, despite the increasing international demand (Jehle, 2004), due to degradation and low productivity of the main species used. HMAP are facing many constraints, such as limited number of species used, lack of qualified labour, lack of scientific research, limited number of distillation units, and lack of collaborative development of bilateral projects.

However, despite the importance of the HMAP sector in generating income for many poor, rural households and its increasing contribution to the GDP, this sector is still marginal and traditional. Considering desertification problems and water scarcity, development of HMAP cultivation instead of other water consuming crops will contribute to better management of limited natural resources. Local HMAP could react well even under stress conditions. Obtained products are of high quality and may have an important added value.

The ethno-botanical knowledge and use of Tunisian plants have been transmitted over generations. In addition to enhancing health care and well-being, medicinal and aromatic plants (in the wild or in cultivation) protect the soil from excessive degradation and desertification in the range and forest areas of Tunisia. Medicinal and aromatic plants are important for the well-being of the population, especially of the rural poor, who depend on these resources to treat human and livestock ailments and diseases. Additionally, they are a potential source of income for the resource-poor people, especially women, who are involved in most of the fieldwork, processing and marketing of medicinal plants. Preservation of these species and knowledge of their uses will require specific intervention to ensure that this knowledge and these plants are not lost through environmental degradation, agricultural expansion and over-exploitation.

For the promotion, organization and establishment of a national strategy for this sector, a research development project was implemented by IRA Tunisia (l'Institut de régions arides), ICARDA (International Center for Agricultural Research in the Dry Areas) and USDA-ARS (United States Department of Agriculture – Agricultural Research Service) during 2002–2004. The project was designed to preserve biodiversity, promote the use of HMAP and create business opportunities for Tunisians, mainly the poor, rural population. The project supports the conservation, management and sustainable utilization of medicinal and aromatic plants in Tunisia through conservation, cultivation and propagation as opposed to collection from the wild. It also contributes to the development of effective in-situ protection of threatened habitats and ecosystems.

The intervention and activities of the project allow for global benefits and alleviation of poverty conditions through productivity improvement integrated with sustainable management of natural resources, including medicinal and aromatic plants.

2 Objectives and Methodological Approach

The overall objective of the project is to improve livelihoods in rural areas through sustainable use, conservation, management and marketing of herbal and medicinal plants in southern Tunisia. The project's specific objectives are to:

1. Conserve, manage and use effectively, both in situ and ex situ, medicinal, herbal and aromatic plants in arid and semi-arid areas.
2. Strengthen partnerships of collaborating institutions to form a coalition of stakeholders, which include scientific research institutes, extension services, universities, NGOs and industry, to increase the value of medicinal, herbal and aromatic plants through processing, chemical analysis and marketing.
3. Improve public awareness of the importance of medicinal plants and build on traditional knowledge and cultural heritage.
4. Prepare a national database on indigenous medicinal and aromatic plants, starting with southern Tunisia, in order to assess their use and status within key ecosystems.
5. Augment the plant database and disseminate research results and progress in product development by (a) development of a project website, (b) attendance of project scientists at national and international meetings, (c) participation of project scientists in exchange programmes/visits and scientific capacity-building efforts (e.g. graduate and postgraduate training), and (d) publication of research results generated from the project in peer-reviewed scientific publications.

To meet the project objectives, a new multidisciplinary approach was developed. The project has initiated a national network of collaborators by connecting more than 100 companies, research organizations, NGOs and individuals. These partners include project management and research (IRA), extension agencies (CFRA, *Centre de formation et de Recyclage Agricole*; CRDA, *Commissariat Régionale de Développement Agricole*; and IRA), plant and food science institutions, pharmacists and other health professionals from universities and the private sector, marketers and exporters, and development agencies.

3 Accomplishments and Achievements of the Project

The results of the project showed that all stated objectives were accomplished. The main achievements in the framework of the project are the following:

3.1 Choice of the Target Plant Species

In Tunisia, the number of species considered aromatic and medicinal varies from 40 to 200 depending on inventories and several factors, such as the extent of the inventory areas, the major use of species targeted by the survey (medicinal, aromatic, condiment, etc.) and the economic and social importance of the considered species. The choice of the important species depends on the objectives of activities to undertake on these species and the natural region considered.

At the time of discussions, which took place at different meetings organized within the framework of the project (meetings of the steering and technical committees, monitoring missions, etc.), it was agreed to select a limited number of species presenting higher ecological, economic and social interests at the level of the project zone (*Allium roseum, Artemisia herba-alba, Rosmarinus officinalis, Thymus capitatus, Capparis spinosa*).

3.2 Development of Technical Brochures for Target Species

Technical brochures have been developed for *Capparis spinosa* and *Rosmarinus officinalis*. They include information on biological characteristics, geographic distribution, ecological requirements, multiplication, propagation and cultural techniques, uses and conservation. Technical brochures for the three other species are being prepared.

3.3 Establishment of an HMAP Database and a Project Website

Many activities have been accomplished for the establishment of a database about HMAP and a website for the project. These activities include:

- The establishment of a national database for indigenous, herbals, medicinal and aromatic plants including several species and hundreds of accessions. The information includes: the collection site, origin, and germination and cultivation requirements.

- A database of literature references about HMAP (pamphlets, theses, articles and technical reports) was developed. These references have been researched both at national and international levels. Thanks to USDA-ARS researchers' help and support, many references about target plants for the project have been identified.
- Establishment of GIS with several layers of information relative to the following parameters: climate, soil, vegetation, level of exploitation, and infrastructure. A training session for two researchers was held at ICARDA headquarters.
- The creation of a website for the project in collaboration with an ICARDA specialist. On this site, the following information is available:
  - Presentation of the project (objectives, expected results, partners).
  - Presentation of target species.
  - A list of the main scientific and technical reports produced within the framework of the project.
  - Photos illustrating the different activities undertaken within the framework of the project.

3.4 Socioeconomic Importance and HMAP Chain Study

This study was carried out at three levels: local, national and international.

3.4.1 Local Level

At the local level the study presented the cultural and socio-economical importance of HMAP in the rural areas of the Matmata Mountains (the project target zone). The methodology followed relied on questionnaires that covered a representative sample of household heads involved or interested in HMAP (Sghaier et al., 2004).

The main results of this local level study are the following:

- Sixty-three and a half percent of farmers exercise an activity outside the farms. The collection and sale of HMAP constitute an important source of income for some households in the zone.
- The collection of HMAP in the Matmatas chain is largely destined for auto-consumption. However, 25% of households may sell the plant material when they find the opportunity. Seemingly low, this proportion hides an important potential of a latent predisposition of the population to develop the economic activities based on the valorization of HMAP.
- From a total of 72 species collected and used at the level of the study zone, the sale of the PAMS is limited to four main species (*Rosmarinus officinalis, Thymus capitatus*, *Juniperis phoenicea* and *Artemisia herba-alba*). The available mean quantity on the market is 750 kg/year by household (30 kg to 4,500 kg).
- Sale prices and the mean quantities sold of HMAP are marked by a high variability in species, period of sale, climatic conditions of the year and quality of the

product. The frequency of sales is more important for *Thymus hirtus* and *Rosmarinus officinalis*.
- Chain maps of main species are relatively simple, since there are a limited number of intervening parties (producers/operators, mediators, local consumers).
- According to households, the main problems hindering the development of the HMAP sector are related to drought, inadequate methods of harvest, overgrazing and overuse.

3.4.2 National Level

At the national level the study covered several aspects, including the importance of HMAP within several sectors, their contribution to the Gross Domestic Product (GDP), exports, imports, the trade balance equilibrium, national stakeholders and a global sector chain. The main results of this national study (Ghoudi, 2002) are as follows:

- On the basis of exports in the last decade of the twentieth century and evaluation of local consumption, the mean national production of the main HMAP and their derivatives are about 8,500 tons per year, of which 23% are exported.
- The value of this production is estimated at 14.2 million TND, of which 5.7 million (40%) are generated by the exported products, mainly to European countries. Essential oils contribute more than 65% of the value of these exports.
- About 13.3 MD per year, the part of the GDP generated by the main HMAP, represents 0.06% of the total GDP and 0.4% of the GDP generated by the agricultural sector.
- The mean value of imports over the last ten years is about 2.3 MD, representing a relative decrease of 17% over the last five years.
- The commercial balance of HMAP over the last ten years is, however, still positive with a mean cover rate of about 180% in 1992.

3.4.3 International Level

An international market study entitled *Building an International Marketing Strategy for the Tunisian HMAP Sector: Identifying Opportunities for and Constraints on the Export of Tunisian HMAP to EU and USA* has been completed (Jehle, 2004). This study described the global HMAP market trends, described and assessed the potential Tunisian HMAP export market, identified the constraints and opportunities through contacts with Tunisian HMAP processors and exporters, and developed recommendations for the improvement of the Tunisian HMAP export sales.

The study evaluates how Tunisian aromatic and medicinal plants can better compete in the global aromatic and medicinal plants market. The acronym HMAP is used to refer to herbal, aromatic and medicinal plants, as well as the extracts and essential oils from these plants. The study also provides an overview of the international market for HMAP, identifies constraints and opportunities for increased exports from Tunisia and recommends measures to overcome the identified constraints and maximize opportunities.

- In Section I of this study, the Tunisian HMAP export market and details on the production, transformation and export of HMAP and derivative products are characterized. The principal cultivated and wild HMAP varieties used for essential oil, and as medicinal and culinary herbs and spices for export are discussed. Flavour and fragrance compositions, essential oils and natural extracts, and aroma chemicals have the greatest potential for entering EU countries and the USA. Increasing vertical integration of production and the growth of contract production with foreign partners are identified as important market parameters.
- In Section II, the constraints and opportunities for expansion of the HMAP sector are presented. These were ascertained through meetings with Tunisian HMAP exporters and processors, literature reviews, and by collating responses to the Tunisian Exporter Marketing Survey. Long-term and short-term marketing constraints and way to capitalize on Tunisia's comparative advantages and marketing opportunities are recommended.
- Section III looks at the HMAP market parameters and trends. The USA, EU and Japan consume 78% of world HMAP and derivatives; the market is worth tens of billions of US dollars per year, when all uses are included. Competition among suppliers creates a squeeze of margins for primary products, and market volatility is compounded by the market entry of new producers – China, India and Turkey. Value-added and medicinal applications allow manufacturers and exporters to differentiate their products by standardizing natural extracts, promoting organic and chemicals free production, as well as compound natural ingredients and development of nutraceuticals and herbal medicines. World demand for essential oils grew at an average rate of 6%, botanical extracts at 15%, plant-derived chemicals at 10%, and gums, gels and resins at 7%. The increasing importance of quality control, phytosanitary regulations, product traceability and organic certification is discussed.
- In Section IV, project findings based on visits to production areas and transformation facilities, and interviews with industry leaders and government officials are presented. Principal concerns identified were lack of information about international market parameters, the competitiveness of Tunisia's HMAP products on the world market, establishing and maintaining contact with foreign buyers and end-users, and how to promote Tunisian HMAP products abroad.
- Section V sets out the following study recommendations:

  1. Diversify HMAP **cultivars** and production methods.

     (a) Allocate funding for Tunisian research facilities to assess new plant varieties and biotechnologies.
     (b) Increase production of marjoram, orange, white Artemisia, geranium, verbena, peppermint, clove, wild rose, arbutus, vanilla, lavender and chamomile, since world demand for essential oils of these HMAP cultivars and wild HMAP exceeds world supply.

   (c) Increase production of carob, prickly pear and fenugreek for national consumption and export.
   (d) Evaluate the potential for Malva and white Artemisia in **cosmeceutical**, nutraceutical or pharmaceutical preparations.

2. Undertake structural changes in HMAP production and invest in infrastructure development.

   (a) Promote greenhouse production.
   (b) Investigate potential for drip irrigation in Tunisia and assess the feasibility of introducing new varieties in drip irrigation production systems.
   (c) Develop an organic certification programme and foster organic HMAP production and marketing in Tunisia.
   (d) Convert to modern distillation equipment; offer credit programmes or tax incentives.
   (e) Encourage the vertical integration of production, processing, distillation and export, and the establishment of strategic partnerships by initiating direct contact with the major industry players, pharmaceutical firms and major international end-users through trade missions and participation in trade shows.

3. Build on existing Tunisian infrastructure.

   (a) Promote the analytical and quality control services provided by the Tunisian laboratories and encourage coordination between researchers and industry on the development of HMAP standards for Tunisia.
   (b) Encourage import substitution through the development of value-added processing and manufacturing activities in Tunisia.
   (c) Encourage import substitution of bergamot, peppermint, geranium, clove, white Artemesia, lavender and citrus essential oils by increasing local production of cultivated HMAP and extending the harvest seasons through greenhouses and drip irrigation.
   (d) Initiate an evaluation of existing infrastructure for processing dried herbs and spices to assess the need for drying, processing and storage facilities.
   (e) Encourage import substitution by increasing production of cumin, coriander, caraway, corette, fennel, sesame, anise and fenugreek.
   (f) Intensify local collection of capers since the regeneration and proper management of the caper-producing rangelands and forests allows for controlled harvests and encourages development of modern caper processing facilities in Tunisia.
   (g) Facilitate the development of value-added activities through incentives.
   (h) Strengthen the commercial viability and competitiveness of women's organizations and women-owned businesses manufacturing HMAP products.
   (i) Intensify agronomic and botanical research foci on marketable cultivars and **wild collect** species by establishing marketing advisory committees made up of Ministry of Agriculture officials and key exporters to communicate marketing knowledge to the agronomic and botanical research communities.
   (j) Differentiate Tunisian HMAP products on the international market; establish and promote geographical indications and appellations of origin.

4. Undertake a second phase of research to develop and implement international marketing strategies for the Tunisian HMAP sector.
   (a) Prepare Tunisian HMAP sector promotional materials.
   (b) Prepare Tunisian HMAP supplier directory.
   (c) Develop trade show representation as an HMAP marketing tool.
   (d) Prepare a directory of European and North American end-users of HMAP products.
   (e) Establish HMAP exporter group to develop commercial linkages.
   (f) Set up a seed program for institution building of marketing and industry associations.
5. Conduct a study of principal HMAP processing and transformation facilities in Tunisia.
6. Develop a regional marketing strategy to service the southern Mediterranean Basin.

3.5 National and International Conferences and Meetings

In addition to the annual meetings of the steering and the technical committees, an international conference on medicinal, herbal and aromatic plants in the Mediterranean Basin was organized and held on 1–3 June 2004 and attended by about 150 participants representing many Tunisian stakeholders and participants from six other countries (Morocco, Algeria, Greece, Egypt, France and Jordan). The conference fostered cooperation and communication among stakeholders, establishing a mechanism for regional cooperation between Tunisia and other countries interested in the sustainable use of HMAP, exchanging ideas, know-how and disseminating technological and marketing information. The participants recommended the establishment of a regional network involving all stakeholders, with a focal person in each country to: (a) organize regular meetings to promote HMAP; (b) initiate mechanisms to elaborate a regional project on HMAP in the Mediterranean Basin; (c) harmonize legal laws in the Mediterranean region on HMAP and their use in accordance with international regulations; (d) publish a newsletter for participants of the regional network; (e) develop national strategies using national expertise and research results on HMAP; and (f) promote multilateral cooperation in the area on these plants.

3.6 Training and Extension

This action not only aims at presenting the project to potential partners but also permits the wider public to discover the plants with herbal, aromatic and medicinal uses, thereby raising awareness of the ecological and economic interest of these plants, whose continued existence is severely threatened.

To meet these objectives, the following activities were developed:

- Dissemination of information through media (newspapers, radios and TV). Project news articles were published in different national magazines and newspapers.
- Presentation of southern Tunisian plants with medicinal interest among neglected species in the framework of a scientific documentary called ‘Under-utilized Crops’, achieved by Austrian Broadcasting Corporation/Radio 8 Television (ORF) in collaboration with IPIGRI (International Plant Genetic Resources Institute).
- Presentation of the project in several meetings held in Tunisia and organized by different institutions and NGOs.
- Teaching of a module about HMAP to master’s degree students at the University of Monastir’s Faculty of Pharmacy.
- Convinced by the results of the project, many partners have expressed their hope to valorize these achievements. Such valorization, which has taken many forms, was assured by several cooperation conventions signed with governmental and private agencies for the technical support and supervision for producing target species seedlings.

4 Conclusion and Lessons Learned

The major lessons learned from the information collected through the studies relative to the HMAP sector in Tunisia is the necessity to treat this sector as a global chain with a set of functions with several operators. As it concerns actors from several departments (such as health, agriculture, research, trade, industry), the development of this sector can be assured only through a multidepartmental and multidisciplinary approach. Different operators must be involved in order to assure the requisite complementarity and the discounted synergies in the framework of a national strategy.

Moreover several other lessons and results were learned and achieved by the end of the project, including:

- Identification of the main actors involved that should be grouped in order to achieve sufficient complementarity according to their role in the chain.
- The choice of the target medicinal plants must take into account their efficient and/or potential utilization and their economic interests at both national and international levels, making it necessary to establish some specific lists for each agro-ecological zone.
- The promotion of this sector requires:
  - The creation of an economic and legislative environment that encourages production and transformation dynamics, as well as the development of actor initiatives (private and public).
  - The development of multidisciplinary research that achieves better knowledge of the HMAP heritage, to preserve it and to suggest solutions to all questions

asked at different levels. Consequently, the **Institut des Régions Arides** (IRA) has established a plot of 4 ha for the cultivation of several HMAP. This plot will be important for research and extension and will eventually be converted into a national park for promotional and educational purposes.

- Due to the increase in awareness about the importance of HMAP, the project is welcomed by the general population and the regional participating institutions who consider its continuation a great help towards biodiversity, research, education and financial gain for southern Tunisia.
- Special emphasis has been placed on the knowledge and role of farmers and local inhabitants in the management and use of medicinal plants for human and livestock needs.

Many activities have been programmed to be completed in the near future. The most important are:

- The preparation of a development project request for financial support.
- The organization of an international symposium 'SIPAM2006', which took place in November 2006.

References

Boukef, M. K. 1986. *Les plantes dans la médecine traditionnelle tunisienns*. Collection medicine traditionnelle et pharmacopée. Agence de Coopération Culturelle et Technique, Paris.

Floret, C. and Pontanier, R. 1982. L'aridité en Tunisie présaharienne. Climat Sol. Végétation et Aménagement, Travaux et Doc. *Cahier ORSTOM*, Paris. No. 150. (Thesis in French.)

Ghoudi, Z. A. 2002. *Importance socio-économique et étude de la filière des plantes aromatiques et médicinales, des épices et des huiles essentielles en Tunisie*. IRA- ICARDA-USDA, Tunisia.

Jehle, P. 2004. *Building an International Marketing Strategy for the Tunisian Aromatic and Medicinal Plant Sector: Identifying Opportunities for and Constraints on the Export of Tunisian Aromatic and Medicinal Plants to the European Union and United States*. IRA-ICARDA-USDA, Tunisia.

Le Floc'h, E. 1983. *Contribution à une étude ethnobotanique de la flore tunisienne*. Publ. Sc. Tunisiennes, Programme 'Flore et Végétation Tunisiennes'. Editions Ministère de l'enseignement supérieur et de la recherche scientifique, Imprimerie Officielle de la République Tunisienne, Tunis. (In French.)

Le Houerou, H. N. 1995. *Bioclimatologie et biogeography des steppes arides du Nord de l'Afrique. Diversité biologique, développement durable et désertification. Options méditerranéennes*. Serie B: *Etudes et recherches*, No. 10. (In French.)

Pottier-Alapetite, G. 1979/1981. *Flore de la Tunisie. Angiospermes-Dicotylédones : Apétales - Dialypétales – Gamopétales*. Première et deuxième partie. Ministère de l'Enseignement Supérieur et de la Recherche Scientifique et le Ministère de l'Agriculture, Imprimerie Officielle de la République Tunisienne, Tunisie. (In French.)

Sghaier, M., Mahdhi, N., Gammoudi, T. and Issaoui, M. 2004. *Exploitation, usage et écoulement des PAM dans la chaîne des Matmata (Sud-est de la Tunisie)*. IRA- ICARDA-USDA, Tunisia. (In French.)

Session II
Dryland Hydrology and Watershed Management

Session chair: Prof. Houcine Khatteli (Tunisia)
Rapporteur: Donald Gabriels (Belgium)

Synthesis of Presentations

Session II, on dryland hydrology and watershed management, began with questions from Howard Weather, who discussed the G-WADI-UNESCO Global Network for Water and Development Information for Arid Lands.

How can we share and exchange scientific information? Do we need more scientific understanding of the characteristics of dryland systems? What can technology do? How can we help in the development of appropriate decision-support tools? One of the ambitions of the G-WADI Global Network is to provide computer-based materials for distribution to interested groups and to support regional activities. Howard Weather made clear that 'Hydrological science and dryland management are key areas where knowledge is needed.'

But dryland management, and in particular the water resources management, has evolved from shared costs (1960s) over shared benefits (1990s) towards sharing of common risks and uncertainty, as Bo Appelgren noted.

Management also requires monitoring, quantification and determination of indicators, which is in line with G-WADI ambitions. Also the question remains whether degraded soils lead to loss of productivity. Will we continue with intensive agriculture or shall we sustain the traditional systems? Or do we give opportunity for advanced primary treatment for agricultural reuse? The example was given of Africa, where areas affected by desertification have groundwater dominance. Reference was also made to Lake Chad, where an integrated groundwater–surface water–land management plan was worked out on a regional scale. For this management plan to work, more information on the evolution of rainfall regimes in drylands is required, as was explained by Mohamed Meddi, in his case study of a number of meteorological stations from the north of the Algerian Sahara.

In order to study the evolution of winter and spring rains, two methodologies were used: the *moving average* and the *sum of the differences between the values and their means*, whereby appropriate statistics were applied. It was interesting to note that since 1950 an increase in the rainfall deficit occurred with a peak or maximum deficit in the 1980s which continued thereafter. This change in rainfall regime places stress on the water resources in general and on its use for agriculture in those regions in particular. More extreme rainfall events with subsequent inundations and damage are observed with negative consequences for the socio-economic development of the region.

Referring once again to collecting, sharing and exchange of information, Stefan Saradeth and Thomas Weißmann claimed that the 'Water community needs the remote sensing community'. The AQUIFER project, an ESA (European Space Agency) initiative, on completion of its second phase, brings together national and international water management entities with remote sensing and GIS service providers from three Maghreb, three African and five European countries. The project will provide a number of products as "land use–land cover" maps, estimates of water abstraction, surface water extension and dynamics, digital terrain models, estimation of ETP and P, water and vegetation monitoring, among others.

Also some interesting concepts of water harvesting systems were presented. Referring to floodwater harvesting, Ahang Sayyed Kowsar made the following statements: 'Flood in deserts is a blessing in disguise!' and 'Coarse-grained alluvium worth more than oil!' And if desertification is seen as a disaster, he noted, 'The cost of prevention is much lower than the cost of remediation'.

We also have to keep in mind some floodwater harvesting concepts, to mention just a few:

- Water is the most precious commodity in drylands.
- The available water capacity of soils is the most important direct driving characteristic.
- Harvested floodwater is a land renovator and a soil builder.
- Large dams offer the most hydro-illogical technology in drylands where potential aquifers exist.

But can we take those concepts into account and what are the practical results of floodwater harvesting? 'Kowsar's project called 'AQUATOPIA' in the Gareh Bygone Plain in southern Iran has harvested more than 200 million m^3 of floodwater since 1983, of which 80% has recharged the aquifers.

Dirk Raes tried to model the effect of the floodwater spreading system of the Gareh Bygone Plain on the soil–water balance and crop production. A soil–water balance model linked to a crop–water productivity model was used to evaluate the recharge of the aquifer and the increased crop production on the terraces of the floodwater systems. It was estimated that only during wet years was the aquifer recharged with rainfall; but rainfall and floodwater runoff could recharge the aquifer during dry, normal and wet years. The model, however, still needs validation and input improvement and will be tried out in other environments for various types of rainfall years and for different crops.

Also Mohamed Ouessar felt the growing need for evaluating and assessing the impact of water harvesting techniques. An evaluation tool, based on USDA Best Management Practices, was applied to evaluate the structural status of *jessour*, *tabias* and gabions check dams. The effectiveness of recharge wells was assessed and improvements of the well design were proposed. Current work is being conducted to couple a hydrological model to erosion models to simulate the water harvesting structures and their impact on water availability and sediment transport.

Finally, Michel Malagnoux touched upon a sensitive issue. Can we continue with the traditional reforestation work of the 1980s, based on hand-labor of woman and children? No, we cannot, is his answer, since labour is becoming scarce in abandoned, degraded lands. Modern technology should be employed, as it was by the Italian expert Vallerani when he introduced two types of ploughs that were able to reclaim large areas of degraded lands. These ploughs can automatically build 600 to 800 ‘half-moon’ micro-basins per hour compared with one to two handmade ‘half-moons’ per day per worker. This technology has been tested in ten African countries and has shown potential in land reclamation programmes, such as ‘TerrAfrica’ and ‘the Green Wall for the Sahara’.

I wish to conclude with a personal view and statement: ‘Traditional technology should go hand in hand with modern knowledge and so will modern technology go with traditional knowledge’.

Session II
Dryland Hydrology and Watershed Management

Chapter 1
G-WADI – UNESCO's Global Network for Water and Development Information for Arid Lands

Howard S. Wheater

Abstract Arid and semi-arid regions face immense pressures to deliver and manage freshwater resources. Problems are exacerbated by population growth, expansion of agricultural activities and agricultural/urban pollution. Water stress, over-abstraction of groundwater, salinisation and desertification are common problems. However, although the scientific understanding of arid areas is poor, it is developing rapidly, new tools and management information are becoming available and there is extensive experience of water management, both of the application of new scientific and technical knowledge to mitigate against water scarcity and the reapplication of traditional technologies to conserve water. UNESCO has therefore established a global network for the exchange of knowledge and information. Its aims are to promote: improved understanding of the special characteristics of hydrological systems in arid regions

- awareness of the potential of new technologies for data provision, data assimilation and system analysis
- the development and use of appropriate decision support tools for integrated basin management
- the exchange of management experience, for example through case studies
- the exchange of data
- the broad dissemination of understanding of these systems and their integrated management to stakeholders and the general public

This paper reviews the activities and products of the G-WADI programme to date, highlights the need for appropriate modeling tools based on improved science to support integrated catchment management, and identifies the challenges associated with assessment of impacts of land use and land management change on water resource availability and management.

Keywords Hydrological systems, data and information exchange, rainfall characteristics, modeling

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1 Introduction

This paper reviews the activities and products of UNESCO's G-WADI programme to date, highlights the need for appropriate modeling tools based on improved science to support integrated catchment management, and identifies the challenges associated with assessment of impacts of land use and land management change on water resource availability and management.

2 Background to G-WADI

Arid and semi-arid regions face globally the greatest pressures to deliver and manage freshwater resources. It has been estimated that some 80 countries, home to 40% of the world's population, were suffering from serious water shortages by the mid-1990s and that in less than 25 years two-thirds of the world's people will be living in water-stressed countries, many of these in North Africa, the Middle East and western Asia (GEO-3, 2002). Already several countries in these regions show a deficit in water budgets; water tables are in decline; and prolonged droughts currently affect many countries in semi-arid regions. Problems are exacerbated by population growth, expansion of agricultural activities, natural salinity increases and agricultural/urban pollution. Other marginal areas, such as southern Europe and the Great Plains of the USA, also suffer from water stress, over-abstraction of groundwater and desertification. These problems are likely to increase under projected climate change.

Clearly water management in arid and semi-arid areas is of fundamental importance to local communities and the global economy, and presents major management challenges. To address these requires good scientific understanding of the hydrological systems, appropriate data and appropriate models for decision support. The scientific challenges are considerable. It is difficult to assess with reasonable accuracy the water balance in semi-arid regions. Rainfall is infrequent and of highly variable intensity and extent; flood events are difficult to quantify; and estimation of recharge to aquifers is particularly challenging. The sustainability of resources is thus difficult to quantify, and in some regions, much of the water being abstracted from deep aquifers is non-renewable, being a legacy from wetter climates in the past. There is also a need to share knowledge and experience concerning water resource assessment and management. Some countries have already developed scientific and technical knowledge to mitigate water scarcity. Others have reapplied traditional technologies to conserve water. Scientific understanding of water-related issues is gradually becoming integrated with other aspects of water resource management. And there is also a widespread need to raise awareness of water scarcity with all end users, including the general public.

In recognition of the above, a special need has been identified by UNESCO to develop and exchange know-how on scientific aspects of water resources (quantity and quality) in arid and semi-arid lands. In November 2001, UNESCO's general conference approved that water resources and supporting ecosystems be given the highest priority for UNESCO activities between 2002 and 2007, with particular attention given to water resource management in arid and semi-arid areas. This was identified as a priority of the International Hydrological Programme, Phase VI (2002–2007) and thus led to an action plan, which included the establishment of a global network. This new global network was launched in 2003 as G-WADI, a Global Network for Water and Development Information for arid lands, to support networking between centres and individuals across the arid and semi-arid regions of the world. A major principle is to ensure that the network activities and materials provided are of practical use and value to water resource managers and stakeholders.

3 G-WADI Objectives

The strategic objective of the network is to strengthen the global capability to manage the water resources of arid and semi-arid regions. The network seeks to provide support systems for individuals and regional centres and facilitate:

- Improved understanding of the special characteristics of hydrological systems in arid regions.
- Awareness of the potential of new technologies for data provision, data assimilation and system analysis.
- The development and use of appropriate decision support tools for integrated basin management.
- The exchange of management experience, for example, through case studies.
- The exchange of data.
- The broad dissemination of understanding of these systems and their integrated management to stakeholders and the general public.

4 Network Activities

G-WADI is managed by a core steering group, which includes wide representation from the different arid regions of the world. An ambitious programme has been defined, but progress is dependent on the level of available financial support. Start-up finance has been provided by UNESCO, with additional support from the UK's Department for International Development. A programme of activities is underway and various network products are available. The key activity is the establishment and maintenance of the G-WADI website (www.gwadi.org). This is the main outlet for information on network activities and for availability of network products. The material provided includes:

1. A *news watch feature* about water resource and hydrologically relevant issues related to arid and semi-arid regions. This is an expanded version of SAHRA's

news watch site (www.sahra.arizona.edu) developed at the University of Arizona in Tucson, USA. Underlying this are web-based forms and database structures that allow stories to be searched for, entered, summarized and posted in a dynamic fashion. It features major breaking stories, and highlights the most recent articles in each topic area.
2. Educational and knowledge-based modules related to key hydrologic processes and water resource issues of the dryland regions. These modules are designed with different levels of detail and complexity so that users can select features relevant to their interest and level of expertise. An example of this is the section ‘Isotopic and Chemical Tracers in Hydrology’.
3. Data products. Data and information exchange is being facilitated and a number of hydrologic data sets, both observed and model-generated, will be developed and provided in near real time (when possible) for arid and semi-arid regions. Examples are satellite-based precipitation data, soil moisture maps, NDVI maps, topography and a number of ground-based global observations such as ground water level information. Currently, the HyDIS section of the website provides precipitation products.
4. Educational modules prepared for short-course and seminar purposes, for example, the 2005 Roorkee workshop on ‘Hydrological Modeling in Arid and Semi-Arid Areas’, and the Cairo workshop on ‘Climate Change in North Africa and the Middle East’.
5. Software tools of various kinds provided through the SAHRA Hydroarchive.
6. Educational information provided through SAHRA’s GLOBE education and science programme.

Plans for further development, dependent on available financial support, include:

- Hydrometerological and hydroclimatological forecasts from a number of modeling centres, customized to cover the dryland zones.
- Additional workshops and associated training products.
- Establishing a series of reference systems (aquifers and catchments) to illustrate data acquisition, hydrological processes and best management practice.
- The provision of common data sets for model intercomparison.
- The provision of chat room facilities.

5 Links to Other International Activities

The principal key words emphasized by the network are: capacity-building, water resources, arid and semi-arid zones. Nonetheless, the objectives of the network are linked to many international programmes and activities inside and outside UNESCO. Appropriate links are being developed, with the aim of building on synergies and avoiding duplication of effort and activities. Partnerships are being developed with international and national centres, including, for example, the International Atomic Energy Agency (IAEA) in the area of isotope hydrology, and

WMO in areas related to water and climate. As the network develops, it will be the responsibility of the steering group and of UNESCO's regional centres to involve other partners at country level as appropriate.

6 Hydrological Science and Dryland Management

The linkage between land management and water has been identified as a priority by G-WADI, and hence this session has been designed to bring together researchers and practitioners to discuss the causes of land use change, their impacts on hydrology and water resources, and the integrated management of land and water resources, including the sustainable management and governance of groundwater.

The increasing pressures on water in arid and semi-arid areas mean that optimal use must be made of available resources, within the limits of sustainable resource development and management. For arid and semi-arid areas this poses particular challenges. Better knowledge is needed of hydrological systems and their functioning under current conditions, and a predictive capability is necessary to evaluate the potential impact of management options. Data records are limited in spatial coverage, record length and quality, and the hydrological processes that characterize arid zone response are very different from those of humid areas and not always well understood. Models used for decision support are often based on humid zone experience and may not represent the relevant hydrological processes.

It is also necessary to broaden the scope of our understanding of arid zone hydrological systems. It is increasingly recognized that water management is inextricably linked to land management, and that land use and land management are strongly influenced by socio-economic factors. The interactions between vegetation, land management and water resources are not well understood, and are likely to be strongly affected in arid areas by climate variability and climate change. Hence a more integrated view is required of water management at the basin scale, and improved understanding of the dynamic interactions between climate, vegetation and water. The special features of arid and semi-arid hydrological response are briefly outlined below and the significance of dryland vegetation and management is discussed.

6.1 Rainfall Characteristics in Arid and Semi-arid Areas

Rainfall in arid and semi-arid areas is commonly characterized by extreme temporal and spatial variability. The temporal variability of point rainfall in arid areas is well-known. The number of raindays per year is small, inter-annual variability is marked and observed daily maxima can exceed annual rainfall totals. For spatial characteristics, information is much more limited. Until recently, the major source of detailed data has been from the south-western U.S., most notably the two, relatively small, densely instrumented basins of Walnut Gulch, Arizona (150 km^2) and Alamogordo Creek, New Mexico (174 km^2), established in the 1950s (Osborn et al., 1979). The dominant rainfall for these basins is convective. Raingauge densities were increased at Walnut Gulch to give improved definition of detailed storm structure and are currently better than 1 per 2 km^2. This has shown highly localized rainfall occurrence, with spatial correlations of storm rainfall of the order of 0.8 at 2 km separation, but close to zero at 15–20 km spacing.

The extent to which this extreme spatial variability is characteristic of other arid areas has been uncertain. Anecdotal evidence from the Middle East underlay comments that spatial and temporal variability was extreme (FAO, 1981), but data from south-western Saudi Arabia, obtained as part of an intensive five-year study of five basins, have provided a quantitative basis for assessment. The spatial rainfall distributions are described by Wheater et al. (1991). The extreme spottiness of the rainfall is illustrated for the 2,869 km^2 Wadi Yiba. Typical inter-gauge distances were 8–10 km, and on 51% of raindays only one or two raingauges out of 20 experienced rainfall. For the more widespread events, sub-daily rainfall showed an even more spotty picture than the daily distribution. The frequency distribution of rainstorm durations shows a typical occurrence of 1- or 2-h duration point rainfalls. Thus rainfall will occur at a few gauges and die out, to be succeeded by rainfall in other locations. It is dangerous to generalize from samples of limited record length, but it is clear that most events observed by those networks are characterized by extremely spotty rainfall; indeed, there were examples of wadi flows generated from zero observed rainfall. However, there were also some indications of a small population of more widespread rainfalls, which would obviously be of considerable importance in terms of surface flows and recharge. This reinforces the need for long-term monitoring of experimental networks to characterize spatial variability.

For some other arid or semi-arid areas, rainfall patterns may be very different. For example, data from arid New South Wales, Australia, have indicated spatially extensive, low intensity rainfalls (Cordery et al., 1983), and recent research in the Sahelian zone of Africa has also indicated a predominance of widespread rainfall. For example, Lebel et al. (1997) and Lebel and Le Barbe (1997) note that a 100 raingauge network was installed in Niger and report information on the classification of storm types, spatial and temporal variability of seasonal and event rainfall, and storm movement. Eighty percent of total seasonal rainfall was found to fall as widespread events which covered at least 70% of the network.

Where the spatial variability of rainfall is marked, it is extremely difficulty to characterize its structure, and important implications for hydrological modeling. Clearly there are potentially important effects on the development of natural vegetation, although as the temporal scale is increased, from event to seasonal to annual, the strong spatial heterogeneity will be markedly reduced.

6.2 Rainfall–Runoff Processes

Rainfall–runoff processes can be strongly influenced by vegetation, which in turn is dependent on climate variability. The relative lack of vegetation cover in arid and semi-arid areas removes protection of the soil from raindrop impact, and soil crusting has been shown to lead to a large reduction in infiltration capacity for bare soil conditions (Morin and Benyamini, 1977). Hence infiltration of catchment soils can be limited, leading to extensive overland flow generation. This overland flow, concentrated by the topography, converges on the channel network, with the result that a flood flow is generated. However, the runoff generation process due to convective rainfall is likely to be highly localized in space, reflecting the spottiness of the spatial rainfall fields, and to occur on only part of a catchment. Linkage between inter-annual variability of rainfall, vegetation growth and runoff production may occur. Clearly the nature and extent of vegetation cover can affect runoff processes and the local water balance. For example, recent modeling in Botswana suggests that runoff production is lower in a year that follows a wet year, due to enhanced vegetation cover, which supports observations reported by Hughes (1995).

Surface water–groundwater interactions in the channel and riparian zone are complex. Commonly, flood flows move down the channel network as a flood wave, moving over a bed that is either initially dry or has a small initial flow. Hydrographs are typically characterized by extremely rapid rise times, of as little as 15–30 min. However, losses from the flood hydrograph through bed infiltration are an important factor in reducing the flood volume as the flood moves downstream. These transmission losses dissipate the flood, and obscure the interpretation of observed hydrographs. It is not uncommon for no flood to be observed at a gauging station, when further upstream a flood has been generated and lost to bed infiltration. The transmission losses from the surface water system are a major source of potential groundwater recharge. The characteristics of the resulting groundwater resource will depend on the underlying geology, but bed infiltration may generate shallow water tables, within a few metres of the surface, which can support vegetation, sustain supplies to nomadic people for a few months, or recharge substantial alluvial aquifers with potential for continuous supply of major towns.

The balance between localized groundwater recharge from bed infiltration and diffuse recharge from rainfall infiltration of catchment soils will vary greatly depending on local circumstances. However, soil moisture data from Saudi Arabia and from Arizona (Liu et al., 1995), for example, show that most of the rainfall falling on soils in arid areas is subsequently lost by evaporation. Methods such as the chloride profile method (e.g. Bromley et al., 1997) and isotopic analyses (Allison and Hughes, 1978) have been used to quantify the residual percolation from soils to groundwater in arid and semi-arid areas.

In some circumstances runoff occurs within an internal drainage basin, and fine deposits can support widespread surface ponding. A well-known large-scale example is the Azraq oasis in northeastern Jordan, but small-scale features (Qaa's) are widespread in that area. Small scale examples were found in the HAPEX-Sahel study (Desconnets et al., 1997). Infiltration from these areas is in general not well understood, but may be extremely important for aquifer recharge.

The characteristics of the channel bed infiltration process are not well understood. Potential effects include air entrapment, which could restrict infiltration rates, bed mobilization and possible pore blockage by the heavy sediment loads transmitted under flood flow conditions. The heterogeneity of observed subsurface response is illustrated by observations of Hughes and Sami (1992) from a 39.6 km^2 semi-arid catchment in South Africa. Analysis of observed flood flows at different locations can allow quantification of losses. Walters (1990) and Jordan (1977) provide evidence that, where available, subsurface storage is not limiting, the rate of transmission loss is linearly related to the volume of surface discharge. The role of available subsurface storage on transmission loss was discussed by Telvari et al. (1998) for the Fowler's Gap catchment in Australia. It was inferred that once alluvial storage is satisfied, approximately two-thirds of overland flow is transmitted downstream. A similar concept was developed by Andersen et al. (1998) at larger scale for the sand rivers of Botswana, which have alluvial beds of 20–200 m width and 2–20 m depth. A single major event was sufficient to fully satisfy available alluvial storage (the river bed reached full saturation within 10 h). No significant drawdown occurred between subsequent events and significant resource potential remained throughout the dry season. It was suggested that two sources of transmission loss could be occurring, direct losses to the bed, limited by available storage, and losses through the banks during flood events.

The relationship between wadi flow transmission losses and groundwater recharge will depend on the underlying geology. The effect of lenses of reduced permeability on the infiltration process has been investigated by Parissopoulos and Wheater (1990, 1991, 1992), but once infiltration has taken place, the alluvium underlying the wadi bed is effective in minimizing evaporation loss through capillary rise (the coarse structure of alluvial deposits minimizes capillary effects). Thus Hellwig (1973), for example, found that dropping the water table below 60 cm in sand with a mean diameter of 0.53 mm effectively prevented evaporation losses, and Parissopoulos and Wheater (1991) showed that bare soil evaporation losses were not in general significant for the water balance or water table response in short-term simulation.

The discussion of channel processes above has largely neglected vegetation, yet a particular area of importance is the role of riparian vegetation in influencing evaporation, alluvial moisture storage and groundwater recharge. Riparian zones can be important habitats in arid areas, but as yet little integrated work has been done to understand and quantify ecohydrological interactions, with some notable exceptions (e.g. Goodrich et al., 2004; Scott et al., 2006).

7 Conclusions

It is argued in this paper that land and water management are inextricably linked, and that effects of land cover and land management can be influential in affecting soil structure, runoff processes, groundwater recharge (due to rainfall infiltration through the soil profile, and through infiltration of surface water from the bed of flowing channels) and the water balance. The scientific understanding of the linkage between climate, vegetation and hydrology is in its infancy, yet this linkage is fundamentally important for management and protection of water resources and ecosystems. Much basic and applied research is required to develop the science base to a point where these effects can be understood and generalized.

Ultimately, for management, modeling is needed to quantify effects of climate variability and/or land management change. While hydrological models can represent vegetation processes such as interception and transpiration at local and even global scale, the interactions between vegetation and climate in arid and semi-arid areas is not well understood, nor are the interactions between vegetation, soil structure and runoff generation (both surface and subsurface), nor the effects of riparian vegetation on flood transmission, infiltration, water use and groundwater recharge. There is a need to bring together such knowledge as is available, to disseminate that information to the global community, and to stimulate the research needed to address these fundamental issues of dryland management. These are key goals of the G-WADI programme, and this conference represents an important step in achieving those objectives.

References

Allison, G. B. and Hughes, M. W. 1978. The use of environmental chloride and tritium to estimate total recharge to an unconfined aquifer. *Australian Journal of Soil Research*, Vol. 16, pp. 181–195.

Andersen, N. J., Wheater, H. S., Timmis, A. J. H. and Gaongalelwe, D. 1998. Sustainable development of alluvial groundwater in sand rivers of Botswana. *Sustainability of Water Resources Under Increasing Uncertainty*, D. Rosjberg, N. Boutayeb, A., Gustard, Z. Kundzewicz and P. Rasmussen (eds.), International Association Hydrological Sciences Publication, No. 240, Wallingford, UK, IAHS, pp. 367–376.

Bromley, J., Edmunds, W. M., Fellman E., Brouwer, J., Gaze, S. R., Sudlow, J. and Taupin, J.-D. 1997. Estimation of rainfall inputs and direct recharge to the deep unsaturated zone of southern Niger using the chloride profile method. *Journal of Hydrology*, Vols. 188–189, pp. 139–154.

Cordery, I., Pilgrim, D. H. and Doran, D. G. 1983. *Some Hydrological Characteristics of Arid Western New South Wales*. The Institution of Engineers, Australia, Hydrology and Water Resources Symposium, Institution of Engineers, Australia, National Conference Publication, No. 86/13, pp. 203–208.

Desconnets, J. C., Taupin, J. D., Lebel, T. and Leduc, C. 1997. Hydrology of the HAPEX-Sahel Central Super-Site: Surface water drainage and aquifer recharge through the pool systems. *Journal of Hydrology*, Vols. 188–189, pp. 155–178.

FAO. 1981. *Arid Zone Hydrology for Agricultural Development*. Irrigation and Drainage Paper No. 37. Food and Agriculture Organization of the United Nations, Rome.

GEO-3 (Global Environment Outlook). 2002. United Nations Environment Programme/UNEP, Earthscan.

Goodrich, D. C., Williams, D. G., Unkrich, C. L., Scott, R. L., Hultine, K., Pool, D. R., Coes, A. L., Hogan, J. F. and Miller, S. N. 2004. Ephemeral channel recharge and evapotranspiration from near-channel vegetation. *Groundwater Recharge in a Desert Environment: The Southwestern United States*, J. F. Hogan, F. M. Phillips and B. R. Scanlon (eds.), Water Science and Applications Series. American Geophysical Union, Vol. 9, Washington, DC, pp. 77–99.

Hellwig, D. H. R. 1973. Evaporation of water from sand, 3: The loss of water into the atmosphere from a sandy river bed under arid climatic conditions. *Journal of Hydrology*, Vol. 18, pp. 305–316.

Hughes, D. A. 1995. Monthly rainfall-runoff models applied to arid and semiarid catchments for water resource estimation purposes. *Hydrological Sciences Journal*, Vol. 40, No. 6, pp. 751–769.

Hughes, D. A. and Sami, K. 1992. Transmission losses to alluvium and associated moisture dynamics in a semiarid ephemeral channel system in Southern Africa. *Hydrological Processes*, Vol. 6, pp. 45–53.

Jordan, P. R. 1977. Streamflow transmission losses in Western Kansas. *Journal of the Hydraulics Division*, Vol. 108, HY8, pp. 905–919.

Lebel, T., Taupin, J. D. and D'Amato, N. 1997. Rainfall monitoring during HAPEX-Sahel.1. General rainfall conditions and climatology. *Journal of Hydrology*, Vols. 188–189, pp. 74–96.

Lebel, T. and Le Barbe, L. 1997. Rainfall monitoring during HAPEX-Sahel.2. Point and areal estimation at the event and seasonal scales. *Journal of Hydrology*, Vols. 188–189, pp. 97–122.

Liu, B., Phillips, F., Hoines, S., Campbell, A. R. and Sharma, P. 1995. Water movement in desert soil traced by hydrogen and oxygen isotopes, chloride, and chlorine-36, southern Arizona. *Journal of Hydrology*, Vol. 168, pp. 91–110.

Morin, J. and Benyamini, Y. 1977. Rainfall infiltration into bare soils. *Water Resources Research*, Vol. 13, No. 5, pp. 813–817.

Osborn, H. B., Renard, K. G. and Simanton, J. R. 1979. Dense networks to measure convective rainfalls in the Southwestern United States. *Water Resources Research*, Vol. 15, No. 6, pp. 1701–1711.

Parissopoulos, G. A. and Wheater, H. S. 1990. Numerical study of the effects of layers on unsaturated-saturated two-dimensional flow. *Water Resources Management*, Vol. 4, pp. 97–122.

———. 1991. Effects of evaporation on groundwater recharge from ephemeral flows. *Advances in Water Resources Technology*, G. Tsakiris (ed.), A. A. Balkema, Rotterdam, pp. 235–245.

———. 1992. Experimental and numerical infiltration studies in a wadi stream-bed. *Journal of Hydrological Sciences*, Vol. 37, pp. 27–37.

Scott, R. L., Huxman, T. E., Williams, D. and Goodrich, D. C. 2006. Ecohydrological impacts of woody plant encroachment: Seasonal patterns of water and carbon dioxide exchange within a semiarid riparian environment. *Global Change Biology*, Vol. 12, pp. 311–324.

Telvari, A., Cordery, I. and Pilgrim, D. H. 1998. Relations between transmission losses and bed alluvium in an Australian arid zone stream. *Hydrology in a Changing Environment*. H. Wheater and C. Kirby (eds.), Vol II, Wiley, Chichester, UK, pp. 361–366.

Walters, M. O. 1990. Transmission losses in arid region. *Journal of Hydraulic Engineering*, Vol. 116, No. 1, pp. 127–138.

Wheater, H. S., Butler, A. P., Stewart, E. J. and Hamilton, G. S. 1991. A multivariate spatial-temporal model of rainfall in S.W. Saudi Arabia: Data characteristics and model formulation. *Journal of Hydrology*, Vol. 125, pp. 175–199.

Chapter 2
Towards Sustainable Dryland Development in Africa: Integrating Groundwater and Land Management

Bo Appelgren

Abstract Long term, irreversible loss in agricultural production from degradation of dryland is a major threat to human, food, and environmental security in the arid and semi-arid parts of Africa. The scope to compensate here for with agricultural intensification has however remained limited. The key limiting factor is water, with the consequent erosion of the very foundation for social and environmental security, exacerbation of rural poverty, and frequent regional famines with increasing food aid dependence.

Land degradation is linked to deforestation and inappropriate agricultural land use, and dealt with by local, community based watershed management practices often with long term consequences for the water balance at basin and aquifer level. In semi-arid areas groundwater resources are being depleted and degraded due to land use changes in aquifer recharge areas resulting in reduced seepage, with desiccation and salinization of humid zones as the main agricultural production areas and habitats for dryland biodiversity. With these signals the benefits, with synergies and reduced overlap, of integrated land-groundwater management interactions to sustain dryland eco-systems and adapt agricultural production to impacts of climatic change are increasingly recognized.

The paper, backing integrated land-water management approaches at professional and policy and institutional levels, draws upon the findings of the recent GEF/STAP – UNESCO/IHP groundwater workshops, and cases of integrated land-water management of African dryland, and discusses the scope for conservation and production benefits in the light of socio-economic and environmental drivers at the local, national and sub-regional scales.

Keywords integrated management, Rio Conventions, desertification control, groundwater management

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C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

1 Introduction

Agricultural production in the semi-arid dryland regions of Africa is characterized by extensive, low input and investment subsistence farming focused on limiting the impacts of hydrological and policy risks. As the consequence, agricultural, labour and natural resource productivity has remained low, however at high environmental costs, for land degradation and loss of natural resources and biodiversity. Agriculture is the primary social and productive economic sector in the semi-arid African countries and forms the basis for rural welfare and food security, and the platform for structural change and economic take off towards sustainable socio-economic development and growth. In this development perspective, the current and largely irreversible loss of agricultural land and production potential from degradation of drylands is a major threat to sustainable social development and poverty reduction for stability in the African region. With emerging global aspirations to build sustainability on integrated management approaches, particularly land and groundwater management, and increased investments for intensification to improve productivity and reduce pressures on marginal lands, the opportunity is increasingly recognized for integrated action to dovetail land, groundwater and watershed management to address land and water degradation and the consequent losses of dryland ecosystems and biodiversity. Integration, with a clear objective of sharing social risk[1] for a common secure future with growth and stability in the dryland zones of Africa, is a principal social and environmental sustainability strategy.

Dryland degradation has traditionally been caused by deforestation and abusive and inappropriate agricultural land and water uses, and addressed with reforestation, watershed management and physical erosion protection practices focused on the hydrological water balance. With the dominant role of groundwater resources in semi-arid areas, and the resulting impact from groundwater depletion and salinization on groundwater dependent ecosystems (GDE) and wetlands, the focus is being geared towards eco-system approaches, based on cooperation on common risk, with opportunities of synergies and reduced overlap from integrated land and groundwater management. Groundwater resources are being depleted and degraded as the joint result of over-abstraction and abusive land uses and resulting in rapid runoff, flooding, high evaporation losses and reduced aquifer recharge, resulting in desiccation and salinization of humid zones, with loss of agricultural productivity, habitats for biodiversity and traditional groundwater management systems. With risk as the common, proactive driver for prevention and mitigation

[1] Economic valuation in dryland management, similar to transboundary water resources management, at local, domestic and international level, *shared costs* has evolved from (1960s) to *shared benefits* (1990s), the current focus is on *shared common risk and uncertainty*. A simple, generally acknowledged explanation for this is the insight that water is not of a considerable value and has only limited tradability on the global market, while degradation and loss of ecosystems and their integrity is a common risk that have impacts on all parties, at the local, regional and even global level and with the common objective, incentive and obligation to be shared, arguably on an equitable basis.

of hydrological, land degradation and socio-economic risk, integrated land–groundwater management interactions to sustain dryland eco-systems and adapt agriculture to impacts of climatic change have been initiated and are becoming increasingly recognized at different levels, from local farming communities to transboundary issues in internationally shared basins. In addition, new water technology, such as reuse and managed aquifer recharge, can now provide alternatives for rehabilitation of the degraded or lost resources. The scope for action therefore needs to be reviewed and defined, with scientific, technical and institutional solutions integrated for synergy gains.

The present paper, on integrated land–groundwater management approaches, draws on the findings of the recent GEF/STAP – UNESCO/IHP groundwater review workshops[2] (GEF/STAP, 2004, 2005), and cases of integrated land-water management in the African drylands. It identifies the scope for sustainable conservation and production benefits in the light of policy, institutional and socio-economic and environmental drivers at local, national and sub-regional scales. Groundwater is proposed as a cross-cutting, dovetailing resource, characterized by limited flows versus large subsurface water storage volumes protected from evaporation and contamination, and with capacity to support sustainable dryland development and conserve habitats and biodiversity also for persistent drought and climate change. Groundwater is critical to support dryland ecosystems and water level monitoring can provide long-term indications of immediate stress and long-term threats in drylands, with impacts on surface ecosystems from land and water use and climatic change. Groundwater is critical to sustainable land management and desertification control, and to provide for synergies and full benefits from joint land and water management.

1.1 Environmental and Development Synergies between the Rio Conventions

Environmental management is already by definition integrated and calls for mobilization of different approaches to action, with synergies and outcomes that exceed the sum of individual sectoral approaches (Fig. 2). The three Rio Conventions (CBD, UNCCC, UNCCD) have evolved at different times, in varying contexts, and out of different visions. They are the products of the global consensus under the common Agenda 21 strategy and reflect the similar ecological, socio-economic and institutional issues. Therefore, as provided under UNCCD,[3] the aim is to work towards a common focus with justification and measures to draw synergies for enhanced benefit from concrete field

[2] The workshops concluded that groundwater management, including managed aquifer recharge and waste water reuse, could enhance projects in biodiversity, climate change adaptation, land management and international waters.

[3] Ref: UNCCD, Art 8, Relationship with other conventions: ‘shall encourage the coordination of activities carried out under this Convention and under other relevant international agreements, particularly the UNFCCC and CBD’.

projects, especially at national and local levels. In view of these opportunities to harvest the synergies between the three Rio Conventions, while there is room for integration and economic gains of scale from the contributions of the Parties, the national focal points under the individual Conventions have remained fragmented and linked to different ministries and sectors, with a consequent risk of overlap and loss in efficiency, while integration could be facilitated through joint consultation mechanisms between the Parties under the three Conventions (OSS, 2002). Ultimately operational opportunities for efficiency and reduced overlap are found in the integration of regional and national strategic action programmes under the different conventions, together with specific regional and national action programmes focused on the management and protection of regional river basins, lake systems and large marine ecosystems.[4]

Desertification and land degradation are linked to depletion and degradation of water resources, destruction of the vegetation cover, and consequent loss of ecosystems, which serve as habitats for biodiversity (Fig. 1). The capacity of drylands to resist degradation depends on the availability of humidity and groundwater that, together with the forest coverage, are critical to resist climatic change and drought, support sustainable agricultural land use and to manage, restrict and mitigate the pressures on the land.

Closer coordination and integrated implementation[5] are expected to be beneficial regarding the implementation of the UNCCD, UNFCCC and CBD through:

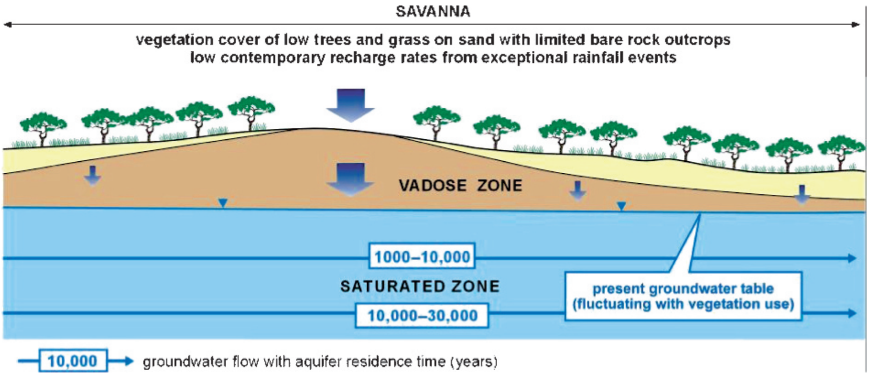

Fig. 1 Decoupled, non-renewable – limited recharge – in arid, semi-arid savanna sub-regions in Africa. The interaction between land and groundwater takes place in the upper phreatic aquifer (UNESCO-GW-MATE, 2006)

[4] As one example, the semi-arid dryland countries along the southern Mediterranean coast are active participants under the UNCCD, with Regional (RAPs), Sub-regional (SRAPs) and National Action Programmes (NAPs). They are open to synergies for beneficial coordination the SAPs and the NAPs under Mediterranean Action Program, under the 1978/1995 Barcelona Convention.

[5] The direction of the GEF strategy for the GEF4 cycle is focused on inter-focal area integration and common central monitoring of catalytic and long-term impacts on the global environment. GEF4 also gives priority attention to the cross-cutting role of groundwater in global environmental management.

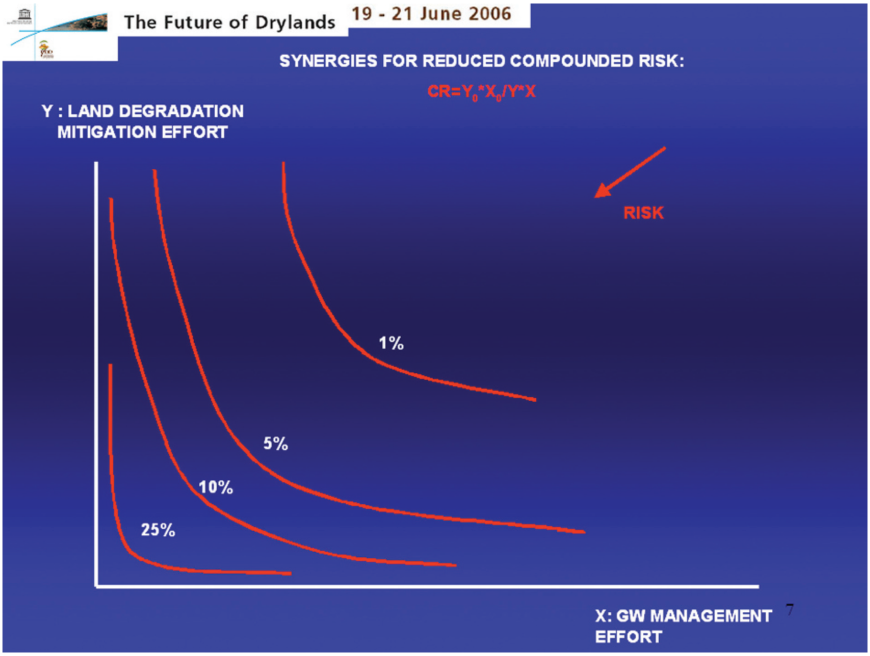

Fig. 2 Synergies in compounded risk reduction from integrated land degradation and groundwater management

- Mainstreaming UNCCD activities in development support programmes, and integrating and prioritizing the National Action Programmes (NAPs) in their national development plans.
- Enhanced integration of desertification control programmes in national development plans.

There are also differences in the effectiveness of institutional focus and arrangements at national government level, where UNCCD is handled by foreign affairs agencies with a lower level of professional focus and support, as compared to UNFCCC and CBD, which are focused on environment and agriculture. It is therefore necessary to call on Parties to designate relevant ministries to be in charge of UNCCD affairs. Implementation would benefit from a common strategy built on political, socio-economic and environmental protection drivers and country and regional commonalities. Enhanced recognition of groundwater as a cross-cutting resource offers the opportunity to spearhead implementation of UNCCD and integration and synergies between the Rio Conventions. Groundwater, as the only available water resource in semi-arid areas, can be critical to sustainable land management in dryland areas, also cutting across biodiversity conservation and adaptation to drought and climatic change under the CBD and the UNFCCC. The focus on groundwater can help to achieve the immediate term objectives for sustainable national development and growth and security for water, food and ultimately growth, structural change and stability and maintenance of humid zones. Groundwater enhancement and protection is a common denominator that, on the one hand, requires attention to land degradation and water balance considerations, and, on the other, to land conservation, vegetation protection and afforestation in the aquifer recharge and outflow zones of immediate importance and with synergies under all the Rio Conventions. From this perspective enhanced groundwater should be central to the development-oriented national water resources and agricultural development sectors and assist in bringing political currency and attention for mainstreaming long-term, low-visibility imperatives to combat desertification and control land degradation.

2 Opportunities and Examples of Integrating Land and Groundwater Management

2.1 Groundwater and Land Governance

With growing water demands, facilitated by improved drilling and pumping technology, development and reliance on groundwater are increasing rapidly, especially in groundwater-dependent dryland and arid areas and accompanied by the requirement for effective groundwater governance mechanisms for use rights and environmental protection of the water resources, as well and the groundwater-dependent land and ecological systems. Traditionally, a specific aspect of land law is the perception of groundwater as a private or an open-access resource; this view has remained strong, and recent attempts to bring groundwater within the administrative water rights regimes have not always been successful. This is important in groundwater-dependent drylands, where access to groundwater is the only means to ensure land production. It points to the importance of recognizing and exploring land- and community-based approaches to groundwater management. While the trend is towards the separation of land and water rights, the concern is that countries attempting domestic land and water reforms need to be well informed and assisted to avoid socio-economic and environmental marginalization (FAO, 2004). Moreover, traditional law treats groundwater as part of the overlying land owned completely by the property owner, and groundwater is rarely considered in conjunction with related surface waters or made subject to common regulatory or management schemes.

On the other hand, domestic law has recently vested the groundwater resource in the State that issues permits for its extraction and utilization. Groundwater, as a strategic, safe and high-quality supply with critical environmental functions, is a high-value resource. In the drylands, groundwater is important as often the only source of drinking water and for agricultural uses that dominate the bulk of groundwater extractions. In the arid zones, groundwater is also critical to support development and to maintain river flows, wetlands and submarine groundwater discharges to support humid zones. The change in domestic legislation from private ownership to public domain status with groundwater rights has facilitated implementation of shared aquifer management at the domestic level. The control of waste discharges and adverse land use practices to protect groundwater from degradation, together with groundwater planning and users' participation, represent other key steps to accommodate and reconcile a diversity of field circumstances with the legislative provisions (Burchi, 1999).

2.2 Integrated Groundwater Indicators

Joint land and groundwater monitoring is the key to guiding well-based policy intervention. Groundwater depletion, accompanied by quality degradation and salinization, represent often irreversible losses and early warning and stress trend indicators of long-term sub-regional desiccation, land salinization and loss of land productivity. Groundwater, as a cross-cutting and dovetailing resource, provides for sensitive and early indication of long-term land and consequent water-stress-driven environmental degradation. It provides opportunities for monitoring to identify (1) driving forces, such as natural conditions, anthropogenic and external/international imperatives, (2) pressures, such as water supply and demand, (3) status, such as groundwater levels and storage and quality, and (4) impacts and synergies on ecosystem integrity and use values.

Specifically it is necessary to monitor and account for the scope, level and scale, with constraints and opportunities for land management and groundwater integration. Special attention should be given to monitor the level of multi-disciplinarity integration of sectoral/professional and policy and implementation approaches, such as forestry–water resource and science/engineering/juridical approaches.

2.3 Focus on Africa: Examples of Integrated Groundwater and Land Management for Sustainable Dryland Development

The UNCCD (Art. 4, 2d, 2e) supports regional cooperation and gives priority to the African region.

The groundwater–land systems in Africa are generally sub-regional and involve transboundary issues. The common denominator for aquifer systems and groundwater as a water resource is that aquifers hold large storage volumes of water protected from evaporation losses that can be extracted and made available to meet growing demands during periods of drought and climatic change.

The common and non-negotiable requirement, particularly in dryland systems, is to sustain the land and groundwater interfaces as follows:

> maintain the integrity of aquifer systems, balancing the water levels of shallow phreatic surface aquifers, and the seepage discharges supporting vegetation cover and GDEs and wetlands, but on the other hand reduce evaporation losses through the vadose zone, and

protect saline intrusion into coastal aquifers with consequent coastal land, and protect the watersheds from deforestation and erosion to support groundwater recharge and reduce losses and degradation from flooding and sedimentation.

Specific aspects and opportunities of joint land and groundwater management approaches to management intervention in relation to sustainable dryland development are exemplified in the following four African cases of integrated dryland and groundwater management approaches[6] at local, domestic and transboundary levels:

Integrated wastewaters reuse technology to support and rehabilitate oasis ecosystems and traditional *foggara* groundwater collection supply systems throughout Western Sahara, threatened from increased abstractions and depletion of groundwater table.

Integrated management and protection of coastal zone dryland and groundwater systems along the African coast.

Priority attention to land and groundwater management linkages in large shared sub-regional aquifer systems in the Sahara/Sahel region, the Iullemeden Aquifer System in Mali, Niger, Nigeria.

Conjunctive surface and groundwater management systems to mitigate land degradation and the depletion and level variation in the Lake Chad water body, in the shared sub-regional Lake Chad basin.

2.3.1 Loss and Option for Supplementing Traditional *Foggara* Systems in the Adrar and Other Areas in Western Sahara

With the increased extractions from pumped boreholes for municipal water supply, and the resulting depletion of groundwater water levels, and reduced or ceased discharges from the ancient *foggara* drain collectors – with *foggaras* only 1,400 in the Adrar area – the dryland wetlands, in particular the traditional oasis agricultural systems, are threatened to dry up. However, with the used water being collected and threatening to pollute the surface aquifers, there is the opportunity to introduce appropriate and affordable treatment and to return the treated waste water to maintain the oasis irrigation systems to make productive use of the waste and the recycled nutrients for plant nutrition benefits.

2.3.2 Land Management in Coastal Foothill Watersheds to Sustain Coastal Groundwater Systems

The run-off, in the form of flash floods and sediment transport from the foothills of the coastal mountain range in eastern Libya, is discharged directly into the sea, without contributing to the recharge of the coastal aquifers and the water supply in the coastal strip, resulting in groundwater depletion with loss of water resources, seawater intrusion and coastal salinization, and also coastal sedimentation with degradation and pollution of coastal and marine waters and related ecosystems. The southern Mediterranean and other coastal dryland zones along the African coast

[6] The cases are drawn from ongoing and proposed integrated land and aquifer projects that are being addressed or recognized by UNESCO/IHP and the GEF.

provide an opportunity to introduce watershed management as a component of integrated coastal zone management.

2.3.3 Land and Groundwater Management Linkages as a Principal Option for Sustainable Development of Large Subregional Aquifer Systems

The riparian countries in the Iullemeden aquifer system have identified and adopted land degradation and salinization as the common priority concern and priority risk for joint integrated management of the regional transboundary aquifer system. Land degradation in the aquifer recharge zones, with consequent desiccation and rapid loss of agricultural productive land, and reduced aquifer recharge with the risk of groundwater depletion and salinization, represent the principal long-term constraints to sustainable sub-regional development.

2.3.4 Conjunctive Surface and Groundwater and Land Management Systems to Mitigate Land Degradation and Depletion and Level Variation in the Lake Chad Water Body

The active extension of the upper phreatic Chad aquifer connected to the Lake Chad water body is estimated to be 5–10 larger (150,000 km^2) than the maximum extension of the Lake (25,000 km^2) (Fig. 3). Conjunctive groundwater and land management for

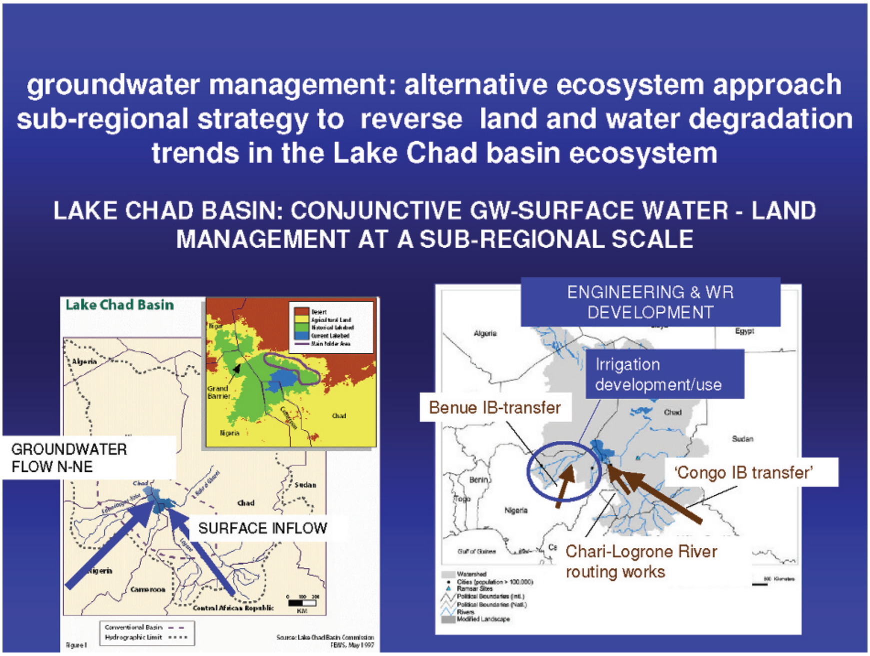

Fig. 3 Conjunctive groundwater – surface water – land management in the Lake Chad aquifer basin

enhanced groundwater recharge and underground water storage for reduced evaporation losses could provide an important supplement to even out water availability, reduce land degradation and maintain the lake level even during extended periods of regional drought. In this sense the approach would supplement an ecosystem-based approach to the principal African problem of the depletion of Lake Chad, and provide alternatives or complements to large inter-basin transfers at high environmental costs.

3 Conclusions

The scope for integration between the international environmental conventions, such as the UNCCD, UNCCC and CBD as well as regional cooperative frameworks, is wide and provides opportunities for substantial environmental synergies. Groundwater, as a critical cross-cutting and dovetailing resource, could provide for strategic integrated land and water management. As exemplified by the African cases presented, there are important opportunities for action and multi-benefits based on integrated, ecosystem-based management approaches. The focus is therefore on action and demonstrations for implementation based on result-monitoring and integrated land and groundwater indicators.

References

Burchi, S. 1999. *National Regulations for Groundwater: Options, Issues and Best Practices*. Seminar on Groundwater: Legal and Policy perspectives. World Bank, Washington, DC., April.

FAO. 2004. *Land and Water: The Rights Interface*, Hodgson, S. (ed.). FAO Legislative Study No. 84, Food and Agriculture Organization of the United Nations, Rome.

GEF/STAP. 2004. *Strategic Options and Priorities in Groundwater Resources*. Global Environment Facility/Scientific and Technical Advisory Panel/UNESCO Review workshop, Paris, April 2004. The GEF Council, GEF/C.24/Inf. 13 November 17–19. See http://stapgef.unep.org/ (Accessed 12 September 2006).

———. 2005. Global Environment Facility/Scientific and Technical Advisory Panel/UNESCO Workshop on Managing the Subsurface Environment, New Delhi, India, September. See http://stapgef.unep.org/ (Accessed 12 September 2006).

JIU. 2005. *Review of the Management, Administration and Activities of UNCCD*. Joint Inspection Unit, Geneva.

OSS. 2002. *La Synergie entre les Conventions de Rio*: *Désertification, biodiversite et changements climatiques*, l'Observatoire du Sahara et du Sahel, Tunis, annot. 2002. (In French.)

UNESCO/GW-MATE. 2006. *Non-renewable groundwater resources; a guidebook on utilisation for water resource policy-makers*, S. Foster and P. Loucks (eds.), UNESCO/IHP.

Chapter 3
Evolution of Pluviometric Regimes in Various Stations of the Northern Algerian Sahara

Mohamed Meddi[1], Amel Talia[2] and B. S. Bekoussa[2]

Abstract At the end of the 1970s, south-western Algeria was marked by a severe, wide-ranging and persistent drought due to its extraordinary rainfall deficit. Rainfall in this region is characterized by taking into consideration the annual data of a certain number of rainfall stations with more than 60 years of observations (1930–1999). For each station we analyzed a series of annual rainfall (P) and considered their coefficient of variation (CV). This coefficient expresses the rate of rainfall in time and can be used for comparative studies. We noted that in this region, rainfall was very low with the greatest variability. In order to study the evolution of the total rainfall for winter and spring, we employed two methods: the moving average and the average of accumulated variations. We noted that the winter and spring rains evolved differently; however, from the 1980s to the present, these seasonal totals are the lowest and show the greatest deficit. For each of the stations selected, a rainfall index was calculated defined as a reduced central variable. We established a cartography of the average for each decade of these indexes with a view to revealing the contrast between the different periods studied. Generally speaking, it seems that there is an upward trend in the 1930s and mid-1940s. From the 1950s, we note an increase in rainfall deficit at the level of the zone studied. The fall in total annual precipitation is greatest during the two decades that follow. However, the most sudden and significant fluctuation (in the statistical sense) was observed around the 1980s. This period of deficiency has since been characterized by its intensity and duration.

Keywords Rainfall regime, deficit or excess rainfall, cartography, Southern Algeria

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[2] LSTE – Centre Universitaire de Mascara, Algeria

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

1 Introduction

South-western Algeria is a region at the boundary of life. It is therefore needless and risky to create poles of activity if they cannot be maintained. There is a risk of transforming what is a relative desert into an absolute desert. Desert life would decline even further without the study of the change in rainfall patterns. Furthermore, changes in this pattern recorded during the last two decades have a damaging socio-economic effect when considering the importance of tourism in the Sahara. It is therefore vital to study this essential factor of life in the Sahara as well as these different variations.

2 Data and Methods

2.1 Data

A great number of rainfall stations have been selected in order to establish a database of annual rainfall for the zone studied. The stations chosen meet the criteria of duration of information available and the quality of data. The choice of stations also provides good coverage of the study zone.

2.2 Methods

To evaluate the variability of the annual precipitation in the region, we have employed climatic formulas that are simple but capable of providing reliable information and that represent the phenomenon effectively. With this is in mind, we have used the coefficient variation expressed as a percentage (%):

$$CV = \left(\sigma / \bar{x}\right) \times 100$$

where $\bar{x}$ is the average in the series and σ is the varition type.

To study the change in spring and winter rainfall totals, we have applied the method of accumulated variations and the flexible average.

The flexible average: Each observation is replaced by an arithmetic average calculated from the value of this observation and its neighbouring values; in the framework of our study, we have used three values: thus, x_i is replaced in the series by:

$$\frac{x_{i-1} + x_i + x_{i+1}}{3}$$

This method reduces the influence of accidental variations, eliminates the effect of very short period fluctuations, and consequently the results are easier to interpret. We opted for this method because of its simplicity.

The method of average variations: The method of average accumulated variations of which the sum equal to zero enables the identification of visible trends by

$$\sum_{i=1}^{n}(xi-\overline{x})$$

Disregarding weak fluctuations from one year to another, when the sum of these variations grows, the trend is towards a rise; when it falls, it will drop.

3 Result

3.1 Statistical Characteristics of Annual Rainfall

To characterize interannual variation in Southern Algeria, we have defined the different descriptive characteristics of the rainfall stations during a period of observations between 1930 and 1999 (Table 1). We have noted that the annual average of total precipitation varies between 110.2 mm and 394.8 mm at the level of the stations in the Biskra sector and Tissemsilet, respectively. At the level of our study zone, the coefficient of variation varies between 25% and 49% at Mederissa and Biskra (limit of the Sahara) stations, respectively. To better evaluate the spatial and temporal significance of the relationship between their precipitation and variability, we sought an effective technique to present the information of the regional characteristics in a simple way. To carry out this technique, we placed all the stations from the west to the east as x-coordinates and the rainfall (in mm) and the coefficient of variation (in %) as y-coordinates. The rainfall is low and the variability is greater in this region (Fig. 1). The coefficient of variation exceeds 49% at the Biskra station.

Table 1 Description of characteristics of the series of observations at the annual scale

Station	Average	Median	Minimum	Maximum	Variation type	CV	Max/Min
Sougueur	361.49	348.90	115.50	730.50	120.87	0.33	6.3
Tissemsilet	394.83	381.50	169.60	784.70	118.60	0.30	4.6
Boughzoul	195.75	190.30	81.30	359.00	62.56	0.32	4.4
Ain Ouessara	262.57	256.30	110.43	556.40	86.64	0.33	5.0
Tadjmout 2	157.32	150.70	5.50	337.50	75.45	0.48	61.4
Biskra	126.66	123.38	14.63	351.10	62.31	0.49	24.0
Biskra sector	110.22	110.70	6.31	238.63	41.38	0.38	37.8
Mederissa	326.35	327.10	159.70	595.50	82.31	0.25	3.7
Ain El Hadjar	384.00	374.50	54.80	997.80	174.44	0.45	18.2
Saida	342.26	335.20	157.90	595.60	97.72	0.29	3.8
Aouf M.F.	566.14	547.70	205.90	991.20	175.72	0.31	4.8
Bouhanifia Bge.	321.11	322.00	135.00	479.00	87.34	0.27	3.5
Mohamadia GRHA	347.94	345.90	165.60	515.90	89.56	0.26	3.1
Djelfa	263.64	241.48	42.30	688.05	114.47	0.43	16.3

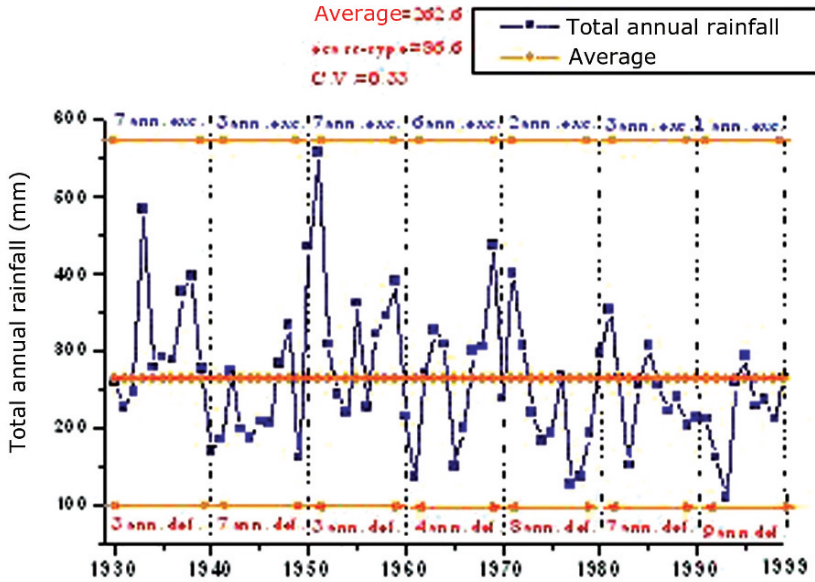

Fig. 1 Chronological evolution of annual pluviometric totals at Ain Ouessara station

3.2 Evolution of Annual Rainfall Totals

At the level of southern Algeria, the study of interannual variability during the period 1930–1999 (Fig. 1) reveals that the greatest number of deficit years was observed during the 1940s, 1980s and 1990s. These results also show the continuance of deficit totals that persist over several successive years. Between the two great droughts, rainfall has generally been normal or in surplus; we even recorded seven consecutive rainy years between the end of the 1940s and the beginning of the 1950s at Ain Fekan station. The driest hydrological year since 1930 was observed at the beginning of the 1980s (1982–1983); during this year, the total annual rainfall reached 32.5 mm at Oued Taria station. This was the case at several stations in the Maghreb and even in the Sahel.

3.3 Change in Spring and Winter Rainfall Totals

The seasonal distribution of precipitation throughout the year and their variations, in relation to thermic factors, influences seasonal flow and consequently the regime of water flow and underground aquifers. This information is therefore indispensable for water resource management.

Figures 2 and 3 demonstrate the change in spring and winter totals. From these graphs, we note:

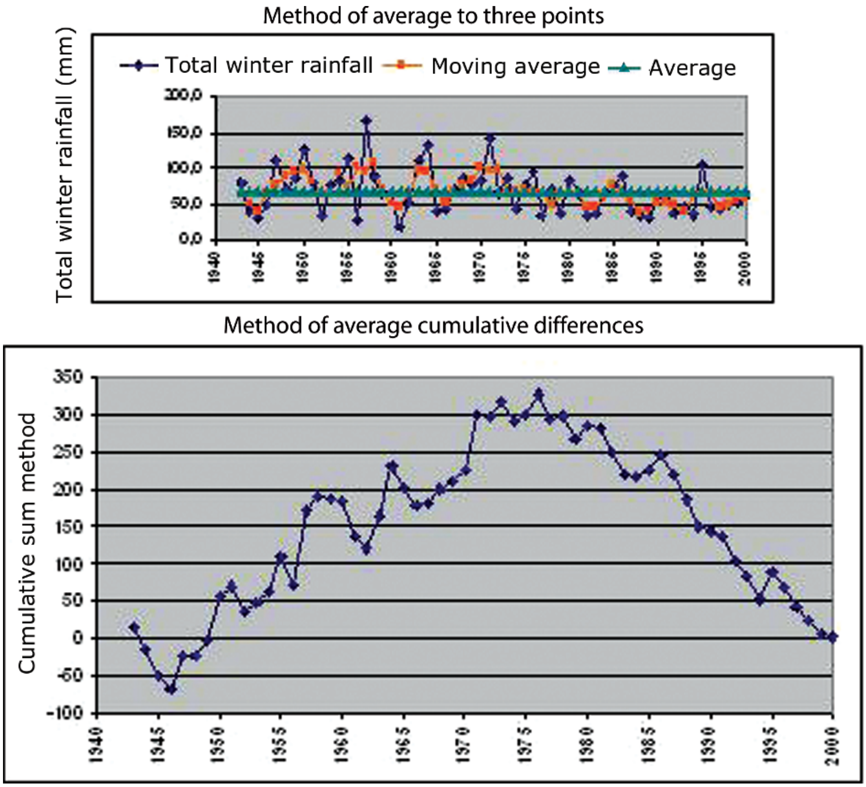

Fig. 2 Chronological evolution of pluviometric winter totals at Ain Ouessara station. Observation period, 1943–2000

- A surplus character of winter rains since the 1930s up until the middle of the 1970s. Moreover, certain episodes that have witnessed a drop in rainfall were recorded during the end of the 1930s and the beginning of the 1940s. Since the 1980s up until the present day, this zone has experienced one of the most deficient periods in terms of intensity and persistence.
- Different variations were recorded for spring rains: these rains increased during the 1930s, then decreased in the middle of the 1940s. At the beginning of the 1950s, the spring totals increased; during the middle of these years, we recorded a deficit that lasted until the mid-1970s. During the 1980s and 1990s, the spring totals were lowest and showed the greatest deficit. We therefore observed that the spring rains truthfully reflects the change and variation of pluviometric regimes in this zone. However, the drought observed during these two decades is principally due to the decline in winter rains.

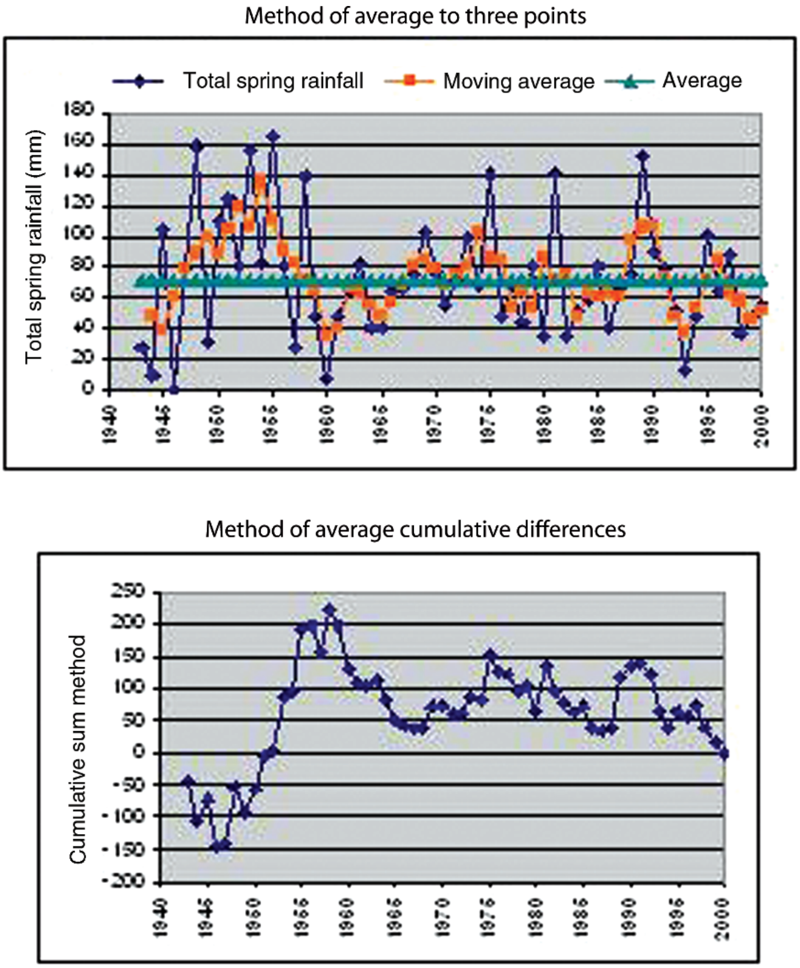

Fig. 3 Chronological evolution of pluviometric spring totals at Ksob Bge station. Observation period, 1943–2000

3.4 Representation by Graphs and Cartographic Analysis

The period covering 1930–1999 is considered a period of reference as it is representative of all the stations studied and presents a wealth of information. In addition, we have established a cartographic study. For each of the stations selected, a pluviometric index was calculated, defined as centered reduced values (Lubes et al., 1994):

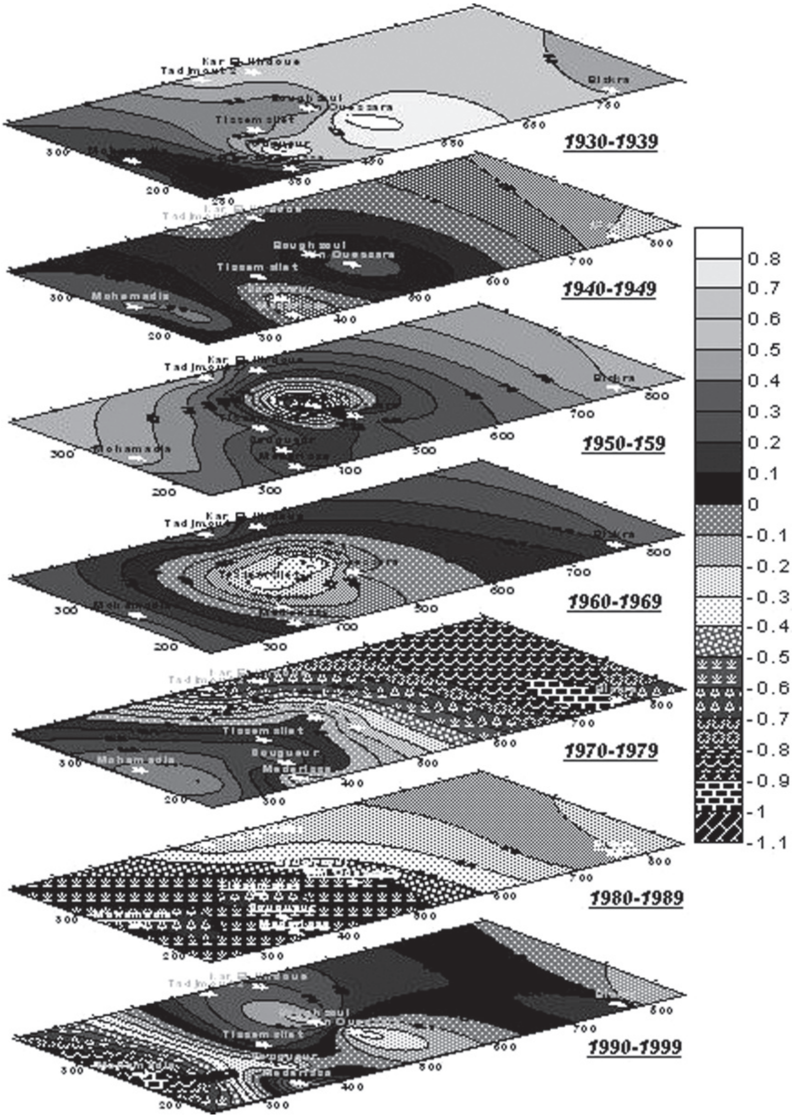

Fig. 4 Evolution of the pluviometric regime, 1930–1999

$$\frac{x_i - \overline{x}}{s}$$

Where xi = annual rainfall, $\overline{x}$ = average interannual rainfall during the period of references, and S-variation type of the interannual rainfall over the period of reference. This pluviometric index reflects a surplus or rainfall deficit for the year reviewed compared to the chosen period of reference. A cartography of the average, by decade, of the pluviometric indexes for each of the rainfall stations considered was established. The cartography of curves of iso-values that results is a cartography of "intensity" of deficit or surplus rainfall. It thus reveals the contrast between the different periods studied. The results are shown in Fig. 4. It generally appears as an upward trend covering the 1930s and the mid-1940s. From the 1950s, we note an increase in rainfall deficit at the level of the zone studied. This drop in total annual precipitation is greater during the two decades that follow. Moreover, the most drastic fluctuation and the most significant (in the statistical sense) were observed around the 1980s. This period of deficit is characterized by its intensity and its duration.

4 Conclusion

This study shows that over the course of last century, south-western Algeria has seen a succession of periods of deficits and of excess without necessarily referring to cycles. Generally speaking, there is an upward trend covering the 1930s and the 1950s. The drop in rainfall was conversely marked during the beginning of the 1940s and the mid-1970s. The most dramatic fluctuation was observed around the 1980s.

References

Aka, A.-A., Servat, E., Paturel, J.-E., Lubes, H. and Masson, J.-M. 1996. Analysis of the temporal variability of runoff in the Ivory Coast: statistical approach and phenomena characterization. *Journal des sciences hydrologiques*, Vol. 41. No. 6, pp. 959–970.

Brancucci, G., Rosetti, R. and Nola, P. 1995. La pluvio-variabilité sur le versant maritime de la Ligurie (Italie du Nord). *Publications de l'Association Internationale de Climatologie*, Vol. 8, pp. 301–310.

Lubès, H., Masson, J. M., Servat, E., Paturel, J. E., Kouamé, B. and Boyer, J. F. 1994. *Caractérisation de fluctuations dans une série chronologique par applications de tests statistiques*-Etude bibliographique; ORSTOM Montpellier. p. 21.

Meddi, M. and Hubert, P. 2003. *Impact de la modification du régime pluviométrique sur les ressources en eau du Nord-Ouest de l'Algérie*. Hydrology of the Mediterranean and Semi-arid Regions. International Association of Hydrological Sciences (IAHS) publication, No. 278, pp. 1–7 (in French).

Chapter 4
AQUIFER – Remote Sensing as Support for the Management of Internationally Shared Transboundary Aquifers in Africa

Stefan Saradeth and Thomas Weißmann

Abstract The AQUIFER project focuses on the development and demonstration of Earth observation-based products and services for supporting national authorities and international institutions in the transboundary management of two prominent, internationally shared ground water resources – aquifers – in Africa, the SASS (Système Aquifère du Sahara Septentrional or North-Western Sahara Aquifer System) and SAI (Iullemeden Aquifer System).

AQUIFER is one of the demonstrator projects of ESA's initiative "Earth Observation for Integrated Water Resources Management in Africa", known as TIGER. It is funded by ESA's Data User Element (DUE) programme. In 2004 the GAF team was awarded a contract to implement AQUIFER. The AQUIFER project brings together national and international water management entities with remote sensing and GIS service providers from three Maghreb, three African and five European countries.

The ongoing implementation of the project consists of three phases. The AQUIFER has achieved:

- user requirements consolidation
- training and extensive on-site cooperation with partners
- generation of prototype products based on satellite imagery
- mapping of 2 test sites in Tunisia with hyperspectral and radar imagery through ESA AquiferEx airborne campaign

The AQUIFER portfolio comprises:

- Land Use / Land Cover – mapping and monitoring based on Earth observation data and derived water abstraction estimates
- Surface Water (mare) extension and dynamics

GAF AG (Gesellschaft für Angewandte Fernerkundung mbH) an internationally active geo-information technology company located in Munich. AQUIFER is one of the demonstrator projects of ESA's "Earth observation for Integrated Water Resources Management in Africa" initiative, known as TIGER and funded by ESA's Data User Element (DUE) programme. GAF AG is the leader of the AQUIFER team

- Digital Terrain Models
- Estimate of the actual evapotranspiration and precipitation
- Water and Vegetation Monitoring over entire Aquifer
- Subsidence Monitoring and correlation with water abstraction

The AQUIFER website (www2.gaf.de/aquifer) is continuously updated to keep the public informed about all aspects of AQUIFER. The internal section is a forum for the more than twenty AQUIFER project partners.

Keywords Earth observation, water resources management, transboundary aquifers, land use mapping

1 General Overview

The AQUIFER project focuses on the development and demonstration of Earth-observation-based products and services for supporting national authorities and international institutions in the transboundary management of two prominent, internationally shared groundwater resources – aquifers – in Africa, the SASS (Système Aquifère du Sahara Septentrional, or North-Western Sahara Aquifer System) and SAI (Système d'Aquifère d'Iullemeden) (Fig. 1).

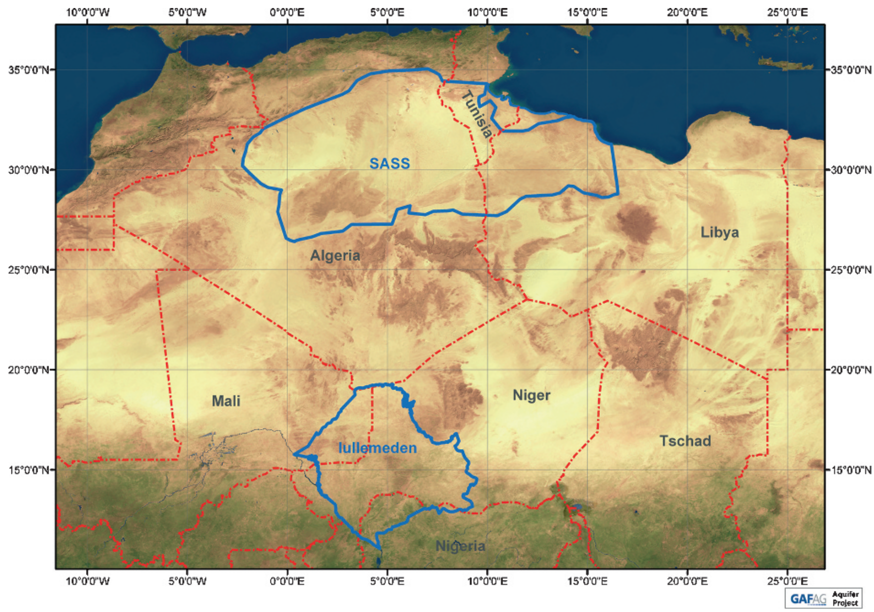

Fig. 1 Geographic location of the ESA Tiger Aquifer project – SASS and SAI

AQUIFER is one of the demonstrator projects of the joint ESA–UNESCO TIGER initiative, which focuses on 'Earth Observation for Integrated Water Resources Management in Africa'. AQUIFER was initiated by ESA and is funded under its Data User Element (DUE) programme. In 2004, the GAF team was awarded a contract to implement AQUIFER. The AQUIFER project brings together national and international water management entities with remote sensing and GIS service providers – from three Maghreb, three African and five European countries. The project has entered its final phase and is planned to be concluded by September 2007.

2 The AQUIFER Team

The AQUIFER project brings together user organizations and remote sensing institutes from Maghreb and Africa with partners in the domain of Earth observation, geo-information and water resources management in Europe. The AQUIFER team consists of the following members:

User Group:

- Mali: Ministère des Mines, de l'Energie et de l'Eau
- Niger: Le Ministère de l'Hydraulique, de l'Environnement et de la Lutte Contre la Désertification
- Nigeria: Federal Ministry of Water Resources & Rural Development
- Algeria: Agence Nationale des Ressources Hydrauliques
- Libya: General Water Authority
- Tunisia: Direction Générale des Ressources en Eau
- User Co-ordinator: Observatoire du Sahel et du Sahara (OSS), Tunis

African Partners in Remote Sensing and Earth Observation:

- The AGRHYMET Regional Centre, Niger
- Centre National des Techniques Spatiales, Algeria
- Center for Remote Sensing & Space Science, Libya
- Centre National de Télédétection, Tunisia

European Partners:

- GAF AG, Germany
- CS-Scot, France
- Joanneum Research, Austria
- Telespazio SpA, Italy
- University of Jena, Germany
- Vista, Germany

3 Objectives

The main objective of the AQUIFER project is to support the users in the management of internationally shared water resources and aquifers by means of Earth Observation (EO), as well as to strengthen overall and integrated water management practices. In the project, a number of tailored and GIS-compatible demonstration products and services are generated and integrated into daily work-flows.

Strengthening of the African capacity for generating products, delivering and using services will help to ensure sustainability after the project conclusion. Special emphasis is on the cooperation between African and European partners and on-site training and exchange.

The users play a critical role: they are involved in the definition of the products and services, the delineation of the geographic priority areas, and the validation of results.

4 SASS and SAI: Two Transboundary Aquifers

The SASS and SAI aquifers are two of the largest transboundary aquifers in northern Africa. The basins give the overall geographic framework; specific areas of interest were defined according to the requirements and wishes of users. There are two or three areas of interest with a total size of approximately 100,000 km^2 defined in each basin.

4.1 SASS

The North-Western Sahara Aquifer System, better known by its acronym in French as SASS (Système d'Aquifères du Sahara Septentrional), is a groundwater resource and freshwater reservoir underlying parts of Algeria, Libya and Tunisia. It occurs at varying depths (as deep as 1,000 m) and has negligible recharge.

SASS groundwater resource is sufficient for many centuries to come (500–600 years at projected consumption rates), but intense development by the three countries over the past 30 years has exposed the aquifer to a serious risk of groundwater drawdown, loss of artesian pressure, and salinization, salt water intrusions along the coast, and deterioration of water quality across the national borders (Fig. 2). The situation is aggravated by growing population pressure and a strong development of irrigation schemes.

4.2 SAI

SAI (Système d'Aquifère d'Iullemeden) is a transboundary sedimentary basin and is defined by the surrounding major mountain ranges with the Air in the north, the

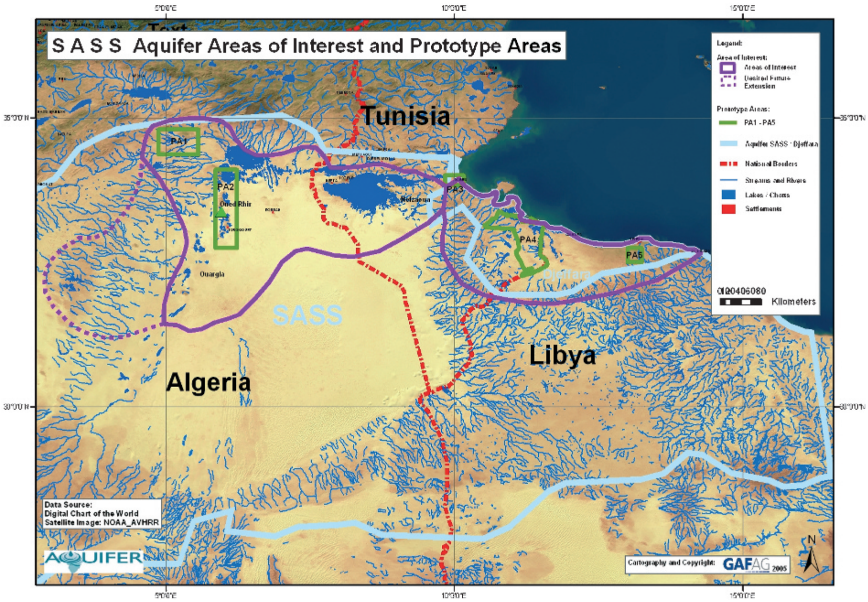

Fig. 2 SASS: Areas of interest

Adrar in the northwest and the Jos Plateau in Nigeria in the south. In the east, along a line from the Jos Plateau to the Air massive, the basin is partly separated from the confined aquifers in the Chad Basin by the South-North Continental Dorsal. To the west, in Mali and Niger, the system is bounded by the Hamadien Sandstone and may be connected to the Tamesna extension basin to the west of the Adrar highlands through the Gao Trench. In the southwest, the basin limit follows the basement range along the River Niger.

The Iullemeden is a multi-aquifer system composed of inserted cretaceous continental intercalaire sedimentary formations and with overlying final tertiary continental terminal regroupings (Fig. 3). In some parts the system is overlain by the marine cretaceous aquifers that extend along the northern fringes of the basin. In the southeast, in the North-West Nigeria Basin, the Iullemeden multi-aquifers are known as the Rima Group with the Cretaceous Gundumi-Illo and Wurno and Sokoto Group and the Tertiary Gwandu aquifers and the Kalambina limestone formation. There are a number of major threats to the aquifer and the related ecosystems, including a change in water levels, a loss of water resources, groundwater depletion, water quality degradation and salinization, and land degradation. The stress on the aquifer and the environment in the SAI basin is further pronounced by recent climatic changes with reduced precipitation and increased evaporation.

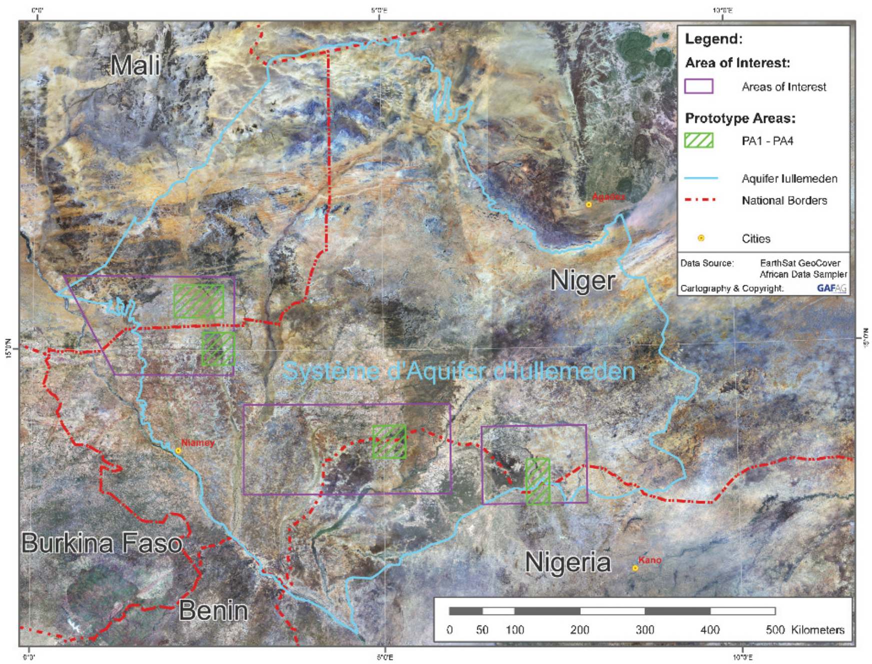

Fig. 3 Iullemeden aquifer basin extends over parts of Mali, Niger and Nigeria

5 Earth Observation and Groundwater

Remote sensing is a unique tool: it offers simultaneous area-wide coverage and is truly transboundary in nature. It can provide a uniform spatial data layer to correlate/extrapolate isolated field data and thus can provide cost efficient mapping/monitoring on an area-wide basis. Satellite remote sensing is confined to the surface: optical sensors measure reflectance of surface features; radar and thermal sensors allow to detect and to identify features at or very close to the surface. For groundwater applications, this means that Earth observation will usually work only indirectly by means of proxy information or secondary effects. This is further explained by the product and service examples of AQUIFER, as summarized below.

And Earth observation is not a stand-alone tool: it requires ground truthing for calibration. In AQUIFER this is the responsibility of the users. In addition, to develop its full use and benefit, Earth observation results have to be integrated and assimilated with other available information and data, such as well information or geological maps, by means of geographic information systems, data modeling and decision-support systems.

6 AQUIFER Products and Services

The AQUIFER portfolio consists of nine products and services, as identified and specified together with the users. The portfolio ranges from products with a mature and operational status to a more scientific nature. Results are generated in two phases: in a prototype phase, a first set of products is developed and tested in small prototype areas. Subsequently, the area is extended and all products are generated. The work is still ongoing, however. The following overview gives a cross-section of all products and services and some examples of the results achieved by now are given.

6.1 Land-Use/Cover Maps (SAI and SASS)

Principally the product 'Land Use/Land Cover Maps and Change Maps' is based on the compilation of land coverage mapping from satellite imagery using an optimized and multi-step processing strategy (Fig. 4). Therefore, a combination of multi-temporal ENVISAT ASAR and multi-spectral data, such as Al-SAT and P6, are used, and a well-established classification process chain with filtering and manual post-processing is involved.

The output and results will be used for determination of ground-water extraction (cropped area, area of irrigation). Furthermore, the change maps can be used to

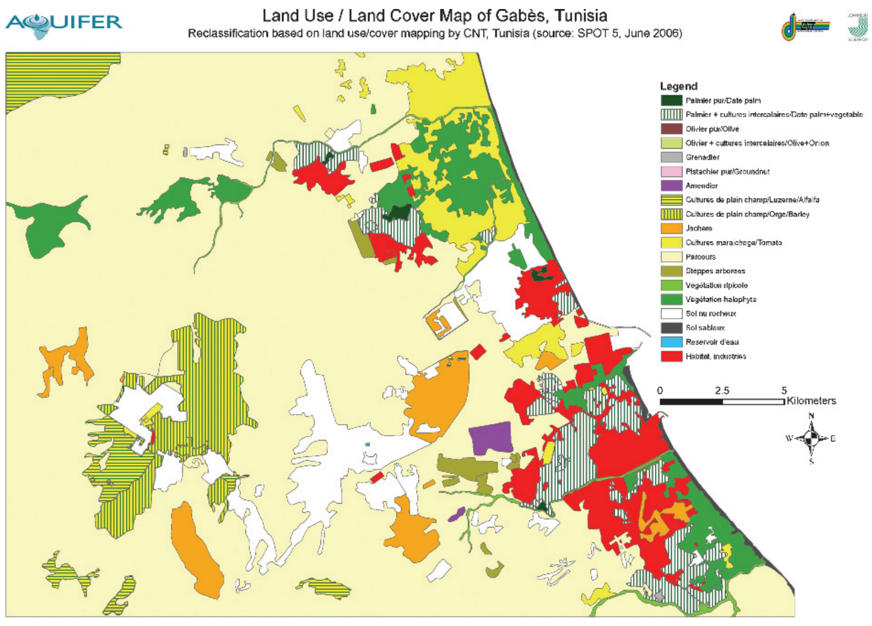

Fig. 4 Land use/cover map of Gabès, Tunisia

monitor soil deterioration and evolution of agricultural sector. An example of the results is given above.

6.2 *Estimation of Crop Water Requirement of Irrigated Areas (SASS)*

Measurement of irrigation water use consists primarily of measuring surface water withdrawals from rivers, lakes and streams; groundwater withdrawals; and diversions and conveyance losses in surface-water delivery systems. However, determining irrigation water use over large areas, which may include hundreds or thousands of irrigation systems, requires reliance on data from other sources, or developing methods to derive irrigation water use values from coefficients related to power consumption, or estimating water use through irrigated acreage and crop consumption coefficients (Fig. 5).

The product ‘Water Abstraction Estimation’ is an estimation of the optimal amount of water to be extracted and applied to the irrigation scheme to satisfy the crop water demand during the 2005 growing season. The advantage is the ability to use it for analyzing water abstractions from an internationally shared aquifer. An example of a map showing the mean annual water abstraction estimation is given below.

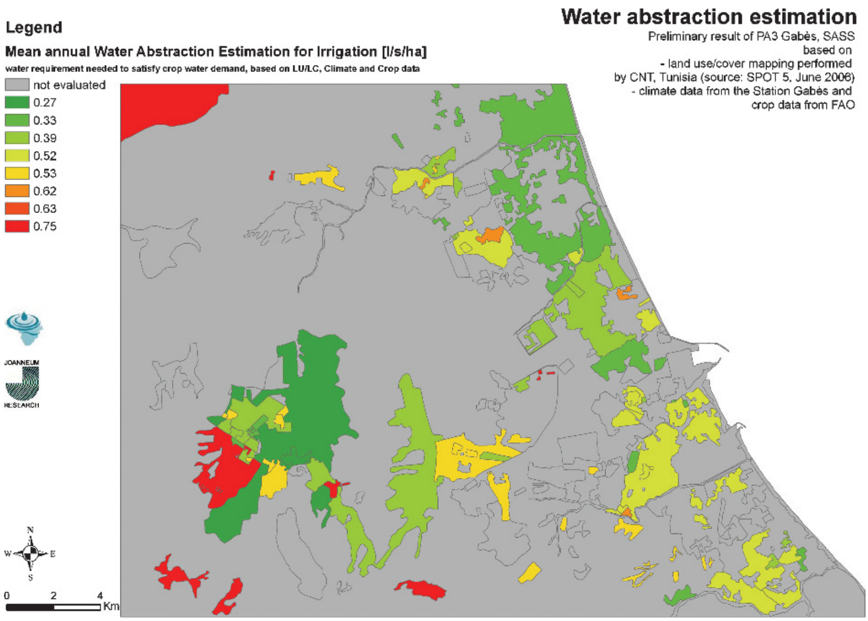

Fig. 5 Water abstraction estimation

6.3 Surface Water Extension and Dynamics (SAI)

The product 'Surface Water Extension and Dynamics' includes the mapping of flooded areas, wetlands and mares over a specific temporal range (Fig. 6). The study of the evolution over time provides important input to the calculation of the aquifer recharge and confirms whether study results already achieved for local areas are valid on a larger area.

The product is derived from EO optical satellite imagery and SAR data, discriminating open water surfaces at the time of observation. In detail, flooded areas, wetland and mares are delineated.

6.4 Digital Terrain Models (SAI and SASS)

This AQUIFER product is twofold. First, a basin-wide Digital Terrain Model (DTM) is provided in a customized form of direct use to the users. It is based on the SRTM digital terrain model – the Shuttle Radar Topography Mission (SRTM), a joint project of US NIMA, NASA, ASI and DLR.

The second part is the processing of DTMs based on SAR data. Synthetic aperture radar (SAR) interferometry is an imaging technique for measuring the topography

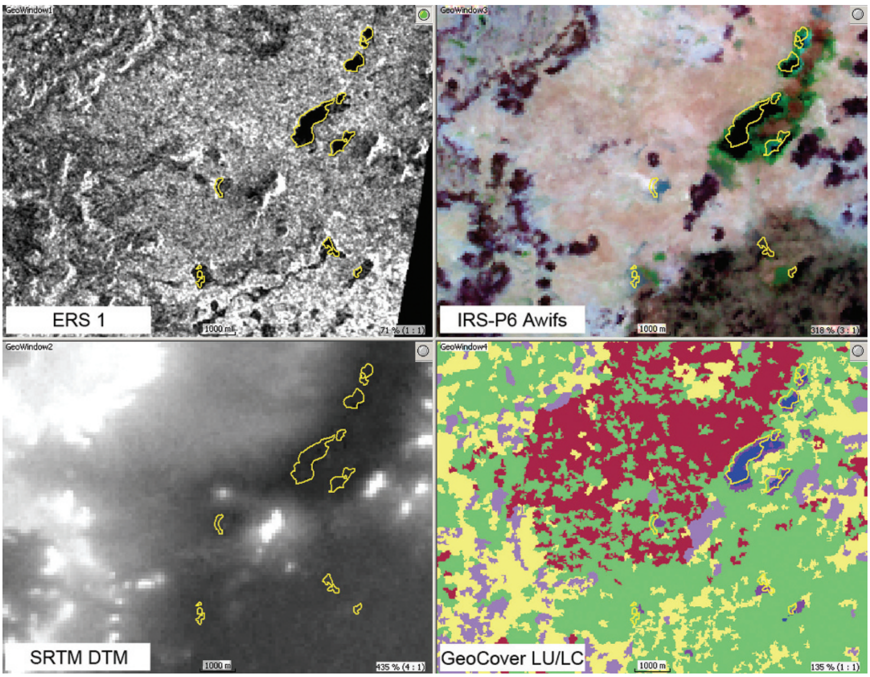

Fig. 6 Open water bodies detected on different EO data

of the surface and its changes over time. A radar interferometer is formed relating the signals from two spatially separated antennas; the separation of the two antennas is called a baseline. Given two single-look SAR images acquired with slightly different geometry, assuming no changes on the observed surface, the phase difference is proportional to the radiative path difference that is directly related to the topography. Since the phase difference is measured in units related to the wavelength of the SAR, the interferometric measurements can provide extremely sensitive and precise topographic results.

The following color coded digital terrain model of the prototype area 'Bani Bangou' (Niger) as derived from EO SAR data using interferometric methods and procedures (Fig. 7). It has a resolution of 15 m and covers an area of 50 × 60 km, which equals a total area of 3,000 km^2. The light blue spot in the image above represents a large water body and is caused by the backscatter characteristic of radar beams being reflected by smooth water surfaces.

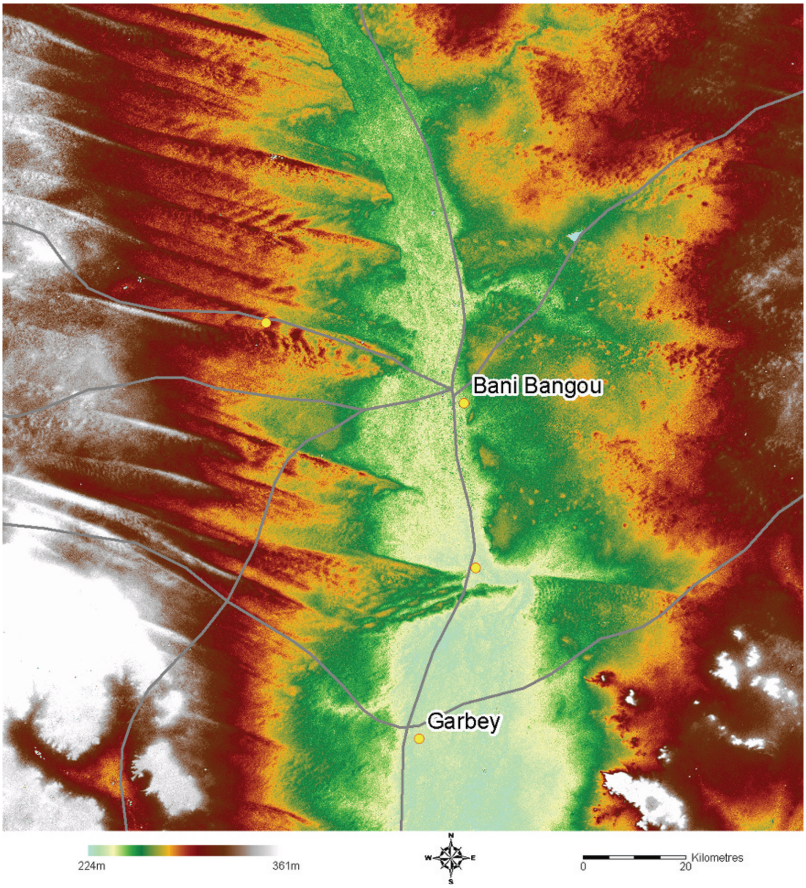

Fig. 7 Interferometric DEM Bani Bangou

6.5 Water and Vegetation Monitoring over Entire Aquifer (SAI and SASS)

The results of the product ‘Water and Vegetation Monitoring over Entire Aquifer’ are useful for the mapping and monitoring of wetlands, mares and desertification processes within the limitations of the geometric and temporal resolution input. Based on optical and radar EO data, which provides large area coverage, it is regarded as a tool to promote transparency and technical consultation among the countries sharing the aquifers.

6.6 Actual Evapotranspiration and Precipitation (SAI)

Evapotranspiration and precipitation are central components of the water balance. These two components will be provided for the entire Iullemeden Basin in low spatial resolution as basic input information for aquifer management.

Within the users environment the products will be merged and the water balance will be calculated and presented in the form of maps on annual water balance determined from the difference between precipitation sum and actual evapotranspiration sum. The approach is based on METEOSAT 7 data.

6.7 Refined Land Use Mapping (Tunisia)

The refined land use map will be based on radar and hyperspectral image acquisitions obtained within the ESA AQUIFEREX airborne campaign. Polarimetric C and L band radar images plus hyperspectral images for two test areas in Tunisia (Gabès and Ben Gardane) are available in high spatial resolution. As background information for refinement, the standard land use/land cover map produced within AQUIFER is being used.

It is observed that this refined land use/cover product, like all science products, is meant to demonstrate the potential and application of latest sensors and developments. They are not meant yet for operational use or application, because of the high costs involved in such aerial survey as AquiferEx.

6.8 Subsidence Monitoring and Associated Error Maps (SASS)

SAR differential interferometry allows reconstructing the terrain displacement along the line of sight (LOS). The main limits of this technique are the decorrelation noise, the atmospheric artifacts and the limited accuracy of the geometry acquisition knowledge. To overcome these problems, some robust and innovative techniques are utilized. The key points are the ‘sparse phase unwrapping’ and the ‘multitemporal combination’ that makes it possible to obtain a reliable measurement with only few interferometric pairs.

7 Cooperation and Training

Joint work, cooperation, formal and on-the-job training covering key aspects in the development, generation and use of the AQUIFER products, joint performance of ground truth and results assessment is ongoing in all six partner countries (Algeria, Libya, Mali, Niger, Nigeria and Tunisia). This is complemented by joint workshops and meetings. In total, ten man-months are devoted to this key component of the project.

8 Outlook and Conclusion

AQUIFER project works are ongoing. The AQUIFER website (www2.gaf.de/aquifer) is continuously updated to keep the public informed about all aspects of AQUIFER. In addition, its internal section is a forum for exchange and information for the more than 20 AQUIFER project partners.

Project completion is planned for September 2007, so final conclusions cannot yet be made. However, a few observations can be summarized here:

The project has followed an ambitious plan, involving a great number of partners, products and services in six countries. This plan has to be constantly revisited to take into account that partners in Africa have different background and facilities, different training needs and expectations, which result in different priorities and speeds of progress in the partner countries. This makes necessary a constant refocusing on priorities and key factors of success.

The importance of training and joint cooperation with local providers and users cannot be overestimated. Understanding work flows on the user side is most important to assure proper integration of the EO-based AQUIFER results. Different levels of capabilities at user organizations are observed, some with full-fledged databases, GIS and modeling, and others are just about to start. Without integration and assimilation, the EO-based AQUIFER results will remain rather limited.

AQUIFER products and services together and combined with training are key to assuring sustainability. Our thus hope is thus to develop a nucleus of future demand and supply of EO-based products. It is also noted that AQUIFER has helped its African partners to conceive and formulate a follow-up project and to seek continued funding from international donor organizations.

Chapter 5
Desertification Control through Floodwater Harvesting: The Current State of Know-How

Sayyed Ahang Kowsar

Abstract The ecologically disastrous sedentarization of nomads in the Gareh Bygone Plain, southern Iran, along with the application of inappropriate technologies, ploughs and pumps, has desertified a sandy scrubland teeming with wildlife. This resulted in *mass* cityward migration of the unskilled nomads. Floodwater harvesting for the artificial recharge of groundwater has reversed the migration tide and converted consumers into producers again. We have proven that floodwater harvesting can mitigate flooding and drought, and modify the marginalities of climate and soil for a sustainable agricultural production. We have harvested upwards of 200 million cubic meters of floodwater since 1983, of which 80% has recharged the aquifers. A few of our findings are:

- The slope of the conveyor-spreader channel is 0.0003 along 85% of its length, decreasing to zero for the next 5%, and flat for the last section.
- The safe distance between the channels on low slopes is 70–100 m.
- The number of gaps and their capacity should increase in the downstream direction as a safeguard in case of breaching of embankments during exceptional floods.
- The mean annual yield of floodwater-irrigated indigenous range plants is 445 kg per ha, 5 fold that of the control. The quail bush planted at 625 seedlings per ha is 1,500 kg.
- The mean annual stem and fuel wood yield of river red gum is 4.68 and 0.78 t per ha. The annual mean above ground C-sequestration of same trees is 2.97 per ha. Root channels of these trees facilitate deep percolation.

Keywords Floodwater harvesting, artificial recharge of groundwater, indigenous technology

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1 Introduction

Water, the most precious commodity in deserts and the substance without which life as we know it is impossible, is also a desertification agent. Not only does it degrade the land through erosion, salinization and inundation, but it also provides the material transported by the wind. Moreover, flooding is a major hazard that causes untold damage and misery. Therefore, water management is often the key to many aspects of desertification control (Mabbutt, 1987). As freshwater is one of the ecosystem services deemed ‘well beyond levels that can sustain current demands, let alone future ones’ (Anon., 2005), harvesting this irreplaceable substance and protecting it from pollution is extremely important in deserts.

A common misconception of laymen about deserts is their extreme water shortage. This wrong notion has developed through the ages from travellers who had crossed the barren land, missing the chance to be soaked by the torrential rains and observe the roaring floods. A classic case of this is the convective storms that usually occur on summer afternoons and that ruin the life and belongings of those living in deserts. Application of a time-proven indigenous technology could mitigate many of the water-related problems in deserts and break the downward spiral of factors that lead to desertification.

According to Glantz (1994) the marginalities of the climate, soil and topography are deterrents to a sustainable agricultural production. The ancient Persians, who lived on desert margins, faced the former two constraints in the plains and all three constraints in the foothills. Furthermore, as many other desert-dwelling nations, they had to contend with the extreme meteorological events of floods and droughts. Therefore, they turned the problem into a solution by developing the art of “water husbandry”, living in deserts through harvesting the ephemeral floods for runoff farming, and using it prudently. This drought-coping mechanism mitigated the flooding hazards, too. A related advantage of this simple practice, besides storing the surplus water in underground reservoirs, was building soil by depositing the nutritious sediments on severely eroded land, thus simultaneously mitigating ‘pseudo-drought’ (Wolman, 1985) and modifying the topography. The Persians regained upwards of 600,000 ha of land from deserts using the multipurpose water harvesting techniques. This paradigm-based technology led to the invention of *qanat*, the best means of water collection and delivery in hot climates where agricultural drought is an ever present threat to the very existence of desert-dwellers.

Although the application of an inappropriate technology, namely pumping of water from any imaginable depth, has made more than one-half of our qanats inoperative, the sound scientific basis – water storage in potential aquifers – is perfectly valid today. This variation on the theme of “genesis strategy” is most appropriate where potential, easy to reach aquifers exist.

This principle is implemented for recharging the overexploited and potential aquifers, along with other benefits accrued from harvesting the turbid floodwater, such as desertification control (Kowsar, 1991). In a world facing the diminishing availability of arable land, this is of vital importance, as most of the non-marginal land has already been taken. Therefore, we have to build arable land to ensure that future generations have the right to life, too!

Recurrent and prolonged droughts, exacerbated by overpopulation and overdevelopment of a fragile ecological landscape, desertified the Gareh Bygone Plain, which was once a healthy scrubland teeming with wildlife. The elders, who massacred the gazelles, reported encountering flocks of over 100 of them 50 years ago. The advent of diesel pumps and moldboard ploughs hitched to powerful tractors delivered the *coup de grâce* to this productive land. The plain was reminiscent of a moonscape when we first arrived there on 6 November 1982. The depth of the water table, which had been 10 m before the arrival of the first pump, was 26 m in a well dug in the summer of 1982. This well went dry after only 10 min of pumping by a 24 hp diesel engine through a 4 in. (10.6 cm) pipe. *Mass* cityward migration of mixed farmers was a consequence of anthropological desertification.

2 Floodwater Harvesting Concepts

1. While the mean annual rainfall in drylands is very low, its variability is extremely high (erratic in distribution and frequency). The chance of receiving the desired rainfall at the expected time is meagre, indeed. Therefore, water is the most precious commodity, and flood is its largest supplier in drylands. Although floodwater is a renewable capital, its use must be optimized.
2. Available water capacity (AWC) is the most important direct driver of ecological sustainability in drylands. Soil *texture* and *depth* are the two major determinants of AWC.
3. Water, an erosion agent, may become a land renovator and soil builder by transporting to and depositing nutritious sediment on the slightly sloping, drastically disturbed lands, thus improving their texture and increasing their depth, and enhancing their AWC. This process also modifies the topography, stabilizes the moving sands and deprives the wind of the erodible material at its source.
4. High evaporation rate from surface waters, rapid siltation, inundation of productive lands and dwellings, forced migration of the inhabitants of the inundated area and construction sites, threat to biodiversity, reservoir leakage, earthquakes and other related environmental hazards, and the very high costs and relatively long time needed for their construction, make large dams the most inappropriate technology in drylands. Furthermore, such schemes do not benefit the inhabitants of the runoff-producing headwater catchments. They not only lose most of the water that nature bestows upon them, but also the surface soil, the life-giving substance that nothing can replace.
5. Turbid floodwater should be harnessed to build soil and produce virtual water through spate irrigation, and/or it should be stored in aquifers by employing artificial recharge of groundwater (ARG) methods and used commensurate with needs. Doing so would help to mitigate flooding hazards.

3 Materials and Methods

Soil and water quality and the presence or absence of potential aquifers are the determining factors in planning and implementing optimization of their use. Three methods may be used:

1. **Freshwater and clean alluvium**. This is the simplest form of ARG. Runoff from rocky outcrops (massifs, batholiths, some conglomerates, etc.), which is devoid of eroded material or snowmelt water of low velocity, is suitable for recharging clean alluvium and karst formations. The very high infiltration rate of these materials necessitates construction of the smallest recharge ponds. Infiltration rate of the Ab Barik, Bam ARG system in southeastern Iran, exceeds 10 m per day; i.e., each square meter of a recharge pond floor could pass $10\,m^3$ of freshwater in 24 h. The extent, depth and macro-porosity of the alluvium determine the volume of the underground reservoir. Although the ARG of karst formations and confined aquifers is practical when employing this method, the necessity of detailed, and very expensive, geological studies eliminates this option for most deserts.
2. **Spate irrigation of agronomic crops and adopted trees**. Small-grained cereals (e.g., wheat and barley in cold and temperate climates, sorghum and millet in temperate and hot climate) are suitable crops for runoff farming. Perennial or annual forages may be programmed into the farming plans. Adapted annual legumes (e.g., *Trifolium alexandrinum* L. in mild and hot climates) fit nicely with fallowing in cereal production. Incidentally, this legume is suppressive and checks the growth of most weeds. Establishment of woodlots and growing fruit trees is another possibility where potential aquifers are nonexistent. Fodder trees and shrubs are particularly important as they provide a minimum of forage for a few livestock that may be used for building a healthy flock when the prolonged hydrological drought is over. Covered cisterns and disinfectants can provide hygienic water for domestic consumption. Rooting depth and water requirement of the intended crops, the AWC of the soil, and the estimated annual or biennial expected floodwater volume determine the area needed for its harvesting by means of the floodwater spreading (FWS) techniques. The system consists of a conveyance canal, a conveyor-spreader channel (CSC), a few level-silled channels and a tail drain. Installation of a cistern or a tank upstream of the FWS system and another one ahead of the tail drain ensures an adequate supply of domestic water. Phillips (1957), Newman (1963) and Quilty (1972a, b) have presented the methods of FWS system construction. Our contribution to the overall success of this technique is the design of the CSC and the introduction of the safe distance between the channels. These and other relevant points for the design, operation and maintenance of the FWS systems, acquired during 34 years of work throughout Iran but mostly in the Gareh Bygone Plain in the southern part of the country, will be presented later.
3. **Spate irrigation along with the ARG.** At least 6 million ha of arable soils in Iran are underlain with coarse-grained calcareous alluvium of good quality.

A large amount of sands and sandy soils have the same property. This provides an excellent opportunity for the simultaneous irrigation of crops and trees, and the ARG. Assuming identical flows in these three situations, the FWS area is larger than the first and smaller than the second system. Here we are concerned with neither the water requirements of plants nor the AWC of the soil, because the water that does not remain in the rooting zone recharges the aquifer. As the clogging of the vadose zone by the very small clay-sized particles is inevitable (Mohammadnia and Kowsar, 2003), planting of deep-rooted plants, particularly fodder trees, is strongly advised. *Acacia salicina* Lindl., which is a fodder tree and supplies nectar and pollen for honey bees from September to March in relatively warm climates, is a good candidate. Introduction of burrowing macrofauna, such as the sowbug (Kowsar, 2005) and the dung beetle, facilitates formation of preferential flow paths in the deep and hard crusts.

4 Reclamation of a Desert

The politically expedient and ecologically disastrous sedentarization of nomads in the 1930s in the Gareh Bygone Plain, southern Iran (28° 35´ N, 53° 53´ E, 1,140 m above mean sea level), with the mean annual precipitation of 243 mm (the coefficient of variation = 0.46) and Class A pan evaporation of 3,200 mm, wreaked havoc on a sandy scrubland teeming with wildlife. Overgrazing and fuelwood collection, the inevitable outcome of concentrating transhumant nomads in a limited area along with the application of inappropriate technologies of moldboard plows and pumps, made life unbearable for most settlers. The water table receded 10 m in 12 years, very close to the bedrock. Saltwater intrusion into the aquifer compounded the water shortage problem. Soil salinization was the outcome of irrigation with saline waters. These conditions resulted in the *mass* cityward migration of the nomads. Only a few hardy souls stayed and eked out a meagre living from the remaining natural resources.

Reversing the migration tide was the logical way to relieve the overcrowded cities of unskilled people who eke a living, sometimes by illegal means. Brainstorming sessions with the refugee elders revealed that supplying abundant and safe freshwater was the most important incentive for their return to their former homes and restarting mixed farming enterprises. Thus, the provision of water security became the litmus test of the government's integrity.

Floodwater harvesting for the artificial recharge of groundwater has reversed the migration tide and converted consumers into producers again. We have proven that floodwater harvesting can mitigate flooding and drought, and modify the marginalities of climate and soil for sustainable agricultural production.

We have harvested upwards of 200 million cubic meters of floodwater since 1983, of which over 160 million cubic meters have recharged the aquifers. Furthermore, the turbid floodwaters have deposited about 2 million tons of nutritious suspended loads in the sedimentation basins, converting them into arable land. More than 1,000 ha of the moving sand have been fixed and become arable with the result that there are no more dust storms from the floodwater spreading areas. The area of irrigated fields has increased eight-fold to 1,193 ha. There are reportedly 200 wells, 12.5 times the number in 1983. This is bad news because we should have 60 high-yielding wells at most. Unfortunately, expediency prohibits the responsible authorities from taking harsh actions against the infringers. Our findings are as follows:

- The most frequently asked question in FWS concerns the slope of the spreading area, as it affects the erosive power of surface flows. We recommend 2% as the maximum slope of the annually ploughed land. However, we have worked on slopes of up to 6% by constructing contour furrows at suitable intervals (50–40 m for 3% and 4% slopes, and 30–20 m for 5% and 6% slopes, respectively). This spacing may be increased on non- and minimum-tilled fields. FWS on rangelands and pastures of 5–6% slope is implemented provided that they have good vegetative cover.
- To obtain a rather uniform water distribution along the head of the command area, we lay the conveyor-spreader channel at 0.0003 gradient along 85% of its length, starting at its junction with the conveyance canal. The gradient is gradually reduced to zero in the adjacent 5% of the channel's length. The final 10% is flat. This final section ensures a good harvest in years with hydrological drought, when the system does not receive the design flow (Fig. 1).
- The distance between the channels should be determined in such a way that the flow does not acquire an erosive velocity. Empirically, we have found 100 m to be a suitable distance. Performing detailed hydraulic studies, Adelpoor (personal communication) has arrived at 70 m for our conditions – loamy sand at 0.6% gradient.
- A very important point to remember is to cultivate only on the contour, leaving a 3 m wide sill of the channels out of cultivation. The gaps in the embankments should be covered with perennial grasses that are not considered weeds for the crops grown in the system. Installation of masonry chutes and drops may become relevant in very erodible soils.
- A common cause of chute collapse is the growth of tree roots below it. The root channels formed due to decomposition of the dead roots results in piping that erodes the soil beneath the chute and undermines it (Fig. 2). To prevent this loss, we select 10 m as the closest distance between a tree and the wing wall of a chute.
- The presence of geologic nitrogen in the watershed that generates flow is a financial advantage provided that its concentration in floodwater is not harmful. This may eliminate the need to apply N-fertilizers to crops. *Eucalyptus camaldulensis* Dehnh. and many other plants filter this element from percolating water. Moreover, the livestock dung carried by floodwater not only provides some of the nutrients to the vegetative cover but also increases the soil organic matter. As the vadose zone filters most of the pollutants and pathogens from the recharge water, groundwater of good quality will be available in the aquifer.

- Formation of a thick crust on the surface and deposition of very fine clay minerals in the vadose zone (Mohammadnia and Kowsar, 2003) is the natural outcome of using turbid floodwaters for the ARG. Fortunately, the sowbug (*Hemilepistus shirazi* Schuttz), which drills burrows 7 mm in diameter and up to 180 cm deep, and *Eucalyptus camaldulensis* Dehnh. trees, which take root down to the water table (30 m so far), have solved the problem. As a scarab beetle (*Peltotrupes youngi* Howden) may burrow to depths of 5 m (Kalisz and Stone, 1984), the introduction of the sowbug and deep-burrowing adapted beetles is therefore a strategy against the eventual clogging of the ARG systems. The dung beetle (*Heliocopris andersoni* Hope) is a good candidate for floodwater-irrigated pastures that serve as sedimentation basins (Fig. 3).
- Selection of trees, shrubs and bushes for enhancing the hydraulic conductivity of the vadose zone is of utmost importance. Only the thrifty, drought-enduring, nitrogen-fixing trees, shrubs and bushes (pioneer species) that do not consume a lot of water when it is available should be planted. Moreover, the number of stems per ha should be the minimum required for facilitating percolation. We have made the mistake of planting *Eucalyptus camaldulensis* Dehnh. at 3 × 3 m spacing in the Gareh Bygone Plain. Each single 6-year-old tree consumes about 50 l of water per day in summer, more than the per capita requirements in the same area. This tree, which can tolerate drought for a long time, evolves into an efficient pump when water is available. Each ha of this tree deprives a community with 1,000 residents of domestic water.
- The loss of water holding capacity, a consequence of soil erosion, is an important factor in the processes leading to desertification. Soil building on eroded land is a companion benefit of application of FWS methods, particularly in sandy deserts. This is of utmost importance in a world facing accelerated land degradation and loss of arable land, as well as a water-shortage crisis.
- Contrary to common knowledge, sandy soils are suitable for growing small grains and range plants if floodwater carries silt and clay particles. Moreover, we have observed grain wheat yields of up to 5 t per ha downstream of our station in a loamy sand irrigated at a three-week interval. The normal irrigation cycle on soils of finer texture in our area is 10–14 days. This anomaly requires a methodical study.
- In hot deserts embankments provide a humid and cool place for rodents and small carnivores. Flow of floodwater through their burrows usually ends up in embankment breaching. As this mishap causes a surge, and this may cause chain breaching of downstream embankments, the overall capacity of gaps for conveying the flow in each downstream embankment must therefore increase relative to its upstream one. Positioning larger gaps in strategic places overcomes this problem.
- Headwater erosion, where surplus water returns to a waterway, may end up in the irreversible destruction of the FWS systems. Positioning the outlet on exposed rocks, or constructing a solid drop or a chute with an adequate stilling basin, prevents this process.

- Simple gabion aprons, placed directly on the coarse alluvium or exposed rock riverbeds, are the most economical structures for floodwater diversion into the inlet of conveyance canals. As sedimentation in the FWS area raises its level, crown elevation of the apron should be raised by adding rocks to the gabion, or placing another layer on top of the original one. These aprons have right triangular cross-sections in which the shortest side forms the upstream wall, and the hypotenuse functions as the chute. We have successfully tried such aprons on streambeds with a slope of up to 2%.
- A solid structure at the inlet of the inundation canal prevents its enlargement during exceptionally high floods. We have observed the complete diversion of a river through an unarmored inlet.
- A very interesting discovery, which is important when working in sandy deserts, is the needleleaf sedge (*Carex stenophylla* Wahl.), a rhizomatous plant that forms a 5–10 cm armour that holds sand in place. This species is a drought-avoiding plant that inhabits hot areas with a mean annual rainfall of 150 mm. It is important not to plough through this armour if you do not have enough water to irrigate the land all year round.
- Quail bush *Atriplex lentiformis* Torr., at 625 seedlings per ha, can provide 1,500 kg of nutritious fodder for three livestock all year round. This very valuable C_4 shrub, which is the favourite food of sowbugs, can neither regenerate itself in our environment nor tolerate inundation. However, an equally palatable indigenous species but of lower yield, *Atriplex leucoclada* (Boiss.), is replacing it.
- The ten-year mean yield of native, floodwater-irrigated forage has been 445 kg per ha, five-fold the control (Fig. 4).
- The mean annual honey yield of our ARG systems, planted with eucalypts and acacias, is 200 kg per ha. We have not yet reached potential production.
- The carbon sequestration potential of the ARG systems is remarkable. Above ground, the annual C-sequestration of an 18-year-old stand of *Eucalyptus camaldulensis* Dehnh. at the Gareh Bygone Plain is 2.97 t per ha. For *Acacia salicina* Lindl. this is 1.30 t per ha per year. This indicates the potential of deserts for global warming mitigation. Signatories of the Kyoto Protocol are offered a great opportunity to green the deserts through their carbon rent contribution in the context of the Clean Development Mechanism**.** The mean annual stem and fuel wood yield of the eucalyptus at age 18 has been 4.68 and 0.78 t per ha, respectively (Fig. 5).

5 Conclusions

Floodwater harvesting for desertification control is a positive step towards achieving five of the eight Millennium Development Goals by 2015:

1. It provides the resources for food production and employment opportunities for those who are genuinely eager to work (Goal 1).

Fig. 1 The faint, straight line in the upper part of the picture is the conveyor-spreader channel that flows from right to left. In this event, which occurred on 6 March 1983, 5 m^3s^{-1} of floodwater was spread along 1,000 m of this 1,342 m canal. The mean depth over the sedimentation basin was 5 cm, and the velocity was 20 cm^{-1}.

Fig. 2 Copious growth of eucalyptus roots has undermined a masonry chute. The minimum distance between a *Eucalyptus camaldulensis* Dehnh. tree and a solid chute should be 10 m.

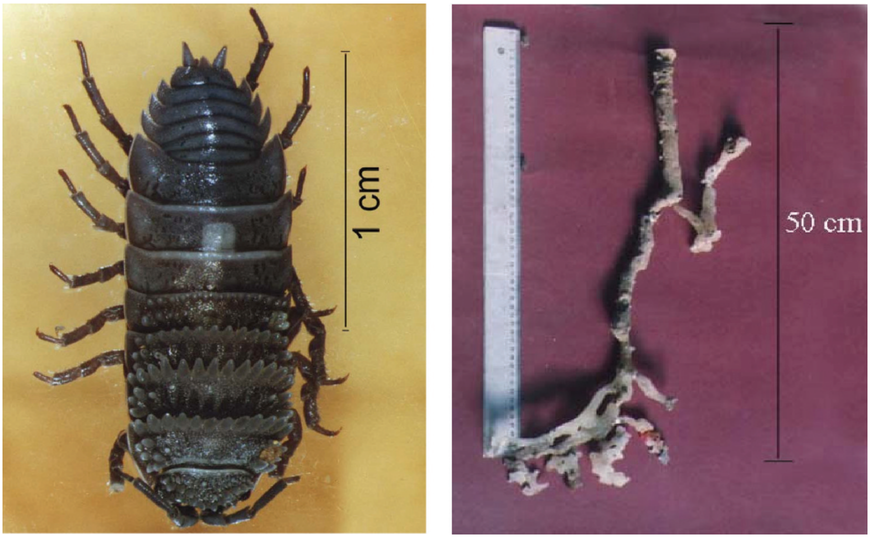

Fig. 3 The sowbug (*Hemilepistus shirazi* Schuttz) and a cast of its burrow. Were it not for this crustacean and the root channels, clogging of the vadose zone would have occurred (Gholamreza Rahbar).

Fig. 4 Floodwater irrigation of a depleted rangeland has increased its annual yield 5 times to 445 kg ha^{-1}. The mean annual yield of quail bush (*Atriplex lentiformis* (Torr.)) adds another 1,500 kg ha^{-1} to the forage yield of the floodwater spreading systems. These and the fodder trees have increased the grazing capacity of the systems by about thirty-fold.

Fig. 5 The author is standing at the very place that a man was standing 22 years before this picture was taken and holding the photograph of the second floodwater spreading event. The annual above-ground carbon sequestration of the background eucalyptus forest is 2.97 t per ha.

2. By relieving the children from their daily chores of fetching water and fuelwood, it gives them the opportunity to attend school (Goal 2).
3. As pregnant women do not have to carry water and fuelwood, which may result in miscarriage, and they receive more nutritious meals, maternal health is improved. This in turn reduces child mortality (Goal 4).
4. Environmental sustainability is ensured through provision of safe drinking water, reclamation of degraded land, greening of the environment, and carbon sequestration (Goal 7).
5. Should industrialized countries decide to pay carbon rent to the desert-dwellers in return for greening their habitat, one aspect of global partnership for development may be achieved. This also provides employment opportunities for many desert-dwellers (Goal 8).

6 Food for Thought

1. Contrary to common wisdom, flood is not a proverbial curse but a blessing in disguise for the desert-dwellers. Therefore, the FWS systems, particularly for ARG, should be designed and constructed for the largest possible flood peaks. Ancient water marks on the river walls or trees are good indicators of the maximum expected flood level. The true value of water in deserts makes over-designed systems economically viable.

2. Although we employ rubber-tyre front-end loaders and tracked bulldozers for FWS system construction in sand and firm soils, respectively, each horse power of the earth-moving machinery may be replaced with an able-bodied labourer on an 8-h shift. Thus, 160 unemployed labourers can replace a 160 hp bulldozer and install 4 ha of FWS system per day for themselves, and make a decent living in most deserts. Shovels, picks, wheel barrows and buckets, the required tools for construction, are available almost anywhere. A piece of transparent hose, filled with water and some colouring agent, replaces the very expensive type at engineering level. In this regard, on average each ha of an ARG system in the Gareh Bygone Plain supplies irrigation water for 0.5 ha. Moreover, 5.5 ha of irrigated land in the same plain provide a livelihood for a family of 7.64, of owner-operators (farmers who own and work the farm fields; however, as they need help during certain periods of the growing season, they hire labourers for 0.38 part of a year, about 138 days per annum). Therefore, it is safe to assume that the livelihood of a frugal desert-dweller can be gained from 2 ha of FWS and 0.5 ha of irrigated field under our conditions. *It is better to give small wages instead of alms to the idle masses to make the deserts bloom*! Generous governments always come to the aid of drought-stricken people only after the famine materializes. *Why not prevent famine in the first place by channelling the relief funds to desertification control through floodwater harvesting projects?*
3. The politically expedient and ecologically disastrous sedentarization of transhumant nomads in the Gareh Bygone Plain in the 1930s has generated in their offspring a hostile attitude towards public servants. Moreover, abolishment of the old system, in which an authoritarian chieftain managed a tribe, has left a group of unruly people who do not believe in the sustainable management of marginal drylands. It appears that the nomad mentality cannot accept the rule of law legislated by urbanites. It is unfortunate in this age of enlightenment to resort to force for the benefit of the majority. The absence of a democratic tribal chieftain is therefore badly missed! We hope to make inroads here by proselytizing the younger generation into forming a cooperative together with the research scientists and technicians. We expect that the concrete outcomes of this active research will serve practitioners and policy makers working on water management issues in diverse settings.
4. Assuming a minimum of scientific truth in the reasoning that the mean annual precipitation will decrease in dry areas due to global warming and lead to inevitable famine, it is prudent to prepare for it through the planning and implementation of water harvesting structures in arid and semi-arid zones. Moreover, the rise in sea level due to melting of glaciers may be mitigated, even compensated, by the large-scale floodwater harvesting in the world's deserts.
5. Development and implementation of a water-based economy is essential if the well-being of desert-dwellers is genuinely intended. A hydro-agro-silvo-pastoral economic plan is therefore suggested. It should be emphasized that many factors determine the priority of the last three enterprises. For instance, if the land is not suitable for growing food crops but capable of becoming pasture, a hydro-silvo-pastoral economic programme should be planned and implemented.

We even envision a time when optimization of water use may dictate its sale to the highest bidder. In this case, we forgo growing crops or fruit trees and keep livestock beyond our immediate needs. Floodwater harvesting – particularly for the artificial recharge of groundwater – is technically practicable, environmentally sound, economically viable, and in most cases, socially acceptable and politically prudent.

References

Anon. 2005. Experts warn ecosystem changes threaten development. *A World of Science,* Vol. 3, No. 3, pp. 8–9.

Glantz, M. H. 1994. *Drought fallows the plow*. Cambridge, UK, Cambridge University Press.

Kalisz, P. J. and Stone, E. L. 1984. Soil mixing by scarab beetles and pocket gophers in north-central Florida. *Soil Science Society of America Journal*, Vol. 48, pp. 169–172.

Kowsar, S. A. 1991. Floodwater spreading for desertification control: An integrated approach. *Desertification Control Bulletin*, United Nations Environment Programme, Vol. 19, pp. 3–18.

———. 2005. Abkhandari (aquifer management): A green path to the sustainable development of marginal drylands. *Journal of Mountain Science*, Vol. 2, pp. 233–243.

Mabbutt, J. A. 1987. Implementation of the Plan of Action to Combat Desertification: Progress since UNCDD. *Land Use Policy*, Vol. 4, pp. 371–388.

Mohammadnia, M. and Kowsar, S. A. 2003. Clay translocation in the artificial recharge of a groundwater system in the southern Zagros Mountain, Iran. *Mountain Research and Development*, Vol. 23, pp. 50–55.

Newman, J. C. 1963. Waterspreading on marginal arable areas. *Journal of Soil Conservation, New South Wales*, Vol. 19, pp. 49–58.

Phillips, J. R. H. 1957. Level-silled bank outlets. *Journal of Soil Conservation, New South Wales*, Vol. 13, No. 2, pp. 15.

Quilty, J. A. 1972a. Soil conservation structures for marginal arable areas-Gap absorption and gap spreader banks. *Journal of Soil Conservation, New South Wales*, Vol. 2, pp. 116–130.

———. 1972b. Soil conservation structures for marginal arable areas: Diversion spreader banks and tank drains. *Journal of Soil Conservation, New South Wales*, Vol. 28, pp. 157–168.

Wolman, M. G. 1985. Soil erosion and crop productivity: A worldwide perspective. *Soil Erosion and Crop Productivity*. R. F. Follett and B. A. Stewart (eds.). pp. 9–21.

Chapter 6
Modeling the Effect of Floodwater Spreading Systems on the Soil–Water Balance and Crop Production in the Gareh Bygone Plain of Southern Iran

Dirk Raes[1,*], Donald Gabriels[2], Sayyed Ahang Kowsar[3], Peter Corens[1] and Nosratollah Esmaeili[2]

Abstract Between 1983 and 1987, eight floodwater systems were constructed covering 1,365 ha in the Gareh Bygone Plain of southern Iran. The floodwater systems have areas between 25 and 365 ha and on average 10 million m^3 of floodwater is diverted annually to the systems. A soil–water balance model was used to evaluate the recharge of the groundwater and the increased crop transpiration on the terraces of the floodwater systems. A simulation showed that, as a result of the construction of the system, the recharge increases on average on the terraces by four-fold. In a dry year, 27% of the infiltrated rain and floodwater percolates on average to the aquifer and the recharge increases up to 69% in a humid year. Indigenous vegetation of bushes and shrubs grow well on the terraces. Commercially more attractive trees, such as the eucalyptus, are, because of their high water consumption, only very productive in years where runoff/run-on events are important both in magnitude and number. Nevertheless, thanks to their vigorous growth, eucalyptus trees produce on average more above-ground biomass than the indigenous vegetation. It is estimated that thanks to the additional water supplied by run-on, the cultivation of barley on the terraces during the rainy season can triple their production in the region.

Keywords Floodwater spreading, terrace cultivation, soil water balance, aquifer recharge, BUDGET

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1 Introduction

The Gareh Bygone Plain, located in southern Iran, is an arid region with an average annual precipitation of 219 mm and a reference evapotranspiration (ETo) of 1,550 mm (FAO, 2005). The mean monthly precipitation and ETo are plotted in Fig. 1. As a result of the over-exploitation of the groundwater in the region, the aquifer has dropped below 20 meter, and the 3,000-year-old *qanats* are running dry.

To remediate the water shortage in the area, projects were launched to recharge artificial the groundwater (Table 1). Therefore several floodwater spreading systems (Kowsar, 1990, 1991 and 1998) were constructed between 1983 and 1987 in a 6,000 ha sandy area of the plain (28°37° N, 53°55° E, 1,140 m above m.s.l.). In the plain, located 200 km southeast of Shiraz, on average 10 million m^3 of floodwater is diverted annually to the system.

In one of the systems composed of 550 ha of terraces (part of Bisheh Zard and Rahim Abad), water from the Bisheh Zard River is diverted to the conveyance-spreader channels by means of a gabion step weir (Fig. 2). The conveyance-spreader channels are actually very long and shallow stilling basins, converting most of the kinetic energy of the flowing water into potential energy. The slowing of the floodwater elevates the water level a few centimetres above the lower sill of the channel. The overtopping of the channel brings a sheet of water over a very long front, on top of the slightly inclined terrace. The water is retained on the 100–300 m wide terrace by a contour bank of 2 m high, located at the down slope side of the terrace. The bank is in fact the excavated soil from a levelled channel dominating the next, lower located, terrace. The retained water on the terrace

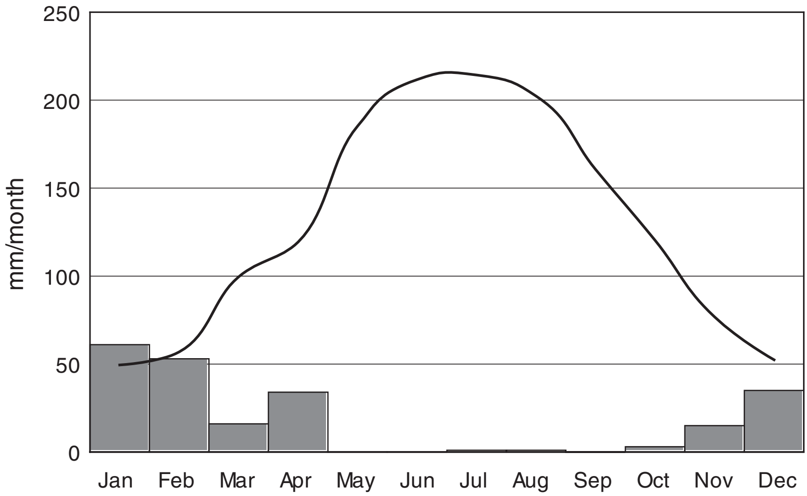

Fig. 1 Mean monthly precipitation (bars) and reference evapotranspiration (line) in the Gareh Bygone Plain (28°37’N, 53°55’E, 1140 m above m.s.l.; source: FAO, 2005)

Table 1 Characteristics of the floodwater-spreading systems in the Gareh Bygone plain of Southern Iran (source Kowsar, 1991)

Name of the system	Construction period	Area (ha)
Bisheh Zard 1	January–February 1983	200
Bisheh Zard 2	March–June 1983	250
Bisheh Zard 3	December 1983–March 1984	25
Bisheh Zard 4	January–March 1984	25
Rahim Abad 1	January–June 1984	200
Rahim Abad 2 & 3	May 1984–February 1987	300
Tchah Qootch	November 1985–February 1987	365

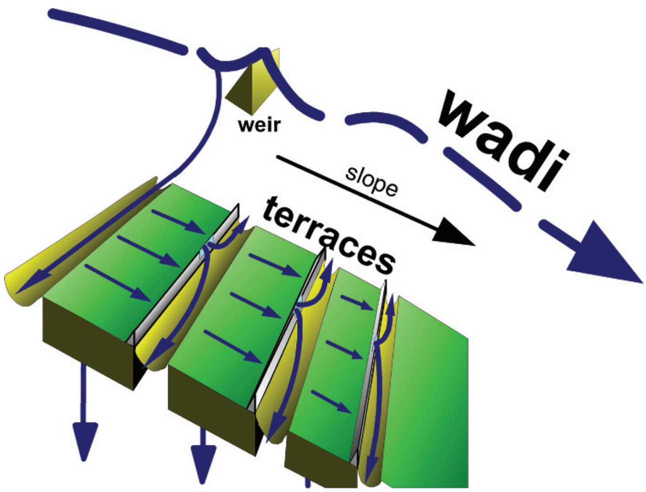

Fig. 2 Use of a series of terraces for the recharge of the groundwater (Raes et al. 2005)

infiltrates and sedimentation of the suspended load takes place. Excess water from one terrace is transferred to the next through wide overflow outlets installed in the banks at certain intervals. The excess water is collected in a levelled channel that overflows when enough floodwater is collected. The overtopping of a levelled channel spreads the water evenly over its lower lying terrace. This process is repeated four to ten times until rather clear water enters the infiltration ponds located at the far end of the system.

This paper presents our study of the effects of the floodwater spreading system in the 550 ha Bisheh Zard – Rahim Abad terraces. The artificial recharge of the groundwater and the crop production on the terraces has been quantified with the help of a soil water balance model for various environmental conditions and type of years.

2 Materials and Methods

2.1 Climatic Data

Reference evapotranspiration (ETo) was determined with the FAO Penman-Monteith equation from climatic data collected in the Kowsar station (28°38′ N, 53°55′ E, 1,200 m.a.s.l.). As only a full data set of climatic data was available over a period of two years in order to calculate the evapotranspiration rate with the standardized FAO procedures (Allen et al., 1998), ETo was estimated from a minimal data set. The minimal set consisted of the daily minimum and maximum air temperature and a mean annual wind speed of 1.3 m/s recorded in the period 1996–2004. By comparing the daily estimates of ETo obtained with the minimal data set and the full data set, the procedure was calibrated on a ten-day basis by determining empirical coefficients (Corens, 2005):

$$\mathrm{ETo} = 1.307 + 1.086\,\mathrm{ETo}_{\text{minimal data set}} \left(\mathrm{R}^2 = 0.991\right)$$

In the Kowsar station, daily rainfall has been recorded since 1998. The data set was completed with daily rainfall recorded since 1983 in the Baba Arab station, located 15.7 km from the Kowsar station at approximately the same altitude on the same side of the mountain range. The determined Kendall coefficient of agreement (Doorenbos, 1976) between the two stations was 0.87 (Corens, 2005). The homogeneity test in RAINBOW (Raes et al., 1996, 2006c) proved that the composed data set of the annual rainfall of the last 20 years is homogeneous. A frequency analysis was carried out on the yearly rainfall with the help of the RAINBOW software. As such, the years of the data set could be classified as either dry (80% probability of exceedance), normal (50%) or humid years (20% probability of exceedance).

2.2 Flood Analysis

When it rains in the Bisheh Zard Mountains, surface runoff of excess rain water is transferred to the project site by Bisheh Zard River. Unfortunately, only for some floods has the volume of water diverted from the river to the considered 550 ha of terraces of Bisheh Zard and Rahim Abad been determined. By comparing rainfall with 34 recorded flood events in the period 1982–2004, Corens (2005) developed a simple model to estimate floods from the precipitation of previous days ($R^2 = 0.60$).

2.3 Vegetation

Various crops are cultivated on the terraces. The major crops are indigenous bushes and shrubs, planted atriplex (*Atriplex lentiformis* [Torr.] Wats), eucalyptus trees, date palms and barley. Crop characteristics for the crops (Table 2) were obtained

Table 2 Crop coefficient (Kc), effective rooting depth (Zr) and depletion fraction for no stress (p) for perennial crops and barley cultivated in the area

Crop	Kc	Zr (m)	p
Perennial crops			
Eucalyptus	0.75	2.5	0.55
Natural vegetation outside the system	0.36	0.8	0.65
Natural vegetation on terraces	0.60	0.8	0.65
Barley			
- Initial stage	0.45	0.30	0.55
- Crop development stage	0.45–1.20	0.30–1.15	0.55
- Mid season stage	1.20	1.15	0.55
- Late season stage	1.20–0.47	1.15	0.55

from literature (Farshi et al., 1997) or derived by Corens (2005) and Raes et al. (2005) from procedures presented by FAO (Allen et al., 1998). As a result of a more intense crop development and soil cover on the flooded terraces, the crop coefficient (Kc) of the natural vegetation differs from the Kc of the vegetation outside the system. The effective rooting depth (Zr) refers to the soil depth from which crop roots extract most of their water. The soil–water depletion fraction for no stress (p) refers to the average fraction of the total available soil–water (TAW) that can be depleted from the root zone before water stress occurs.

2.4 Soil Parameters

As a result of sedimentation of water-borne silt, clay and organic material, the sandy soils of the terraces are gradually transformed into sandy loam soils. Undisturbed soil samples (100 cm^3) were taken with Kopecky rings to determine the soil water retention at different matric potentials for the different soil layers. Six samples were taken from the sediment layer, three from the intermediate layer and three from the deeper original sandy soil layer. The average soil water retention curves are plotted in Fig. 3. Three soil types can be considered: the original sandy soil (Type 1) and two soil types (Type 2 and 3) with a sediment layer that differ in the thickness and composition of their top layers (Table 3). By means of ring infiltrometer, the saturated hydraulic conductivity of the top layer of the three soil types was determined at 31 locations. The average saturated hydraulic conductivity (Ksat) is 494 mm/day for the sandy layer, 98 mm/day for the intermediate layer and 31 mm/day for the sediment layer. However, thanks to the active of the sowbugs (*Hemilepistus shirazi* Schuttz), the sediment layer, when punctured with large holes, has a Ksat of 1,848 mm/day.

2.5 Soil–Water Balance

The soil–water balance model BUDGET (Raes, 2005; Raes et al., 2006a) was used to quantify the artificial recharge of the groundwater. In the model, the

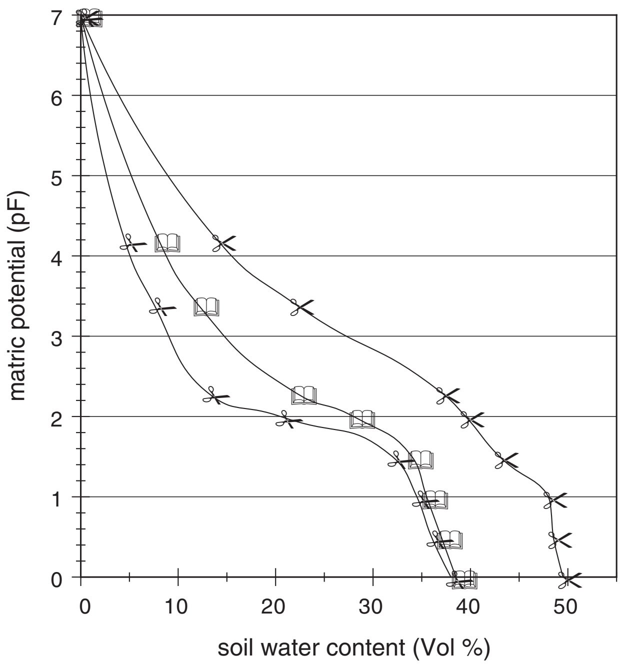

Fig. 3 Soil water retention curves for the original sandy soil (asterisk), the intermediate layer (diamonds) and the sediment layer (plus sign)

Table 3 The composition of the soil profile of the 3 composed soil types

Soil layer	Type 1 Sandy soil	Type 2	Type 3 Sandy-Loam soil
Sediment layer	–	0–0.05 m	0–0.15 m
Intermediate layer	–	0.05–0.40 m	0.15–0.40 m
Sandy layer	0–2.50 m	0.40–2.5 m	0.40–2.5 m

change of water stored in the root zone is determined on a daily basis by keeping track of the incoming (rainfall and run-on) and outgoing water fluxes (evapotranspiration) at its boundary. The run-on of floodwater was considered as irrigation. If, as a result of heavy rain or the run-on of floodwater on the terraces, the soil water content in the root zone exceeds field capacity, water percolates to the aquifer.

Since rainfall and floodwater is stored on the terraces between high bunds to facilitate infiltration, the runoff sub-model of BUDGET is bypassed. The maximum amount of water that can infiltrate daily into the soil is, limited however, by the maximum infiltration rate (Ksat) of the topsoil layer. The infiltration and internal drainage are described by an exponential drainage function that takes into account the initial wetness and the drainage characteristics of the various soil layers.

With the help of the dual crop coefficient procedure (Allen et al., 1998), the soil evaporation rate and crop transpiration rate of a well-watered soil is calculated in BUDGET. Water stress will occur when a certain amount of the plant extractable water is depleted from the root zone.

To describe accurately the retention, movement and uptake of water in the soil profile throughout the growing period, a mesh of grid lines with spacing Δz and Δt is established throughout the region of interest occupied by the independent variables: soil depth (z) and time (t). In BUDGET the depth increment (Δz) is by default 0.1 m and the time increment is fixed at 1 day. The flow equation and water extraction by plant roots is solved for each node at different depths z_i and time levels t_j so that the dependent variable – the moisture content $\theta_{i,j}$ – is determined for each node of the solution mesh and for every time step.

Given the simulated soil–water content in the root zone, the actual transpiration rate and crop water stress can be estimated. The relative (evapo)transpiration rate (ETa/ETc) is a good index for crop water stress and is closely linked with biomass production (Doorenbos and Kassam, 1979; Steduto et al., 2006). It is the ratio between the actual evapotranspiration (ETa) and the evapotranspiration that would have occurred if the soil was well watered (ETc).

2.6 Simulations

The soil–water balance for fields inside as well as outside the floodwater spreading system were simulated by considering the various crop types, soil types and type of years. From the data series of 20 years, 11 years were selected: three humid years, five normal years, and three dry years (Table 4). For the three different types of years, the soil–water balance was simulated with a daily time step. The simulations started on 1 July by assuming that the soil profile was at wilting point and

Table 4 Observed rainfall and estimated transferred floodwater (run-on) to the terraces for the different type of years considered in the simulations

Year (1 July–30 June)	Type of year	Rainfall (mm/year)	Run-on (mm/year)
1983–1984	dry	117	640
1986–1987	wet	332	1344
1987–1988	normal	229	487
1989–1990	normal	210	293
1990–1991	normal	254	617
1992–1993	wet	556	433
1993–1994	dry	146	185
1995–1996	wet	515	809
1996–1997	normal	212	50
1997–1998	normal	253	126
1999–2000	dry	90	180

stopped at 30 June. For each of the years, the model was actually run three times by using the simulated soil–water content at the end of each run as the initial conditions for the next run. This iteration procedure guaranteed a good approximation of the actual initial soil–water conditions in the soil profile. Only after the third run was the output recorded.

2.7 Results and Discussion

By assuming that the floodwater is equally spread over the total area of the 550 ha of connected terraces, it is estimated that in a humid year on average 862 mm of water was applied by run-on. In normal and dry years, the run-ons are about 60% lower than in wet years and on average only 322 mm is transferred to the terraces. The run-on differs however very strongly from one year to another even within the three considered types of year. The magnitude and number of flood events strongly determine the amount of run-on.

The introduction of floodwater spreading systems strongly affects the recharge of the aquifer. In dry years, there is no recharge of the aquifer in the absence of a floodwater spreading system. As a result of soil evaporation and crop transpiration, all rain water is lost by evapotranspiration to the atmosphere. When a floodwater spreading system exists, on average 183 mm of the infiltrated water (rainfall and run-on) percolates to the aquifer in a dry year. This corresponds to a recharge of 1.0 Mm^3 of water on a 550 ha terrace system. In normal and wet years, the recharge is on average 4–5 times larger inside the system than outside the system. The simulated mean recharge of the aquifer was 1.3 Mm^3 water for a normal year and 5.1 Mm^3 for a wet year on the 550 ha terrace system.

In Fig. 4 the simulated recharge of the aquifer for each of the 11 years as well as the average recharge in a dry, normal and humid year is plotted as a percentage of the infiltrated water for the three types of year. Although the simulation results differ slightly for the different considered soil types and crop types, the largest differences occur between the years in each of the groups. The standard deviations are 30% for the dry years, 24% for the normal years and 4% for the humid years.

For the 550 ha of the Bisheh Zard – Rahim Abad terraces, the simulated average annual recharge of the aquifer for the 11 years is 412 mm. By considering the total of 1,365 ha of all the terraces of the floodwater spreading systems in the Gareh Bygone plain in Southern Iran (Table 1), the simulated average annual recharge corresponds with 5.6 Mm^3 per year. This result is of the same order of magnitude as the 5 Mm^3 per year that has been estimated before (Kowsar and Pakparvar, 2003).

The mean yearly relative evapotranspiration (ETa/ETc) for the perennial crops cultivated on the terraces does not differ widely between the types of year. It increases from 29% in a dry year, to 32% in a normal year and to 43% in a humid year. As a rule of thumb, it is often taken that as long as ETa is less than 1/3 of ETc (i.e. $ET_{relative} < 33\%$) the crop water stress will be very severe. As such, the results

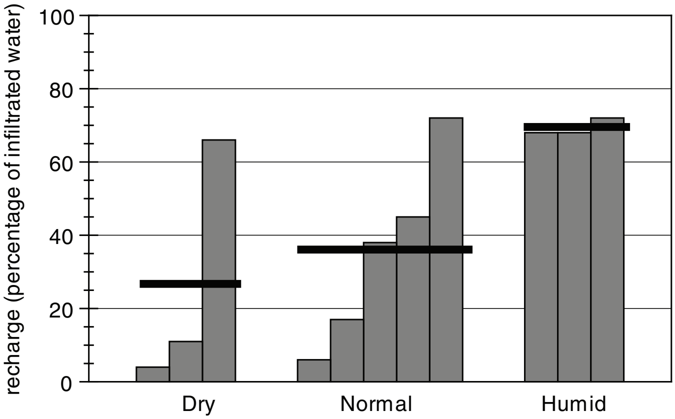

Fig. 4 The simulated recharge of the aquifer by the floodwater spreading system for each of the 11 years (bars) and the average recharge in dry, normal and humid years (bold lines) expressed as a percentage of the infiltrated water

indicate that almost in all types of year the transpiration rate is seriously affected and the biomass production will be rather limited.

The relative evapotranspiration differs strongly, however, between the various crop types. It was simulated that in a wet year the bushes and shrubs can reach a relative evapotranspriation level of 75% on the sandy loam soils, while on the same type of soils and same type of years, the relative evapotranspiration for the eucalyptus trees was only 40%. Since indigenous bushes and shrubs require less water than eucalyptus trees (differences in Kc), their ET_{rel} is larger than the ET_{rel} of eucalyptus trees. Since it is safe to state that the tolerance to water stress of indigenous vegetation is larger than the tolerance of eucalyptus trees, the relative biomass production related with a specific ET_{rel} will be larger for bushes and shrubs than for eucalyptus trees. However, since the eucalyptus trees grow much more vigorously than the indigenous shrubs and bushes, their above-ground biomass production (about 5 $Mg.ha^{-1}.year^{-1}$) is larger than that of the indigenous plants (about 0.5 $Mg.ha^{-1}.year^{-1}$). When evaluating biomass production, the economic value of crop production as fodder, firewood, construction material, etc. will have to be considered as well.

By sowing barley on the terraces at the start of the rainy season (end of October), the annual crop will benefit not only from rainfall but also from the diverted floodwater during large parts of the cropping period. It was simulated that the relative transpiration (T_{rel} = Ta/Tc) is on average 65%. It fluctuates, strongly however, between 33% and 89%, depending on the type of year, soil type and the number and intervals between flood events. For the two years for which yields of barley were available, the average recorded yield was 700 kg/ha outside the floodwater system and 2,150 kg/ha on the terraces of the system. For those years there exists a good correlation between the simulated relative transpiration and the observed yield (R^2 of 0.83).

3 Scope of Further Research

Ongoing research focuses on a better assessment of the environment and the use of a crop water productivity model:

- To better quantify the flood events, the Curve Number method (USDA, 1964) is actually tested by considering the area of the watershed, the soil cover and hydrologic conditions in the region and the spatial distribution of the rainfall. Observed flood events will be used to calibrate the curve number.
- By considering the surface of the individual terraces, the height of the contour banks, the number and dimensions of the overflows, the water distribution within the floodwater spreading system can be better described.
- The incorporation of the FAO crop water productivity model (Steduto et al., 2006) in the BUDGET model resulted in the development of a prototype of the crop production simulator AquaCrop (Steduto et al., 2006; Fereres et al., 2006; Raes et al., 2006b). Once the model is fully calibrated, AquaCrop can be used to simulate more accurately the crop production on the terraces and outside the system.

4 Conclusions

With the help of the BUDGET model, indicative values for the recharge of the aquifer and the relative (evapo)transpriation were estimated which can be expected inside and outside floodwater spreading systems in dry, normal and humid years. The simulated average annual recharge of 5.6 Mm^3 per year with the floodwater system corresponds well with the 5 Mm^3 per year reported in literature.

The simulations indicate that, almost for all types of year, the transpiration rate of commercial perennial crops is seriously affected and the biomass production will be rather limited. Only for well-adapted perennial crops, such as indigenous bushes and shrubs which have low transpiration rates (low Kc) and are tolerant to water stress (high p), a relative evapotranspriation level of up to 75% could be reached by cultivating them on the terraces. An alternative might be to cultivate tolerant cereal crops such as barley during the rainy season. In addition to rainfall, the crop will receive a large amount of floodwater, which can be stored in the root zone. This will help to reduce the crop water stress between the sparse rain events. It was simulated that on average the relative transpiration of barley cultivated on the terraces is 65% and can increase up to 89% if rainfall and the corresponding flood events are important and well-distributed throughout the growing period. Given the tolerance of the indigenous perennial crops and barley, it is expected that the relative biomass production (actual versus potential crop production) will be larger than the simulated relative (evapo)transpiration rates.

Although the limited available data already give a hint that with the model good indicative values can be obtained, more observations are required to fully validate the calculation approach. Once the model is validated, aquifer recharge and crop production can be studied for various environmental conditions, types of year and different layouts of the floodwater spreading system. From such type of research, guidelines for the management of drylands and for the design of floodwater spreading systems can be formulated for southern Iran.

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References

Allen, R., Pereira, L. S., Raes, D. and Smith, M. 1998. *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper No. 56. Food and Agricultural Organization of the United Nations, Rome.

Corens, P. 2005. *The Effect of Floodwater Spreading on the Field Soil–Water Balance in the Gareh Bygone Plain, I.R. Iran*. Master Research, Faculty of Bioscience Engineering, K. U. Leuven University, Belgium.

Doorenbos, J. 1976. *Agro-meteorological Field Station*s. FAO Irrigation and Drainage paper No. 27. Food and Agricultural Organization of the United Nations, Rome.

Doorenbos, J. and Kassam, A. H. 1979. *Yield Response to Water*. FAO Irrigation and Drainage Paper No. 33. Food and Agricultural Organization of the United Nations, Rome.

FAO. 2005. *New_LocClim, Local Climate Estimator*. Environmental and Natural Resources Working paper, No. 20 (CD-ROM).

Farshi, A. A., Shariati, M. R., Shahabifar, M. and Tavallaei, M. M. 1997. An estimate of water requirement of main field crops and orchards in Iran (Vol. 1 and 2). Ministry of Jihad-E-Agriculture, agricultural research and education organization. Teheran, Islamic Republic of Iran.

Fereres, E., Steduto, P., Hsiao, T. C. and Raes, D. 2006. Modeling approaches for the simulation of water-limited crop production used in the FAO Aquacrop model. *Proceedings of International Symposium on Water and Land Management for sustainable irrigated agriculture*, 4–8 April. Cukurova University, Adana, Turkey (CD-ROM).

Kowsar, S. A. 1990. Artificial recharge of groundwater for small-scale water development in rural areas: A case study. Paper presented at the International Symposium in Development of Small-Scale Water Resources in Rural Areas, 21–25 May. Khon Kaen, Thailand.

———. 1991. Floodwater spreading for desertification control: An integrated approach. *Desertification Control Bulletin*, No. 19. United Nations Environmental Programme/UNEP, pp. 3–18.

———. 1998. Aquifer management: A key to food security in the deserts of the Islamic Republic of Iran. *Desertification Control Bulletin*, No. 33, pp. 24–28.

Kowsar, S. A. and Pakparvar, M. 2003. Assessment methodology for establishing an Aquitopia, Islamic Republic of Iran. In: *Proceedings of the Second International Workshop*. 29 Nov–2 Dec. 2003. Shiraz, I. R. Iran, pp. 40–55. UNESCO-MB Drylands Series No. 3. UNESCO, Paris.

Naderi, A. A., Kowsar, S. A. and Sarafraz, A. A. 2000. Reclamation of a sandy desert through floodwater spreading: I. Sediment-induced changes in selected soil chemical and physical properties. *Journal of Agriculture, Science and Technology*, Vol. 2, pp. 9–20.

Raes, D. 2005. BUDGET – A soil water and salt balance model. Installation disk and Reference Manual, Version 6.2 (http://www.iupware.be and select downloads and next software) (Accessed 9 September 2006).

Raes, D., Mallants, D. and Song, Z. 1996. RAINBOW – A software package for analysing hydrologic data. *Hydraulic Engineering Software VI*, W.R. Blain (ed), Computational Mechanics, Southampton, UK and Boston. MA, pp. 525–534.

Raes, D., Corens, P., Kowsar, S. A., Nosratollah, E. V. and Gabriels, D. 2005. Use of terraces for soil water conservation in the Gareh Bygone Plain in southern Iran. *Proceedings of the 3rd International Workshop on Sustainable Management of Marginal Drylands.* Djerba, Tunisia, 11–15 December 2004, pp. 41–50.

Raes, D., Geerts, S., Kipkorir, E., Wellens, J. and Sahli, A. 2006a. Simulation of yield decline as a result of water stress with a robust soil water balance model. *Agricultural Water Management*, Vol. 81, No. 3, pp. 335–357.

Raes, D., Steduto, P., Hsiao, T. C. and Fereres, E. 2006b. Structure, algorithms and functionalities of AquaCrop. *Proceedings of International Symposium on Water and Land Management for Sustainable Irrigated Agriculture*, 4–8 April. Cukurova University, Adana, Turkey (CD-ROM).

Raes, D., Willems, P. and Gbaguidi, F. 2006c. RAINBOW – A software package for analyzing data and testing the homogeneity of historical data sets. *Proceedings of the 4th International Workshop on Sustainable Management of Marginal Drylands*. Islamabad, Pakistan, 27–31 January.

Steduto, P., Fereres, E., Hsiao, T. C. and Raes, D. 2006. Yield Response to Water: The FAO revision framework and the crop-water productivity model AquaCrop. *Proceedings of International Symposium on Water and Land Management for Sustainable Irrigated Agriculture*, 4–8 April. Cukurova University, Adana, Turkey (CD-ROM).

United States Department of Agriculture (USDA). 1964. *Estimation of Direct Runoff from Storm Rainfall*. National Engineering Handbook, Washington, DC, Section 4 Hydrology, Chapter 4, pp. 1–24.

Chapter 7
Future of Drylands – An Overview of Evaluation and Impact Assessment Tools for Water Harvesting

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Abstract In the arid regions of Tunisia, huge efforts are being made in the construction and maintenance of water harvesting and soil conservation structures. A growing need for their evaluation and assessment of their impact is felt. To this end, a simple tool has been developed and applied to evaluate the structural stability of *jessour*, *tabias* and gabion check dams. The total gives a measure of the structure's present-day overall condition based on physical inspection of a number of key characteristics vital to its functionality. The evaluation tool was applied to a random sample of structures in southern Tunisia. This paper also describes an adaptation and evaluation of the ArcView soil and water assessment model (SWAT) for the assessment of the hydrologic impact of water harvesting systems. Some modifications were made to the model code to adapt the model to the processes in the study area. Evaluation of the hydrologic goodness-of-fit of the model based on the observed and simulated runoff data in the study site, using four statistical criteria, gave reasonable results.

Keywords Water harvesting structures, evaluation tools, SWAT modeling

1 Introduction

Traditional water harvesting techniques existed for decades in Tunisia for soil and water conservation in support for agricultural production (El Amami, 1984). Advantages of water harvesting include groundwater recharge, increased crop production and soil conservation (Prinz, 1996). Currently, the Tunisian authorities are evaluating the need for additional construction and maintenance of these structures.

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An evaluation that assesses the water harvesting structures would aid decision-makers in supporting the construction and maintenance of these structures.

Being aware of the importance of natural resources in those arid environments, the Tunisian Government has initiated a vast programme for the conservation and mobilization of those resources. In the Jeffara region, which encompasses the study site, huge works for soil and water conservation (water harvesting) have been implemented whose immediate effects are visible but their efficiency in both the short and the long term need to be assessed and evaluated in detail (De Graaff and Ouessar, 2002). By simplifying and simulating natural processes, models have become efficient tools for analyzing the impact of land use changes and the development of management practices.

The first part of this paper discusses the development and application of an evaluation tool to evaluate the structural efficiency of three of the most commonly used water harvesting structures in southern Tunisia, the *jessour*, *tabias* and gabion check dams (Ben Mechlia and Ouessar, 2004). The second part describes the adaptation and evaluation of the GIS-based SWAT model for the assessment of land use change impact in an arid watershed in southeastern Tunisia.

Other research activities related to the impact of water harvesting practices in southern Tunisia, but not presented in this paper, include: the evaluation and development of alternative designs for recharge wells, which were constructed in the wadi bed upstream of some of the gabion check dams to improve groundwater recharge; and the application of detailed models to simulate the impact of water harvesting structures on hydrological, erosion and sedimentation processes, as well as and the water availability for upstream and downstream areas. Coupled with the assessment tool, this integrated hydrological tool is expected to assess the feasibility of maintaining these structures at the farm and watershed levels.

2 Materials and Methods

2.1 Study Site

The application was carried out for the Wadi Oum Zessar watershed, which covers about 336 km^2 (Fig. 1). The watershed is located in southeastern Tunisia and has an arid Mediterranean bioclimate with an annual rainfall ranging between 150 and 230 mm. The watershed starts at the Matmata mountain range (Kef Ennsoura) and ends in the Mediterranean Sea. It has three main tributaries: Wadi Nagab, Wadi Moggar and Wadi Hallouf. The hydraulic history of this watershed is very ancient and rich, as witnessed by the remains of a dam built in the Roman era near the village of Koutine, and the ancient terraces encountered in the hills of Wadi Nagab. At present, the upstream area is terraced with *jessour*, which are ancient water harvesting techniques constructed in the form of small earthen retention dams with spillways typical for the mountains of southeastern Tunisia (El Amami, 1984; Ben Mechlia and Ouessar, 2004). The intermediate zones incorporate *tabias,* which are similar to

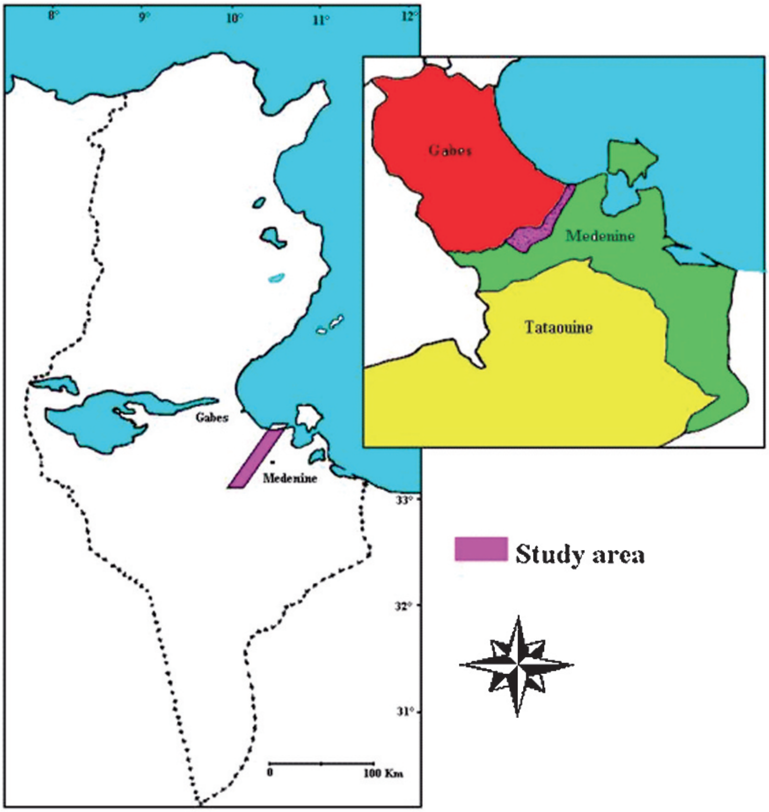

Fig. 1 Location map of the study site. Source: Derouiche (1997)

jessour but encountered mainly on the foothills and the flat areas (Alaya et al., 1993), and floodwater diversion structures. In the beds of the main wadi, several gabion check dams were built for the recharge of the Zeuss-Koutine aquifer. Detailed descriptions of the area are found in Ouessar et al. (1999) and Mahdhi et al. (2000).

2.2 Water Harvesting Structure Evaluation Tool

Water harvesting structure evaluation tools were developed following a similar procedure conducted by Bracmort et al. (2004) for the evaluation of best management practices (BMPs) in the Black Creek watershed (Indiana, USA). The tool requires the evaluator(s) to rate characteristics of the structure through physical inspection and to compute an overall condition score. The evaluation tool includes:

1. Evaluation form description and intended use
2. Type of structure being evaluated

3. Materials needed
4. On-site instructions on the use of the tools that include:
   (a) Quantitative code description for the structure cross-sections; infiltration potential; vegetation for cultivated areas and drainage areas, material of the dike; and dike erosion
   (b) Computation of the overall structure condition score based on the quantitative code data above
5. Guide for the quantitative code described above
6. Actual evaluation data sheet and criteria used for evaluating the final condition score

For simplicity and because the practices serve many of the same purposes, a single evaluation tool was composed. The characteristics rated include cross-section for the water and sediment components of the structure, infiltration potential, vegetation quantity for the cultivated and catchment areas, dike material and dike erosion. The same characteristics are rated for each structure using a three-point scale rating table to score individual characteristics for each structure based on physical inspection. Due to the uneven distribution of importance of some characteristics, each characteristic was assigned a weight based on its contribution to the functionality of the structure (Table 1). The condition score is the summation of the characteristics score multiplied by the assigned weights.

Before rating the structure characteristics, general information and a series of measurements of the dimensions of the structure and the catchment and its drainage area should be collected. Once the measurements are recorded, the evaluator can proceed to rate all characteristics except for the cross-section characteristics, which require calculations are best completed after returning from the field. The cross-section component of the evaluation for *jessour* and *tabias* compares free water volume to soil storage capacity, while the cross-section sediment component is scored based on the depth of sediment. For the gabion check dam cross-section measurements, sediment storage volume is compared to the total volume. Infiltration potential measures direct recharge for a gabion dependent upon the existence of a recharge well. For all structure types, surface infiltration is assigned a score based on location of the structure in a favourable recharge area and surface drainage ability. Cropping potential for cultivated areas and drainage area vegetation requires the evaluator to score the quantity of vegetation and soil depth. Dike material is scored based on its condition, and dike erosion is scored based on the degree of visible erosion.

Table 1 Water harvesting techniques characteristic weighting factors

Weights	Jessour	Tabia	Gabion
Cross-section (water)	1	0.75	1
Infiltration potential:			
– Direct recharge	N/A	N/A	1
– Surface infiltration	0.5	0.5	1
Vegetation quantity	1	1	0.5
Dike material and erosion	1	0.5	1

Table 2 Structures conditions score ranges

	Jessour	*Tabias*	Gabions
Maximum condition score	13.5	10.5	14.25
Minimum condition score	4.5	3.5	4.75
Good condition	10.5–13.5	8.1–10.5	11.2–14.25
Fair condition	7.5–10.4	5.8–8.0	8–11.1
Poor condition	4.5–7.4	3.5–5.7	4.75–7.9

Due to the varying distribution of assigned characteristic weights, there is a maximum and minimum condition score for each structure. A condition score falling in the interval range "good" indicates that a structure is fully functional. A condition score falling in the interval range "poor" indicates that a structure performs unsatisfactorily (Table 2).

2.3 Modeling

2.3.1 SWAT Model and Parameter Selection

SWAT is a physically based, watershed-scale model developed by Arnold et al. (1998) and has a GIS (ArcView) interface (Di Luzio et al., 2002). It is a continuous time model that operates on a daily time step to estimate the effects of land and water management and pollutant releases in stream systems in large complex watersheds with varying soils, land use and management conditions over long period of time. SWAT has a database with default crop and soil parameters for US conditions. These parameters had to be modified and tested for the study area conditions. In addition, the model code was adjusted to represent the typical conditions of watersheds in dry Mediterranean environments (details may be found in Ouessar [2007] and Ouessar et al. [2007]).

Daily rainfall measurements were collected from ten stations in and around the watershed. Daily values of maximum and minimum temperature were obtained from the weather stations of Médenine, Béni Khédache and El Fjè (IRA). Considering the availability of data, the potential evapotranspiration was calculated using the Hargreaves method.

The sub-basin delineation was obtained from a 30 m DEM generated by the interpolation of digitized contour lines and altitude points obtained from topographic maps and information from a SPOT stereo pair. A soil map of the region (Taamallah, 2003) was adjusted to include the characteristics of the soils of the water harvesting systems. The soil texture and organic matter were determined for representative profiles. The water holding characteristics were calculated with the texture triangle of Saxton et al. (1986).

To assess the effects of different land use changes resulting mainly from the implementation of water harvesting projects, two diachronic conditions were chosen. The year 1991 was considered as the condition before the large scale implementation of water harvesting system "pre-project" and the year 2004 as the "post-project" condition. The land use map elaborated for the Jeffara region by Hanafi et al. (2003) was modified with the help of a semi-supervised classification of the

Spot XS image of 1991 of the area undertaken by Zerrim (2004). In addition, field checks were conducted. The following classes were distinguished: fruit trees (mainly olives) on *jessour*, fruit trees (mainly olives) on *tabias*, rangelands (mountains, plains, halophytes), and cereals. The runoff curve number (CN) was determined based on the land use and the soil hydrologic group.

To collect the runoff water behind the various water harvesting structures (*jessour* and old and new *tabias*), the SWAT code was modified to allow the use of surface runoff within the sub-basin. This option is referred to as "irrigation from surface runoff". The new structures, which were developed to reduce floods and improve groundwater recharge, were represented in the model as follows: (i) the gabion check dams, installed on the main wadi beds (reach), were modelled as reservoirs but with relatively high K-values (leaky bottoms); (ii) the recharge wells, built for direct recharge of groundwater just upstream of the check dams, were modelled by increasing the K-value of the checks dams.

Runoff events recorded between 1975 and 1992 near the village of Koutine in the downstream area of the watershed were used for model evaluation. Eighteen events were used for model calibration and 16 events for model validation.

2.3.2 Representation of Water Harvesting Practices in SWAT

During rainfall events the runoff generated at the level of the impluviums (catchments) runs onto the terraces of the *jessour* and *tabias*. Part of the runoff water will form temporary ponds with a depth equal to the height of the spillway. It will infiltrate into the soil slowly after the runoff event. The *jessour* are found along the tributaries (talwegs); they receive runoff from the mountain rangelands. The *tabias* receive the runoff generated on their impluviums and the outflow from the *jessour* if they are installed on the same tributary. The outflow from the *jessour* and *tabias* flows into the reach and continues towards the outlet.

The SWAT considers that the runoff coming out of any HRU flows directly to the reach. To harvest the runoff water behind the *jessour* and old *tabias*, an option involving "irrigation from surface runoff" was added to the model code. To control the amount of water to be applied to the HRU, this option used the same parameters as those of the "irrigation from reach" option. The SWAT allows the user to specify a fraction of the runoff (FLOWFR) and a maximum height of water to be put on the HRU (DIVMAX). The value of DIVMAX was set as the equivalent spillway height, which was estimated based on field knowledge. The flow fraction was assumed to be 100%.

2.3.3 Model Evaluation

For the evaluation of the SWAT model application to the study area, runoff events (total daily volumes) recorded at the Koutine station during the period 1975–1992 (DRE, 1974–1992; Fersi, 1985; Ayadi, 1992) were used. The hydrometric Koutine station was installed by the Hydrological Service of the Ministry of

Agriculture (DRE) in 1974. A battery of scales were installed in a cross-section on the wadi close to the village of Koutine and monitored by an observer who lives nearby. During flooding, the observer made notes of the time and the height of the water in the wadi. The data were converted to flow based on a calibration curve (Fersi, 1985).

The runoff events recorded in the annual reports of the DRE were checked first. Records with anomalies (runoff without rainfall, very low rainfall with high runoff, etc.) were discarded. In addition, some events were combined because they occurred on consecutive days. For the daily rainfall data, some events in 1975–76 and 1990 had a shift of one day; these were adjusted accordingly. A total of 34 events were retained: 18 events (Oct. 1975–Nov. 1979) were used for calibration and the remaining 16 events were used for validation. The model was calibrated by changing the values of the representative dike height (DIVMAX) of the *tabia* and *jessour* within reasonable limits.

Graphic and statistical measures were used to evaluate the model performance based on the above data. Using a single goodness-of-fit measure for model evaluation is generally not sufficient (Chu and Shirmohammadi, 2004). Therefore, four statistical criteria were used to evaluate the hydrologic goodness-of-fit: the regression coefficient (r^2); the model efficiency, or the Nash-Sutcliffe coefficient, R^2_{NS} (Nash and Sutcliffe, 1970); the standard error (STE); and the Mean Absolute Error (MAE). The r^2 is an index of the degree of linear association between the observed and the simulated values. The Nash-Sutcliffe coefficient indicates how close the plot of observed versus simulated data is to the 1:1 line. It is calculated as follows:

$$R^2_{NS} = 1 - \frac{\sum_{i=1}^{n}\left(Oi - Pi\right)^2}{\sum_{i=1}^{n}\left(Oi - \bar{O}\right)^2}$$

where O_i is the measured value, P_i is the predicted value, $\bar{O}$ is the average observed value, and n is the number of observed values. The STE expresses the difference between the predicted values (P_i) and the observed data (O_i) as follows:

$$STE = \sqrt{\left[\frac{1}{n(n-2)}\right]}\sqrt{\left[n\sum Pi^2 - \left(\sum Pi\right)^2 - \frac{\left[n\sum OiPi - \left(\sum Oi\right)\left(\sum Pi\right)\right]^2}{n\sum Oi^2 - \left(\sum Oi\right)^2}\right.}$$

Although the Mean Absolute Error (MAE) tells nothing about over- or under-prediction, it is a deviance measure considered for assessing the agreement between observed values and predicted values. It is calculated as:

$$MAE = \frac{1}{n}\sum \left| Oi - Pi \right.$$

3 Results and Discussion

3.1 Water Harvesting Structures Evaluation Tool

A sample of practices along the wadi Hallouf within the wadi Oum Zessar watershed was evaluated using the structures evaluation tool. A total of 12 structures (4 *tabias*, 4 *jessour* and 4 gabion check dams) were evaluated in June 2004 (Table 3).

The evaluation tool shows that all the practices were in fair to good condition (Table 3). The evaluation tool results confirmed this. The cross-section water characteristic for *jessour* and *tabias* received the lowest characteristic scores. Cross-section sediment, surface infiltration, dike material and dike erosion received the highest condition scores for *jessour* and *tabias*. For the four gabion check dams evaluated, dike material was assigned the maximum condition score. A condition scoring pattern for the other gabion characteristics as a whole could not be determined. For a quasi-validity testing of the developed tools, the evaluators ranked the water harvesting techniques (WHT) based on the field observations before computing the WHT condition score using the tool. The evaluators' ranking matched that of the ranking using the evaluation tools.

Three of the four *jessour* evaluated were in good condition and one was in fair condition. All four *tabias* were in fair condition. The two gabions with a recharge well evaluated were in good condition. The two gabions without an evaluation tool evaluated were in fair condition. The presence of a recharge well seems to influence the condition of the gabion.

Due to the long functional life of the WHT and lacking as-built design parameters, the WHT were evaluated using physical inspection of vital characteristics and not by comparison to design measurements. The condition scores provide the present-day level of functionality for the WHT. However, more research is needed to analyze the robustness, repeatability and validity of the evaluation tool. Additionally, more WHT should be evaluated using the developed method to allow for comparisons amongst the functionality of the varying WHT type. An extension of the WHT evaluation tool could involve using the functionality condition scores to represent the impact of WHT in the hydrological model.

3.2 SWAT Modeling

The calibrated values of DIVMAX were 0.20 m and 0.25 m for *jessour* and *tabias*, respectively. The observed and the simulated outflow for the calibration and validation data sets are presented in Fig. 2. The plot shows a reasonably good match between the observed and the simulated values except for some events that occurred on consecutive days. When SWAT is calibrated for continuous streams, it often does not predict exceptional events well (e.g., Chu and Shirmohammadi, 2004; Bouraoui et al., 2004). For the ephemeral flow of Wadi Oum Zessar, the model performed well for some exceptional rainfall events (1975, 1976, 1984, 1990). Nevertheless, some

Table 3 Structures condition score

	Coding								
	Cross-section water	Cross-section sediment	Infiltration potential – direct recharge	Infiltration potential – surface infiltration	Vegetation quantity – cultivated area	Vegetation quantity – catchment area	Dike material	Dike erosion	Condition score
Structure	M_{csw}	M_{css}	M_{RG}	M_{WL}	M_{VG1}	M_{VG2}	M_{DK1}	M_{DK2}	Cs
Jesser 1	1	3	N/A	3	3	2	3	3	10.25
Jesser 2	3	3	N/A	3	2	2	2	3	11.25
Jesser 3	2	3	N/A	3	3	2.3	3	3	11.4
Jesser 4	1	3	N/A	3	3	3	3	3	10.75
Tabia 1	1	3	N/A	3	3	1	3	3	9.75
Tabia 2	1	3	N/A	3	2	2	3	3	12
Tabia 3	1	3	N/A	3	2.7	3	3	3	10.75
Tabia 4	1	3	N/A	3	3	3	3	3	12.75
Gabion 1	1	3	1	3	3	1	3	3	9.75
Gabion 2	3	1	3	2.7	1.3	2	3	1.3	12
Gabion 3	2	2	1	3	3	2	3	3	10.75
Gabion 4	3	1	3	2	Not quantifiable	3	3	3	12.75

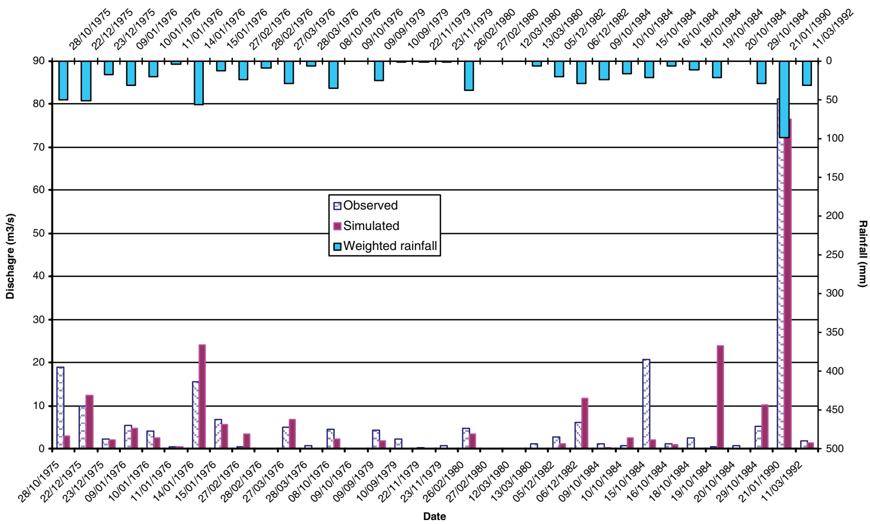

Fig. 2 Observed and simulated outflow during the evaluation period (1975–1992)

Table 4 Goodness-of-fit statistics for observed versus predicted outflow

	Calibration (1975–1979)	Validation (1980–1992)	Whole period
r^2	0.46	0.83	0.80
$R_{NS}{}^2$	0.26	0.83	0.80
STE	4.06	8.39	6.42
MAE	0.68	0.21	0.26

r^2: regression coefficient, $R_{NS}{}^2$: Nash-Sutcliffe coefficient, STE: Standadrd error, MAE: mean absolute error

events were either largely underestimated or overestimated. This could be expected considering that the runoff coefficients of the observed events varied from as low as 3% to as high as 70%. In addition, the spatial and temporal rainfall pattern in the area is never perfectly captured due to the low density of the raingauge network (ten stations).

The results of the goodness-of-fit tests between the observed and the SWAT predicted outflow for the calibration and validation data sets is presented in Table 4. Reasonable correlations were obtained for these outflow data. However, better relations were obtained for the validation period than for the calibration period.

Taking into consideration the scarcity and uncertainty of the data in this typical arid environment, the above results showed that, even under dry conditions with coarse resolution of input information, SWAT could simulate reasonably well the watershed runoff. The values of the performance indicators were similar to those reported for SWAT applications in other regions of the world, such as in the USA (Srinivasan et al., 1998; Chu and Shirmohammadi, 2004), Germany (Fohrer et al., 2001), and India (Kaur et al., 2003).

4 Conclusions

A WHT evaluation tool was developed for *jessour*, *tabias* and gabion check dams. The same characteristics were evaluated for each WHT, but the characteristics were assigned varying weights based on the importance of their contribution to WHT functionality. The evaluation tool was applied to 12 water harvesting techniques (4 *tabias*, 4 *jessour*s, 4 gabion check dams) in southern Tunisia. Five of the 12 practices were in good condition and the others were in fair condition. It is possible that the presence of a recharge well influenced the condition score for gabion check dams. Of the three structure types, *jessour* were found to be in better condition than the *tabias* and gabion check dams. *Tabias* were in the worst condition of the three WHT types. Further research is needed to test the consistency and validity of the tools.

Although watershed modeling is very useful, it is a labour-intensive and time-consuming task, especially the collection and preparation of input data (soil, land use, climate) and the selection of the parameter values. The scarcity and uncertainty of available data, typical for watersheds in the dry areas, complicated this task. Nevertheless, the model is very attractive for application, considering the gradual generalization and widening of the scope of the use of digital data layers and spatial decision support systems by different end-users (e.g., agriculture, environment, planning) in the country (Min. Agr., 2002; OSS, 2004).

4.1 Current and Future Work

Additionally, the effectiveness of the recharge well associated with the Gabion Creek Dam was assessed and improvement to the well design was proposed that will improve the recharge potential of these structures.

Current work is being conducted to couple the hydrologic and erosion models to simulate the water harvesting structures and their impact on sediments, water availability in upstream and downstream areas of the watershed. Coupled with the assessment tool, this integrated hydrologic model is expected to help to assess the feasibility of maintaining these structures at the farm and watershed levels.

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References

Alaya, K., Viertmann, W. and Waibel, T. 1993. *Les tabias*. Imprimerie Arabe de Tunisie, Tunis, Tunisia.

Arnold, J. G., Srinivasan, R., Muttiah, R. S. and Williams, J. R. 1998. Large area hydrologic modeling and assessment. Part I: Model development. *Journal of American Water Resources Assessment*, Vol. 34, No. 10, pp. 73–89.

Ayadi, M. 1992. *Les précipitations et les crues exceptionnelles du 21 et 22 Janvier 1990 dans le sud est tunisien*. Rapport interne, Direction Générale des Ressources en Eau (DRE), Ministère de l'Agriculture, Tunis, Tunisia.

Ben Mechlia, N. and Ouessar, M. 2004. Water harvesting systems in Tunisia. Oweis, T., Hachum, A. and Bruggeman, A. (eds.), *Indigenous water harvesting in West Asia and North Africa*, ICARDA, Aleppo, Syria, pp. 21–41.

Bouraoui, F., Benabdallah, S., Jrad, A. and Bidoglio, G. 2005. Application of the SWAT model on the Medjerda River basin (Tunisia). *Phys. Chem. Earth* Vol. 30, No. 8–10. pp. 497–507.

Bracmort, K. S., Engel B. A. and Frankenberger, J. R. 2004. Evaluation of structural best management practices 20 years after installation: Black Creek Watershed, Indiana. *Journal of Soil and Water Conservation*, Vol. 59, No. 5, pp. 191–196.

Chu, T. W. and Shirmohammadi, A. 2004. Evaluation of the SWAT model's hydrology component in the piedmont physiographic region of Maryland. *Trans. American Society of Agricultural Engineers*, Vol. 47, No. 4, pp. 1057–1073.

De Graaff, J. and Ouessar, M. 2002. *Water Harvesting in Mediterranean Zones: An Impact Assessment and Economic Evaluation*. Tropical Resource Management Paper, No. 40, Wageningen University, The Netherlands.

Di Luzio, M., Srinivasan, R. Arnold, J. G. and Neitsch, S. L. 2002. *Arcview Interface for SWAT 2000: User's Guide*. Texas Water Resources Institute, College Station, Texas, USA.

DRE. 1974–1992. *Annuaire hydrologique*. Direction Générale des Ressources en Eau, Tunis, Tunisia.

El Amami, S. 1984. *Les aménagements hydrauliques traditionnels en Tunisie*. Centre de Recherche en Génie Rural (CRGR), Tunis, Tunisia.

Fersi, M. 1985. *Etude hydrologique d'oued Oum Zessar à Koutine*. Ministère de l'Agriculture, Tunis, Tunisia.

Fohrer, N., Eckhardt, K., Haverkamp, S. and Frede, H.-G. 2001. Applying the SWAT model as a decision support tool for land use concepts in peripheral regions in Germany. Stott, D. E., Mohtar, R. H. and Steinhardt (eds.), *Proceedings of the 10th ISCO conference*, USDA-ARS, West Lafayette, Indiana, pp. 994–999.

Hanafi, A., Genin, D. and Simmoneaux, V. 2003. Occupation des sols et relations entre dynamique des milieux et systèmes de production. Genin, D., Attaia,W., Ciadella, N., Hanafi, A. and Ouled Belgacem, A. (eds.), *Ressources pastorales et dynamique des usages agro-pastoraux*. Rapport scientifique final du thème 1, Projet Jeffara, IRA/IRD, Tunis, Tunisia, pp. 12–21.

Kaur, R., Srinivasan, R., Mishra, K., Dutta, D., Prasad, D. and Bansal, G. 2003. Assessment of a SWAT model for soil and water management in India. *Land Use Water Resources Research*, Vol. 3, pp. 1–7.

Mahdhi, N., Sghaier, M. and Ouessar, M. 2000. *Analyse d'impacts des aménagements de CES en zone aride cas du bassin versant d'Oued Oum Zessar*. WAHIA (Water Harvesting Impact Assessment) Project Report, Institut des Régions Arides (IRA), Médenine, Tunisia.

Ministère de l'Agriculture. 2002. *Carte agricole de la Tunisie*. Ministère de l'Agriculture, SCOT/STUDI/SODETEG, Tunis, Tunisia.

Nash, J. E. and Sutcliffe, J. V. 1970. River flow forecasting through conceptual models: Part I. A discussion of principles. *Journal of Hydrology*, Vol. 10, No. 3, pp. 282–290.

OSS. 2004. *Stratégie 2010 de l'OSS*. Observatoire du Sahara et du Sahel, Tunis, Tunisia.

Ouessar, M., Bruggeman, A., Abdelli, F. and Mohtar, R. 2007. Use of GIS-based SWAT for assessing the effect of water harvesting techniques in Oum Zessar watershed, Tunisia. Bruggeman, A., Mohtar, R. and Ouessar, M. (eds.), *Proceedings of the International Workshop, Watershed Management in Dry Areas: Challenges and Opportunities*, Djerba, Tunisia, 4–7 January 2005, ICARDA publications, Aleppo, Syria, pp. 47–56.

Ouessar, M. 2007. *Hydrological Impacts of Rain Water Harvesting in Wadi Oum Zessar Watershed (Southern Tunisia)*. Ph.D. thesis, Faculty of Bioengineering, University of Ghent, Ghent, Belgium (submitted).

Ouessar, M., Sghaier, M., Barneveld, R. and Zerrim, A. 1999. *Watershed of Wadi Oum Zessar (Médenine, Tunisia): State of Knowledge and Research Methodology*. WAHIA (Water Harvesting Impact Assessment) Project Report. Institut des Régions Arides (IRA), Médenine, Tunisia.

Prinz, D. 1996. Water harvesting: Past and future. Pereira, L. S. (ed.), Sustainability of Irrigated agriculture. Proceedings, NATO Advanced Research Workshop, Vileiro, 21–26 March 1994, Balkema, Rotterdam, The Netherlands, pp. 135–144.

Saxton, K. E., Rawls, W. J., Romberger, J. S. and Papendick, R. I. 1986. Estimating generalized soil-water characteristics from texture. *Soil Science Society of America Journal*, Vol. 50, No. 4, pp. 1031–1036.

Srinivasan, R., Ramanarayanan, T. S., Arnold, J. G. and Bednarz, S. T. 1998. Large area hydrologic modeling and assessment. Part II: Model application. *Journal of American Water Resources Association*, Vol. 34, No. 1, pp. 91–101.

Taamallah, H. 2003. *Carte pédologique de la Jeffara*. Rapport interne, projet Jeffara, IRA/IRD, Tunis, Tunisia.

Zerrim, A. 2004. *Cartographie de l'occupation du sol par l'usage des données de télédétection: Cas du bassin versant Oum Zessar*. Projet de fin d'études, ESIER, Mjez El Bab, Tunisia.

Chapter 8
Degraded Arid Land Restoration for Afforestation and Agro-Silvo-Pastoral Production through New Water Harvesting Mechanized Technology

Michel Malagnoux

Abstract The Keita Integrated Development Project implemented in Niger during the 1980s was an Employment Intensive Investment Project. While working within the project's framework in 1987, Venanzio Vallerani, an Italian expert, noted the slow pace of land reclamation and the demanding nature of the work due to the scarce availability of workers (low population density). Hence, most of the degraded lands with heavy soils were abandoned. To achieve a significant impact, he noted that rapid reclamation of large areas was needed. He invented two ploughs, the "Delfino" (dolphin) and the "Treno" (train), which were adapted to different soil types and were able to reclaim large areas of degraded land. These automatic ploughs built micro-catchment basins at a rate of 700–1,500 "half-moons" per hour (compared with the 1–2 hand made "half-moons" built per day per worker on comparable soils).

This new technology has been tested from 1988 to the present in ten countries (Burkina Faso, Chad, Egypt, Kenya, Morocco, Niger, Senegal, Sudan, Syria and Tunisia), where nearly 100,000 ha were treated. This report is based mainly on results obtained within the framework of the projects Forestry and Food Security in Africa and the Acacia Operation. This technology is compared with other mechanized technologies and hand-made water catchments. Its potential contribution to huge land reclamation programmes, such as TerrAfrica and the Green Wall for the Sahara, is presented.

Keywords Land reclamation, mechanized techniques, water and soil conservation, contour lines

1 Introduction

The Keita Integrated Development Project implemented in Ader Doutchi Maggia in Niger (Department of Tahoua, Keita District) began in 1984 and was a project involving high investment in manpower. While working within the framework of this project in 1987, Venanzio Vallerani noted the slow pace of land reclamation and

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the demanding nature of the work due to the scarce availability of workers (low population density). This explained why the majority of degraded lands made up of heavy soils were abandoned by the farmers. To achieve a significant impact in combating desertification, Dr. Vallerani believed it was necessary to quickly reclaim large areas of the degraded lands. He invented two ploughs, the "Delfino" (dolphin) and the "Treno" (train), which were adapted to different soil types and able to reclaim large areas of degraded lands. These automatic ploughs built water catchment micro-basins at a rate of 700–1,500 "half-moons" per hour (compared with the 1–2 hand made "half-moons" built per day per worker on comparable soils).

2 Traditional Methods of Rainwater Harvesting for Agricultural and Forest Production

In arid and semi-arid zones in the Sahel, between continuous open forest stands in the south and shrub steppes in the north, lies a transition zone characterized by natural fragmented ligneous vegetation cover of more-or-less large swathes of bare soil. This transition zone is commonly known as "striped bush". The input of rainwater in these zones is inadequate to maintain a continuous shrub cover. The bare areas in the ecosystem, act as a catchment basin of both runoff and collected rainwater, and thus provide the complement of water necessary for the area with vegetation cover. This natural example has served as a model for the regional populations, who over thousands of years have developed methods of rainwater harvesting for the benefit of their crops and trees.

2.1 Traditional Methods of Water and Soil Conservation in Agricultural and Agro-Forestry Lands

There are several traditional techniques that have been practiced by populations in various arid and semi-arid zones of the planet. This paper treats only methods that concentrate runoff in productive zones where crop and plantations are situated, and where water extraction or irrigation is not required.

2.1.1 Contour Lines of (Isohypses[1]) and Agricultural Terraces

In order to combat the drop in soil fertility due to the loss of the smallest elements that are washed away by runoff, it is necessary to diminish the rate of water discharge by

[1] An isohypse connects points of equal geopotential height. Isohypses are also called "height contours" (or contour lines).

erecting a barrier made of dry stones or a raised barrier, which are more-or-less permeable and follow the contour lines. These barriers can be improved by planting perennial plants, shrubs or trees. Technically speaking, this is not a water harvesting technique but a means to hamper water flow so as to increase water infiltration in the soil while accumulating the more fertile elements upstream of the barrier.

Over the years, a bench terrace has progressively taken shape and the barrier has been raised whenever necessary. These agricultural terraces can be constructed more rapidly by digging upstream and building an embankment downstream, thus modifying the relief. However, this requires either a large workforce or major mechanical means. The barriers should follow the contour lines very closely because any low point will concentrate runoff, possibly resulting in the loss of the constructions themselves and the origin point of devastating erosion. To minimize this risk, perpendicular compartments can work to limit the lateral movements of water.

It should be noted that the totality of the surface between barriers are cultivated; no micro-reservoir is created on the slope. However, this can be adapted to more arid zones by leaving bare the area directly downstream of the barrier while growing crops in the area directly upstream of the lower barrier. The area that remains bare constitutes a catchment reservoir. This is known as “alternate cultivated strips”.

2.1.2 The *Teras*

In Sudan the *teras* is a plot of land of small dimensions (0,2–3 ha), surrounded by a raised barrier of earth designed to retain runoff from neighbouring zones. It is a method employed by farmers for food crops and allows them not only to capture runoff but also to combat erosion and conserve soil fertility. The arable land is surrounded by a barrier made of earth and raised on three sides (height: 50 cm, width at the base: 2 m). The fourth side, facing upstream, is left open so as to collect runoff. The downstream soil barrier (50–300 m in length) follows the contour lines. Excess water is evacuated by the lateral extremities of the barrier (20–100 m length). The non-cultivated side, for upstream rainwater harvesting, represents approximately 2–3 times the surface cultivated. This method requires between 17 and 34 man/days work per hectare to set up, which is relatively low compared to other manual methods. This method is actually expanding in Sudan and neighbouring countries.

2.1.3 The *Zai*

In arid zones of West Africa, farmers have developed a technique to recuperate degraded lands by planting their crops in micro-basins. This technique, which has gradually improved over time, is called *Zai* (or *Saai*) in Burkina Faso and *Tassa* in Niger. The dimensions of the basins vary according to the nature of the soil (on average, 20–30 cm in diameter and 10–15 cm in depth). They are wider on lateritic (porous) soils and smaller on clayey soils. The distance between the basins is variable, and we note between 12,000 and 15,000 basins per hectare. When digging, the farmer accumulates the removed soil in the form of an enrolled mound downstream of the basin, which is designed to retain runoff. Often, the farmer will add organic fertilizer to the bottom of the basin. Dead and thorny branches are placed on the top of the basin to protect individual crops against herbivores (mostly goats). This method requires about 60 man/work days per hectare.

2.2 Methods of Water and Soil Conservation in Forest Lands

The methods of rainwater harvesting developed by foresters are for the most part, but not solely, founded on the creation of individual micro-catchment basins, i.e. for each tree or for each group of trees. Unlike on agricultural land, where measures employed must be regularly checked in order to maintain efficiency due to the sequence of ploughing, this is not so necessary in forest lands. The measures to collect water are especially important for the installation of young plants (the first years); afterwards the tree draws water resources at greater depths than are needed afterwards. In addition, the measures employed naturally resist for longer due to the absence of ploughing and working of the soil for years following the installation.

2.2.1 The "Herring-bones"

The trees are planted according to the contour lines and in staggered rows between the lines. The earthen mounds meet the plants at a diagonal and bypass them downstream so as to concentrate and retain runoff at the level of the worked area and improve infiltration where the plant is situated (Fig. 1). This technique leaves marks on the ground that have the appearance of herring-bones, or are diamond-shaped. The method is also known as *negarim* in the Middle East and in India.

2.2.2 The Steppe Method

The steppe method is essentially a mechanical method. It is designed to promote the growth of trees and shrubs in extremely arid zones. It involves modifying the soil surface with the use of rooters, deep ploughs or wide discs that break and mix the deep layers of the soil, widely spaced parallel ridges of earth that follow the contour lines are then constructed. These ridges are made from humus, and trees or shrubs are planted on the lower half of the ridges faced towards the slope. It is here that the depth of the humid soil is greatest due to the accumulation of water following the rains. The aim of this method is to maintain a reserve of humidity in the deep soil layers. The ridge spacing is wider as rainfall is lower, thus the water harvesting area between the ridges is expanded. Smaller perpendicular ridges can be made to impede the lateral displacement of water and thus create basins.

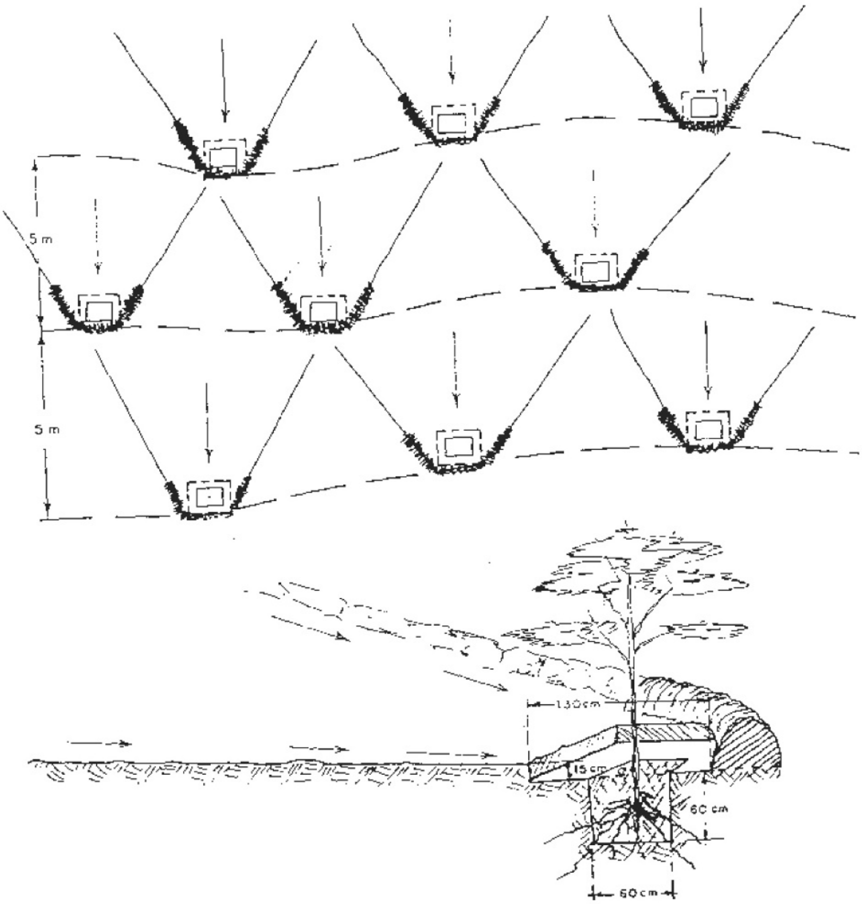

Fig. 1 Herring-bone technique for soil preparation (FAO Conservation Guide No. 20: Arid Zone Forestry: A guide for field technicians)

2.2.3 Alternate Strips

As previously mentioned, crops positioned in alternate strips on agricultural land have been widely used by foresters. On mild slopes in arid and semi-arid zones, this helps obtain linear plantations (of one or more rows of trees) along the contour lines separated by bare zones each making up the catchment basin of the downstream line(s).

2.2.4 Trenches and Hilly Terraces

Techniques consisting of trenches and hilly terraces are used in undulating terrain. The trenches can be continuous, divided by transversal banks, or short and discontinuous. They are dug along the contour lines, and are staggered from one line to

Fig. 2 Hand made hilly trenches (aerial view): The Keita Integrated Development Project. Photo by F. Paladini, 1989

another so that the total runoff can be captured (Fig. 2). The trenches are constructed either manually or mechanically.

Generally speaking, the hilly terraces are narrower than agricultural terraces with only one or two rows of plants. They can be formed on the slope of a hill by either manual or mechanical means, digging upstream while placing the soil downstream. In general, the base of the terrace leans towards the hill in order to collect runoff between the terraces. Due to improved soil humidity, the terrace creates the best conditions for the growth of trees.

2.2.5 The "Half-Moons"

Half-moons consist of a barrier of earth in the form of a radius of a circle, the interior of which is positioned upstream. The barrier is often reinforced by stones. The lowest part of the interior of the half-moon is loosened so that it promotes the penetration of runoff collected by this device. The half-moons are positioned to follow the contour lines and are staggered from one to the other so as to capture the total amount of runoff. They are used for soils on mild slopes and thus follows the sequence of trenches and terraces presented above along the topocline. The size of the half-moon varies considerably: large for pasture improvement on a mild slope, and small for a tree plantation on steeper slopes. In some cases, one or occasionally a few trees are planted at the bottom of the small dike at the interior of the half-moon

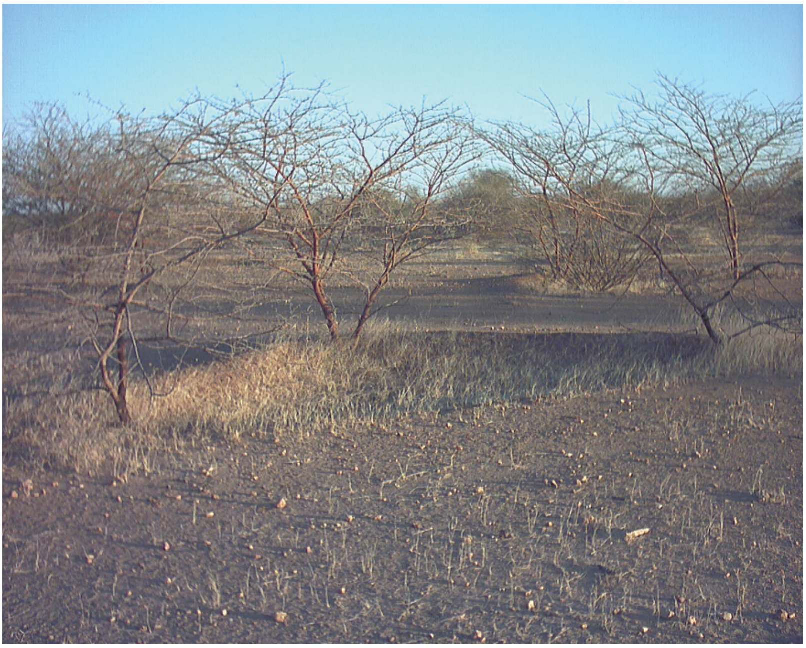

Fig. 3 Half-moons, 3 to 4 years after establishment; three *Acacia senegal* planted in each half-moon, Al Ain (North Kordofan, Sudan). Photo M. Malagnoux, 2002

(Fig. 3). These works require an investment of labour, which varies depending on soil quality, the type of half-moon and the density (number per hectare). An average of 80 man/days per hectare are required. On very hard soils, the norm observed was one to two half-moons per man per day!

2.3 The "Vallerani" Technique

While working within the framework of the Keita Integrated Development Project in 1987, Venanzio Vallerani noted the demanding work needed to restore the degraded lands and requiring 'a high investment of labour'; the work was laborious and slow. He believed it was necessary to quickly reclaim large areas of the degraded lands. To do so, he invented two ploughs, the "Delfino" (dolphin) and the "Traino" (train), which were adapted to different soil types and were able to rapidly construct micro-basins that could collect, concentrate, infiltrate and stock most of the runoff in a basin dug into the ground. The ploughs were proposed by the inventor and accompanied with other technical propositions, such as the ripper (Scarabeo) and the seeder (Lombrico).

2.4 The "Delfino" (Dolphin) Plough

The automatic movement of the plough, alternating from an upwards to a downwards motion, suggests the movement of dolphins riding the waves. With each plunge, the plough digs a semi-circular trench (half-moon) and forms a pad of earth towards the exterior. Each half-moon is broken up when the plough is raised. However, the successive half-moons along the contour line remain connected to each other by a section of the soil made by the ripper, which remains plunged. The work carried out on the soil should follow the contour lines. For the weight of this plough to be lifted and the movement that animates it, and the necessary execution speed for the work to be of good quality, a heavy tractor with the power of at least 180 CV is required. The Delfino plough digs between 12 and 20 half-moons a minute (or 700–1,200 half-moons per hour). The average length of the half-moons is 5 m, with a width of 60 cm and a depth of 50 cm. The theoretical capacity of run-off retention is 1,000 l per half-moon. The number of half-moons per hectare varies depending on the slope and the rainfall of the site under consideration. The soil found between the lines of the half-moons should remain bare and un-worked because it makes up the catchment basin or the half-moons where production will be concentrated.

Unfortunately, this plough cannot be reversed; so should we wish to systematically conserve the lines of half-moons with respect to the slope of the land, withdrawal (without working the soil) of the mechanized unit should be foreseen. Moreover, experience has shown that the runoff is recuperated even by the half-moons in an inversed position – thanks, probably, to the continuous sub-soiling lines.

2.5 The "Treno" Plough (Train)

This plough is heavier than the Delfino, but does not have to be lifted. It digs partitioned furrows and deposits in the furrow shallow and fertile soil at regular intervals (adjustable), which has been collected by a mobile blade situated at the front of the machine, thus creating partitions. The plough is reversible and systematically deposits soil on the downstream side of the furrow. As with the Delfino, the Treno allows the user to work the soil at two levels (subsoiling and micro-basins); on the one hand, it better valorizes the residual fertility of shallow soil horizons, and on the other hand, the runoff benefits because of its highly efficient method of recuperation. It is particularly well adapted to very heavy sub-horizontal soils or on mild slopes. It allows the user to work along the contour lines. The weight of this plough and the speed of the work also requires a heavy tractor of at least 180 CV. It creates between 15 and 25 micro-basins per minute, i.e. 900–1,500 micro-basins per hour. In this case, the number of micro-basins per hectare, i.e. the distance between the furrows, varies according to the slope and the rainfall of the site under consideration. In the same way, the soil situated between the furrows should remain bare and un-worked because it makes up the catchment basin for the furrows where production is concentrated.

2.6 Experiments

Financed by the Italian Cooperation, the first experiments were carried out as early as 1988 within the framework of the Integrated Rehabilitation Project of Damergou (IRPD) in Niger. The results obtained were immediately spectacular. The land treated in the project (clayey plain, easily flooded, abandoned because of the difficulty of manually working the land) obtained, at the first cropping, cereal production that was two to three times greater (1,000–1,500 kg/ha) than that obtained traditionally on dunes (400–500 kg/ha). These results, equally excellent as regards direct sowing of forest tree species, have attracted the attention of neighbouring projects, notably the GTZ (German Technical Cooperation) Agro-Sylvo-Pastoral Project (ASPP) in Niger where this technology was adopted essentially for the sylvo-pastoral land restoration of the abandoned plateau. Between 1990 and 2000, more than 51,000 ha have been treated with excellent results.

The experiments were later repeated; for example, by the International Fund for Agricultural Development (IFAD) in Chad within the framework of the Wadis of Kanem Agricultural Development Project (PDAOK) and the Pilot Programme to Combat Desertification (PPLCD). As concerns environmental improvement and afforestation, the results were disappointing due to the inappropriate selection of worked soils (dunes) and especially because of strong pastoral pressure. However, the results were positive with respect to cereal production. Moreover, the project managers considered that the technology was ill-adapted because of the low lifespan of the constructions (2 years) on sandy agricultural land and the difficulties in maintaining the machines (several breakdowns) in an enclosed territory such as Kanem. A better definition of the objectives and limits of this technique proved necessary.

The Swiss Agency for Development and Cooperation (SDC) (dealing with international cooperation and humanitarian aid) and the International Center for Agricultural Research in the Dry Areas (ICARDA), together with the Syrian and Jordanian governments, carried out experiments in the Middle East. The Danish agency, the International Development Assistance (DANIDA), non-governmental organizations (in Burkina Faso), and private enterprises (in Morocco) have also tested the technology. The Italian Cooperation has supported many projects for testing this technology either directly (e.g., in Sinai, Egypt), through NGOs or even through the FAO (see the following section). The Italian Cooperation is currently undertaking an experiment in the Autonomous Region of Inner Mongolia (China), where 300 ha were treated in May and June 2006 (Alessandro Vallerani, personal communication, 2006).

2.7 Experiments in the Framework of FAO Projects

The Food and Agriculture Organization of the United Nations (FAO) has experimented with Vallerani's technology within the framework of several projects financed mainly by Italy but also, by the Netherlands, such as the project “Prowalo” (GCP/SEN/035/NED) in Senegal, the project “Forests and Food Security in Sahelian Africa” (GCP/RAF/303/ITA), notably in Burkina Faso and Niger, and finally the current project “Acacia Operation” (GTFS/RAF/387/ITA), the full name of which is “Support to Food Security, Poverty Alleviation and Soil Degradation Control in the Gums and Resins Producer Countries”. Some results are spectacular (Figs. 4 and 5), but all, even the failures, provide a wealth of information.

The species that produce gums belong for the most part to the *Acacia* genus, one of the most represented ligneous families on the African continent, especially in arid and semi-arid regions. The “Acacia Operation” project addresses agro-pastoralists of the sub-Saharan drylands, and particularly targets the improvement of agro-pastoral systems on which they depend. In fact, in addition to their role in gum, fodder and fuelwood production, which diversifies household income, these trees ensure the maintenance of conditions favourable to agriculture while at the same time protecting crops against rain and wind erosion, alleviating climatic extremes and, above all, restoring soil fertility. By reinforcing local resources, the project therefore aims to improve and perpetuate the agrarian and pastoral systems, to diversify and reinforce sources of household revenue and thus to contribute to the food security of the populations concerned, not to mention the direct role of gum in their traditional diet. Furthermore, the work involved in harvesting, cleaning and conditioning the gum at the family business level is essentially carried out by women and children. The project therefore particularly addresses the poorest and most vulnerable in rural society.

The project is composed of three distinct and complementary components:

- Development and control of pilot projects’ actions in six producer countries in the targeted region
- Development of a decennial programme for participating countries
- Assistance with respect to regional cooperation within the framework of Network of Natural Gums and Resins in Africa (NGARA) and other related or associated networks

The first component called “pilot actions”, is a series of experiments/demonstrations of this technology in six countries (Burkina Faso, Kenya, Niger, Senegal, Sudan and Chad), aimed at the reclamation of degraded lands for agricultural, forestry and pastoral production or a combination of these productions at the heart of agro-sylvo-pastoral systems.

This project, conceived as a first phase of a long-term project (10–15 years), was particularly determined to collect technical, economic, social and environmental data provided by these experiments. Respecting the limits of technological efficiency, the population affected by these activities maintained responsibility for the choice of sites and especially the choice of production envisaged. In fact, there were many failures due to pressure imposed by promoters and speculators who disregarded possibilities, needs and wishes of the population. In addition to the wide variety of situations demonstrated by the different sites in the six countries, many lessons have been learned and drawn from these experiments and are currently being applied.

Fig. 4 'Glacis' zone; degraded land with superficia crust impeding strongly water infiltration, Gaïkgoata, Burkina Faso, Photo M. Malagnoux, January 2003

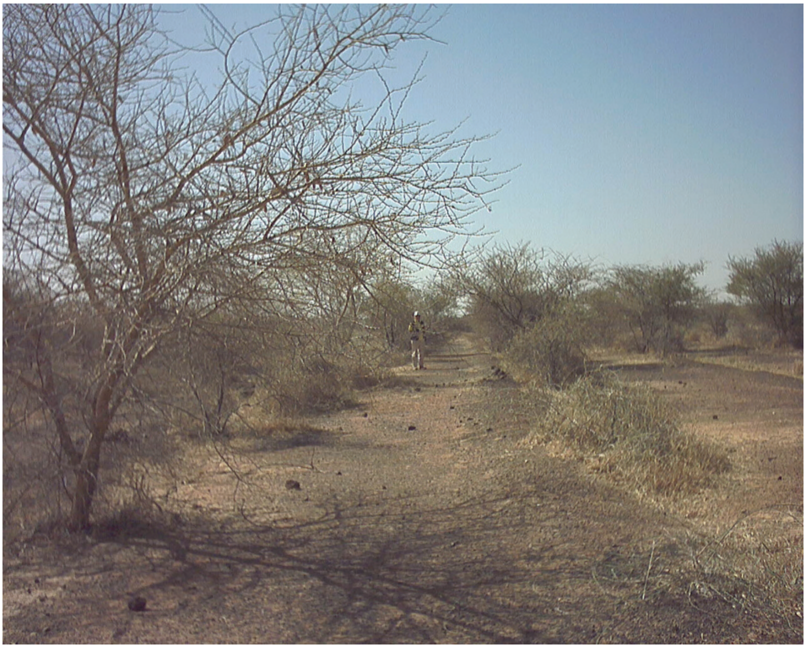

Fig. 5 Identical 'glacis' zone, reclaimed in 1997 by the 'Treno' plough (Project GCP/RAF/303/ITA 'Forests and food scarcity in Sahelian Africa'; Acacia senegal, 6 rainy seasons), Gaïkgoata, Burkina Faso. Photo M. Malagnoux, January 2003

3 Principal Lessons Learnt

Thus far about 100,000 ha have been treated. The principal lessons learnt from past or current experiments concern all the technical, land-use, social, economic and environmental aspects.

The technical aspects concern the conditions of use of the ploughs. The limits of validity of the technology (quality of the soils, slopes, lower and upper rainfall limits depending on fodder, agricultural and forest production objectives) should be clearly defined and scrupulously respected. The quality of the work should be optimal (notably by ensuring that the contour lines are respected). The complexity of the equipment and its relative fragility means that its use should be within an appropriate context and framework including follow-up and maintenance. Finally, the economic use of the material is such that it merits treating as big a site as possible– the surface area of a sole tenant.

This requirement has implications at the land tenancy level. An agreement between all the beneficiaries should be obtained so that the zone treated should not need to consider the issue of land tenancy; plot limits can be re-established once the work has been completed. Note that the recuperation of the productive capacity of sterile land can lead to conflicts of interest between new tenants and former holders of land rights who earlier abandoned these lands.

The social and cultural aspects are particularly important and greatly condition the success and permanence of land recuperation. The local populations should be clearly informed of the technological possibilities, limits and constraints. They should decide on the choice of lands to rehabilitate and of the production possibilities, with full knowledge of the implications of the choices (participative approach). For example, promoters of a project to introduce trees in the pastoral environment complained of the total apparent failure of their work. Conversely, they were greatly surprised to observe that the population was extremely satisfied and had requested an extension of the project due to the immense production of fodder that appeared on the treated lands. These populations regretted the disappearance of the trees, which they could not protect from their herds, and whose fodder value they understood.

Several studies of economic aspects of degraded land reclamation have been carried out. They revealed that the return on investment for agricultural speculation was obtained only after several years. It would therefore be desirable for a private company to carry out land reclamation on behalf of farmers, who would then reimburse this service from the profits obtained from future harvests. However, due to the actual economic conditions of these populations, it is hardly thinkable that they would get into debt over several years with this aim in mind. Providing the restoration of degraded land implies action to combat desertification; environmental restoration or agricultural, pastoral and forest production must be considered an investment payable through national development programmes and international aid.

Certain effects of land recuperation on the environment have been observed. The mineral soil often starts with very low organic matter content. The treatment initiates a gradual humification and a biological increase of micro- and macro-flora and fauna. When the treated surfaces are significant, this biological increase is apparent at the level of entire regions with spontaneous regeneration of plant species that had disappeared or had become very rare, as well as the reappearance of wild animals (e.g., the "agro-silvo-pastoral" project in Niger). In-depth studies still need to be carried out. The humification of soils should also be studied from the point of view of carbon dioxide sequestration; since even this sequestration is low per surface unit, the treatable zones are so vast that this possibility should not be ignored.

Finally, it is futile to restore land if the causes of their degradation have not been tackled. The investments should be made on the condition that a formal agreement to adopt sustainable management of the restored lands, new productive capacities and resources. The tools and means of this sustainable management should be made available to the population.

4 Conclusions

Correctly utilized, the Vallerani technology is a new tool capable of recuperating significant areas of degraded lands – 1,500–2,000 ha/year per mechanized means (a tractor and a plough). Naturally, it has its place alongside other techniques in important programmes to combat desertification, such as the second phase of the "Acacia Operation" and initiatives, such as the African Union is green belts to hamper the spread of the Sahara, and programmes such as TerrAfrica.

Bibliography

Antinori, P. and Vallerani,V. 1994. Experiments with water harvesting technology with new special ploughs. *Water Harvesting for Improved Agricultural Production: Proceedings of the FAO Expert Consultation, Cairo (Egypt, 21–25 November 1993)*. Rome, FAO, pp. 113–132.

Antinori, P., Vallerani, V. and Vallerani, S. 2002. *Le Système Vallerani: Une technologie spécialement conçue pour la lutte contre la désertification dans les régions arides et semi-arides* Rome, FAO. (English version).

Besse, F., Guillobez, S. and Pirot, R. 2002. *Projet pilote de lutte contre la désertification (PPLCD): Projet de développement agricole des ouadis du Kanem (PDAOK): Mission d'évaluation de la campagne 2001*. CIRAD, Montpellier.

Casadei, G. 2005. *Manual on the Use of Mechanized Water Harvesting Technology (Vallerani System)*. Project GTFS/RAF/387/ITA "Acacia Operation". FAO, Rome.

Critchley, W., Siegert, K., Chapman, C. and Finkel, M. 1991. *Water Harvesting: A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production*. FAO, Rome. Accessed: http://www.fao.org/docrep/u3160e/u3160e00.htm#Contents

Detraux, M. and Keita, M. N. 1999. *Etude de l'impact du travail des charrues 'Delfino' et 'Treno' sur la récupération des terres fortement dégradées en Afrique sahélienne*. Projet GCP/RAF/303/ITA. Forêts et sécurité alimentaire en Afrique sahélienne: composante Burkina Faso. FAO, Accra, Ghana.

Detraux, M. and Lankoande, I. 1999. *Guide méthodologique et technique pour la récupération des terres fortement dégradées au nord du Burkina Faso à l'aide des charrues 'Delfino' et 'Treno'*. Projet GCP/RAF/303/ITA. Forêts et sécurité alimentaire en Afrique sahélienne: Composante Burkina Faso. FAO, Accra, Ghana.

Fall, M., Ndiaye, O., et al. 2006. *Recherche/développement sur les impacts biophysique et socio-économique de la « Technologie Vallerani » dans les sites pilotes au Sénégal: Rapport préliminaire*. Projet GTFS/RAF/387/ITA. Opération Acacia; FAO, Dakar (Sénégal).

FAO. 1980. Conservation des ressources naturelles en zones arides et semi-arides. *Cahier FAO Conservation,* No. 3. FAO, Rome, 1980.

———. 1992a. Foresterie en zones arides: Guide à l'intention des techniciens de terrain. *Cahier FAO Conservation,* No. 20. FAO, Rome. Accessed: http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/T0122F/T0122F00.htm

———. 1992b. Rôle de la foresterie dans la lutte contre la désertification; Travaux de la Consultation FAO d'experts sur le rôle de la foresterie dans la lutte contre la désertification. Saltillo, Mexique, 24–28 juin 1985. *Cahier FAO Conservation,* No. 21. FAO, Rome. Accessed: http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/T0115F/T0115F00.htm

———. 1994. Water harvesting for improved agricultural production. *Proceedings of the FAO Expert Consultation, Cairo, Egypt, 21–25 November 1993*. FAO, Rome.

FIDA. 1999. *Projet pilote de lutte contre la désertification (PPLCD): Projet de développement agricole des ouadis du Kanem (PDAOK). Test de la technologie mécanisée de conservation des eaux et des sols: Document de conception*. FIDA, Chad.

Hudson, N. W. 1987. *Soil and Water Conservation in Semi-Arid Areas*. FAO, Rome. Accessed: http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/T0321E/T0321E00.htm

Long, A. 2003. *Etude économique sur la récupération de l'eau pluviale par la technologie mécanisée: Cas de la province du Soum, au nord du Burkina Faso*. FAO, Ougadougou, Burkina Faso.

Prinz, D. and Malik, A. H. *Runoff Farming*. WCA InfoNet. Accessed: http://www.wca-infonet.org/servlet/BinaryDownloaderServlet?filename=1028018182875_wca_infonet_runoff_farming_prinz_malik.pdf

Roose, E. 2002. *Analyse du système des banquettes mécaniques: Propositions d'améliorations, de valorisation et d'évolution pour les gouvernorats de Kairouan, Siligana et Zaghouan, Tunisie*. Projet GCP/TUN/028/ITA. FAO, Montpellier.

Session III
Monitoring and Forecasting of Dryland Ecosystem Dynamics

Session Chair: Dr. Gisela Alonso Dominguez
Rapporteur: Gertjan B. Beekman

The presentations in Session III on the monitoring and forecasting of dryland ecosystem dynamics for sustainable development policies, treated a vast spectrum of topics covering institutional, policies and conceptual models dealing with planning and development approaches to desertification issues.

Comprehensive views were also outlined concerning the monitoring, assessment and definition of land degradation indicators. Forecasting and prediction models were also discussed, as were integrated management practices, which were reported at the village level and involved local stakeholders.

A further synthesis of the papers covering the aforementioned topics is given below.

Synthesis of Presentations

A. Dr. Mohamed S. Abdel Razik, University of Alexandria, Egypt
Thematic procedures to evaluate the impact of anthropogenic activities on the loss of biodiversity as a component within the context of climatic changes were presented. Uncontrolled actions are seen as a further threat to perennial species.

B. Dr. Mongi Sghaier, Institut des Régions Arides (IRA), Tunisia
Monitoring for the assessment of desertification provided the data for a GIS – Local Environmental Information System that produces spatial, ecological and agricultural balances. The final output of the model is to be made available to the various development agencies of Spatial Decision Support System in the planning and monitoring of plans to combat desertification and natural resources management in dryland areas.

C. Dr. Jesse T. Njoka, University of Nairobi, Kenya
The coalition of national government institutions was discussed as a need in subregional and eastern Africa to establish a long-term environmental observatory system in line with the ROSELT premises.

D. Dr. Moussa Karembé, Université de Bamako, Mali
Evaluations of the effects of soil protection, production of firewood and anthropogenic activities as components of climatic change were considered with respect to Sahelian region located in Mali.

E. Dr. Freddy Nachtergaele, FAO, Italy
The Land Degradation Assessment in Drylands (LADA) aims to develop assessment tools to collect up-to-date information on the status, impact and drivers of land degradation at local, national and global levels. To achieve this, it has developed a flexible methodological framework that relies on traditional and digitally assisted methods of data collection. The assessment tools represented invaluable input information for GIS and DSS modeling.

F. Dr. Abdi Jama, Texas A&M University, USA
To assist production systems, a new toolkit was developed. As an automated modeling package, it is intended to help mobile dry-rangelands livestock keepers in East Africa to cope with meteorological condition extremes. With such tools, decisions about current and future prevailing forage conditions will guide their mobility and decision-making patterns, which are thereby made more consistent.

G. Dr. Mohamed Ismail, Ministère de l'Environnement et du Développement Durable, Tunisia
The presentation proposed a conceptual model to evaluate the outcomes of institutional and structural changes that take place by considering a set of benchmarks as time references in modeling scenario changes.

H. Mr. Ryan L. Perroy, University of California, Santa Barbara, USA
Approaches to forecasting dryland degradation and recovery processes based on remote sensing and geostatistical analysis to predict the future consequences for drylands were presented. The focus was on the development of an interdisciplinary approach for dryland ecosystem forecasting that combines remote sensing, soil science and geostatistical analysis of limited territories such as islands.

I. Dr. Raghuvanshi Ram, Regional Research Laboratory (CSIR), Bhopal, India
The application of a Decision Support System (DSS) for drylands watershed management at village community level is highlighted as a sustainable development approach in semi-arid regions. GIS and DSS modeling could provide methods to decision makers and stakeholders in the decision-making processes for the integrated watershed management programme in drylands concentrating on aspects of water resources management.

J. Mr. Abdoulaye Saley Moussa, North-West University, South Africa
Research on indicators of soil degradation is necessary in communally managed rangelands in order to assist land managers to develop strategies for conservation, restoration and sustainable use of soil resources in these rangeland ecosystems.

Conclusions

a. There is an evident need for further scientific assessment of desertification and land-degradation processes, taking into account their negative social, economic and environmental impacts.
b. Mismanagement of soil, water and other natural resources, as well as human impacts, have been aggravating factors contributing to poverty, food insecurity and human suffering.
c. Local dryland communities should be active participants in R&D projects implemented for their benefit, guided by national scientific communities and in close connection with decision-making bodies.
d. Certain relevant themes deserve particular consideration: soil and freshwater management; conservation of biological and cultural diversity; monitoring and forecasting of dryland ecosystems.
e. GIS and Decision Support Systems have an important role to play in plans to combat desertification, and in natural resource management in dryland areas.

Session III
Monitoring and Forecasting of Dryland Ecosystem Dynamics

Chapter 1
Plant Diversity Changes in Response to Environmental Drivers and Pressures at El Omayed 'ROSELT/OSS' Observatory, Egypt

Mohamed S. Abdel Razik

Abstract The Observatory adopted a thematic procedure of evaluating and monitoring changes in natural resources. Data from previous studies were also reworked to fit into the themes being monitored. Temporal trends were evaluated using polynomial curve fitting, which were confirmed by statistical analyses. The extracted trends indicate a steady increase in air temperature, relative humidity and annual rainfall, while wind speed declined. The standardized seasonal rainfall shows an autumn trend that approximates the annual trend with amplitude of five years, while rainfall during the winter declines and inclines during above the long-term average during spring. Concurrently, sodium, sulfate and chloride soil concentrations increased rapidly in the late 1990s, together with increases in the very fine sand fraction, which reflects the active erosion and deposition processes associated with recent human interference. There is a general process of recharging plant species diversity (long-term records; 122 perennials and 104 annuals) in the late 1990s following a sizeable decline; 26 perennials with declining density and spatial occupation can be considered at threat. Some of these species are transient and show a three-year cycle of species replacement (turnover when related to added species). The change in the diversity of perennial species is allied to changes in rainfall, temperature and wind speed related to the climatic, salinity, bicarbonate, calcium, and sulfate of the edaphic variables. This also applies to endangered species, where especially air temperature and soil sulfates are the most determinant driving factors. Further, a shift of the rainfall above the long-term average from winter to spring elucidates the trend of change detected in the diversity. It is concluded that the diversity of biotops (spatial heterogeneity in habitats) in the area is the influential base for the biodiversity and is greatly affected by human impact. Concurrently, climatic changes and the associated environmental degradation of soil resources are more cyclic (recurring) phenomena, which reflect specific feedback effects on biodiversity in the region.

Keywords Plant species diversity, global environmental change, long-term monitoring

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1 Introduction

The need for the detection and understanding of environmental change is evolving, especially in view of the increasing rate and extent at which it is happening. This has caused greater interest in long-term monitoring of global environmental change and biophysical components, including biodiversity.

From an ecological perspective, studies on biodiversity (alpha diversity) cover local samples in limited areas of the community in order to determine the degree of dominance, equity or the number of rare species as a basis for estimating the structure and function of these communities (Halffter, 1998). Complementarily, the landscape scale, or the mesoscale perspective as Ricklefs and Schluter (1993) termed it, uses a study unit that varies in size between the local and regional spatial scales with a time scale ranging from decades to centuries.

Dominant ecological effects at the local level and historical effects – biogeographical or evolutionary – at broader levels are registered on the landscape scale where the consequences of human impact are most evident (Halffter, 1998). Thus, species diversity from a landscape perspective could be analyzed as a function of the heterogeneity of the physical and biological environment on the one hand and as a function of human activity on the other hand (Noss, 1983; Franklin, 1993).

From the conventional perspective, all anthropogenic modifications to pristine communities result in a loss of species richness. Halffter (1998) argues that this can occur at the local level (alpha diversity), but may produce the opposite effect over a landscape (gamma diversity). Fjeldsa and Lovett (1997) also referred to the minor attention given to the study of the cyclic change impacts of the global climate on local and regional turnover rates of species that show erratic changes.

This paper concerns El Omayed ROSELT Observatory[1], which was established in 1996 in the western Mediterranean region of Egypt, in an area where, over the last few decades, human impact is interacting with natural causes, notably climate change, leading to the degradation of natural habitats. This article presents some of the work conducted in the Observatory (first phase programme, 1996–2000) and provides examples of analyses and interpretations undertaken to detect change in biodiversity at the local and regional levels in relation to contemporary and future environmental issues.

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[1] El Omayed Observatory (Egypt) is a unit of the programme of 'Long-term Ecological Monitoring Observatories Network (ROSELT)' of the Observatoire du Sahara et du Sahel (OSS), which conducts the monitoring of the basic environmental drivers, of pressures on and responses to environmental change with the aim of combating desertification and implementing sustainable development plans. The programme links field data, remote sensing data and a modeling approach for the detection and understanding of long-term change in natural and disturbed areas.

2 Material and Methods

One major theme involved in the programme of the Observatory is the use of climatic and edaphic data to explain the trends of change in species diversity, and to evaluate species turnover (beta diversity) under the influence of land-cover conversion (human impact), including identification and mapping of habitats (and of land-use types) most apt to affect biodiversity (biotopes).

The Observatory has 12 permanent sampling plots representing the different habitats and/or ecosystems, and 17 pilot areas along a fixed transect layout (25 km, north-south) which cover the variations at the landscape scale. The plots are intensively studied and monitored on a seasonal basis, while the transect is extensively sampled on an annual basis.

The habitats covered in the programme are: inland plateau (plots 1 and 2), inland ridges (plots 3), non-saline depressions (plots 4), cultivated areas (plot 5), saline depressions (plots 6), and coastal dunes (plots 7). A, B and C designates representative plots within a habitat. Concurrently, there are 16 microhabitats (T1–16) represented by 24 micro-sites (designated by a, b and c) that crosses the sampling transect.

The monitoring themes include recording and analyzing climate variables, soil status, plant abundance and species diversity. The database is included in the Annual Reports of the Observatory. The trends of temporal change in the different measures and variables were evaluated using polynomial-curve-fitting methods, while statistical and numerical analyses were used to confirm the degree of these associations.

Data from previous studies in the area (some 20 years) was reworked to fit into relevant themes. The method adopted to overcome the problem of inconsistent units and procedures in collecting data by different researchers was simply applying independent ranking of measures into classes (pseudo-values). These are then used for detecting the trends of change using the curve-fitting technique.

Species diversity indices (or genetic diversity) are evaluated at the levels of habitat (alpha), community (beta), and the whole area of observatory (gamma) Whittaker, 1972; Pielou, 1975; Magurran, 1988; Ricklefs and Schluter, 1993).

3 Results

The general trends of change in climatic variables on a long-term temporal scale indicates a steady increase in the mean daily temperature, relative humidity and annual rainfall (by 2–3°C, 10–15%, and 20–30 mm, respectively), while that of the wind speed is declining (Fig. 1).

The standardized rainfall measurements over the annual and the seasonal temporal scale result in a trend of temporal change for autumn seasons, which is similar to that of the annual measures, implying consistency of rain events during autumn

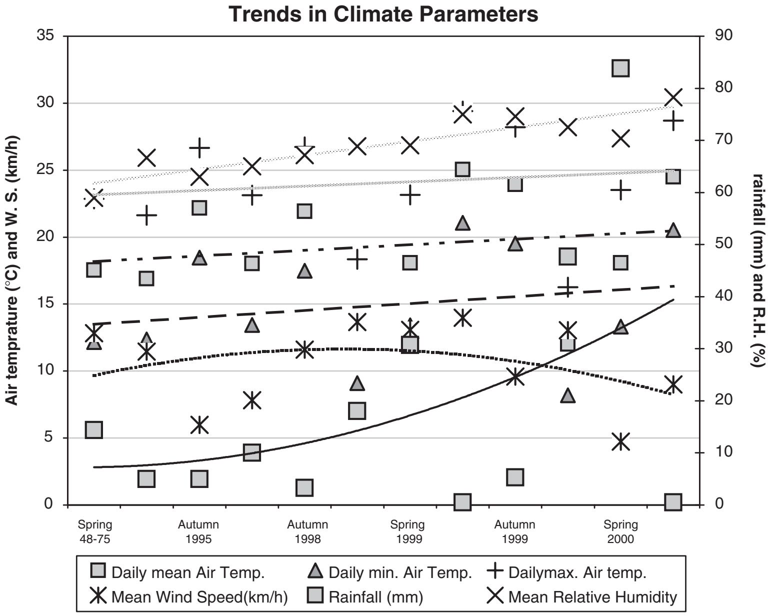


Fig. 1 Trends of change in the climatic measures on the long-term temporal scale

(both have a "sin" curve around a long-term mean with amplitudes of five years period; Fig. 2). At the same time, while the rainfall trend during the winter seasons shows a stepwise decrease below the long-term average, starting in 1995, it shows a continuous increase above the average during the spring seasons.

Soil trends assigned the largest variation to sodium, sulfate and chloride contents (salinity), which increased rapidly late in the 1990s associated with similar trends, but to much less extent, for both calcium and bicarbonate contents (Fig. 3). These trends correspond to a remarkable change in the soil texture during the same period, incorporating larger components of the very fine sand fraction.

The temporal changes in the soil properties of the different habitats define the inland ridges as having the most stable conditions (least differences among years) with an obvious increase in its soil finer particles (Fig. 4). All habitats exhibit increases in soil contents, especially calcium and bicarbonates, while the inland plateau is experiencing a sharp change in its soil texture associated with the increase of sulfate content. However, this trend was lately reversed with declining sodium and sulfate and increasing calcium and bicarbonate contents associated with the increase in the coarse and fine fractions of the sand.

The long-term records at the landscape scale of the Observatory assign species richness values to 122 perennials and 104 annuals, of which the sampling plots account for 77%. Some species have common occurrences in several habitats (12 species), while others have a restricted distribution to a single habitat (total of 72 species).

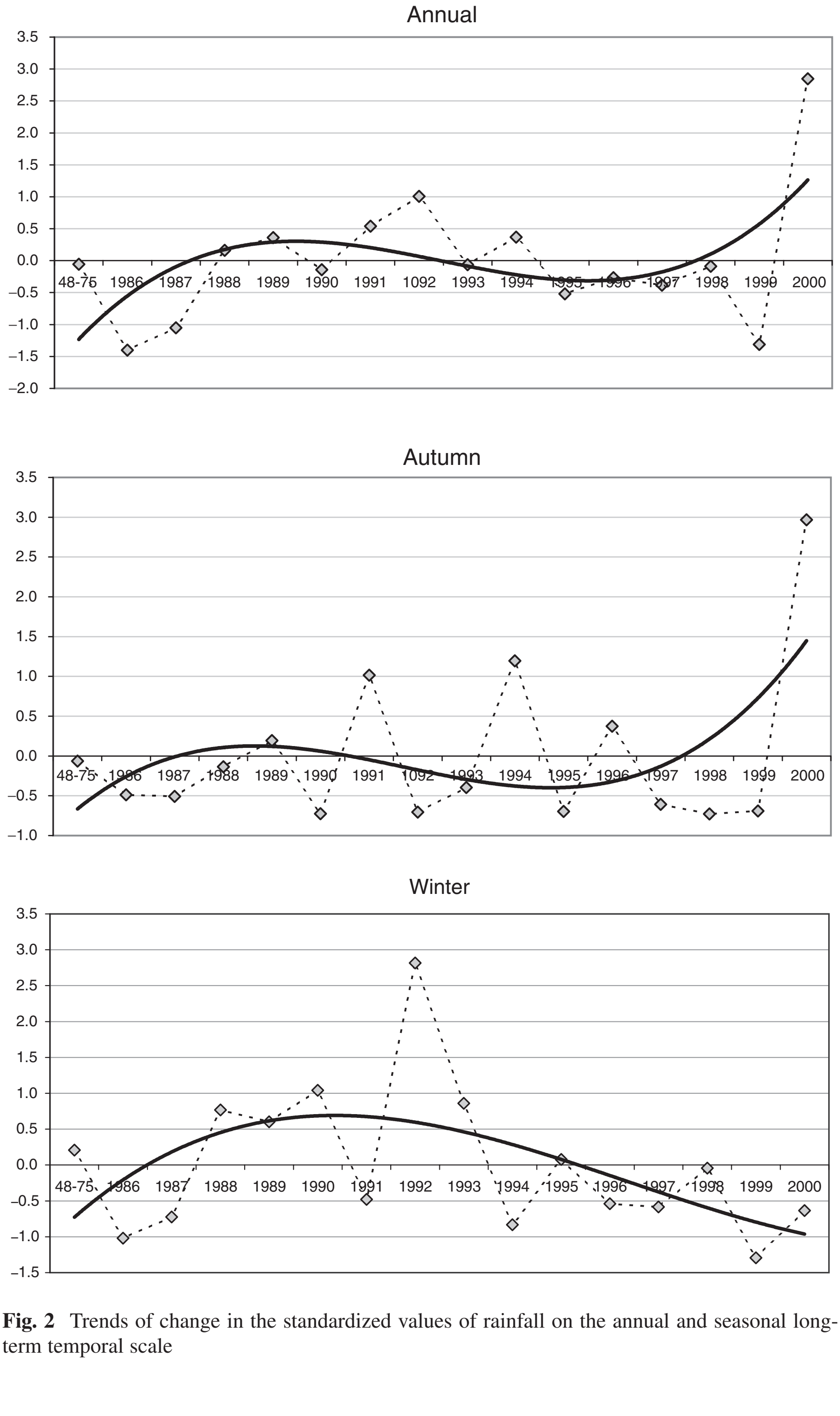


Fig. 2 Trends of change in the standardized values of rainfall on the annual and seasonal long-term temporal scale

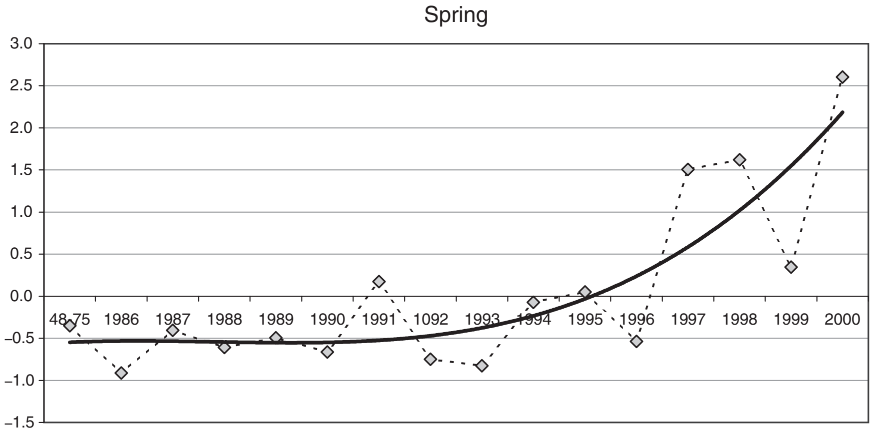


Fig. 2 (continued)

The trends in the change of richness in perennial species at both the spatial (habitats) and the temporal scales demonstrate two general findings (Fig. 5). The first is that inland ridges support the highest plant diversity (plots 3A and 3B; where 18 species are habitat-specific). The second finding is that, except for the inland plateau (1A and 2A; 14 species are habitat-specific), where the trend of plant diversity is declining, there is a process of rapid recharge of species diversity (starting in 1999) after a sizable decline along the preceding time period (starting in 1990). Moreover, the source data reveals that the change in density of the various plant species is unresponsive among habitats (having similar change behaviour) while changing with time in all habitats as imposed by the driving factors (e.g. climate) generally in force.

In terms of change of richness in the perennial species, it tends to increase slightly along the temporal scale with a trend average of about 60 species. This trend differs with life form – notably the chaemephytes (the dominant form) and phanerophytes, the ligneous component of plant communities, are continuously increasing at the expense of the hemicryptophytes and geophytes (Fig. 6), while annuals started to increase in early 1999 after a continuous decline in the preceding years.

The trend in absolute temporal change that relates the perennial species richness to the climatic variables (Fig. 7) indicates the increasing number of species subject to the increasing amount of rainfall irrespective of event timing, while the number decreases with increasing mean daily air temperature, and also decreasing at the intermediate level of wind speed designated by the bottom on the richness-wind curve. Similarly, the number of species drops to a minimum level at intermediate levels of salinity, calcium and bicarbonate content, while it is a maximum at the intermediate level of sulfate content. Moreover, the phenology trends of perennial species at the closing of the last decade (Fig. 8) indicate that the vegetative phase is expanding at the expense of both flowering and fruiting phases. The seedling

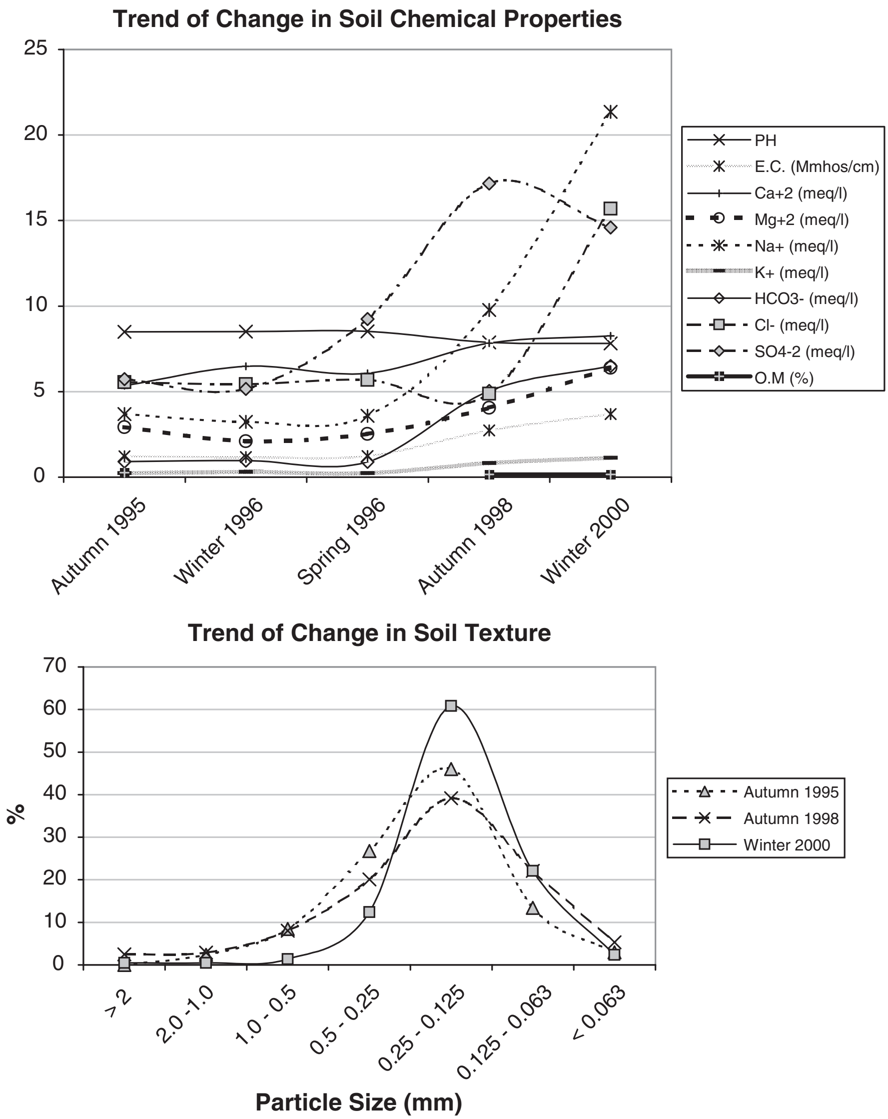


Fig. 3 Trends of change in soil characteristics in five-year period

phase is more-or-less similar to the behaviour of annuals that experienced a decline in their different phenophases towards 2000.

The data inspection testifies that 26 perennial species exhibit a great decline in density and in spatial occupation (restricted niche) since they are mostly linked to specific habitats. The trend of change in their number was slightly increasing

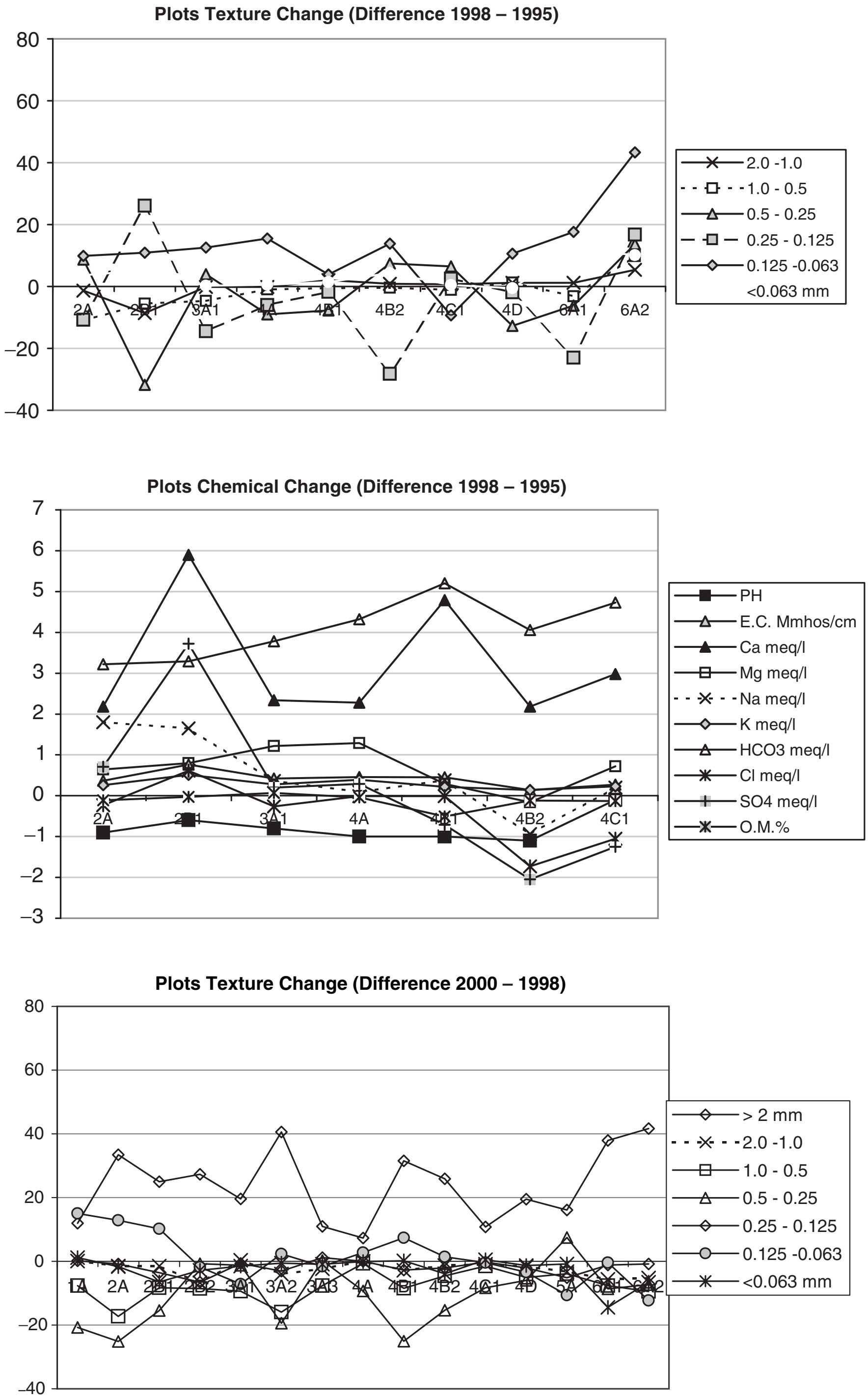


Fig. 4 Variations in soil characteristics of the different habitats 1995–1998 (left) and 1998–2000 (right)

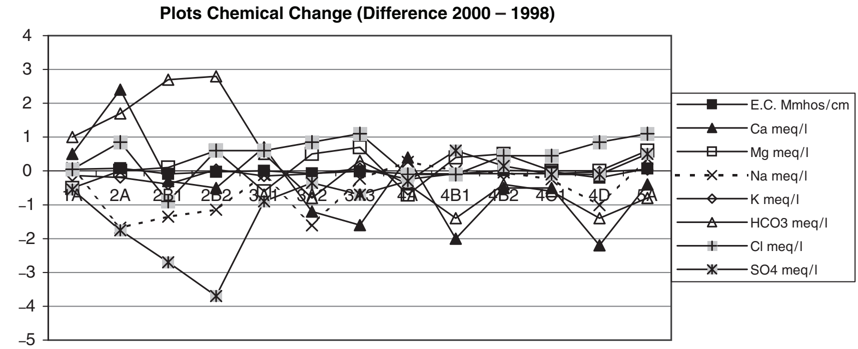


Fig. 4 (continued)

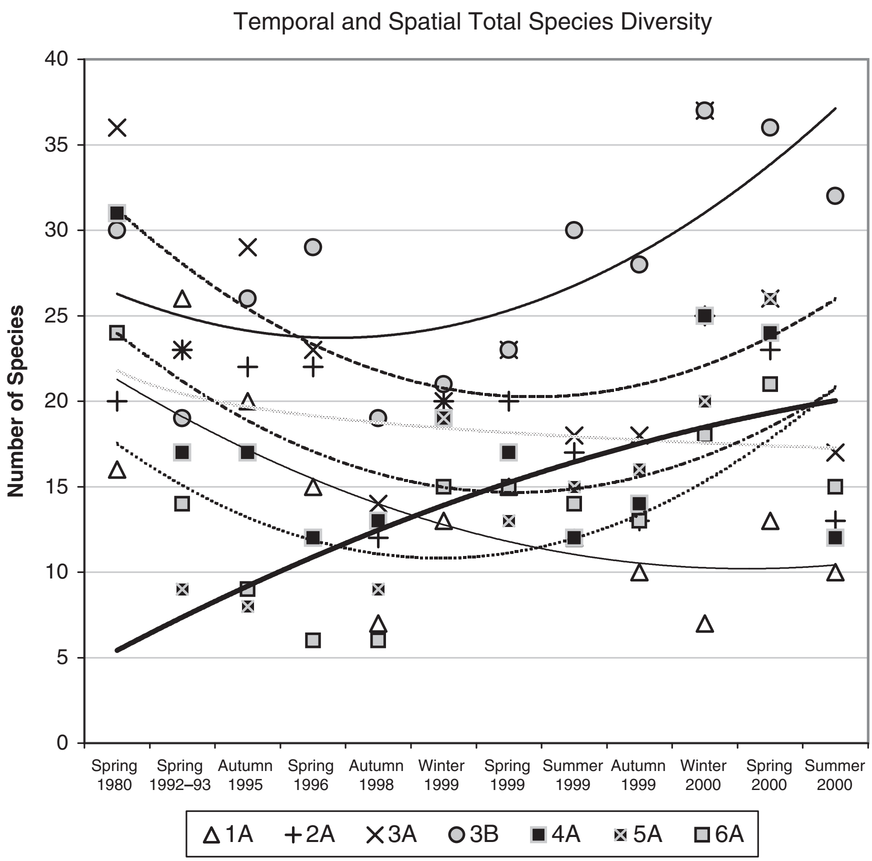


Fig. 5 Trends of change in species richness on spatial (habitats) and temporal (years) scales

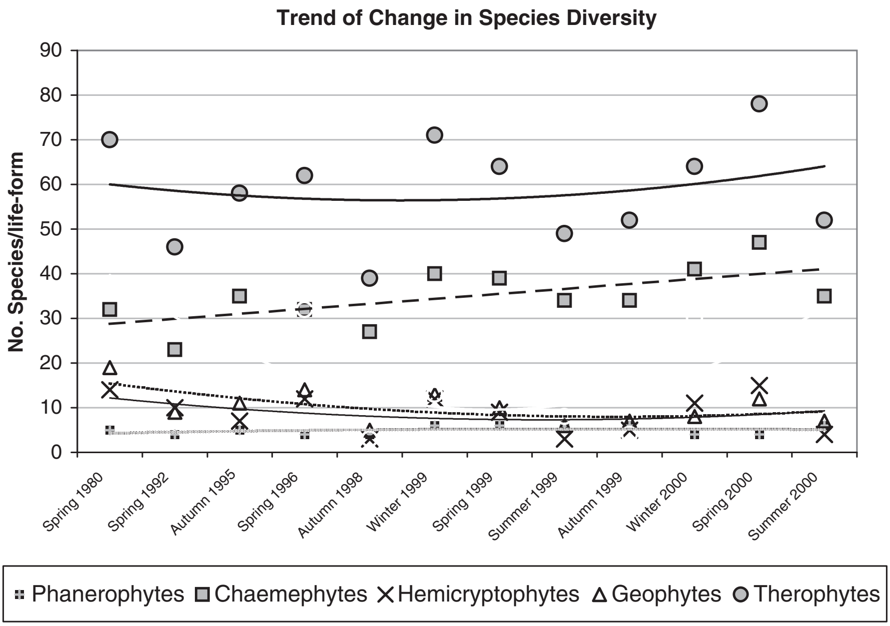


Fig. 6 Temporal trend of change in total perennial species richness and within life forms on landscape scale

while their measures of density and presence percentage were decreasing towards the close of the last decade (1999) followed by reversing the trend towards an increase during 2000 (Fig. 9). The ligneous component approximates 54% of these species (2 phanerophytes, 12 chaemephytes, 6 hemicryptophytes and 6 geophytes).

Relating the number of endangered species to climatic and soil measures (Fig. 10) indicates a trend in terms of temporal change similar to that of other species, while calcium had more rhythmical influence at different concentration levels. Concurrently, many of the endangered species are transient as they are recorded only in one year (23 species) or only in two years (7 species). Of these, five species were recorded only once in the early 1990s (Fig. 11) that were recorded again in the middle of the decade and again at its end, followed by even higher disappearance of certain species in 2000 (up to eight species in a single recording). However, in 2000 the observatory area was recharged by other species that were previously recorded only in one year during the last decade (six species).

The general trend of local species diversity, within the source database, shows a remarkable decrease in alpha diversity and evenness by increased disturbance level coinciding with the increase in dominance of a few species (only one strong dominant species in many plots), which are adapted to live in a disturbed

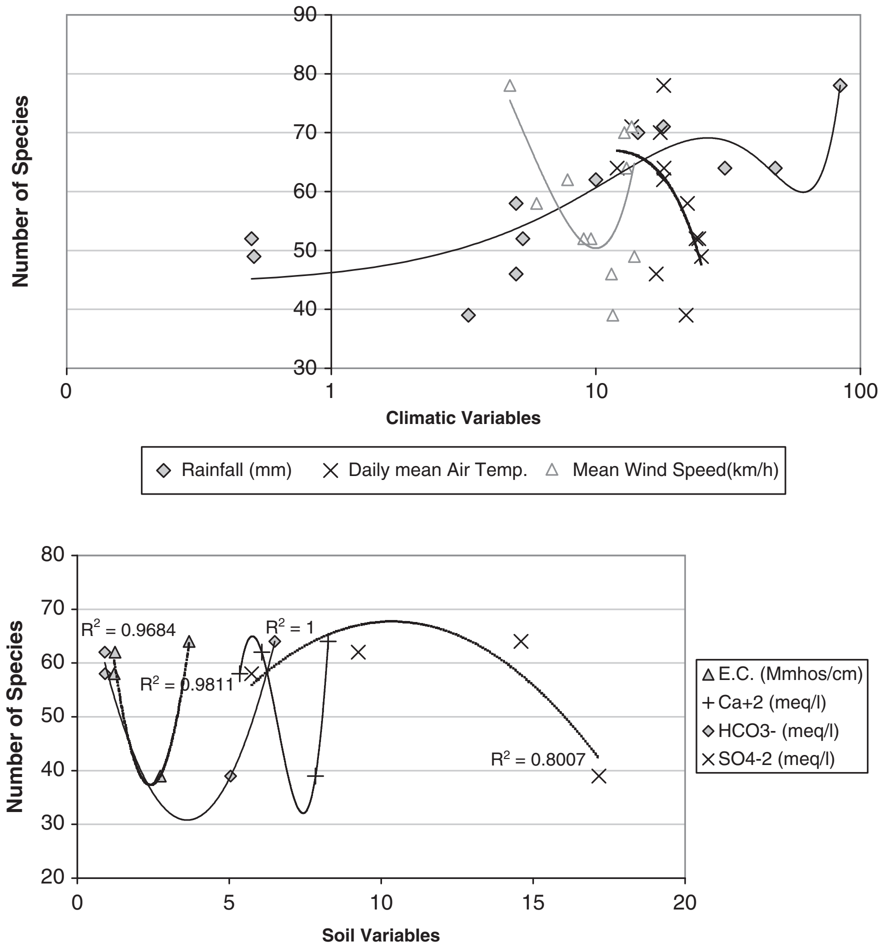


Fig. 7 Trends of the relationship between species richness and selected climate variables (left) and soil measures (right)

environment. On the other hand, less disturbed sites have a larger number of frequent and most frequent species as measured by Hill's number N1 and N2.

Alpha and gamma diversity indices are used here to detect variations on both the spatial and the temporal scales with further measurements of species turnover among habitats. The habitats of inland ridges and the inland plateau, which exhibited the highest values of alpha diversity (richness), also possessed a larger positive value of species turnover. The temporal variations in species diversity of sampling plots on both the local (habitats) and the landscape scales (Fig. 12) indicate trends that both coincide with species replacement throughout the years (beta values) and overall diversity (gamma values). Examining the computed

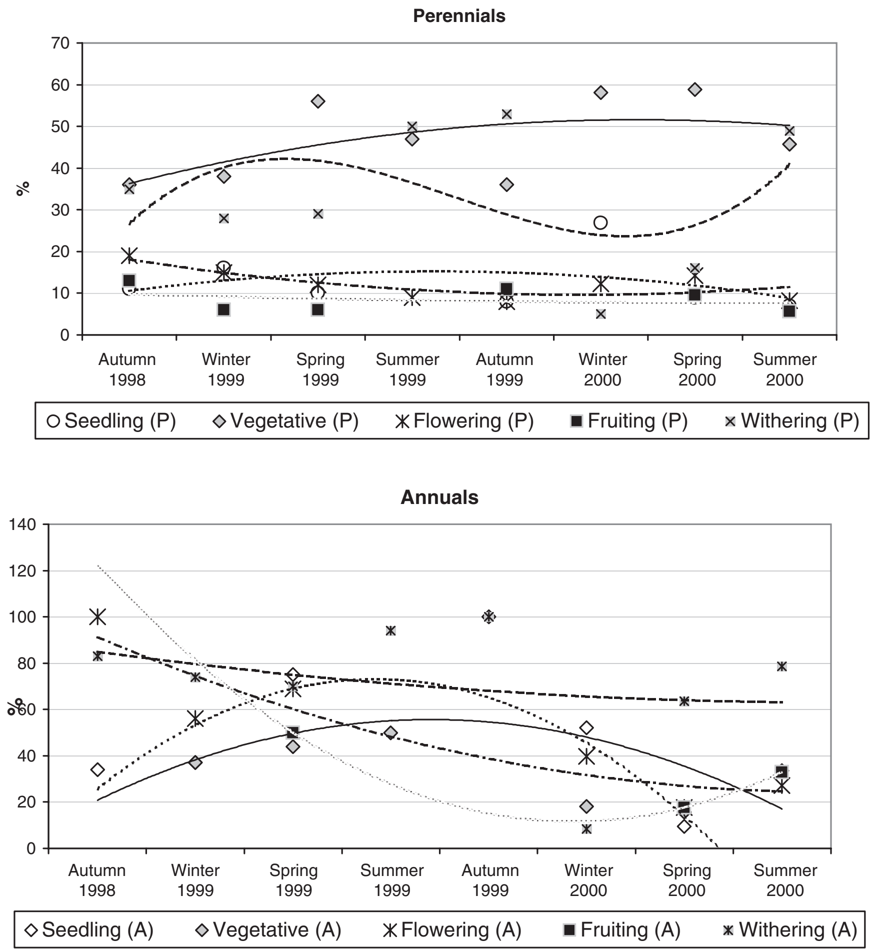


Fig. 8 Trends of change in the average phenological behavior of plants with time

gamma diversity for different years indicates the occurrence of detectable temporal variability at the landscape level that is linked to temporal variations in both alpha and beta diversity values.

The alpha diversity indices of species in pilot areas along the transect shows great variability, representing the different intersected micro-habitats with higher values during 2000 compared to 1999 (Fig. 13). Similar variability is detected for beta diversity and species turnovers in these micro-habitats. While on the landscape scale, the value of gamma diversity is higher for 2000 due to higher alpha and beta diversity indices.

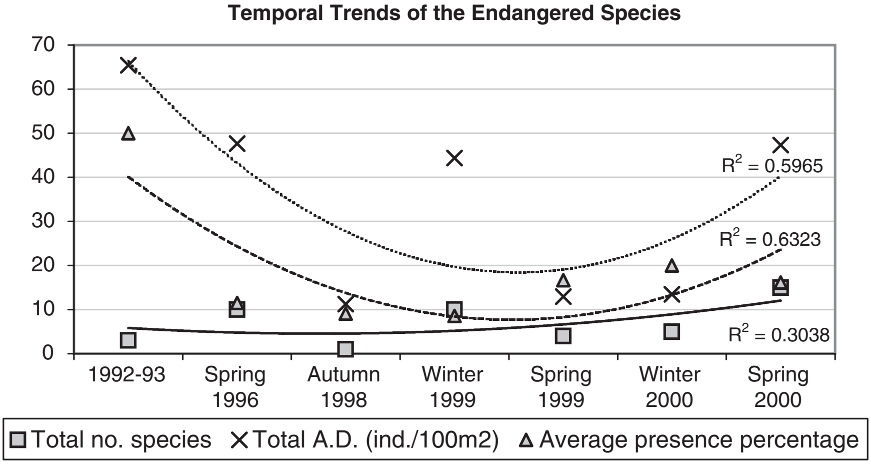


Fig. 9 Trends of change in number of endangered species, their density and occurrence on landscape level

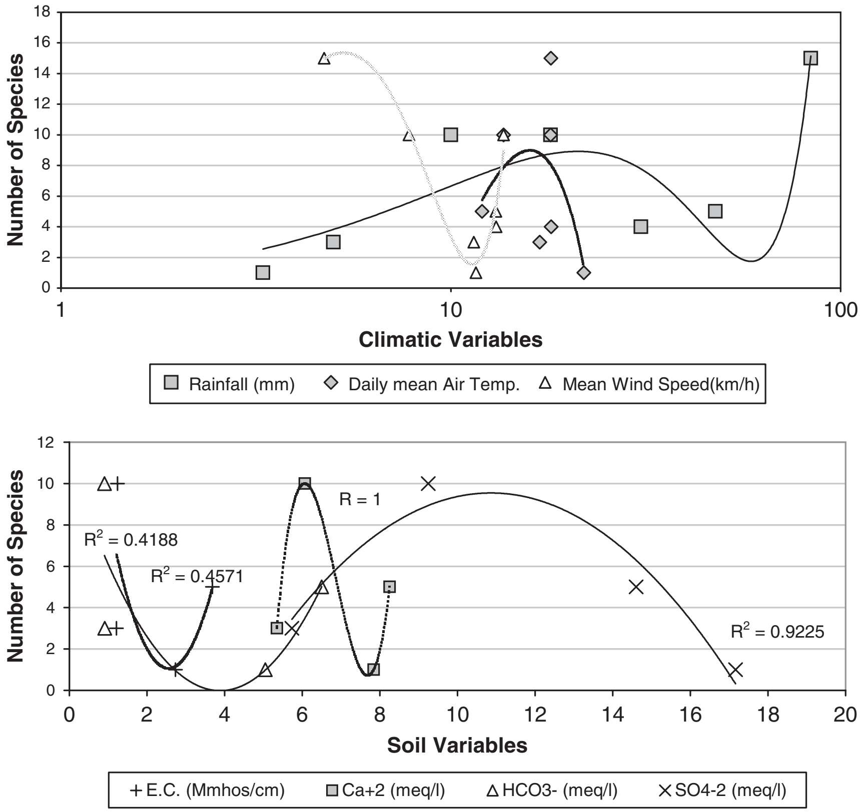


Fig. 10 Trends of relationship between number of endangered species and selected climate variables (top) and soil measures (bottom)

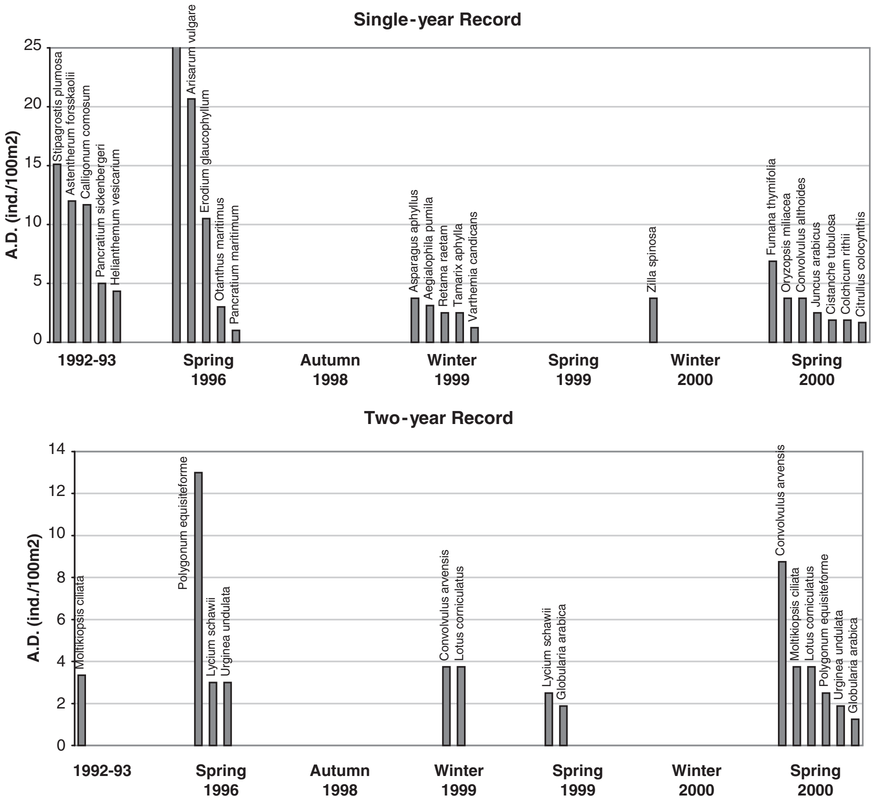
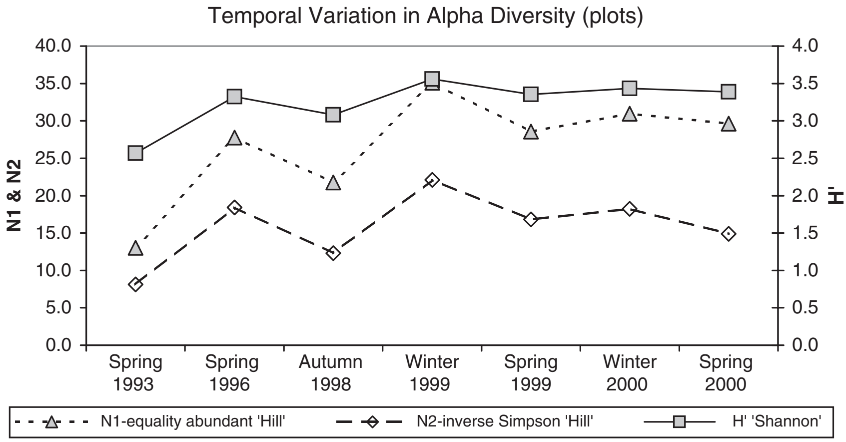


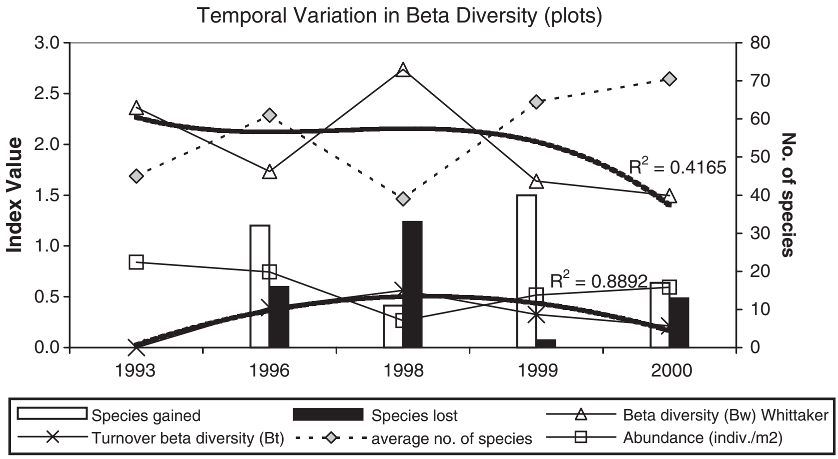
Fig. 11 Changes in transient species over time

4 Discussion

Although long-term temporal trends of climate variables are steadily increasing, except for wind velocity, the trend in terms of calculated moving average (3 years) is more-or-less constant for temperature and relative humidity, while it is bimodal for rainfall and highly irregular for wind speed at the end of the last decade. This would entail the expected impacts of the change in rainfall and wind speed as components of the environmental driving forces, leaning on the specifications of a stable climate characterized by a fully predictable seasonality (Fjeldsa and Lovett, 1997).

Rainfall regimes based on standardization by season, as a climatic driver, reveal a shift in rainfall increase above the long-term average from winter to spring, which explains the detected trend of change for species richness. Furthermore, it supports the earlier initiation of the active plant growth period backed by the recent increase in the above-average rainfall during autumn. Changes in seasonal aspect were also





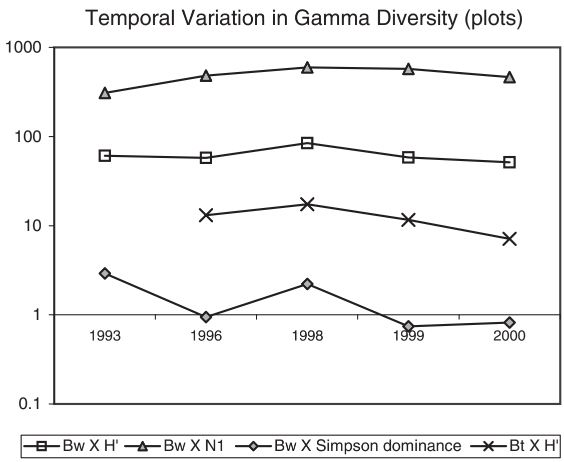


Fig. 12 Temporal variability in diversity indices on local and landscape scales (plots)

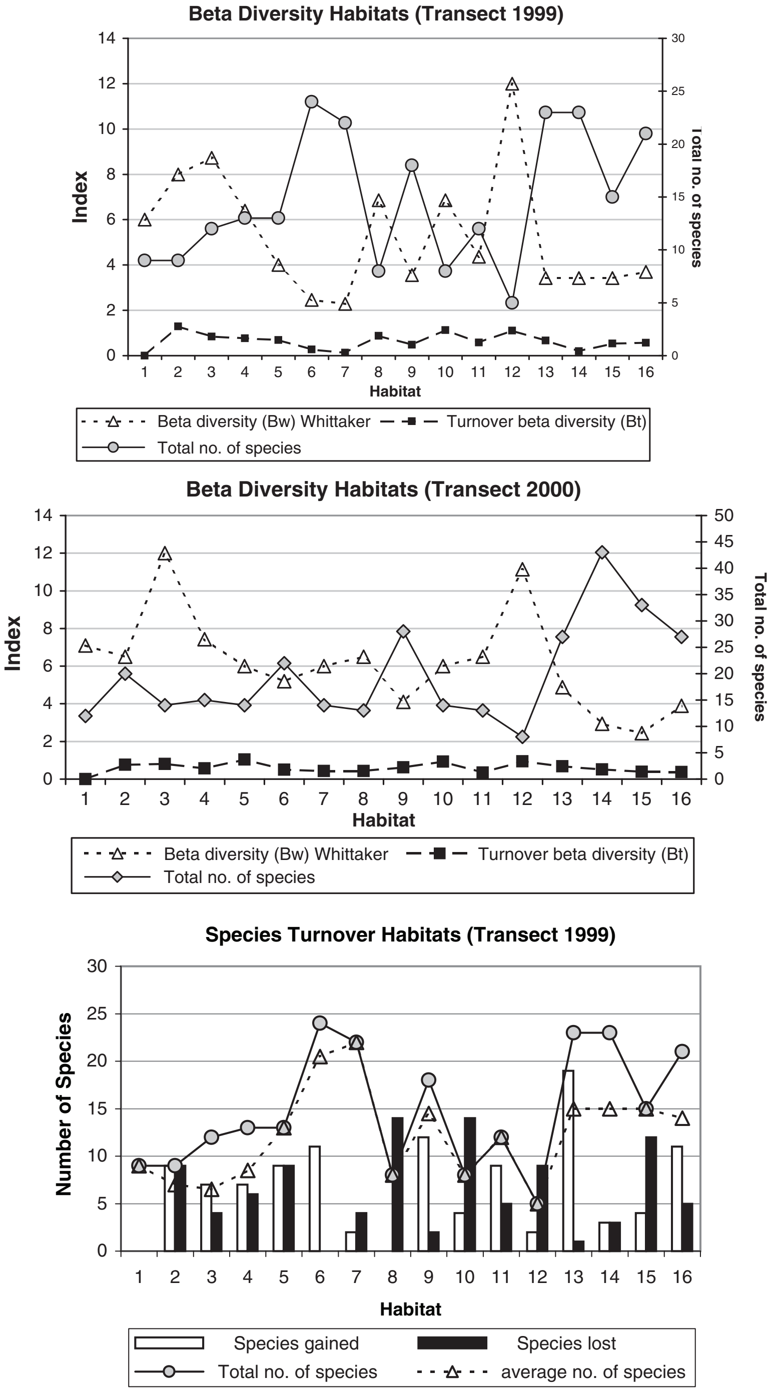
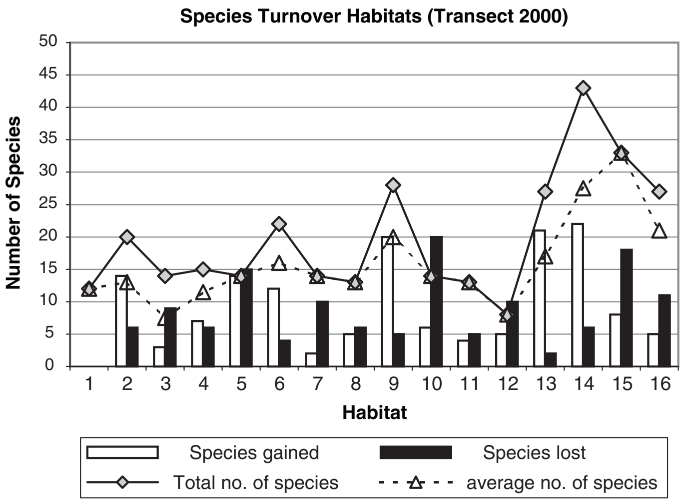
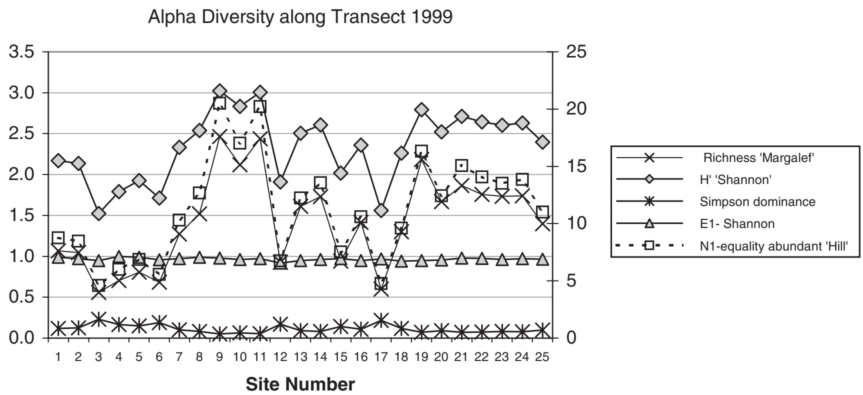


Fig. 13 Temporal variability in diversity indices on local and landscape scales (transect)





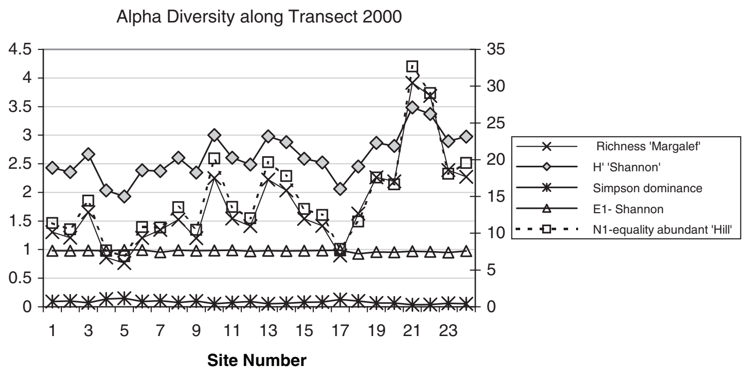


Fig. 13 (continued)

detected in southern Africa with species richness associating the variation in rainfall regimes between seasons (Lovett et al., 2000). Moreover, expanding the vegetative phase of perennials at the close of the decade at the expense of reproductive phases indicates less reproductive effort, while the decline in the seedling phase of perennials and in the establishment of annuals highlights lesser reproduction capacity of annuals. Accordingly, if those species were habitat-specific, an increase in the number of threatened species would be expected during erratic hazards.

The detected increase in the content of calcium and bicarbonates in particular in all habitats would reflect the active erosion/deposition processes resulting from erratic winds (defined as a climatic driver) coupled with recent human interference in the area. Concurrently, the largest variations in soil measurements contributed by salinity components, reflecting the remarkable change in soil texture, would define the edaphic drivers affecting biodiversity, taking into consideration disturbance as a major factor affecting populations and modifying interactions among species in communities (Sousa, 1984; Pickett and White, 1985).

The determination of inland ridges as having the most stable physical and chemical soil conditions, along with its finer soil particles, supports ranking it the highest in terms of species richness; it acts as a refuge site for several species. However, the plant community of this ecosystem is considered fragile (Danielsen, 1997), since artificial disturbances can have the most detrimental effects in such areas (Bagon et al., 1986). This would confirm the high risk imposed on inland ridges and explains why the ongoing active change in soil characteristics on the inland plateau, resulting from the acknowledged climatic and edaphic drivers, is associated with a detectable decline in local species richness.

The association of temporal change in species richness on the landscape scale, which is positive with rainfall and negative with higher air temperature, is obvious; however, its decrease at the intermediate level of wind speed is interesting. It appears that years with below-average wind speed provide soils with a stable surface condition that supports the growth of mostly herbs and an increase in plant cover parallel to low habitat disturbance. Conversely, above-average wind speed results in the creation of new micro-sites on the landscape scale, which, when combined with human disturbance, could encourage the reintroduction of rare and/or exotic species, especially when rainfall is above average. This process may be especially important in a heterogeneous landscape, such as in the observatory area, as plant species can greatly expand their domain by exploring ecotones (Stohlgren et al., 2000) and extend the physiological tolerance of certain genotypes (Bazzaz, 1996). Notably, species richness also decreases at intermediate levels of salinity, and calcium and bicarbonate contents in contrast to the sulfate content, which are also connected to soil erosion/deposition by wind.

The important decline in density and spatial occupation (restricted niche or habitat specificity) of 26 perennial species over time renders them candidates for endangered species status (in jeopardy). A high degree of habitat specialization of both rare and endemic species was shown by Trinder-Smith et al. (1996). With 54% of these being woody species, an anticipated risk is imposed on the structural component of the habitat and hence a change in the functional aspects of the ecosystems concerned. This stems from the fact that the ligneous species constitute the main skeleton of plant communities in the observatory, while higher species richness significantly encourages production and efficiency in resource utilization and retention (Tilman et al., 1996).

Extracting the distribution changes of narrowly distributed plant species (small % presence) along environmental gradients may designate some indicators susceptible to change (Stohlgren et al., 2000). Indeed, the defined "endangered species" satisfies this criterion, and some of them can be used as indicators. The trend in terms of change of these species during the 1990s is that their number is increasing irrespective of the decrease in their abundance measures (density and presence %). These species are also transient with amplitude of five years of species replacement or turnover when related to specific species added at the different measuring dates to the different communities in the area.

The trends of temporal variation in species richness and their life-form spectra are linked to changes in rainfall, air temperature and the wind speed of climatic variables, as well as salinity, calcium, bicarbonate and sulfate content of edaphic variables. This also applies to the change in the number of endangered species in relation to the environmental drivers but with further soil texture effect resulting from soil disturbance and initiation of new micro-habitats. Each of these variables has a specific effect on changes in species richness, with air temperature and soil sulfates as the most determinant driving factors. Extremes of maxima/minima in species richness occurring in some habitats during specific years can thus be attributed, in the first place, to erratic climate variability.

The habitats (biotopes) most supportive of plant diversity are inland ridges and inland plateau, which have the highest alpha diversity and species specificity (bio-indicators) and a larger positive value of species turnover (beta diversity) compared to other habitats. Several studies attributed the high species diversity of ridge communities to their spatial heterogeneity (Puerto et al., 1990; Tilman and Pacala, 1993; Cowling et al., 1996), while others noted the presence of different trends associating diversity–altitude relationships (e.g. Whittaker, 1977; Stohlgren et al., 2000).

Comparing the diversity indices on the landscape scale indicates that the replacement of species along the transect (beta diversity) exceeds by far that of plots representing the major habitats. This supports the idea that when superimposed on broad scale climatic gradients, smaller gradients of micro-sites with diverse edaphic features influence species richness (Stohlgren et al., 2000). The transect traverses different levels of topographic and human interventions in the area that lead to habitat fragmentation with transition areas, resulting in change of species richness and turnover rates on smaller distance scales. Accordingly, the suggestion of Oliveira and Mori (1999) that high species richness is the result of a combination of habitat heterogeneity and geological history is applicable in this case, while high species exchange along the sampling transect can be justified by considering the physiological adaptation to different edaphic conditions as the principle determinant of species turnover (Simmons and Cowling, 1996). In this respect, it is possible to select appropriate indicator species for specific, anticipated environmental changes using the changes in the distribution frequency of selected species linked to their association with soil characteristics along the transect (Stohlgren et al., 2000).

Halffter (1998) speculated that species diversity also has to be examined at the landscape (or mesoscale 'gamma diversity') level, where the consequences of human activities are most evident. Adopting this strategy affirms that the gamma values calculated for the major habitats are decreasing slightly over time corresponding to decreasing beta diversity among them (intrinsic complexity of the dominant ecosystems). In contrast, those calculated for micro-habitats along the sampled transect increased over time due mainly to increasing beta diversity (species exchange), since larger homogeneous patches of micro-sites are developing along with expanding land conversion (landscape heterogeneity).

It can be concluded that biotope diversity (spatial variability in micro-habitats) has a large influence on the biodiversity on the landscape scale. This is greatly affected by human impact detected from change detection in land cover using mapping techniques and by processing satellite images that reflect the land-use/land conversion practices (in the database of the observatory). While the global environmental changes, including the change in the climate and the associated environmental degradation of soil resources, are more cyclic (recurrent) phenomena whose feedback interacts and impacts on biodiversity in the region. Moreover, climate change should also be treated on a seasonal basis to enable the identification and evaluation of climatic drivers acting upon local species diversity.

Finally, the occurrence of a high degree of species exchange (high beta diversity) on the landscape scale, as a function of distance and representing the principal component of gamma diversity, makes questionable the appropriateness of the protected area for conserving global diversity at the landscape scale.

References

Bagon, M., Harper, J. L. and Townsend, C. R. 1986. *Ecology, Individuals, Populations and Communities*, 3rd edn. Blackwell Science, Oxford.

Bazzaz, F. A. 1996. *Plants in Changing Environments: Linking Physiological, Population, and Community Ecology*. Cambridge University Press, Cambridge.

Cowling, R. M., Macdonald, I. A. W. and Simmons, M. T. 1996. The Cape Peninsula, South Africa: physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. *Biodiversity and Conservation*, Vol. 5, pp. 527–550.

Danielsen, F. 1997. Stable environments and fragile communities: Does history determine the resilience of avian rain-forest communities to habitat degradation? *Biodiversity and Conservation*, Vol. 6, pp. 423–433.

Fjeldsa, J. and Lovett, J. C. 1997. Biodiversity and environmental stability. *Biodiversity and Conservation*, Vol. 6, pp. 315–323.

Franklin, J. F. 1993. Preserving biodiversity: Species, ecosystems or landscape. *Ecological Applications*, Vol. 3, No. 2, pp. 202–205.

Halffter, G. 1998. A strategy for measuring landscape biodiversity. *Biology International*, Vol. 36, pp. 3–17.

Lovett, J. C., Rudd, S., Taplin, J. and Moller, C. F. 2000. Patterns of plant diversity in Africa south of the Sahara and their implications for conservation management. *Biodiversity and Conservation*, Vol. 9, pp. 37–46.

Magurran, A. E. 1988. *Ecological Diversity and its Measurement*. Princeton University Press, Princeton.

Noss, R. F. 1983. A regional landscape approach to maintain diversity. *Bioscience*, Vol. 33, pp. 700–706.

Oliveira, A. A. and Mori, S. A. 1999. A central Amazonian terra firme forest, I: High tree species richness on poor soils. *Biodiversity and Conservation*, Vol. 8, pp. 1219–1244.

Pickett, S. T. A. and White, P. S. 1985. *The Ecology of Natural Disturbance and Patch Dynamics*. Academic, Orlando.

Pielou, E. C. 1975. *Ecological Diversity*. Wiley, New York.

Puerto, A., Rico, M., Miatias, M. and Garcia, J. 1990. Variation in structure and diversity in Mediterranean grasslands related tropic status and grazing intensity. *Journal of Vegetation Science*, Vol. 1, pp. 445–452.

Ricklefs, R. E. and Schluter, D. (eds.). 1993. *Species diversity in ecological Communities: Historical and Geographical Perspectives*. University of Chicago Press, Chicago.

Simmons, M. T. and Cowling, R. M. 1996. Why is the Cape Peninsula so rich in plant species? An analysis of the independent diversity components. *Biodiversity and Conservation*, Vol. 5, pp. 551–573.

Sousa, W. P. 1984. The role of disturbance in natural communities. *Annual Review of Ecology and Systematics*, Vol. 15, pp. 353–391.

Stohlgren, T. J., Owen, A. J. and Lee, M. 2000. Monitoring shifts in plant diversity in response to climate change: A method for landscapes. *Biodiversity and Conservation*, Vol. 9. pp. 65–86.

Tilman, D. and Pacala, S. 1993. The maintenance of species richness in plant communities. R. E. Ricklefs and D. Schluter (eds.), *Species Diversity in Ecological Communities: Historical and Geographical Perspectives*. University of Chicago Press, Chicago.

Tilman, D., Wedin, D. and Knops, J. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*, Vol. 379, pp. 718–720.

Trinder-Smith, T. H., Cowling, R. M. and Linder, H. P. 1996. Plant endemism in the Cape Peninsula, South Africa: An analysis, *Biodiversity Conservation*, Vol. 5, pp. 575–589.

Whittaker, R. H. 1972. Evolution and measurement of species diversity. *Taxonomy*, Vol. 21, pp. 213–151.

———. 1977. Evolution of species diversity in land communities. *Evolutionary Biology*, Vol. 10, pp. 1–67.

Chapter 2
Integrated Environmental and Socio-economic Modeling Using LEIS for Desertification Monitoring and Assessment in Menzel Habib Observatory (South Tunisia)

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Abstract In the framework of the implementation of the national action plan (NAP) as part of the UNCCD, a network of observatories for the assessment and monitoring of desertification has been established, covering the main agro-ecological zones of Tunisia. Menzel Habib represents one of the main observatories located in a typical arid zone threatened by desertification. This site is also part of the ROSELT[3]/OSS[4] network and the arid zones observatory implemented by IRA within the framework of the national monitoring system of desertification coordinated by the national focal point of the UNCCD. It is in this framework that the GIS-based model LEIS (Local Environmental Information System) (in French known as SIEL) developed by the ROSELT team in Montpellier (Roselt/OSS, DS3, 2004) was applied to this observatory. The data used were issued from achieved and on-going multidisciplinary monitoring of the observatory covering the biophysical (soil, water, climate, vegetation) and the agro-socio-economic (population, agriculture and pasture practices, land uses, etc.) aspects. Three types of information were used: remotely sensed data (satellite images), field measurements (vegetation biomass, yields, GPS, etc.), and socio-economic surveys (households, income, activities, etc.). Multiple scenarios have been conducted to assess the impact of changing one or many parameters (population, livestock, etc.). In fact, the final objective of the model is to place at the disposal of the various actors of development, researchers and technicians, a Spatial Decision Support System (SDSS) for planning and monitoring in plans to combat desertification and natural resources management in the dry areas.

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Keywords Desertification, monitoring, evaluation, local, Modeling, LEIS, observatory and Tunisia

1 Introduction

Desertification threatens about 52% of the land area in Tunisia suitable for agriculture, forestry and pasture farming (MEAT, 1998). The loss of land productivity has been triggered by incompatible forms of land use that result in soil degradation and salinization, water and wind erosion.

Tunisia has an ancient tradition of combating land degradation and desertification. In fact, the country has been seeking solutions to these problems with their own means and international support for a long time now. Moreover, the investments and organization of efforts to combat desertification started right after independence within the framework of various strategies for the protection and management of natural resources, and has continued to this day with the recent implementation of the National Action Programme to Combat Desertification (NAP-CD) ratified in 1998 as part of the UNCCD (MEAT, 1998). The UNCCD urged that combating desertification cannot be limited only to technical measurements but must be considered a complex unit of coherent actions that take into account socio-economic dimensions, as well as biophysical and environmental aspects.

It is for that reason that UNCCD signatories admitted the importance of controlling programmes to combat desertification through monitoring/evaluation and that the national focal point (NFP) would have a global vision of the implementation process of these programmes.

The OSS developed an environmental monitoring programme that aims to support the establishment, by countries, of dashboards to combat desertification serving the implementation of national policies for environmental protection and sustainable management of natural resources.

Tunisia has set up a number of observatories scattered throughout the country based on agro-ecological and socio-economic zoning (Sghaier, 2002). Menzel Habib, the study site of this paper, is one of the eight observatories in the arid zones of the country and is also certified by the ROSELT network (IRA, 2005).

With the development of GIS and spatial information technologies, huge gains have been made at large-scale levels. Nevertheless, some difficulties still remain on the local scale due mainly to the high cost of setting up heavy monitoring networks, the integration of the various ecosystem components (biophysical, socio-economic, etc.), the specificities of local sites, and the difficulties related to the management and handling of the databases (RS, surveys, biophysical, etc.). The development of Modeling tools, such as LEIS (ROSELT/OSS, DS3, 2004), would contribute to overcoming these difficulties. This paper therefore aims to:

- Test the LIES model developed by the ROSELT team, at the local level of the ROSELT/OSS and NAP observatory of Menzel Habib
- Set up an integrated environmental and socio-economic desertification monitoring network
- Explore the possibilities of developing a spatial decision support system (SDSS) to be used by the local development agencies and decision-makers

2 Materials and Methods

2.1 Study Site

The observatory of Menzel Habib is located between the parallels 34° and 34° 20° north, and meridian 9°15´ and 9°58´ east (Fig.1) and covers an area of approx. 100,000 ha. It forms part of the natural area of the low southern plains of Tunisia. Menzel Habib is a rural county occupying the north-western part of the Gabès province. With annual precipitation of about 150 mm, it lies in the lower arid Mediterranean bioclimatic stage with mild winters. The water resources are the most constrained in this region. The soil potentialities are diversified, but various actual constraints relate to its texture, which is sensitive to erosion, and poor fertility. The principal vegetation formations are steppes with *Rhanterium suaveolens* on sandy soil. Due to extended cropped areas, clearing and pastoral overexploitation, the steppe formations declined rapidly and at an alarming rate in some cases (Ouled Belgacem, 2005).

The 2004 censuses indicate that the local population is made up of 2,122 households with 11,477 inhabitants. The social and economic changes, which occurred during the last four decades, have seriously affected the traditional ways of life and the forms of adaptation to climatic aridity. Demographic rise, sedentarization of herders, privatization of the land, liberalization of the economy, modernization of agriculture, and changes in the use and exploitation of grazing space are the active elements of the ecological and socio-economic dynamics of the area. Many actions and programmes to combat desertification have been carried out in the region. However, the impact on the livelihood of the local population has been far below the sought-after objectives in spite of the full commitment of the various research and development structures (IRA & ROSELT/OSS, 2003).

The area is strongly marked by anthropization related to a pastoral operating system that induced important ecological and socio-economic disturbances. The extension of the rainfed cropped areas has been achieved at the expense of rangelands in the plateaux and the plains. Irrigated agriculture in certain sectors has also begun to mark the agrarian landscape. Nowadays, anthropization there has reached a level that raises serious questions about the ecological future of the area and the sustainability of the social and economic development actions undertaken (Tbib, 1998).

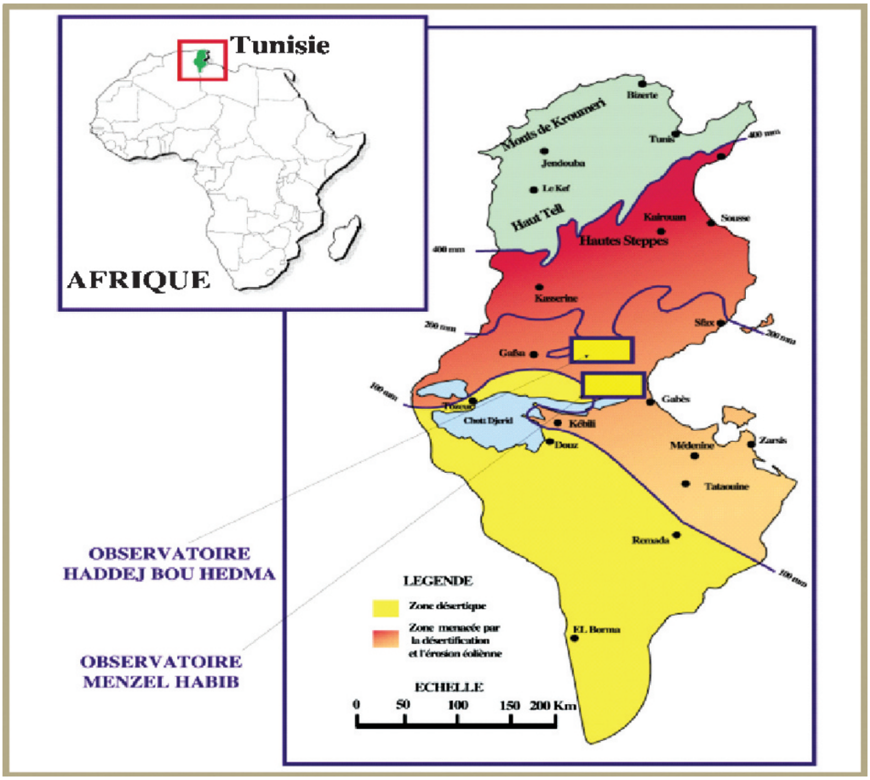

Fig. 1 Location map of the observatory of Menzel Habib (South Tunisia)

2.2 LEIS Model

The LEIS (Local Environment and Information System) model was developed by the ROSELT team (ROSELT/OSS, DS3, 2004). It is a conceptual and information-technology-based tool that is being developed for every observatory in the ROSELT/OSS network.

2.2.1 General Principles of LEIS

The global methodology of the LEIS (MEAT, 1998) is to combine biophysical data and socio-economic data using an integrated spatial approach. Acknowledging the dynamic interactions of these two set of factors, the integrated spatial approach is the core of the tool and the conceptual models derive from it. To be able to distinguish within the landscape the respective parts of factors coming from the afore- mentioned domains, the spatial approach considers two intersecting planes of distinct information: one linked to uses and the other to natural resources; it then involves defining Spatial References Units (SRU) as a functional description (MEAT, 1998). Multi-use balances (availability minus extraction of natural vegetation) and anthropogenic pressure index (PI) computations are based on output of this functional mosaic description of the landscape.

The established Modeling for a defined period leading to the SRU map and the balances maps resulting from them constitute the diagnostic. The plane of resource expression is built using classical GIS methods on a range of different layers, while the plane of uses comes from spatialization models of the exploitation practices. These models encompass the tools originality together with the prediction ability. From an established diagnostic, scenarios of evolution of main driving parameters, such as population and production (depending on "climate parameters"), allow forecasting to be done, i.e. leading to new balances maps based possibly on new SRU.

2.2.2 Modeling Principles of LEIS

The plan of natural resources or plan of environmental conditions distinguishes, from a biophysical point of view, homogeneous areas called landscape units (LU). The LUs are immediately visually perceptible. From a methodological point of view, the LUs are the result of the interaction of three main categories of factors: physical, biological (land cover) and human (land use in the sense of international classifications: forests, pasture land, cultivated land, etc.). The construction of LUs calls for classical cartographical methods combining ground surveys, aerial photos and satellite images.

The plan of uses or human activities delimits areas that are homogeneous from the point of view of resource exploitation practices – these are called 'Combined Practices Units' (CPU). The CPUs, contrary to LUs, are not necessarily visible in the landscape. They are constructed not from processed satellite images and ground surveys but from models of spatial distribution practices.

The construction of CPUs is realized in two main stages:

- The development of the combined practices typology on an observatory territory
- The development of the CPU map via a combined practices spatial distribution model

A particular CPUs class issued from the typology associates one or more natural resource exploitation practices, in time and space, with one or more usages. This combination of practices can be applied to different places in the observatory territory on homogeneous spatial units. The occurrences of all the combined practices classes structure the landscape in the CPUs.

The fundamental principle of the spatial distribution model is as follows: the CPUs are potentially applied to a given location by one or more groups of agents according to:

- The local biophysical characteristics at this location
- The expectation that the production of exploitation at this location (average production per exploitation cycle), will contribute to the satisfaction of a type of need

Availabilities of resources are derived from the LU characteristics, while extractions of resources are modelled and spatialized according to the current usage and the structuring usage that built the CPU.

Implemented under the same GIS software platform, the LEIS tool couples a geographic database and spatialization models. The geographic database is organized in a relational database management system; its structure was formalized using Unified Modeling Language (UML) (OSS, 2004) to conceptualize and represent the spatial area–resource–usage interactions on the local scale. Despite the friendly general user interface, LEIS is a tool designed for scientists.

For this application, the methodology applied comprises five main stages that lead to the final results as shown by Fig. 2.

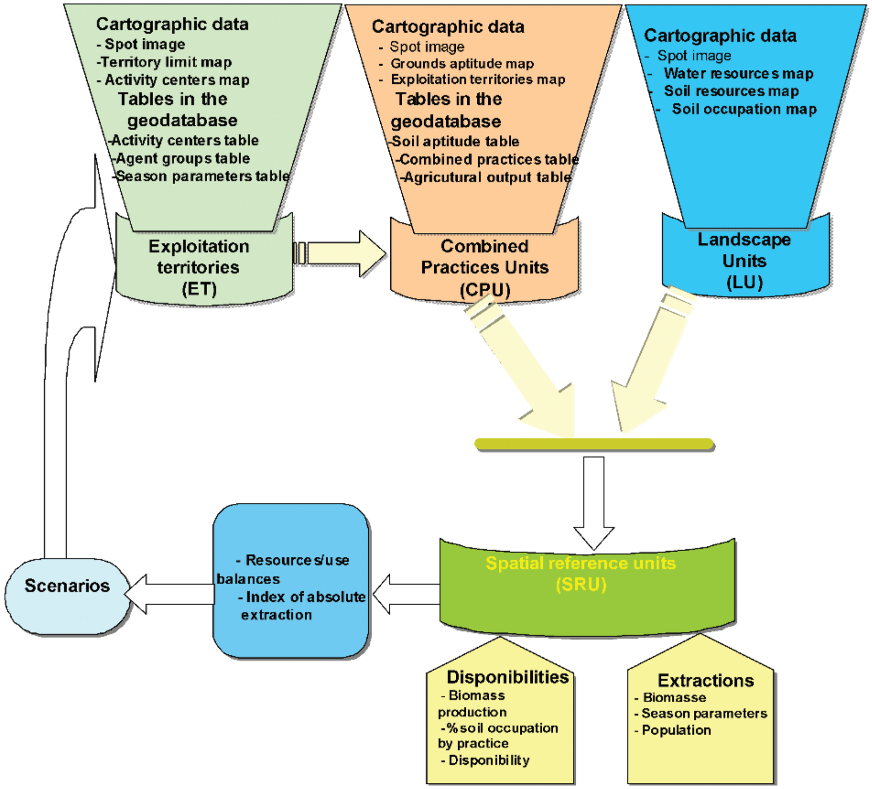

Fig. 2 LEIS Modeling phases as applied to the observatory of Menzel Habib

Figure 2 described the various stages followed in order to apply LEIS Modeling to the observatory of Menzel Habib. The cartographic data needed are carried out using the spot image of March 1999. The input data for each stage are classified in cartographic data and tables resulting from the LEIS geographical database (minimum Kit).

The other input data are: map of ground aptitudes, table of ground aptitudes, table of the combined practices, table of the parameters of combined practices, and table of the agricultural output. The LUs map is constructed by the intersection of three maps: map of water resources, map of ground resources, and map of land cover.

The construction of the SRU map is carried out by the overlaying of the CPU map and the LU map.

The calculation of the balances and indicators is based on the SRUs.

Indeed, in the first stage, named "construction of the potential exploitation territories (ET)", the input data are as follows: map of the observatory limits, map of activity centres (AC), table of AC, table of agent groups (animals and human), and table of season parameters.

In the construction of the CPUs, the result of the preceding stage (potential ET) constitutes a principal input on which the model will spatialize the various classes of combined practices.

According to the choice of ACs (villages) linked to the structuring activity and the choice of the weights (population) expressing land competition between ACs, a weighted Thiessen algorithm builds a mosaic of polygons of potential ET around each selected AC: step of delineation of territories of potential exploitation. In the study case, several criteria combined by the algorithm are linked to a different weight:

- The population by each AC and by each Strategic Groups (SG).
- The age minimum and age maximum of AC, taking into account the evolution history of the population in the observatory, were estimated to be 20–50 years and 23–60 years, respectively, during the considered Modeling period (2001–2004).
- The threshold distance of access to resources indicates the travelling distance to be crossed by the population resident in each AC in order to access resources in the observatory. It was estimated for the whole AC at 4–35 km.

An agro-socio-economic survey (Sghaier et al., 2006) makes it possible to establish a typology of combined practices associated with each strategic group surveyed within the observatory: definition of typology of combined practices. Two agent groups were identified, a Human Agent Group (HAG) and an Animal Agent Group (AAG), for each AC. For the HAG, one typology of the Strategic Groups (SG) was elaborated according to the resource exploitation strategies in the observatory. The multidimensional methods (MM) (factorial correspondence analysis method and ascending hierarchical clustering method) were used on the basis of data collected from field surveys (305 households interviewed in 2004; see Fig. 3).

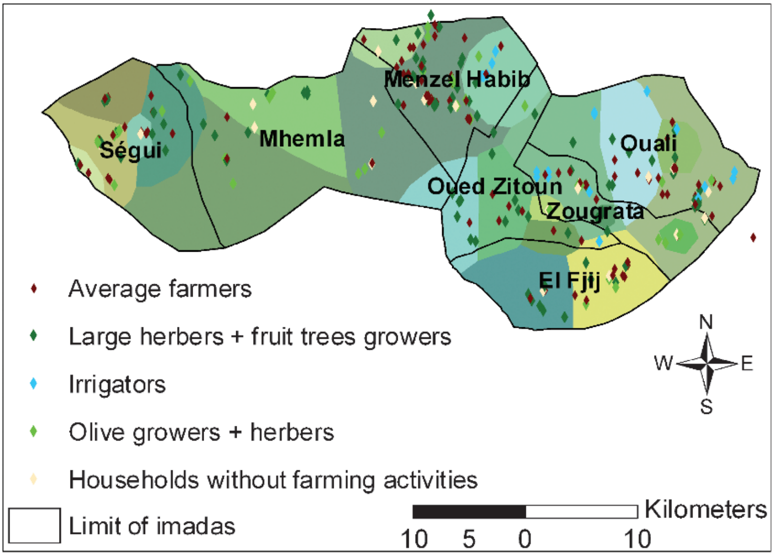

Fig. 3 Spatial distribution of human strategic groups

The formula used to spatialize the CPs:

Production (px)/Effort (px)

According to the formula used by the model, two main factors may affect the appearance of any CPU in an activity centre.

The artificialization degrees calculated for the various CPU are almost the same; therefore the agricultural yield by each soil aptitude and combined practice will be determinant in the spatialization of the CPUs.

Besides, the strategic group has an important role at this step: it will permit us to know the list of CPUs for each activity centre.

The multi-use PI is calculated using the arithmetic average formula applied to pastoral, forestry and pastoral index.

Using the driving parameters of the Modeling, such as population, productions (natural vegetation and or agricultural production) and needs, it is possible to build scenarios of evolution. Two scenarios are selected:

Scenario 1 considers a human population increase by AC similar to that of the period 1994–2004 and doubling the animal population.

Scenario 2 envisages, on one hand, the diminution to 20% of the agricultural output (mainly olive and cereal products), and on the other hand, the diminution of phytomass production to 30%.

3 Results

As indicated in the methodology, the results of the LEIS model evolve from one stage to another until the scenarios are developed. In this section, we present the main results of the model related to the reference situation as well as the scenarios.

3.1 Exploitation Territories (ET)

The human strategic groups (HSG) identified using MM are:

- Large herders and fruit tree growers (106 households, 35%)
- Olive growers and herders (41 households, 13.5%)
- Households without farming activities (23 households, 7.5%)
- Average farmers (114 households, 37%)
- Irrigators (21 households, 7%)

Figure 3 shows the spatial distribution of the identified strategic groups.

The animal strategic groups are defined according to a typology based on the mode of control and the mobility of the animal herds:

- Non-transhumant herds
- Transhumant herds in the observatory of Menzel Habib
- Transhumant herds outside the observatory of Menzel Habib

The first stage allowed the development of the ET map corresponding to the 22 AC in the observatory of Menzel Habib (Fig. 4). It shows the relative importance of the territories of exploitations and the centres of activities of Menzel Habib, Sefia, Ouali and Zougrata, with 14,394 ha (15%), 12,558 ha (13%), 8,630 ha (9%) and 7,687 ha (8%), respectively. The other territories of exploitation, such as Ouled Souissi and Essoud, remain much reduced.

3.2 Combined Practices Units

The CPU map (Fig. 5) shows all the practices we have identified. It shows the prevalence of rainfed olives, cereals and grazing (pasture), covering 49,152 ha (51%), 18,314 ha (19%), and 16,386 ha (17%), respectively. It seems that the map of the soil suitability and the adaptation of these practices to the biophysical and socio-economic conditions of the observatory explain these results (Fig. 6).

The CPU of olives behind *jessour*, irrigated systems, olives behind *tabias* occupying respectively 5%, 1% and 4% seem to be heavily constrained by the importance of the effort (equipment, input) and the degree of artificialization required for their implementation. Whereas in the area occupied by the CPU "no practices", 2,892 (3%) seems to be much reduced.

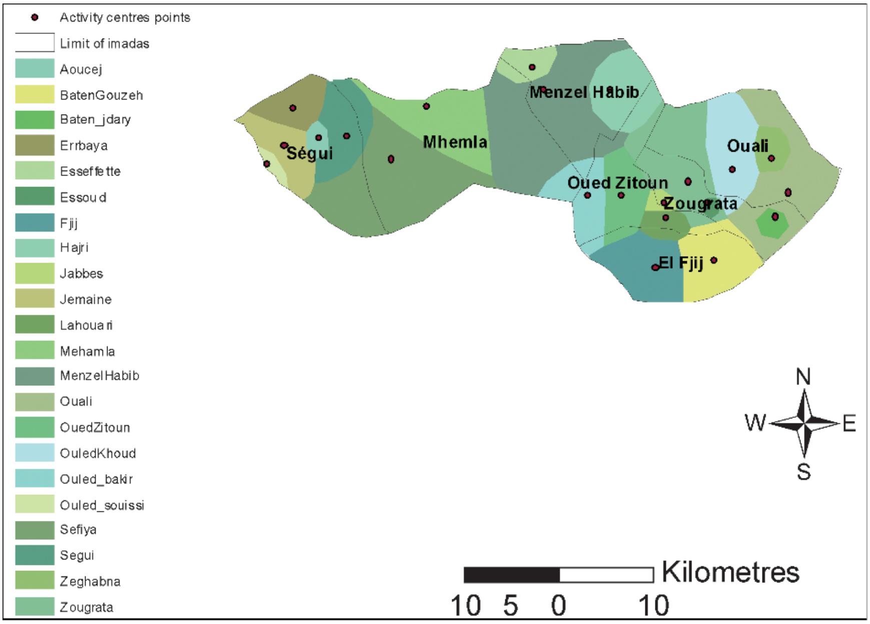

Fig. 4 Map of the exploitation territories

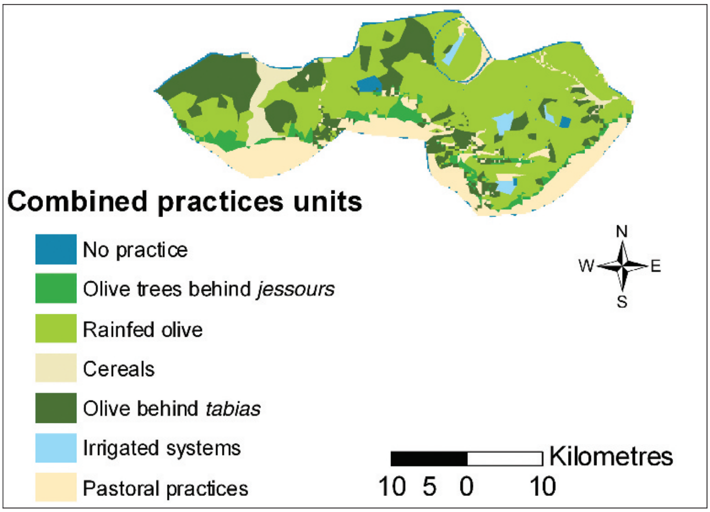

Fig. 5 Map of combined practices units (CPU)

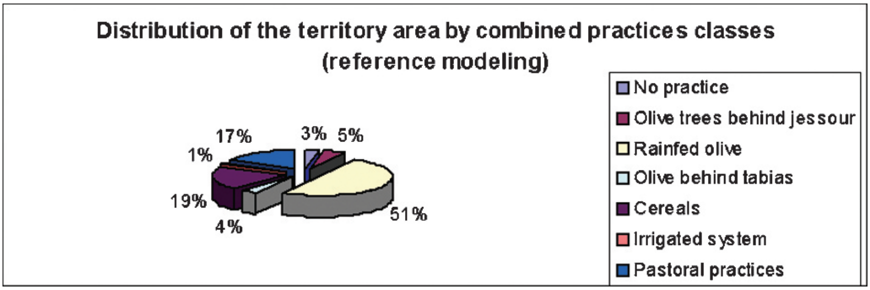

Fig. 6 Surface by combined practices units

3.2 *Spatial Reference Units*

The combination of the two maps of the CPU and the PU produced the map of SRU (Fig. 7), which represents the basis for calculating the balance and the indicators – 2,051 SRUs were identified.

3.3 *The Resource/Usage Balances and Calculation of Indicators*

The multi-use PI map (Fig. 7) shows all the classes identified, which can be explained by the diversification in the soil classes, and the activities carried out in the territory.

In fact, the agricultural PI shown on the map below confirms the diversification of risk. The area with zero risk occupied 54,941 ha, i.e. 57% of the territory. The area with maximum risk (PI ≥ 100%) reached 8,675 ha, or 9% of the territory localized on the alluvial plain.

For pastoral use, all PI classes are present. In fact, the highest area is occupied by the maximum risk class recording 28,916 ha (30%). These results confirm the pastoral vocation of the observatory (Table 1).

From these maps (Fig. 8), we notice that the entire observatory of Menzel Habib is affected by desertification. The slopes, the alluvial plain and parts of the red grounds and the sebkhas have recorded a maximum risk of desertification (PI ≥ 100%). These zones are characterized by the prevalence of agricultural and pastoral extraction and occupy approximately 39% of the total surface of the Menzel Habib observatory. The zones with strong risk (50% ≤ PI < 100%) are localized on the lemony-sand plains occupying 41% of the observatory space.

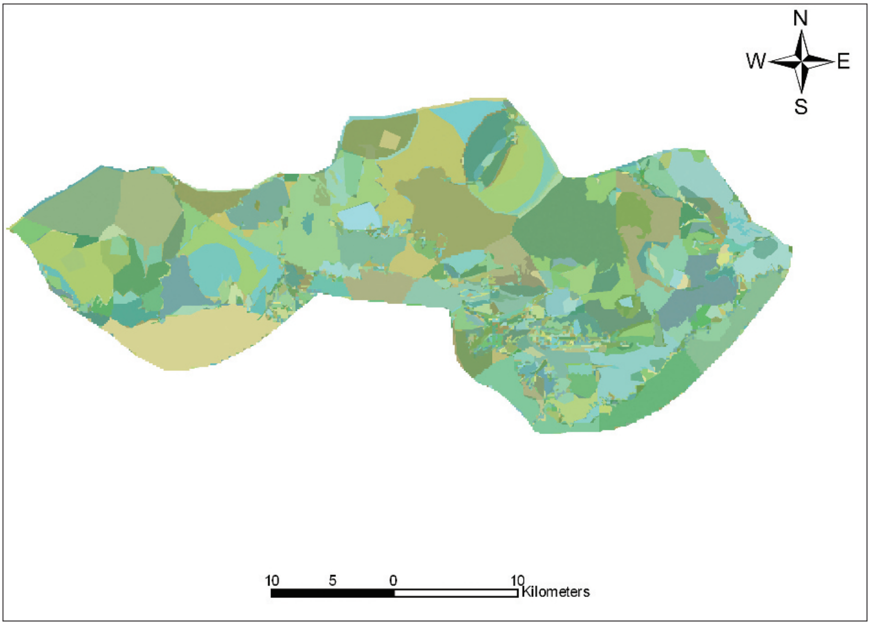

Fig. 7 Map of the spatial reference units

Table 1 Estimation of the area by class of pressure index (PI) for agricultural, pastoral and forestry use (Reference Modeling)

Classes of pressure index	Agricultural PI	Pastoral PI	Forestry PI	Multi-use PI
Risk zero (PI < 5)	57%	5%	73%	0%
Very low risk (5 ≤ PI < 15)	1%	28%	3%	10%
Low risk (15 ≤ PI < 25)	1%	12%	0%	24%
Medium risk (25 ≤ PI < 50)	1%	13%	0%	28%
High risk (50 ≤ PI < 75)	30%	6%	2%	10%
Very high risk (75 ≤ PI < 100)	2%	6%	0%	3%
Maximum risk (PI ≥ 100)	9%	30%	21%	24%
Total	100%	100%	100%	100%

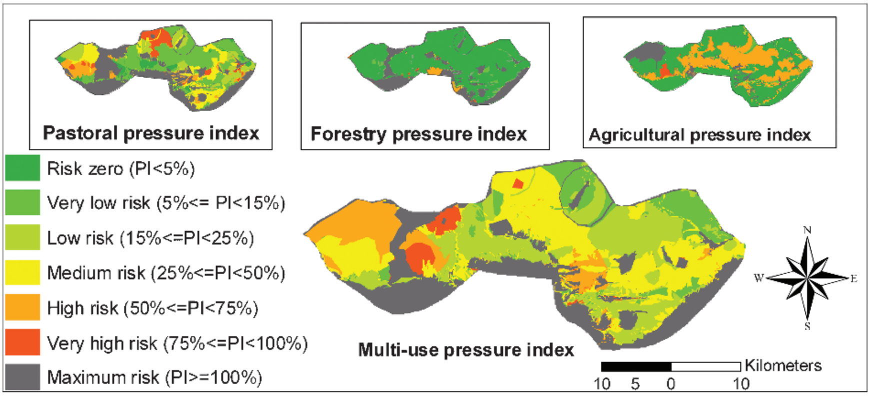

Fig. 8 Multi-use PI (reference Modeling)

3.4 Scenarios

3.4.1 Scenario 1

The area occupied by the seven combined practices remained roughly stable. In fact, the variation has not exceeded 963.88 ha (1%) for all combined practices.

These results (Fig. 9) show the aggravation of the situation for pastoral and forestry uses. In fact, the areas of maximum risk evolved from 28,916 to 44,338 ha and from 20,241 to 38,555 ha, respectively. The agricultural use remained stable. These results confirm the assumption that the risk increases as a function of the effect of anthropogenic actions in this observatory.

The results of the first scenario tested are summarized in Table 2.

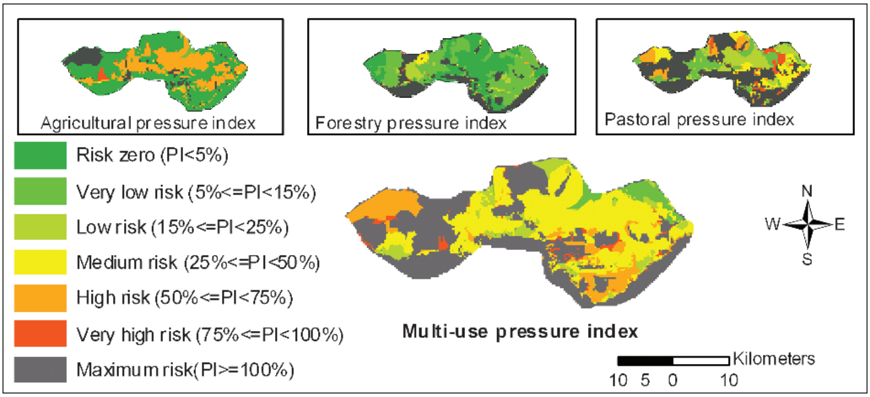

Fig. 9 Multi-use PI (Scenario 1)

Table 2 Estimation of the area by class of pressure index (PI) for agricultural, pastoral and forestry use (Scenario 1)

Classes of pressure index	Agricultural PI	Pastoral PI	Forestry PI	Multi-use PI
Risk zero (PI < 5)	57%	0%	33%	0%
Very low risk (5 ≤ PI < 15)	1%	14%	37%	4%
Low risk (15 ≤ PI < 25)	1%	16%	5%	6%
Medium risk (25 ≤ PI < 50)	1%	12%	2%	36%
High risk (50 ≤ PI < 75)	30%	8%	0%	12%
Very high risk (75 ≤ PI < 100)	2%	5%	0%	2%
Maximum risk (PI ≥ 100)	9%	46%	23%	40%
Total	100%	100%	0%	100%

3.4.2 Scenario 2

The ET remained unchanged because we kept the population parameter, chosen as weight on which the Thiessen Algorithm will work, stable for all activity centres. However, the maps of CPU and SRU had shown many changes compared to the reference situation. For the CPU map, the variation is especially related to "rainfed olive" practice, which recorded a decrease of 9,369 ha in the area occupied or 10% of the territory, whereas the same rate was recorded as an increase for the "cereal" practice. All other practices remained stable. The number of SRU classes became 2,051.

The results of this scenario are shown in Table 3 and Fig. 10.

These results show the aggravation of the situation for the pastoral and forestry uses. In fact, the area with maximum risk (PI ≥ 100%) has recorded an increase of 18,314 ha and 2,892 ha, respectively. For the pastoral use, these zones are localized on the slopes, sebkha, red grounds and setting in defens. However, these zones have taken place on the slopes, alluvial plain, sandy limono plain and sebkha in the forestry use.

Table 3 Estimation of the area by class of pressure index (PI) for agricultural, pastoral and forestry uses (Scenario 2)

Classes of pressure index	Agricultural PI	Pastoral PI	Forestry PI	Multi-use PI
Risk zero (PI < 5)	57%	12%	3%	0%
Very low risk (5 ≤ PI < 15)	2%	10%	24%	2%
Low risk (15 ≤ PI < 25)	1%	4%	15%	7%
Medium risk (25 ≤ PI < 50)	1%	13%	32%	24%
High risk(50 ≤ PI < 75)	30%	9%	1%	8%
Very high risk(75 ≤ PI < 100)	1%	3%	1%	6%
Maximum risk (PI ≥ 100)	9%	49%	24%	53%
Total	100%	100%	100%	100%

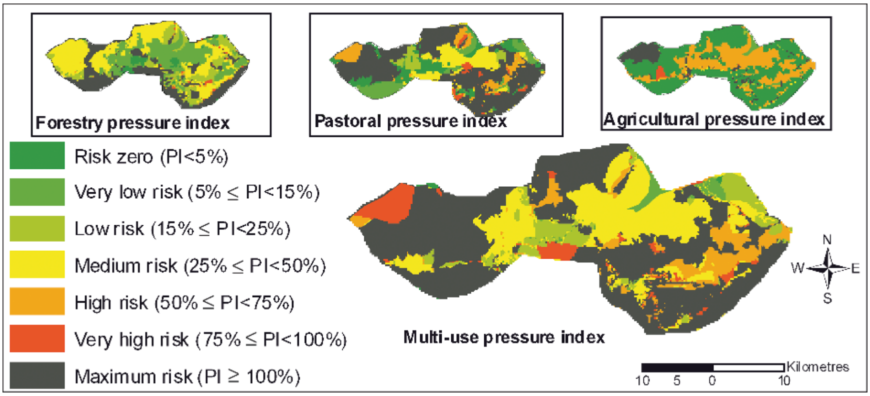

Fig. 10 Multi-use (Scenario 2)

4 Conclusions

Desertification is a major problem in Tunisia and needs monitoring and evaluation through the establishment of local observatories. Since desertification is a multidimensional problem, recourse to Modeling is inevitable. The application of an integrated GIS-based model LEIS in the PAN-LCD and ROSELT observatory of Menzel Habib shows promising results. In fact, the simulation results confirm the pastoral vocation of the observatory and the high risks to be embedded following the intensification and extension of all forms of farming. Therefore, the LEIS shows high potential of use as a spatial decision support system (SDSS). The simulation through scenarios revealed the high vulnerability of the natural ecosystem to anthropogenic actions. Therefore, the LEIS model could be a useful tool for integrated and interdisciplinary approaches. However, several difficulties and issues need to be resolved, such as the integration of the LEIS, applied on the local scale, in the national and regional monitoring and evaluation system of desertification.

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References

IRA. 2005. *Mise en place d'un Observatoire des Zones Aides pour le Développement Durable* (*OZADD*). L'Institut des régions arides, Médenine.

IRA and ROSELT/OSS. 2003. *Programme de travail général pour la période 2003–2005 de la grappe d'observatoires ROSELT/OSS Haddej Bou Hedma/Menzel Habib en Tunisie*. Annexe Technique de Convention de financement n°597.

MEAT. 1998. *Atlas du gouvernorat de Médenine*. BERA, Ministère de l'Environnement et de l'Aménagement du Territoire, Tunis.

OSS. 2004. *Stratégie 2010 de l'OSS*. Observatoire du Sahara et du Sahel, Tunis.

Ouled Belgacem, A. 2005. *Dynamique de la végétation et ressources pastorales de l'observatoire de Menzel Habib*. Rapport Roselt/OSS.

ROSELT/OSS, DS3. 2004. Concepts, méthodes et mise en oeuvre pour l'évaluation des risques de désertification: Système d'Information sur l'Environnement à l'échelle locale (SIEL) du programme ROSELT/OSS. *Collection ROSELT/OSS*, Document scientifique n°3, Montpellier.

Sghaier, M. 2002. *Etude sur le cadre d'organisation institutionnelle du SE/PAN-LCD Tunisie*. Projet de mise en place du suivi-évaluation du PAN-LCD en Tunisie, 12 pp. (In French.)

Sghaier, M., Bennour L., Loireau, M., Leibovici, D., Ben Abed M. A., Fetoui, M. and Jaoued M. 2006. *Rapport scientifique du thème systèmes d'information d'environnement à l'échelle locale (SIEL): Cas de l'observatoire de Menzel Habib et installation de MDweb, Tunisie.*

Tbib, A. 1998. *Conséquences de l'utilisation des ressources naturelles sur l'équilibre écologique en milieu aride tunisien: Cas de Menzel Habib*. D.E.A. d'Ecologie Générale. Faculté des Sciences Sfax.

Chapter 3
The Land Degradation Assessment in Drylands (LADA) Project: Reflections on Indicators for Land Degradation Assessment

Freddy O. F. Nachtergaele and Clemencia Licona-Manzur

Abstract The Land Degradation Assessment in Drylands (LADA) project aims to develop assessment tools to collect up-to-date information on the status of land at local, national and global levels. For this it has developed a flexible methodological framework that relies on traditional and digitally assisted methods of data collection. The LADA project will produce an overview of the global status, pressures and causes of land degradation, indicating hot spots and bright spots. Six pilot countries will produce higher resolution assessments, which will allow the further refinement of the methodological framework. Both the global and the country assessments will serve as a baseline to design policies for combating land degradation and rehabilitating degraded land. This baseline will also allow countries to monitor the success of these policies. An overview of the LADA project and the use of indicators obtained through traditional data collection and remote sensing is set in the larger context of the Driving Forces – Pressures – States – Impacts – Responses (DPSIR) framework, the need for stratification, interpretation and monitoring.

Keywords Global assessment, land degradation, LADA, indicators

1 The Land Degradation Assessment in Drylands (LADA) Project

1.1 LADA Objectives and Achievements

The main objective of the LADA project is to develop tools and methods to assess and quantify the nature, extent, severity and impact of land degradation on ecosystems on a range of spatial and temporal scales. The project aims also to build national, regional and global assessment capacities to enable the design

Food and Agriculture Organization of the United Nations (FAO), Rome, Italy

and planning of interventions to mitigate land degradation and establish sustainable land use and management practices.

During its initial phase, the LADA project has been working towards the development of a methodological approach for land degradation on local, national and global scales. For this purpose a variety of information has been compiled and analyzed and relevant information products have been developed (see lada.virtualcentre.org/pagedisplay/display.asp). Three pilot countries (Argentina, China and Senegal) have worked through the methodological approach (Koohafkan et al., 2003) to different degrees and provided useful insights on the feasibility of the approach. Case studies related to LADA have been carried out in several countries (Mexico, South Africa, Uzbekistan, Kenya, Egypt and Malaysia) (Nachtergaele, 2004). An indicators toolbox with a set of minimum "universal indicators" is being developed and will be an important part of the methodological approach.

1.2 Need for Baseline Information and the Evolving Concept of Land Degradation

Land degradation is a complex process that involves several natural, technical, institutional and policy factors at different levels. To design sound and cost-effective strategies for combating land degradation and rehabilitating degraded land, it is necessary to know the current status of land degradation, and to understand the factors that have contributed to degradation and those that could lead to improvement or further losses of ecosystem functions. The status of the land and the interactions of different factors can be understood only by carrying out multidisciplinary land degradation assessments. These assessments can also serve as a baseline or benchmark against which the success of policies and techniques can be measured.

One should also bear in mind that the concept of land degradation has evolved over time. For instance, consider the following definitions:

- FAO 1979: Land degradation is a process which lowers the current and/or potential capability of soils to produce (quantitatively and/or qualitatively).
- UNEP 1992: Land degradation implies reduction of resource potential by one or a combination of processes acting on land.
- LADA 2005: The reduction in the capacity of the land to perform ecosystem functions and services (including those of agro-ecosystems and urban systems) that support society and development.

Over the last 30 years, concepts have moved from an initial emphasis on productive capability to the more all-encompassing concept of goods and services, while at the same time the earlier focus on soils has been replaced by the more holistic concept of the ecosystem, which comprises:

- Soil: including changes to physical, chemical or biological properties
- Water resources: including changes to both surface and groundwater
- Vegetation cover: including changes or damage to forest, grasslands or crops
- Biological entities: changes both to macro- and micro-organisms

1.3 Land Degradation Assessments

At country level, the approaches and capacities for land degradation assessment have been confined mostly to surveys of soils, vegetation cover and present land use. These surveys have been generally conducted separately by different institutions and often in different areas and on different scales. Their focus has been often more on land resource use rather than on their long-term sustainable use in view of the risks of environmental degradation and resource depletion. The resulting databases on land resources are therefore largely incomplete regarding the biophysical and socio-economic aspects of land degradation. Moreover, as these data are usually not comparable in terms of scale, they cannot be integrated and inter-linked enough to facilitate decision- and policy-making.

At international level, the various scattered land degradation information systems available (Lantierei and Young, 2001; Van Lynden and Kuhlman, 2002; Mahler, 2003; Ponce-Hernandez, 2002; Sonneveld, 2003; Lantierei, 2003) are not sufficiently developed and comparable to facilitate transfer of experience and technologies available elsewhere. These gaps also limit the possibilities for countries to join and implement international conventions, such as the United Nations Conference to Combat Desertification (UNCCD), the United Nations Convention on Biological Diversity (CBD), and the United Nations Framework Convention on Climate Change (UNFCCC), or to seek foreign assistance and investment for land rehabilitation.

Many assessments deal with land degradation risks rather than with degradation status and its direct or indirect socio-economic causes (drivers). Most estimates of soil erosion, for instance, have been of erosion hazard (e.g., the Universal Soil Loss Equation or a variant), not actual, observed erosion.

The only available global assessment of soil degradation to date is the UNEP/ISRIC GLASOD study carried out during the 1980s at a 1:5 million scale (published at a 1:10 million scale). The study highlighted areas where specific types and intensity of effects of soil degradation occur, but has also been criticized because of its reliance on expert judgement only. Since then more specific and objective studies have been undertaken, notably the SOVEUR study for Central and Eastern Europe (FAO/ISRIC, 2000) and the ASSOD study for South-east Asia (UNEP/ISRIC/FAO, 1998). Moreover, since then, an important number of global terrain models and other data have become available with ever increasing resolution, which may to a certain extent refine the findings of the GLASOD study (Nachtergaele and Auricht, 2004).

1.4 LADA Approach: 2005–2009

The full LADA project will aim to use and further test common definitions and methods of assessment that are applicable on different scales and are compatible and comparable.

LADA will test the assessment tools at three levels of study: subnational, national and global. To achieve this, the FAO will work with different international partners and six pilot countries to collect information on land degradation, analyze it, and integrate it into a land degradation information system. The information collected will be used to identify hot spots and bright spots for later proposing policy options for combating land degradation.

Hot spots in the LADA context are areas where swift rehabilitation action is required because land degradation is particularly severe or fast, with actual or expected particularly harmful or extensive impacts on-site or off-site. A hot spot may also be an area where the land is vulnerable and threatened by degradation. A bright spot may be an area without significant land degradation that is stable naturally or under the present conditions of sustainable management, or a formerly degraded or vulnerable area where land protection or land rehabilitation has been successful or is in progress. Bright spots may include low-lying areas where little degradation takes place or areas where degradation was a problem in the past but where successful rehabilitation measures have improved the situation.

The collection of information will be done using several tools, including remote sensing imagery, modeling, statistics, visual soil assessments and participatory local surveys.

In parallel, LADA will strengthen and build on the capacity at national and regional levels through training centres, which will disseminate knowledge on land degradation (LD) topics.

The major products from LADA can be classified as follows:

- An improved approach to LD assessment (strategies, methods and tools)
- Baseline regional and global assessments of LD in drylands
- Detailed local assessments and analysis of LD in hot and bright spots (in pilot countries) with linkages to policy formulation
- Promotion of action & decision making for the control of LD

LADA will therefore catalyze widespread adoption of validated techniques of LD assessment and trained people to deliver improvements.

2 The LADA Indicators Toolbox

2.1 Development, Problems and Characteristics of the Indicators Toolbox

To identify the status of the land, LADA will rely on the use of indicators that have been investigated and tested during the PDF-B phase (Annex I). Indicators have been used in different disciplines, from the natural to the socio-economic sciences. For example, in ecology indicators refer to a group of plants or animals whose presence acts as a sign of particular environmental conditions. For the purpose of LADA, indicators are statistics or measures that relate to a condition or attribute of ecosystems and by means of which the change of quality or state can be recorded. Both qualitative and quantitative indicators can be used for natural resource management, including policy review.

Indicators should detect and identify the types of degradation and assess their severity, determine and analyze the cause-effect relationships involved with a view to identifying trends of land degradation and taking remedial action.

Indicators should be SMART (Specific, Measurable [preferably cheaply], Achievable, Relevant, Time-bound), available or at least observable/obtainable, socially and politically acceptable.

Indicators are not without problems, and one should be conscious of a number of them:

- Often no baseline information is available for indicators; therefore, projects often have to start from scratch to measure them.
- No sub-national data is available for socio-economic indicators; consequently, up- and down-scaling becomes difficult, if not impossible.
- Interpretation of cause-effect is often anecdotal and not mathematically correlated. Even if correlations are high, interpretations may differ (Section 4).
- There may be many indicators to chose from; therefore, a judicial selection is required, although sometimes the selected indicators at regional levels may be in conflict with national information privacy practices.
- Land degradation and its cost is politically a highly sensitive issue.

The LADA project is developing an indicator toolbox containing a minimum set of "universal" indicators that can be measured on local and global scales and that allow for extrapolation on these different scales. The indicators in the toolbox are relatively easy to measure or obtain, and in general are related to several conditions of the land, such that the set of indicators, even if not exhaustive, can describe the system in a cost-effective way.

In summary the indicators contained in the toolbox:

- Study the state of different components of land.
- Are purpose driven and take into account land user perspectives as far as possible.
- Allow for harmonization and standardization of assessment methodologies.
- Form part of a sufficiently flexible framework.
- Allow for up- and down-scaling between the varying scales of LD assessment.
- Are the result of experience on data-gathering on different scales.
- Constitute a minimum set of "universal" indicators.

The indicators developed for the LADA project not only describe the status of the land, i.e. they not only determine whether there is degradation in the system, but also seek to relate it the factors that contribute to the observed state, or the direct and indirect causes of the land status, thereby acknowledging both biophysical and socio-economic factors in land degradation. An example of a LADA indicator description sheet is shown in Annex II.

2.2 Stratification: The Key for Upscaling and Downscaling

Indicators and land degradation assessments have been carried out on different scales (Figs. 1 and 2). Nevertheless, follow-up of the results at any level has been extremely limited, partly because the assessment was often undertaken in isolation without adequate involvement of the local stakeholders and partly because the assessment was done with a specific local or global issue in mind (as was the case for GLASOD), which did not require the linkage of results to other scales.

A prerequisite for any cost-effective assessment is to build in from the start specific key factors that can be used to extrapolate results to nearby areas where no such detailed investigation can be undertaken because of the high costs involved. Stratification in this respect is useful because, by superimposing different attributes of land in a map, it results in units that can be considered useful and homogeneous and can capture the main factors that may influence land degradation. In order to stratify, the following factors are recognized as having an essential impact on the dynamics of land degradation: the resource base (climate, soils and terrain), land cover/land use, and the socio-economic environment. Information on these three factors is available at various degrees of detail in global and national databases (Svenson, 2005; George and Franceschini, 2005).

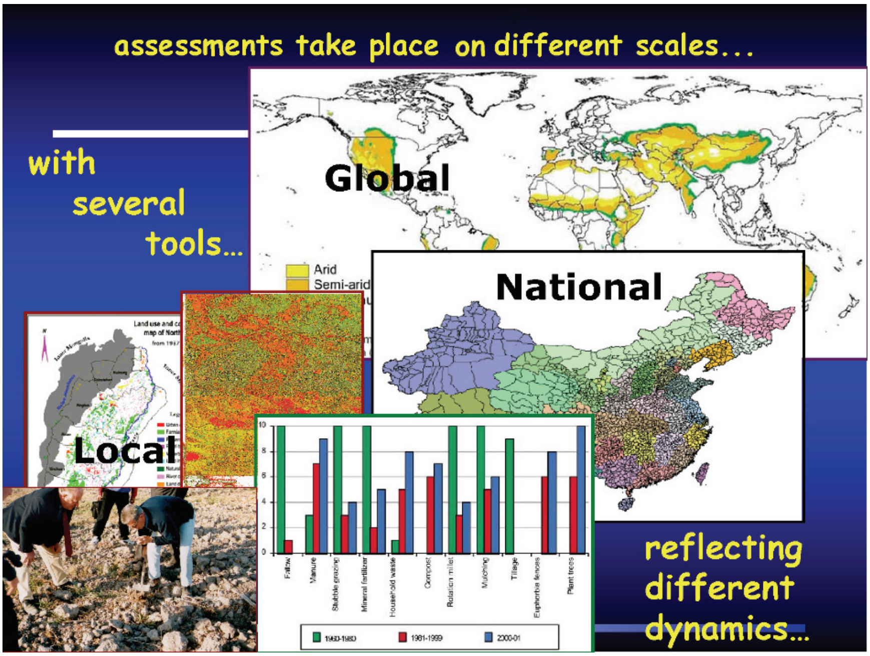

Fig. 1 Land degradation assessments on different scales, using different tools to reflect different dynamics

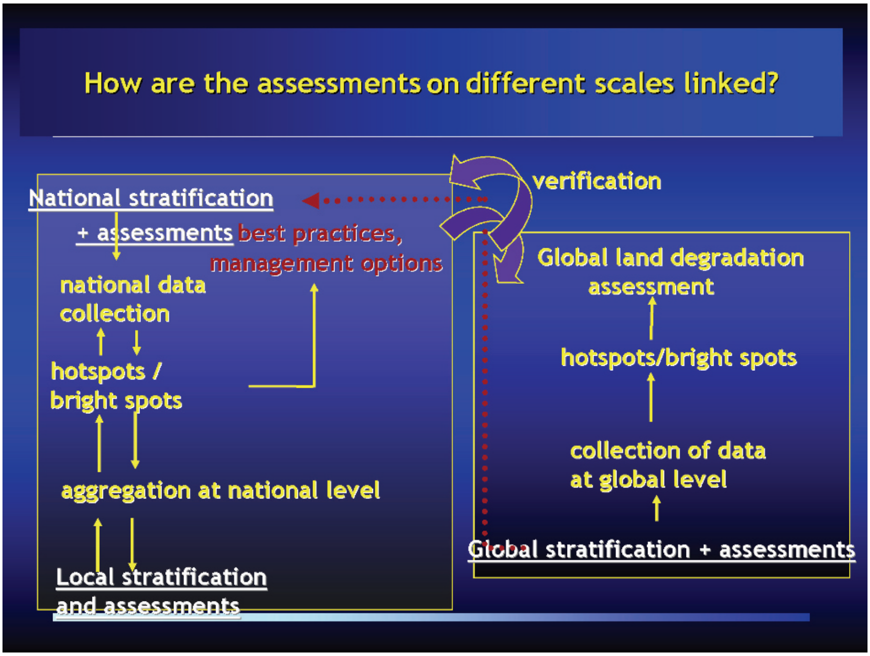

Fig. 2 The linkage between assessments at the three essential levels

These databases can be drawn upon to create more-or-less homogeneous Land Production Units as illustrated in Fig. 3.

A simplified example of such units for China is reproduced in Fig. 4, using the global farming system map (WB/FAO, 2001) and the UNCCD aridity zones and giving attributes for population pressure. More detailed mapping of these units is provided by George and Franceschini (2005) for Senegal, Sierra Leone and Somalia.

All levels of assessment investigation are important, but the national level is the core level at which decisions can most influence impact and initiate remedial action at institutional level. That is the level at which scientific results should be collated first. The local levels are as important to provide valuable information to take concrete action with visible results and involve the land users and direct decision-makers. Therefore, local actors have to be involved in a participatory approach because follow-up and sustainable management cannot take place without them.

Without this prior stratification, no extrapolation is possible from local to national levels, nor is extrapolation possible from the national to the global level. Therefore, local and global indicators selected have to be available or easily and cheaply collected on these scales, if at different levels of detail.

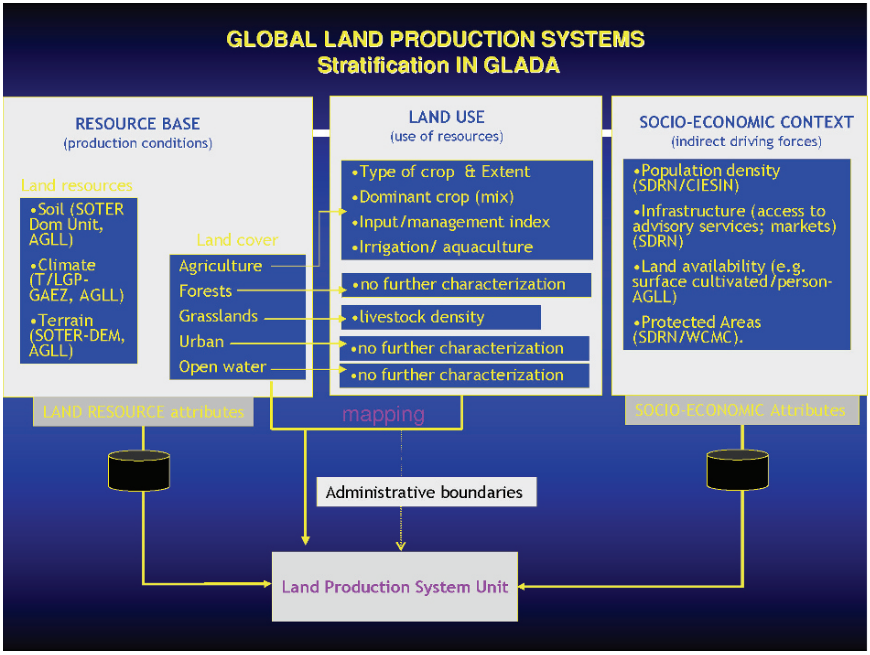

Fig. 3 Land Production System Units characterized by biophysical and socio-economic attributes of mapped land cover/land use units as proposed for the Global LADA assessment (GLADA)

2.3 *Hot Spots and Bright Spots: Focusing on Priority Areas*

A focused approach for investigating land degradation can help to set priorities. These can be set by a national participatory inventory (which is one of the first steps in the LADA approach already carried out in many countries). To complement this national assessment and to assist regional and world bodies concerned with land degradation, LADA undertakes a global approach to hot spots and bright spots, based on two innovative remote sensing technologies adequately underpinned with field checking.

The hot spots and bright spots identified through these techniques can be the basis for higher resolution studies or to take action.

2.3.1 Vegetation Activity Indexes

There are many possible types of remote sensing derived vegetation indexes of which the Normalized Difference Vegetation Index (NDVI) is the most commonly used. The NDVI is a practical way to represent the level or intensity of vegetation activity. In the context of LADA, GIMMS 22-year rectified NDVI data (8 km) will

CHINA - Aridity index + Farming Systems

Aridity/Farming Systems	Mapped %	Mapped Km2	Pop	Pop %	PopDens
3 = Cold / Sparse (cold)	0.00	102	244	0.00	2.39
14 = Humid / Sparse (cold)	0.02	1778	12644	0.00	7.11
15 = Humid / Extensive cereal-livestock	0.01	752	10140	0.00	13.49
17 = Dry sub-humid / Extensive cereal-livestock	0.00	115	200	0.00	1.73
23 = Semi-arid / Extensive cereal-livestock	0.01	919	65548	0.01	71.33
26 = Cold / Sparse (forest)	0.07	6316	34112	0.00	5.40
27 = Humid / Sparse (forest)	1.98	185147	2569056	0.20	13.88
28 = Humid / Upland intensive mixed	17.22	1611291	305276832	24.06	189.46
29 = Cold / Pastoral	0.00	260	796	0.00	3.06
30 = Humid / Pastoral	7.75	725400	10589112	0.83	14.60
31 = Cold / Upland intensive mixed	0.00	52	140	0.00	2.70
35 = Dry sub-humid / Saprse (forest)	0.19	17407	213956	0.02	12.29
36 = Water / Pastoral	0.31	28940	36032	0.00	1.25
37 = Dry sub-humid / Pastora	4.79	448086	9370744	0.74	20.91
38 = Humid / Temperate mixed	3.19	298067	80840128	6.37	271.21
39 = Water / Temperate mixed	0.04	4208	1400120	0.11	332.73
40 = Dry sub-humid / Temperate mixed	3.65	341721	142616640	11.24	417.35
41 = Semi-arid / Pastoral	14.65	1370477	33902952	2.67	24.74
42 = Semi-arid / Temperate mixed	2.21	206382	48373584	3.81	234.39
48 = Dry sub-humid / Upland intensive mixed	1.82	170570	27624068	2.18	161.95
49 = Semi-arid / Sparse-arid	3.79	354922	4097116	0.32	11.54
50 = Arid / Sparse (arid)	18.44	1724649	17728608	1.40	10.28
51 = Water / Sparse (arid)	0.09	8177	21760	0.00	2.66
59 = Semi-arid / Upland intensive mixed	1.61	150381	22406380	1.77	149.00
60 = Arid / Pastoral	0.38	35490	532068	0.04	14.99
63 = Hyper-arid / Sparse (arid)	3.32	310268	791584	0.06	2.55
65 = Humid / Lowland rice	9.51	889420	501442848	39.52	563.79
66 = Humid / Highland extensive mixed	4.63	432929	46907604	3.70	108.35
71 = Water / Upland intensive mixed	0.01	670	177320	0.01	264.65
76 = Dry sub-humid / Sparse (arid)	0.01	1264	1316	0.00	1.04
80 = Humid / Sparse (mountain)	0.00	378	684	0.00	1.81
81 = Dry sub-humid / Sparse (mountain)	0.00	145	600	0.00	4.14
84 = Semi-arid / Sparse (mountain)	0.00	217	1512	0.00	6.96
89 = Dry sub-humid / Lowland rice	0.03	2679	1846644	0.15	689.21
92 = Humid / Highland mixed	0.00	76	396	0.00	5.22
94 = Water / Lowland rice	0.26	24311	9618692	0.76	395.65
104 = Water / Highland extensive mixed	0.01	700	251856	0.02	360.05
--- TOTALS ---	100.00	9354687	1268764244	99.99	135.63

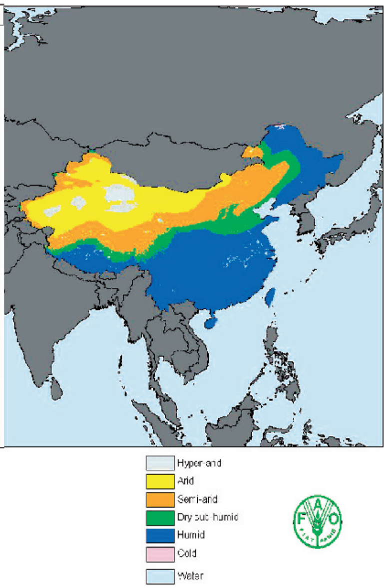

Fig. 4 GIS approach to simplified land production units with information on climate, farming systems and population density in China

be used to analyze the spatial and temporal changes in biomass (Fig. 5). The images will be superimposed with soil/terrain and land use databases to determine deviations from the local norm (hot spots and bright spots). Higher resolution data from Landsat multispectral (30 m resolution) will be used to determine the type of land degradation in the hot spots/bright spots in combination with harmonized field validation and traditional assessment methods.

2.3.2 Land Cover Changes

In theory, high resolution remote sensing data taken at two distant periods can be used to prepare land-cover-change maps or databases. Among the features that can be shown on remote sensing data and that are of prime interest to LADA are: agricultural areas under intensification; reduction of woody cover; reduction of grass cover; forest clearance; reduction of size of water bodies. More particularly, the land cover (use) changes due to agricultural expansion are of interest and can be mapped as illustrated in Fig. 6 by the Global Land Cover Network (GLCN).

In cooperation with GLCN, LADA will undertake these kinds of studies at least in the pilot countries and possibly beyond, which, in combination with the biomass monitoring, should lead to a better identification of land degradation hot spots.

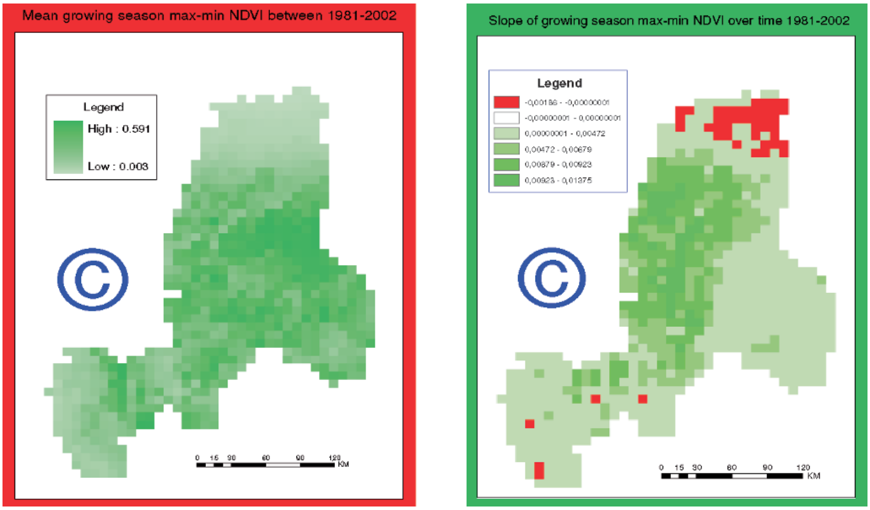

Fig. 5 Spatial analysis of biomass changes (Bai et al., 2005)

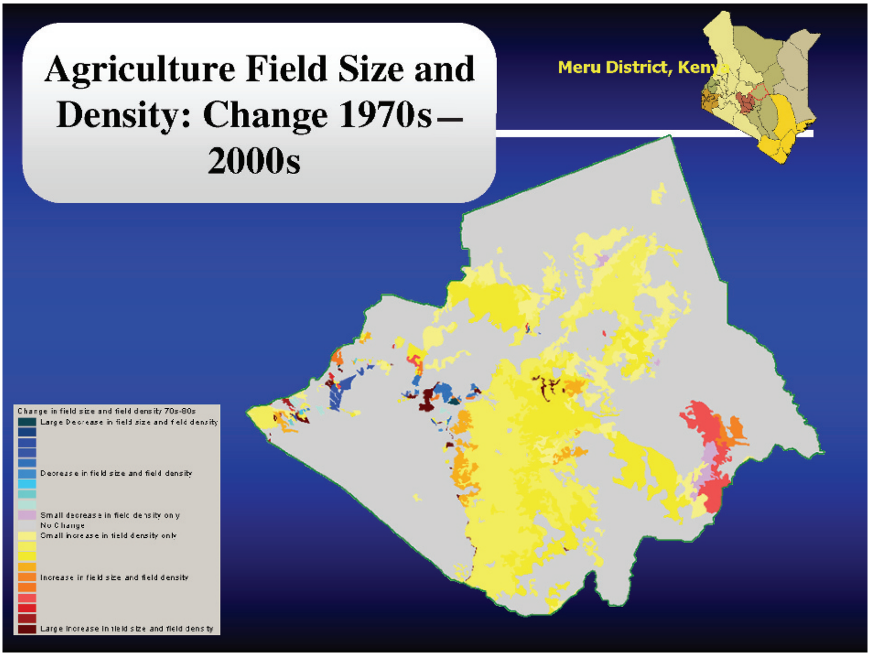

Fig. 6 Agricultural intensification over time as a potential hot spot identifier for land degradation

2.4 The Indicator Framework

To study the status of land and the possible linkages between biophysical and socio-economic factors, the LADA project uses the Driving Force – Pressure – State – Impact – Response (DPISR) framework (Dumanski, 1994). In its general form, the DPSIR framework states that driving forces exert pressures on the environment and that these pressures can induce changes in its state or condition. The subsequent impacts on socio-economic and biophysical attributes cause society to respond by developing or modifying environmental and economic policies and programmes aimed to prevent, minimize or mitigate pressures.

Since the first stage of the land degradation assessment, as conceived by LADA, consists of "scanning" the attributes of land and determining its status, the point of entrance of the LADA methodology to the DPSIR framework is at the state indicators window (Fig. 7).

Once the status of land is determined, the direct and indirect causes of the land status can be investigated through the analysis of pressure indicators and possible socio-economic drivers, respectively. The state indicators, pressure indicators and socio-economic drivers all contribute to the impact observed (e.g., decrease in productivity, loss of cropland, loss of biodiversity) and to which society responds. LADA will therefore generate a complete overview of problems on a global scale, which can be considered as a baseline and based on which countries can decide if a more thorough assessment is needed or if that level is enough to take action.

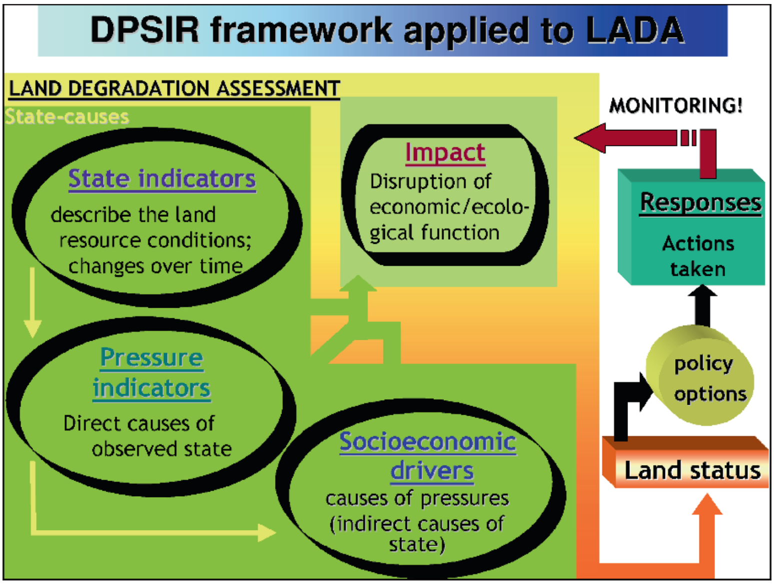

Fig. 7 The DPSIR framework applied to LADA

The DPSIR framework has been maintained as a cornerstone to link cause and effects in environmental studies (Millennium Ecosystem Assessment, GEO-process, LADA preparatory phase). Details and naming within the DPSIR have been controversial and depend on the objective of the assessment. Goods and services provided by the ecosystems are often intangible or it is difficult, if not impossible, to estimate their market value.

Indicators often fit more than one category. There are valid variants to the DPSIR framework (e.g., the Capital Approach), particularly for local level assessments (Stocking and Murnaghan, 2001).

The point however, is, that what matters is not the framework itself but how the framework is interpreted in economic and mathematical terms and can be translated into policies and action at local, national or regional levels. Approaches like DESERTLINK have avoided the framework altogether and aim at starting with the problem as perceived by the stakeholders and reasoning in reverse.

An extract from the indicators toolbox under development is included in Table 1.

3 Methods of Data Collection

LADA uses traditional data collection methods and digital or computer-assisted methods. The traditional methods include: agricultural and other national censuses; resource surveys (soil maps and natural resources maps, previous field investigations); participatory surveys and the Visual Soil Assessment (VSA) tool developed for LADA (Annex III). The digital or computer-assisted data collection methods include models, remote sensing (RS) and geographic information systems (GIS). For remote sensing techniques applied by LADA, see the work of Lantierei (2003) and Licona-Manzur et al. (2005). Socio-economic indicators for LADA were reviewed by Svenson (2005).

4 Indicator Interpretations within the DPSIR Framework and Monitoring

The DPSIR framework provides a quick and good overview of linkages between pressures, exerted directly and indirectly, the changing state of the ecosystem and its effects and costs, as well as possible responses ranging from good agricultural practices to policy and institutional changes. Nevertheless, little attention has been paid to the mathematical and economic soundness of the linkages between the categories of indicators where these have studied (Bot et al., 2000; Wiebe, 2003) and the results have been criticized and considered controversial. For instance, Figs. 8 and 9 from Bot et al. (2000) illustrate some documented statistically sound relationships between slope (biophysical direct pressure) and actual severity of water erosion (state of the resource) and between population pressure (socio-economic indirect

Table 1 Extract from the indicators toolbox developed for LADA

STATE OF THE RESOURCES		
Indicators	Degradation type	Measurement
CLIMATE RESOURCES		
1. Aridity index	Drought/desertification	Analysis climatic stations (LOCLIM)
2. Soil Moisture change	Drought/desertification	Remote sensing
3. Variability of rainfall (Inter-annual and trends)	Drought/water erosion	Analysis climatic stations Modeling
SOIL RESOURCES (local/national to be extrapolated globally for most at a later stage)		
1. Texture	Water logging/water erosion/ wind erosion	Test available
2. Structure	Compaction/sodicity	Test available
3. pH	Nutrient decline/toxic effects/ acidity	Measure
4. Organic matter	Nutrient decline/soil biodiversity decline	Measure
5. Water infiltration (drainage)	Water logging/water erosion runoff	Visual estimate
6. Salinity	Salinization	Measure/RS
7. Soil depth	Nutrient deficiencies Wind and water erosion	Measure
TERRAIN RESOURCES (local, national and global)		
1. Surface aspects	Landslides/gullies/wind erosion	Remote sensing
WATER RESOURCES		
1. Irrigated areas	Salinization	DB available
VEGETATION RESOURCES (Local, nationally and global)		
1. Changes in land cover	Loss of biodiversity/loss of nutrients	Remote sensing

DIRECT PRESSURE ON THE RESOURCES		
Indicators	Degradation type	Measurement
BIOPHYSICAL		
1. Climate extreme events	Salinization (tsunami)	Model/RS
	Landslides (heavy rains)	Model/RS
	Loss of land cover and biodiversity (long drought)	Model/RS
	Sedimentation (dust storms)	RS
2. Disasters	Sedimentation (volcanic eruption)	RS
3. Slope/land use	Water erosion	USLE model
SOCIO-ECONOMIC		
1. Frequency of forest fires	Deforestation/nutrient loss	DB White/Nackoney 2003

(continued)

Table 1 (continued)

DIRECT PRESSURE ON THE RESOURCES		
Indicators	Degradation type	Measurement
2. Presence of land mines	Complete loss of land	UN and US/NGOs
3. Under-management resource	Nutrient loss/erosion	GAEZ/AgroMaps model
4. Urbanization	Sealing (abs. loss of land)	Pop. DB/RS
5. Livestock pressure over CC	Compaction/loss of land cover	Model GAEZ/LS DB
6. Human induced disasters	Isotope fall out (radionuclear)	DB
Local status		
SOIL RESOURCES (local only)		
(Soil colour)	Organic matter content/water logging	Redox Munsell Chart
Root development	Biodiversity loss compaction	Visual
Earthworms (& other)	Biodiversity loss	Measure
Heavy metals	Pollution (only in industrial areas)	Measure
WATER RESOURCES (local/nationally only)		
Level of groundwater	Overexploitation of water resources	Measure
Salinity of groundwater/ irrigation water	Salinization toxic	Measure
Arsenic content	Toxic	Measure

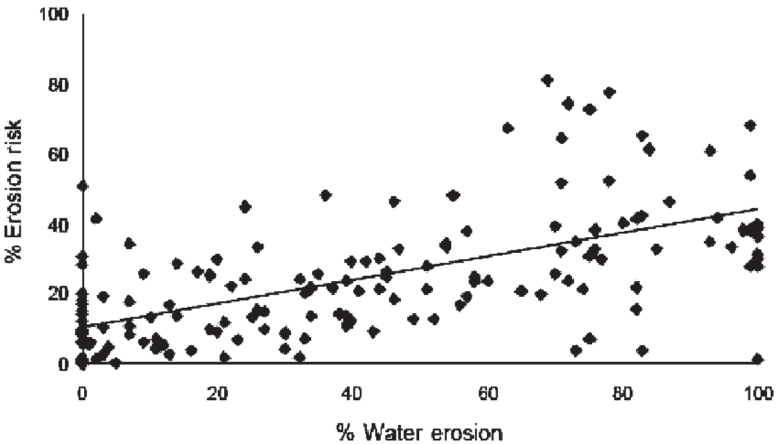

Fig. 8 Correlation between erosion risk and actual water erosion severity as mapped by GLASOD for 160 countries

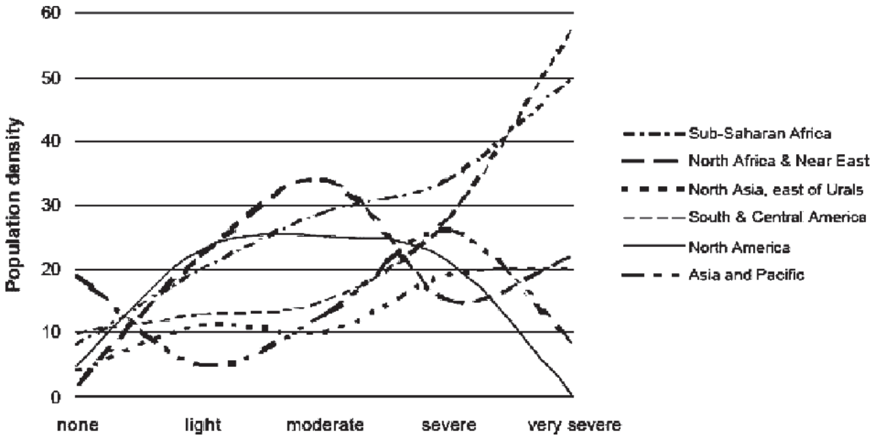

Fig. 9 Correlation between population density and severity of land degradation according to GLASOD aggregated at regional level

pressure or driver) and severity of degradation, respectively. Objections were quickly raised to both of these findings quoting the Machakos example, where higher population pressure did result in better conservation practices. The GLASOD exercise was also criticized as it mapped steep slopes and high population in the first place, rather than actual land degradation status. Another example is the climate change DPSIR, where the overwhelming scientific evidence linked industrial and traffic pollution to global warming, although when translated into political action other factors such as country priorities interfered in the proper use of the DPSIR results.

A recent study by King et al. (2005) on the soil organic carbon (SOC) trend in English arable soils illustrates quite well the problems of monitoring key indicators. In this study the total amount of organic carbon in the topsoil of thousands of sampling sites, over a period of 60 years (1940–2000), was investigated. The study came to the conclusion that the largest influence on the overall mean SOC in arable topsoils was the decline in extent of both temporary and permanent grassland, while the recent overall improvement in SOC levels was attributed to increased acceptance of conservation agricultural practices. The cost of these kinds of studies is not reported, nor is there any attempt to translate the effects in terms of good and services lost or gained by the SOC decline. "Green accounting" has become an occasional practice (carbon sequestration, wetland protection) but has a long way to go to become a standard, though if and when it does, hard data such as these will be required (*The Economist*, April, 2005). More sophisticated statistical methods may be needed to link pressures and impacts as illustrated by Sonneveld and Keyzer (1998) using the mollifier technique.

5 Monitoring

Monitoring key indicators is the only way to observe status changes and impact effects, but the costs (and time) involved may far outweigh the value of the findings or assure that the political will to counteract the environmental decline is maintained. There is a certain bias to monitor the easiest and cheapest data that can be monitored (often remotely sensed forest changes). Examples of ground data monitoring are the soil monitoring of forest soils in Europe (with costs ranging between 5,000 and 25,000 Euro per site per timed observation) and the GTOS (Global Terrestrial Observing System) effort. Two related issues worth mentioning here are the sampling strategy where one has to choose between an unstratified grid design as promoted by the European Union or a stratified one as promoted by LADA. The other issue here well illustrated by the GTOS database is the ownership and access to the monitored information. Often copyright and privacy issues arise and governments and private land owners are not at all eager to share the information collected.

6 Conclusions

- There is an urgent need to obtain baseline information on the state of ecosystems supported by hard data obtained not only by remote sensing but also by ground surveys.
- It is important to use simple methods and the least possible number of indicators to describe the system that is cost effective.
- The LADA indicator toolbox may not be the perfect solution but offers a harmonized way of data collection/analysis that can serve as a starting point.
- Assessments cannot go on forever; in the meantime, mitigating action often should be taken without waiting for results of these ongoing assessments.
- Monitoring is important to assess progress of actions, but problems remain with sampling design, statistical methods to prove correlations, and access to information.

Annex I

LADA stocktaking and preliminary analysis of indicators

Report/activity title	Significant outputs
Dryland Land Degradation Assessment (LADA) International Workshop, 5–7 December 2000	Discussed focal issues on desertification and land degradation. Exploratory workshop that paved the way for further elaboration and development of LADA into a full-blown PDF B proposal for GEF funding.
Some suggested indicators for Land Degradation Assessment of Drylands by Mathilde Snel and Alexandra Bot, 2002	Concept of possible indicators (SMART: specific, measurable, achievable, relevant and time-bound).

(continued)

Annex I (continued)

Report/activity title	Significant outputs
	A list of possible land degradation indicators, data studies/sources relevant to the development of LADA indicators.
	Summarized methods for assessing land degradation from LADA Initiative (expert opinion, remote sensing, field monitoring, productivity changes, sample studies at farmer level, based on field criteria and the expert opinion of land users, modeling).
LADA e-mail conference	Served as an avenue for an excellent forum to exchange ideas among land degradation experts from various organizations, national and private agencies, academic and research institutions. The forum yielded an exhaustive list of indicators (and its limitations) from the very basic to the most complex ones on all scales (potential indicators and currently being used) that LADA can choose from. A number of constructive points to consider when using indicators were stressed in the conference: to use indicators with caution, methods and development of indicators should be purpose- or demand-driven, acknowledge land user perspectives, harmonization and standardization (particularly, indicators and methods), up- and down-scaling between the varying scales (facilitate integration and/of comparison between data and information), synergy with existing land degradation activities and other Conventions, and retain modest and clear objectives.
9 October–4 November 2002	
A four-week e-mail conference conducted to raise awareness on LADA, exchange expert views on land degradation assessments, identify and develop biophysical, socio-economic and institutional (on all spatial scales) that explain the root causes, driving forces, status, and impact of and responses to land degradation.	
Data Sets, Indicators and Methods to Assess Land Degradation in Drylands, FAO, Rome World Soil Resources Report No. 100 2003	The Proceedings of the LADA e-mail Conference conducted 9 October – 4 November 2002.

(continued)

Annex I (continued)

Report/activity title	Significant outputs
	It summarized the activities undertaken, inputs, comments and suggestions gained from the numerous experts who attentively participate in the conference, particularly discussing the approaches and methodologies, selection and listing of indicators for local, national, regional and global scales of land degradation assessments. The subdivision of indicators into biophysical, demographic, institutional and socio-economic groups and the position of each indicator in the DPSIR framework are specified. The conference was attended by 148 experts in land degradation.
Stocktaking of dryland issues in the context of the Land Degradation Assessments of Drylands (LADA): Selection and Use of Indicators and Methods for Assessing Biodiversity and Land Condition prepared by Annie Lane and Sally Bunning (Draft 28 July 2003)	Provided background information on LADA and dryland biodiversity. Described LADA methodological approach and the ecosystem approach in the context of DPSIR framework, and discussed the socio-economic drivers of land degradation, dryland biodiversity and pressures on dryland biodiversity. The report also presented how biodiversity can be integrated into the LADA 7 steps and indicators assessment, and the range of potential indicators to assess and measure biodiversity, land condition and socio-economic conditions on different spatial scales. General guidelines for selecting indicators, monitoring sites and sampling dryland biodiversity and land degradation are also discussed. Application of indicators was illustrated using case studies from four countries (China, Bolivia, Niger and Mongolia), which have both common and different biodiversity and land degradation pressures and issues.
Proposed Framework for indicators of bio-diversity, land and socio-economic condition by Sally Bunning and Annie Lane, July 2003	Provided a list of biodiversity, land condition and socio-economic indicators for local, ecosystem or national scales and briefly discussed the critical role of human management actions to safeguard biodiversity and land condition and a summary of driving force, pressure, and state indicators with corresponding methods and assessment level and limitations. The paper is extracted from the paper on 'Selection and Use of Indicators and Methods for Assessing Biodiversity and Land Condition' conducted as part of 'Stocktaking of Biodiversity Issues in the Context of the LADA' (written by the same authors).

(continued)

Annex I (continued)

Report/activity title	Significant outputs
Potential Use of Satellite Remote Sensing on Land Degradation Assessment in Drylands. Application to the LADA Project (draft), by Dominique Lantieri, 2003	Discussed the paramount importance and usefulness of remote sensing tools, data and capacities of potential interest to LADA; practical application of remote sensing techniques for LADA information needs, assessment and monitoring of land degradation; and an overall remote sensing strategy for LADA.
Methodological Framework for Land Degradation Assessments in Drylands (LADA), simplified version by Raul Ponce-Hernandez with Parviz Koohafkan, August 2004	Simplified version of the proposed structure of methodological framework for LADA. The report discussed how the seven-step approach and the twelve-core activities will complement each other in attaining the LADA goals. The methodological framework is comprised of modular toolboxes (manual and visual field assessment tools, to modeling and remote sensing tools) and how it will be integrated to attain the networks of causal relationships. However, the concept of modular toolboxes and automation is still subject to prototyping.
Socio-economic Indicators for Causes and Consequences of Land Degradation, by Lisa Svensson, 2005	A listing of feasible socio-economic indicators for the different spatial scales and their possible data sources. The author reviewed the possible linkages between socio-economic factors and land degradation to help to establish socio-economic indicators for the assessment processes related to land degradation in drylands.

Annex II

An example of a LADA indicator description sheet

Indicator name	Disasters (sedimentation, volcanic eruptions, geological events)
Definition/description	Disasters are events that occur when significant numbers of people are exposed to extreme events to which they are vulnerable, with resulting injury or loss of life, often combined with damage to property and livelihoods Volcanic eruption is a natural hazard or natural disaster, depending on the damage it causes to the ecosystem (Burton et al., 1978)
Type of degradation	Loss of habitats, reduction of productive lands, land cover change
Objective of the indicator	To design/develop approaches and strategies to rehabilitate damage croplands
Methods of measurement	Remote sensing, field survey
Unit of measure	%

(continued)

Annex II (continued)

Report/activity title	Significant outputs
Spatial scale	Local, national
Temporal scale	After the event
Type of indicator (within the logical framework of DPSIR)	Pressure. Direct pressure on biophysical resources
Significance of indicator and relevance to international conventions	Extreme events often occur in complex cascades. Earthquake may trigger mud or rock-slides, etc. Induced (or increased) poverty Devastation effect would depend on the amount, thickness or volume of volcanic debris, lava, ash fall and mudflow Millennium Development Goals (MDG) of poverty alleviation and environmental sustainability
Limitations of the indicator	No early warning signs
Linkages with other land degradation indicators	Surface aspects, poverty incidence, variability of annual rainfall, landslides, tsunami
Data sources and availability	Columbia Center for Hazards and Risk Research Centre for Research on the Epidemiology of Disasters (CRED) Data provided: number of events, killed, casualties, damage and affected area for drought, disasters, tsunami, landslides, volcanic eruption
Other institution/project using this indicator used/references	Frequency of natural disasters (#/year), core indicator of natural events (environmental and economic indicators, WORLDBANK 2000) Institutional indicator (UN CSD)

Annex III

Data collection at local level using the Visual Soil Assessment tool

The collection of information at local level is an important part of the LADA project. Through exercises in the six pilot countries participating in the project, LADA will test and collect information using a method developed for LADA which is based on a participatory approach. The parameters assessed using VSA allow for collection of information that can be later aggregated at a subnational and national level. The VSA principle is to use simple techniques which can be learned by farmers and that they need for improving land conditions. The VSA has three main types of investigation, covering site details (e.g. previous management, "walk-in" clues, soil morphology [e.g. soil structure, root development, colour, biota], soil measurements [e.g. soil texture, pH, organic carbon, soil slaking and dispersion, water infiltration]). All VSA indicators are related to laboratory-based soil characteristics. The VSA soil structure score was strongly related to the dry aggregate-size distribution, saturated hydraulic conductivity (Ksat) and air permeability, moderately related to macroporosity and bulk density, and weakly related to aggregate stability. The VSA soil porosity assessment was strongly related to dry aggregate-size distribution and macroporosity, and weakly related to dry bulk density. The colour score was strongly related to total carbon and moderately related to anaerobic mineralisable nitrogen of conventionally cultivated mineral soils. The soil colour relationship holds only for those conventionally cultivated soils that do not have strongly bound and/or high amounts of organic matter, and do not show visual evidence of anaerobicity.

Soil structure, bulk density, organic carbon, hydraulic conductivity and soil aeration (as indicated by air permeability and soil porosity) are important characteristics to assess the condition of the soil and whether a soil provides a favourable environment for plant roots.

The methods used in the VSA allow for the transfer of information between sites, soil types, land uses, etc., while providing a "cross check" and physical reality to structure descriptors. VSA is a simple method that is carried mainly with everyday tools, is repeatable between sites, soils and operators, is robust since it is based on scientific approaches, and provides linkages between productivity and land use.

References

Bot, A. J., Nachtergaele, F. O. F. and Young, A. 2000. *Land Resource Potential and Constraints at Regional and Country Levels*. World Soil Resources Reports 90. FAO, Land and Water Development Division, Rome. http://www.fao.org/ag/agl/agll/terrastat

Dumanski, J. 1994. *Proceedings of the International Workshop on Sustainable Land Management for the 21st Century*. Vol. 1: Workshop Summary. The Organizing Committee. International Workshop on Sustainable Land Management. Agricultural Institute of Canada, Ottawa.

FAO/ISRIC. 2000. *Soil and Terrain Database: Land Degradation Status and Soil Vulnerability Assessment for Central and Eastern Europe*. FAO Land and Water Digital Media Series No. 10. FAO, Rome.

FAO/World Bank. 2001. *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*. FAO, Rome, World Bank, Washington, DC.

George, H. and Franceschini, G. 2005. *f-CAM – A Framework for the Characterisation and Mapping of Agricultural Land Use at Sub National Scales Using Pre-existing Data Sets*. (Unpublished FAO report.)

Keyzer, M. A. and Sonneveld, B. G. J. S., 1998. Using the mollifier method to characterize datasets and models: the case of the Universal Soil Loss Equation. *ITC Journal* 1997-3/4, pp. 263–273.

King, J. A., Bradley, R. I. and Harrison, R. 2005. Current trends of soil organic carbon in English arable soils. *Soil Use and Management*, Vol. 21, No. 2, pp. 189–195.

Koohafkan, P., Lantieri, D. and Nachtergaele, F. 2003. *Land Degradation Assessment in Drylands (LADA): Guidelines for a Methodological Approach*. Land and Water Development Division, FAO, Rome.

Lantierei, D. 2003. *Potential Use of Satellite Remote Sensing for Land Degradation Assessment in Drylands: Application to the LADA Project.* Environment and Natural Resources Service, Sustainable Development Department, FAO. p. 77.

Lantierei, D. and Young, A. 2003. *Potential Use of Satellite Remote Sensing for Land Degradation Assessment in Drylands: Application to the LADA Project*. SDRN series. FAO, Rome.

Lantierei, D. and Young, A. 2001. *Report on the First LADA Workshop*. FAO, Rome.

Licona Manzur, C., Nachtergaele, F. O. F and Svensson, L. 2005. *Indicator Toolbox for the Land Degradation Assessment in Drylands Project*. UNCCD, COP-7 Side-event. Nairobi, Kenya.

Mahler, J. P. 2003. *Review and Critical Comments on the LADA Methodology*. AGLL, FAO, Rome.

Nachtergaele, F. O. F. 2004. *Land Degradation Assessment in Drylands: The LADA Project*. Proceedings of EU Joint Research Centre, Ispra.

Nachtergaele, F. O. F. and Auricht, C. M. 2004. *GLADA: Global Land Degradation Assessment. Progress Report*. ftp://ftp.fao.org/agl/agll/lada/glada_project_status.pdf

Ponce-Hernandez, R. 2002. *Land Degradation Assessment in Drylands: Approach and Development of a Methodological Framework*. http://www.fao.org/ag/agl/agll/lada/emailconf.stm

Sonneveld, B. G. L. S. 2003. *Formalizing the Use of Expert Judgements for Land Degradation Assessment: A Case Study for Ethiopia*. Proceedings of the EU Joint Research Centre, Ispra.

Sonneveld, B. G. J. S., Keyzer, M. A. and Albersen, P. A. A non-parametric analysis of qualitative and quantitative data erosion modeling 33 SOW-VU Working paper 99- –07, 73, abstract and pdf

Stocking, M. and Murnaghan, N. 2001. *Handbook for the Field Assessment of Land Degradation*. Earthscan, London.

Svenson, L. 2005. *Socio-economic Indicators for Causes and Consequences of Land Degradation*. LADA Technical paper, FAO, Rome.

Van Lynden, G. W. J. and Kuhlman, T. 2002. *Review of Degradation Assessment Methods*. http://www.fao.org/ag/agl/agll/lada/emailconf.stm

Wiebe, K. D. 2003. *Linking Land Quality, Agricultural Productivity, and Food Security*. USDA-ERS Agricultural Economic Report No. 823.

Chapter 4
A New Toolkit for Monitoring and Forecasting Forage Supply in the Grazing Lands of Eastern Africa

Adbi Jama, Robert Kaitho, Jimmy Wu and Laban Macopiyo

Abstract Pastoral communities in East Africa have faced unprecedented variation in weather, desertification and degradation of forage resources in recent times, leading to large-scale losses of livestock and reducing both marketing and management options, which renders pastoralists dependent on food aid. The increased uncertainty due to drought, coupled with the breakdown of options to use traditional risk management strategies, has led to a need for new approaches for early warning to make proactive decisions before drought sets in. One such possibility is the development of new technologies capable of providing information on emerging forage conditions to assist in improving livestock movement and sales options of pastoralists. The Livestock Early Warning System project of the Global Livestock Collaborative Research Support Program led by Texas A&M University has developed an automated modeling package to assist these mobile dry-rangelands livestock keepers in East Africa to cope with shocks of climate and make informed decisions about current and future forage conditions and thereby guide their mobility and decision-making patterns. The approach makes use of modeling techniques, Geographic Information System (GIS) and information and communication technology (ICT) and takes real-time, satellite weather data to drive a biophysical model called PHYGROW to simulate daily forage conditions and near-term forecasts of these conditions. Using geo-statistics, these point-based model simulations are linked with Normalized Difference Vegetation Index (NDVI) satellite images to create maps of forage supply and its deviation from normal. This information is updated every ten days with situation reports and maps distributed via WorldSpace radios, email, internet, and newsletters in the region. This technology suite has been developed in collaboration with national government agencies in Ethiopia, Tanzania, Kenya, and Uganda and NGOs working in pastoral areas.

Keywords Early warning, East Africa, monitoring, PHYGROW, co-kriging

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1 Introduction

Livestock producers in the arid lands of East Africa are facing conditions where traditional drought coping strategies are being undermined by increased population pressure, erratic climatic patterns with higher frequency of drought, limited marketing opportunities, changing land tenure patterns, rising social conflict, limited water supply and greater incidences of disease. One of the primary manifestations of these combined forces is the degradation of the rangeland resources, resulting in large-scale losses of livestock and famine, which makes pastoralists dependent on food aid from donor communities and agencies. Traditional coping mechanisms have been eroded by the increased frequency of drought, flooding, conflict, inefficient markets, resource deterioration and encroachment of farming into traditional grazing lands. The increased risks and the collapse of traditional risk management strategies have necessitated the search for new innovative ideas, tools and approaches to overcome this vicious circle. One such approach is the development of new technologies capable of providing information on emerging forage conditions ahead of time to assist in improving livestock movement and sales options for pastoralists.

For the past several years, the Global Livestock Collaborative Research Support Program (GL-CRSP) has been leading the implementation of a project to develop a Livestock Early Warning System (LEWS) for the arid land regions of Eastern Africa (Ethiopia, Kenya, Tanzania, Djibouti, Somaliland and Uganda). The LEWS project has assembled a suite of technologies and explored their applications in East Africa, including computer simulation models of plant growth, satellite-based weather data and spatial analysis techniques linked with NDVI (Stuth et al., 2003).

PHYGROW, a Phytomass Growth Simulator biophysical model, which is a hydrologic-based, spatially explicit multiple-species plant growth/hydrology/animal grazing model, is the bedrock of the LEWS toolkit (Fig. 1). The toolkit is designed to monitor the impact of emerging weather conditions on forage supply for livestock in the pastoral regions of East Africa. The model uses soil and plant community characteristics, traditional livestock management decision rules and weather data for a particular location to simulate daily forage available for different kinds of livestock and other major herbivores (wildlife). These attributes are organized in a parameter file to go into PHYGROW to simulate daily forage.

Forage monitoring is becoming increasingly important in East Africa, as frequent and recurring droughts affect large areas of the region. Determining forage production over large regions requires a significant amount of both human and financial resources. Resource limitations have greatly hindered the ability to determine the effects of desertification, particularly as it relates to vegetation loss within the context of rangeland monitoring, assessment programmes, and livestock early warning systems. The technique of linking the PHYGROW model with satellite-based weather data offers a major breakthrough in establishing a point-based sampling system of large landscapes and linking it to other readily available data to interpolate results for areas not actively monitored by using co-kriging methodology. The technique involves the use of a secondary variable (covariate) that is cross-correlated with the primary or sample variable of interest. The secondary variable used in East Africa is

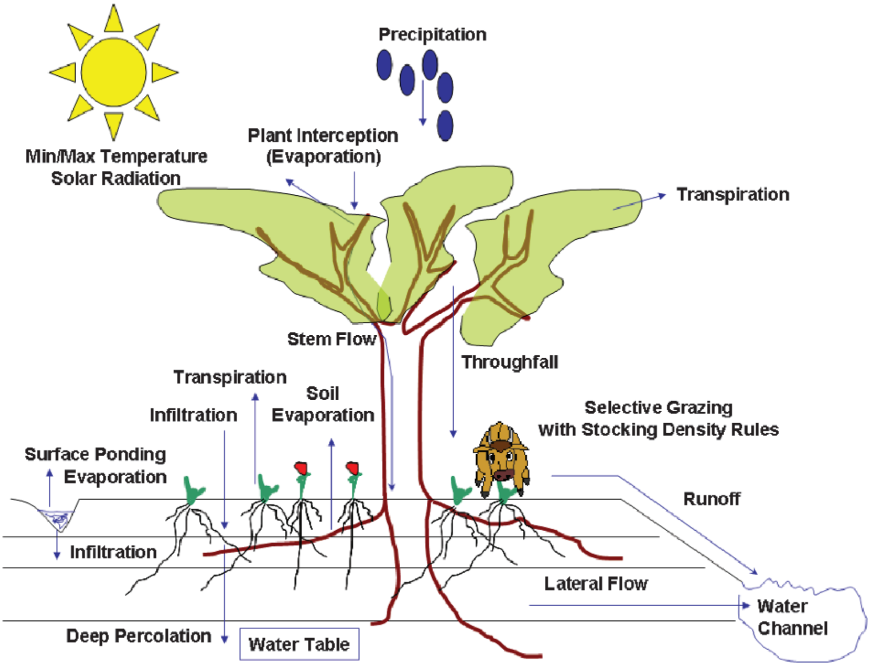

Fig. 1 **PHYGROW** model: A hydrologic-based forage production model that accommodates multiple plants and multiple grazers

the NASA NDVI product for continent of Africa which provides spatially rich data across the landscape which has been correlated with plant biomass production (Tucker et al., 1985). Various geostatistical methods and GIS techniques are then employed to produce surface maps of available forage using the point data generated through the automation process. These techniques allow for the estimation of forage yield for large areas of non-sampled locations. Such techniques offer a cost-effective way for monitoring forage in vast areas in a timely manner.

This paper will focus on the integrated technology toolkit developed by LEWS/ GLCRSP to monitor current and to forecast expected forage situations in pastoralist regions of East Africa.

2 Key Elements of the Livestock Early Warning Toolkit

2.1 PHYGROW Model

PHYGROW is a hydrologic-based plant growth model that simulates daily available forage for livestock. PHYGROW is capable of simulating multi-species or multi-functional plant groups simultaneously across multiple years on daily time steps (Fig. 1). The model requires initial parameterization of a representative site for monitoring locations that are carefully selected to be as representative as possible for corresponding 8 × 8 km satellite weather and NDVI grids. The characterization includes identification and measurement of the plant species in a typical plant community for the monitoring site, measurement of soil properties and collection of information about the traditional livestock management rules to constitute the primary inputs for the model. These inputs can also be directly entered into an on-line version of the model to estimate forage condition. The parameter file contains the listing and is comprised of four major modules, including soils, plant communities/species attributes, grazer stocking rules/plant preferences and weather representing the initial values for all the key variables provided by the user either through field sampling of representative sites or sourcing from available literature. These parts interact in a PHYGROW model simulation driven by weather to produce a final output.

A long-term daily weather data is initially needed to drive the model in order to set up a baseline, or long-term normal, for each site. The weather variables include: minimum and maximum temperatures (C), rainfall (cm), and solar radiation (Langley). Currently, long-term temperature and solar radiation through 1997 are generated by the WXGEN weather generator. The long-term rainfall data is derived from a combination of the 1961–1997 CHARM rainfall data developed by Funk et al. (2003) and the RFE from the Climate Prediction Center dataset for Africa (1998 to present). RFE imagery is an automated (computer-generated) product that uses Meteosat infrared data, raingauge reports from the global telecommunications system, and microwave satellite observations within an algorithm to provide approximate RFE in mm. The methods of generating and use of satellite-based rainfall and temperature data have been extensively explored by Xie and Arking (1998), Grimes et al. (1999) and Funk et al. (2003). Similarly, the use of NDVI satellite data has been well established (Tucker et al., 1991).

Once all the inputs are provided, the model is implemented with long-term weather to stabilize the simulation for each site. During stabilization, a scientist examines both the input and the output parameters for reasonableness in key variables in the output for how they track the situation on the ground and for inadvertent errors in the input. Once a parameter file is set up and stabilized, the only module that is updated for each simulation period is the weather that drives the model. Stabilized model parameter files are placed in a web-based automation process to run and report daily forage conditions, percentile ranking of forage on offer and deviations from a long-term average with projections for the next 90 days on a near, real-time basis (http://glews.tamu.edu/africa) with minimum human interference. This information forms the basis of a livestock early warning system.

Another integral component of the early warning system is the process of verification of results to help to build user confidence in the system. Verification of model-simulated forage production (Jama et al., 2003) is conducted and the ensuing analysis and information is shared with key institutions to build "strength of evidence" of emerging forage conditions, thus allowing increased confidence in the products to allow policy-makers and users to act on the information.

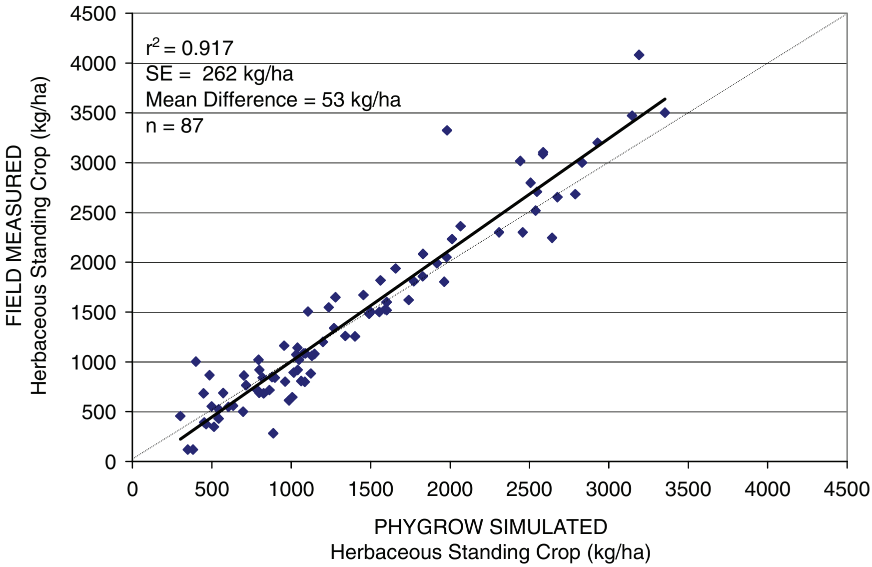

Fig. 2 Relationship between PHYGROW simulated forage production and ground measurements of available forage in selected monitoring sites in East Africa

PHYGROW model outputs of strategically selected sites are ground-truthed by the LEWS team to insure adequate tracking of the forage conditions on the ground. So far, the results indicate that PHYGROW accounted for 96% of the observed variation in herbaceous forage on offer with a standard error of prediction of 161 kg/ha. Mean difference in sampled and predicted forage on offer was 15 kg/ha (Fig. 2). This indicates that when parameterized properly, the PHYGROW model performs well for the resolution of analysis required for LEWS programme in East Africa.

2.2 Spatial Analysis and Co-Kriging with NDVI

The point-based PHYGROW forage output is further correlated with NDVI data through a geostatistical technique called "co-kriging" in order to build forage supply maps of deviation from normal and rate of change of forage (Fig. 3). Co-kriging allows the use of biophysical model data collected for a small set of samples in a large landscape to be coupled with a more spatially rich NDVI data set to interpolate forage responses for sampled areas across a region. However, for co-kriging to work effectively, a good linear relationship must exist between the model-simulated forage values and corresponding NDVI data. Since the correspondence between model output and NDVI in co-kriging is spatially dependent, areas that lack correspondence can be identified, thus allowing the

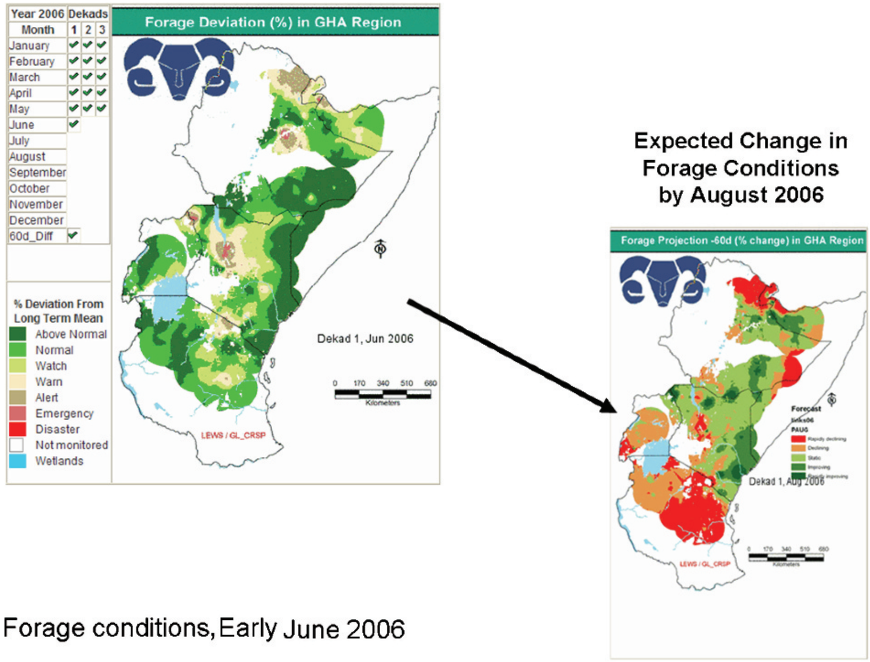

Fig. 3 Forage deviation in June 2006 and expected change in forage conditions by August 2006 for the Greater Horn of Africa region

LEWS teams to determine where new monitoring points need to be located using GPS technology to situate these sites. Presently, the co-kriging is conducted using commercial software (GS+); however, preparations are underway for an automated mapping system based on GSTAT algorithms that will be deployed in the near future.

2.3 *Projections into the Future*

Using the relationship generated by PHYGROW and weather data, historically derived forage estimates are coupled with spatially and temporally coherent NDVI data to forecast likely forage production up to 90 days in advance with a level of accuracy that is within normal field sampling error (Kaitho et al., 2003). The forecasting procedure analyzes and projects the data using an AutoRegressive Integrated Moving-Average (ARIMA) model. This approach combines past forage conditions with current forage estimates from the PHYGROW model to predict future standing crop (Fig. 3).

The ARIMA procedure analyzes and forecasts equally spaced univariate time series data using the ARIMA model. This model (Box et al., 1994) predicts a value in a response time series as a linear combination of its own past values (autoregressive), past errors, shocks or random disturbances (moving average), and current and past values of other related time series (covariate). The PHYGROW output data series is first made stationary by applying the appropriate differencing. Seasonal dependency (seasonality) patterns are then identified, and given the variability in weather patterns over the region and differences of the onset and end dates of rainfall, an annual circle produced the best correlation in most cases. Serial dependency is removed by differencing the series to identify the hidden nature of seasonal dependencies in the series and to make it series stationary, which is necessary for the ARIMA. Finally, the stationary forage data are used to estimate ARIMA parameters using the function minimization procedure (nonlinear estimation), so that the sum of squared residuals are minimized. These parameter estimates are used in the forecasting stage to calculate new values of the series (beyond those included in the input data set) as well as confidence intervals for those predicted values. Since the estimation process is performed on transformed data (differenced) before the forecasts were generated, the resulting series are integrated so that the forecasts are expressed in values compatible with the input data.

2.4 Automation and Analysis Portal

The lack of trained personnel constitutes one of the major constraints to deploying a complex technology such as LEWS in developing countries. Therefore, the LEWS team has strived to devise methods where data is automatically acquired with pre-designed analysis conducted by resident programmes that are scheduled to run unattended to generate output for dissemination to outreach partners in the region. Currently, it is only the mapping technology that requires human intervention to select the best model fit for the co-kriging process. Concerted research efforts are underway towards full automation, including the mapping module. The LEWS automation system is presently located at the Texas A&M University Center for Natural Resource Information Technology (CNRIT). CNRIT has a large ongoing programme in information technology and therefore provides a minimal cost locale to insure that the data is acquired, analyzed and disseminated in a timely manner to all partner organizations in East Africa.

2.5 Reports and Dissemination

Dissemination of the LEWS information suite is critical to the success of the programme. After all, the impact of the Livestock Early Warning System will ultimately be determined by the extent to which livestock producers, practitioners, development agencies and policy-makers utilize the information generated to aid their decision processes. It is important to note that dissemination of any livestock information in the remote underdeveloped pastoral areas in East Africa remains a formidable challenge. Currently, LEWS places all analyses on the Africa Livestock Early Warning System website portal (http://glews.tamu.edu/africa) with daily updates. Furthermore, subsets of the analyses are reconfigured for broadcast via WorldSpace satellite radios using African Learning Channel bandwidth and containers from the Arid Lands Information Network (ALIN) and RANET. The maps and minimal narrative goes to ALIN for distribution in their network of 200+ radios across East Africa. The full situation reports are distributed by RANET in their larger container.

The WorldSpace radio technology allows for the deployment of Mobile Communication Nodes (MCN) consisting of a computer laptop, solar panel, adapter, portable printer and a satellite radio receiver. The satellite receiver will pick up the broadcasts, which can be downloaded and viewed via a connection to a computer, preferably a laptop. The downloaded information can be printed out for posting in public locations or incorporated into existing communication pathways. The inclusion of a solar panel gives the MCN more flexibility to be deployed in remote pastoral zones where electricity is not available. Communication nodes are established across East Africa involving a satellite radio linked to an inexpensive laptop or desktop computer via an adapter to transfer reports at scheduled times each day. Many of these communication nodes are located in NGO offices, district offices and communication offices of early warning agencies of the countries.

The LEWS situation reports are made available on the LEWS analysis portal on monthly basis. Condensed versions of the situation reports are also e-mailed to the appropriate country-level information officers in the host countries through an e-mail list server. LEWS advisories are delivered by a network of over 800 key decision-makers representing a large number of NGOs, regional organizations and early warning units of each of the four country's governments and their district offices throughout the region. A consortium of FEWS NET, USGS, WFP, ICPAC and LEWS also produces a monthly *Greater Horn of Africa Food Security Bulletin*, with LEWS focusing on forage situation outlook in the pastoral areas within that bulletin.

3 Institutionalization and Sustainability

A key element in the implementation of a livestock early warning programme is developing a vision for sustainability to ensure institutionalization of these activities and connecting institutional decision-makers using the information with the analytical tools. The issue of identification of key decision-makers and training of those individuals to correctly interpret the data generated by the system and act upon the information in an expedient manner was one important aspect of LEWS dealt with in the early days of the programme. The LEWS programme emphasized developing an automated analysis within the CNRIT at Texas A&M University. CNRIT is committed to maintaining a mechanism to provide a stable home for generating the LEWS analyses even after the current donor support ends. However, the same computing platform can be also be replicated in collaborating institutions with staff training provided in maintaining the equipment, running the models, distributing the data and educating institutional and community users of the products generated by the system if the commitment and local resources are available. Because the PHYGROW system can run on UNIX/LINUX or WINDOWS operating systems, the LEWS automation environment can be implemented in a wide variety of institutional arrangements.

The LEWS project of GLCRSP uses the model of the university research environment conducting the research and development of ICT to be applied in developing countries. Access to that ICT is stabilized for relevant host country organizations by maintaining it within the university system until that organization has the staffing, funding and institutional commitment to transfer the technology. This arrangement allows developing countries and GLCRSP to work on lower cost outreach activities to accelerate the impact of the technology until government or institutional commitment is attained. The key to making this approach work is the concept of fully automated ICT. The LEWS team has made a concerted effort to design software that can monitor and acquire model input data on a pre-scheduled basis, check that data for quality control and then implement the data applications to compute current and future forage conditions. This automation technique allows LEWS to deliver the technology long into the future at minimal costs to the host country institutions. Another key ingredient is building strong and stable networks of organizations that report data. The goal is to lower the upfront burden of technology, develop low-maintenance automated systems for advanced organizations to support emerging skills and capabilities in developing countries. This will allow developing countries to focus initially on high impact outreach and then eventually to grow into the technology as the institutional and human commitments emerge.

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References

Box, G. P., Jenkins, G. M. and Reinsel, G. C. 1994. *Time Series Analysis: Forecasting and Control*. Third edition. Prentice Hall, Upper Saddle River, NJ.

Funk, C., Michaelsen, J., Verdin, J., Artan, G., Husak, G., Senay, G., Gadain, H. and Magadazire, T. 2003. The collaborative historical African rainfall model: Description and evaluation. *International Journal of Climatology*, Vol. 23, pp. 47–66.

Grimes, D. I. F., Pardo-Iguzquiza, E. and R. Bonifacio. 1999. Optimal real rainfall estimation using rain gauges and satellite data. *Journal of Hydrology*, Vol. 222, pp. 93–108.

Jama, A., Kingamkono, M., Mnene, W., Ndungu, J., Mwilawa, A., Sawe, J., Byenkya, S., Muthiani, E., Goromela, E., Kaitho, R., Stuth, J. and Angerer, J. 2003. *Field Verification of*

Simulated Grazed Forage Standing Crop Using the PHYGROW Model and Satellite-Based Weather Data. USAID Global Livestock CRSP, Research Brief 03-03-LEWS April.

Kaitho, R., Stuth, J., Angerer, J., Jama, A., Mnene, W., Kingamkono, M., Ndungu, J., Mwilawa, A., Sawe, J., Byenkya, S., Muthiani, E. and Goromela, E. 2003. *Forecasting Near-Term Forage Conditions For Early Warning Systems in Pastoral Regions of East Africa*. USAID Global Livestock CRSP, Research Brief 03-02-LEWS April.

Stuth, J. W., Angerer, J., Kaitho, R., Jama, A. and Marambii, R. 2003. Livestock Early Warning System for Africa rangelands V. Boken (ed.), *Agricultural Drought Monitoring Strategies in the World*. Oxford University Press, Oxford UK.

Tucker, C. J., Van Praet, C. L., Sharman, M. J. and Van Ittersum, G. 1985. Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel: 1980–1984. *Remote Sensing of the Environment*, Vol. 17, pp. 233–249.

Tucker, C. J., Newcomb, W. W., Los, S. O. and Prince, S. D. 1991. Mean and inter-year variation of growing-season normalized difference vegetation index for the Sahel 1981–1989. *International Journal of Remote Sensing*, Vol. 12, pp. 1113–1115.

Xie, P. and Arkin, P. A. 1998. Global monthly precipitation estimates from satellite-observed outgoing long wave radiation. *Journal of Climate*, Vol. 11, pp. 137–164.

Chapter 5
Characterizing Dryland Post-grazing Change Trajectories on Santa Cruz Island, CA, with Multitemporal Landsat Data

Ryan L. Perroy

Abstract In the last part of the 20th century, Santa Cruz Island, California, was abruptly converted from a privately held ranch into a national park and natural preserve. During this conversion, tens of thousands of sheep were eradicated from the island, drastically changing its ecological system. This study uses a combination of spectral mixture analysis and time series trend analysis to characterize and quantify land-cover change on Santa Cruz Island in the post-grazing period of 1985–2002. These changes range from substantial re-vegetation in pastures most affected by overgrazing to massive landslides. This study identified nine classes of land cover change and explored the roles of geology, slope, and aspect in assessing the underlying factors controlling spatial differences in the recovery of overgrazed areas. Historic land use in the form of grazing intensity was found to be the single most important factor for predicting land cover change on Santa Cruz Island, followed closely by underlying geology. Slope and aspect also affect land cover change, but their contributions are much more subtle.

Keywords Remote sensing, grazing, soil erosion, land cover change

1 Introduction

Erosion due to overgrazing is a global problem resulting in declining rangeland and agricultural productivity, the spread of invasive non-native species and increases in flooding events. Once erosion processes begin, reversing or limiting their impact is a daunting challenge requiring considerable resources and major changes in land management practices (Dregne, 2002; Redman, 1999). Identifying areas most vulnerable to erosion within a grazed landscape and accurately predicting the likelihood and magnitude of recovery for eroded areas are important tasks for land management and monitoring applications (Hostert et al., 2003a). Remote sensing, with its strengths of excellent spatial coverage, temporal repeatability and cost-effectiveness, is well-suited for accomplishing these tasks.

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Santa Cruz Island, California, presents a unique opportunity for studying trends associated with land-cover change given its extreme grazing history, topographic and geologic variability and isolation. The relatively abrupt and recent conversion of the island from a working sheep ranch to a non-grazed natural preserve allows a number of questions to be explored using remotely sensed imagery. These include the following:

- How has Santa Cruz Island responded to the removal of grazing animals?
- Which underlying factors control spatial differences in the recovery?
- How can this information be applied to areas where erosion due to overgrazing is still a serious problem?

Two main hypotheses were developed to answer these questions:

1. In the absence of grazing, barren soil exposure will decline over time, while green vegetation, non-photosynthetic vegetation and shade will increase.
2. The date of sheep removal, grazing intensity, geology, slope and aspect are major factors in explaining differences in vegetation recovery across the island.

The goals of this study were to characterize and quantify land-cover change on Santa Cruz Island in the post-grazing period using a combination of spectral mixture analysis and time series trend analysis, and to identify key factors controlling the spatial pattern, form and magnitude of those changes. The analysis will focus on temporal trends in the percentage of soil exposure at a pixel level and the effects of slope, aspect and underlying geology on land-cover change.

2 Previous Studies

A number of studies have been published assessing the utility of remote sensing for characterizing and identifying soil erosion (Metternicht and Fermont, 1998; Hill and Schutt, 2000; Haboudane et al., 2002; Flügel et al., 2003; Hochschild et al., 2003; Hostert et al., 2003a, b). Although still not widely used by land managers, the techniques developed in these studies have steadily improved our ability to map at-risk areas and quantify potential erosion losses. Limited work using soil brightness properties in black-and-white aerial photographs to characterize soil erosion has been published (Shoshany, 2002; Martínez-Casanovas, 2003), potentially allowing spectrally limited but temporally rich historic aerial photographic data sets to be analyzed for erosion studies. Although a large number of remote sensing studies examining vegetation recovery have been published (Riaño et al., 2002; Peterson and Stow, 2003; Lawrence and Ripple, 1999; Ricotta et al., 1998), the majority of these deal with recovery after fire and other catastrophic events. The grazing-related remote sensing studies that have been published generally depict an ever-increasing degree of land degradation (Hostert et al., 2003a, b; Hill et al., 1998).

Modeling land-cover change trajectories with linear or polynomial regression curves has considerable potential for remote sensing time series analysis. Lawrence and Ripple (1999) calculated change curves for vegetation recovery following the 1980 Mount St. Helens eruption using a 1984–1995 Landsat time series. Hostert et al. (2003a) coupled spectral mixture analysis (SMA) and trend analysis to monitor vegetation dynamics associated with active grazing on the island of Crete.

2.1 Study Site

Santa Cruz Island, the largest of the California Channel Islands, is located 38 km off California's is central coast at 34°N, 119°45' W. The island is roughly 37 km long east to west and ranges from 3 to 11 km wide north to south. It is comprised of two main mountain ranges tending slightly north of west, separated by the Santa Cruz Island fault and a low valley and hill terrain (Dibblee, 2001). Topographic relief on the island is severe and the geology of the island is complex, containing roughly 20 different geologic units and dozens of faults.

Grazing livestock were first introduced in the mid-1800s after the island became a privately held ranch (Brumbaugh, 1980). Introduced livestock included sheep (*Ovis aries*), cattle (*Bos taurus*) and pigs (*Sus scrofa*), with sheep ultimately responsible for most of the degradation on the island. Estimates of Santa Cruz Island's sheep population in the latter half of the 1800s reveal unsustainable growth, with the population rising from 200 sheep in 1852 (Dunkle, 1950) to 45,000 sheep in 1870 (U.S. Census of Agriculture, 1870). Problems associated with sheep overpopulation, including erosion due to overgrazing (Fig. 1), eventually became so severe that sheep removal efforts began as early as 1939 (Junak et al., 1995). Tens of thousands of sheep were rounded up or shot in the following decades as part of removal efforts (Santa Cruz Island Company records, Van Vuren, 1981). Ninety percent of Santa Cruz Island was sold to The Nature Conservancy in 1978, and the National Park Service acquired the

Fig. 1 Overgrazing-induced erosion and the vegetation boundary effect of fence lines. This photograph was taken by J. Howarth in the mid-1990s near the Nature Conservancy (left) – National Park (right) border on Santa Cruz Island. At the time of the photo, the Nature Conservancy land had already experienced a number of years of recovery in the absence of grazing.

remaining eastern portion shortly thereafter. By June 1989, approximately 40,000 sheep had been shot and killed on the Nature Conservancy property, essentially completing the sheep removal programme on that part of the island. By 2000, the remaining sheep on the National Park property were removed. It is important to recognize that the height of erosional activity due to overgrazing on Santa Cruz Island was over well before 1985, the first year included in this study, and significant re-vegetation had already been observed in some areas (Brumbaugh, 1980).

3 Data

Three types of remotely sensed data were used in this project: a single Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) scene; a Landsat time series consisting of six fall (September and August) images from 1985–2002; and a digital elevation model from the NASA Shuttle Radar Topography Mission (SRTM). AVIRIS is an airborne hyperspectral imaging system with a spatial resolution of 20 m and 224 bands ranging from 373.4–2503.3 nm. The AVIRIS scene was collected on 11 April 1994, at 19:43:00 GMT with a solar zenith of 25.695 and a solar azimuth of 167.823 and captures only the southern half of the island. The NASA SRTM digital elevation model was used to produce slope and aspect information, and geologic information was digitized by Shaun Wallbridge, Park Williams, Mark Gorecki and Colin Ebert from Dibblee's 2001 map of the island (Fig. 2).

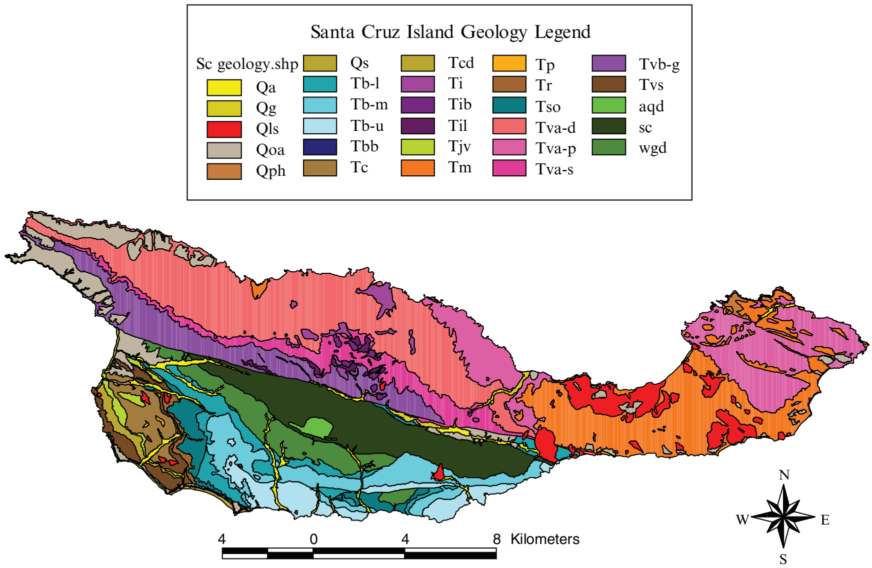

Fig. 2 Geologic map of Santa Cruz Island, from Dibblee 2001. Volcanics (pinks, purples) and Monterey shale (orange) of the north block are separated from the crystalline basement rocks (blues, greens, browns) of the south block by the SC Island fault. Landslides are shown in red.

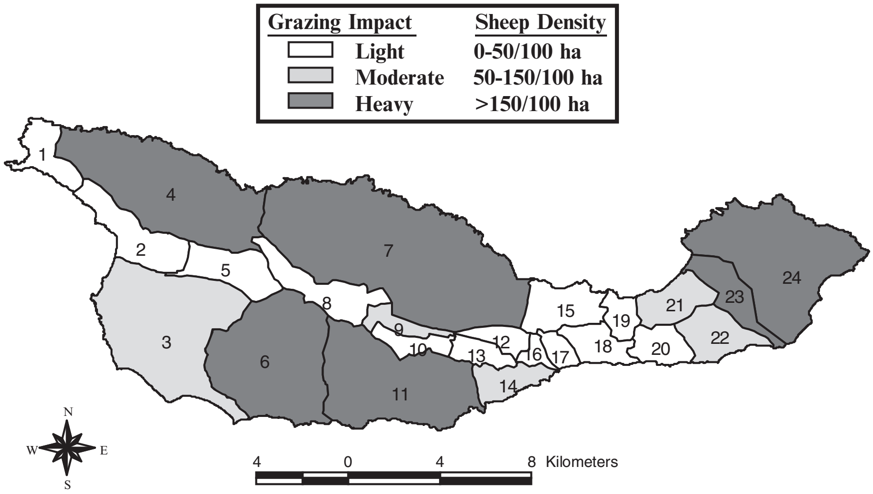

Fig. 3 Grazing intensity pasture map, modified from Schuyler, 1993, original data from Santa Cruz Island Company records. Although Pastures 23 and 24 were labelled "unknown" by Schuyler, they were both extensively grazed and the last pastures to be cleared of sheep.

Monthly precipitation data were acquired from a single weather station in the central valley of Santa Cruz Island. Grazing intensity information is shown in Fig. 3 (Schuyler, 2003).

4 Methods

4.1 Preprocessing

The original Landsat NLAPS (National Landsat Archive Production System) data format provided the georeferencing information used in this project. Reflectance conversion was performed on the AVIRIS image and the 3 September 2002, ETM + (Enhanced Thematic Mapper) image using ACORN (Atmospheric CORrection Now), a radiative transfer model software package (Inspec, CO). The AVIRIS scene was further corrected using a beach ground target collected with an Analytic Spectral Devices (Boulder, CO) field spectrometer on Santa Cruz Island on 19 October 2003. A relative reflectance retrieval method was used to bring the additional Landsat imagery into reflectance (Furby and Campbell, 2001). Slope and intercept values for the Landsat time series scenes were derived at San Diego State University using pseudo-invariant targets to bring them into reflectance. In order to normalize the time series dataset from year to year, the ocean surrounding Santa Cruz Island and various clouds appearing over the island throughout the time series were masked out.

4.2 Spectral Mixture Analysis (SMA)

In heterogeneous environments, pixels derived from spaceborne and even airborne imaging platforms will contain mixtures of multiple land cover types rather than a single uniform land cover. These mixtures can be modelled as a blend of spectral signatures from known pure land cover types, called endmembers, and unmixed to produce contributing fractional estimates of endmembers for each pixel (Smith et al., 1990; Roberts et al., 1993). A four endmember SMA model was used to calculate fractions for green vegetation, non-photosynthetic vegetation, soil and shade for each pixel in the Landsat time series. The shade endmember was set by user-defined null values, while the green vegetation, non-photosynthetic vegetation and soil spectral endmembers were all derived from the 1994 AVIRIS scene.

4.3 Time Series Trend Analysis/Curve Fitting

In this study, trends in land-cover change were modelled on a pixel-by-pixel basis using a time series of SMA-derived soil fractional images. Nine classes of land-cover change were established using linear and second-order polynomial regression curves to model the data. A hierarchical system based on overall change and minimum r squared values determined which class was ultimately assigned to a pixel in the time series. This resulted in a categorical land-cover change trajectory classification of the entire island. The nine classes were chosen to capture significant differences in land-cover change over time with minimal computational complexity. An example of curve fitting for two different pixel locations is shown in Fig. 4.

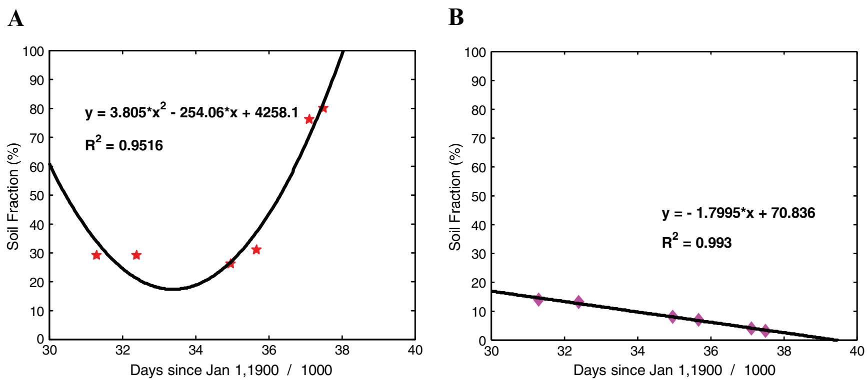

Fig. 4 Examples of fitted land-cover change trajectory curves for two different pixels on Santa Cruz Island from the 1985–2002 fall soil fraction time series. Time is presented on the x axis in days since 1 Jan 1900, divided by 1,000 for scale. Point data are measured soil fractions from a 30 × 30 m Landsat pixel over the time series. Linear or 2nd-order polynomial regression curves were used to fit the data. (A) Example of a concave-up trajectory of sharply increasing soil fraction associated with a landslide. (B) Example of a linear trajectory of decreasing soil fraction.

4.4 Factors Affecting Differences in Land Cover Change

To assess the underlying factors controlling spatial differences in the recovery of overgrazed areas, heavily grazed pastures were targeted for additional analysis. The roles of geology, slope and aspect in determining land-cover change classification were examined for the different pastures in an attempt to identify some basic relationships and rules for land-cover change.

5 Results

The first and last fall soil fraction images of the time series were compared to assess land-cover change from 1985 to 2002 (Fig. 5). Fractional soil contributions, i.e., the percentage of a pixel composed of bare soil, were placed into four categories: 0–10% (green), 10–25% (blue), 25–50% (yellow) and greater than 50% (red). Areas with low soil fractions can be considered highly vegetated, areas with high soil fractions highly eroded.

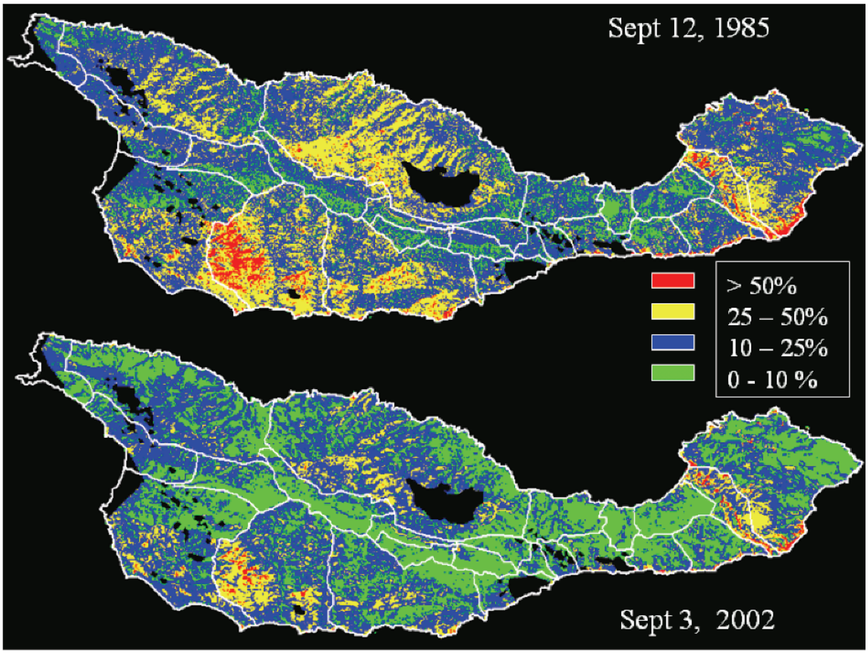

Fig. 5 Soil fraction images of fall 1985 and 2002. Pasture fence lines are highlighted in white. Areas with the most exposed soil in 1985 (yellow and red) are found in the most heavily grazed pastures on the island. Fence lines separating heavily and lightly grazed pastures delineate sharp boundaries between soil fraction classes. There has been an overall reduction in exposed soil fraction on the island between 1985 and 2002.

An island-wide land-cover change trajectory classification was produced using the hierarchical system shown in Table 1. The following is an overview of the nine land-cover change trajectory classes on the island.

5.1 No Change (nochng)

Although some areas of the island changed quite dramatically over the course of the time series, almost 70% of the island falls into the "no change" category (Table 1). Even within the heavily grazed pastures, a majority of the land has not undergone any significant change. "No change" areas closely correspond with areas of low soil exposure; in other words, those areas that were able to maintain a high percentage of vegetation cover during the grazing period kept that same degree of cover once the sheep were removed.

5.2 Linear Increase (lin incr)

Areas of linearly increasing soil exposure on Santa Cruz are insignificant, covering less than 0.1% of the island. With the removal of sheep and the cessation of grazing activity, the relative absence of areas with steadily increasing soil exposure is to be expected.

Table 1 Land-cover class, slope, and aspect information for total island and heavily grazed pastures

Land-cover class	Total island	Pasture 4	Pasture 6	Pasture 7	Pasture 11	Pasture 23	Pasture 24
nochng	68.46%	74.02%	50.22%	58.89%	59.42%	56.99%	68.50%
lin incr	0.09%	0.05%	0.07%	0.10%	0.05%	0.54%	0.12%
lin decr	12.93%	13.58%	23.97%	18.20%	19.84%	4.20%	6.62%
incr neg a0	0.09%	0.04%	0.07%	0.09%	0.07%	0.59%	0.11%
incr pos a0	0.25%	0.17%	0.21%	0.28%	0.10%	1.18%	0.39%
decr neg a0	3.36%	2.12%	3.27%	2.81%	2.51%	11.12%	12.04%
decr pos a0	2.99%	2.25%	5.06%	4.75%	4.98%	0.53%	0.48%
unmod incr	2.76%	1.54%	3.57%	2.60%	2.08%	10.24%	3.96%
unmod decr	9.05%	6.23%	13.57%	12.29%	10.96%	14.61%	7.78%
Slope							
0–10	8.83%	7.65%	7.50%	4.36%	8.45%	5.16%	19.86%
10–20	32.92%	28.08%	36.09%	29.00%	39.39%	25.79%	39.15%
20–40	54.75%	58.59%	55.01%	62.50%	50.12%	64.04%	38.22%
40+	3.51%	5.67%	1.41%	4.15%	2.05%	5.01%	2.77%
Aspect							
N 315–45	23.94%	37.60%	12.93%	33.26%	12.36%	16.43%	31.06%
S 135–225	20.69%	20.21%	22.39%	24.01%	19.60%	12.04%	25.91%
E 45–135	35.30%	24.71%	40.98%	24.54%	44.70%	44.17%	32.72%
W 225–315	20.07%	17.48%	23.71%	18.19%	23.34%	27.37%	10.31%

5.3 Linear Decrease (lin decr)

Areas of linearly decreasing soil exposure show a steady increase in vegetation and are considered to be recovering. These areas generally began with a high percentage of exposed soil in 1985 and are concentrated in the heavily and moderately grazed pastures, as well as the eastern half of Pasture 24. They cover 13% of the island with a mean rate of change of −1.05% soil exposure/year and a maximum of −5.8% soil exposure/year. Areas with the highest rate of change are found in Pastures 6, 23 and 24. In Pasture 6, the areas recovering at the fastest rate began the time series with exposed soil fractions well over 80%. These areas represent some of the sites on the island most severely eroded during the ranching period. In Pastures 23 and 24, the areas with the greatest rate of linear decrease are located over the highly unstable and erosive band of Monterey shale running through all of Pasture 23 and the western edge of Pasture 24.

5.4 Second-order Polynomial Increase (incr neg a0, incr pos a0)

Less than 1% of the island was modelled using 2nd-order polynomial curves with an overall increase in soil exposure. Pixels modelled with concave up 2nd-order polynomial curves that show an overall increase in soil exposure, although covering only 0.25% of the island, do have a strong spatial pattern associated with them. Generally associated with pixel trajectories that remain essentially flat until sharply increasing in soil percentage in the last few years of the time series (Curve A, Fig. 2), these curves clearly identify a large 1998 landslide that occurred on the northern coast of Santa Cruz Island.

5.5 Second-order Polynomial Decrease (decr neg a0, decr pos a0)

Areas modelled with 2nd-order polynomial curves showing an overall decrease make up 6.35% of the island, with almost equal parts modelled with concave up and concave down curves. Areas modelled with concave up curves are scattered in isolated pixels across all the heavily and moderately grazed pastures without any strong spatial pattern. These areas generally show a decrease in soil cover between the first two years of the time series of 5–20%, followed by smaller decreases in subsequent years. It is the dominant decrease in soil cover between the first two years of the time series that forces these pixels into the decreasing concave up class.

Pixels modelled with concave down curves are also found scattered across the heavily and moderately grazed pastures, but are concentrated in Pastures 23 and 24 in south-facing areas. These pixels typically show a slight rise in soil exposure between the first and second years of the time series, followed by a considerable decrease in soil fraction of 10–30% near the end of the time series. This behaviour is captured in the decreasing concave down class. The strong spatial grouping of these areas in Pastures 23 and 24 and unusual land-cover change trajectory suggests that these areas may all be a part of the same vegetation community.

5.6 Un-modelled Increase (unmod incr)

Areas that were not modelled with a minimum r squared value of 0.7 by either linear or 2nd-order polynomial regression curves and had an overall increase of soil fraction of over 10% fell into the un-modelled category. These areas cover 2.76% of the island and were scattered across the island though there was a light concentration in Pastures 23 and 24. Areas of un-modelled increase seem to be associated with drainages, either located directly within the drainage channel or to one side.

5.7 Un-modelled Decrease (unmod decr)

Areas of un-modelled decrease in soil fraction were the third largest category, covering 9% of the island. These areas, like those in other classes showing an overall decrease in soil exposure, were concentrated in the heavily and moderately grazed pastures as well as Pastures 23 and 24. Areas that were characterized by an un-modelled decrease in exposed soil followed land-cover change trajectories that were too erratic to be accurately modelled using linear and 2nd-order regression curves, but still exhibited significant vegetation recovery.

6 Discussion

6.1 Grazing Intensity and Land-Cover Change

The primary factor in controlling the spatial pattern and magnitude of land-cover change for Santa Cruz Island is pre-removal grazing intensity. The heavily grazed pastures, including Pastures 23 and 24, are the areas where the most significant land-cover change occurred, illustrating the importance of historical land-use information in this type of analysis. Areas with the highest fractional soil contribution roughly correspond to Schuyler's heavy grazing pasture designations and in many areas fence lines clearly delineate boundaries between high and low soil fraction areas (Fig. 4).

6.2 Heavily Grazed Pasture Analysis

Pastures 6, 7 and 23 were examined to investigate the effects of geology, slope and aspect on land-cover change in areas strongly impacted by grazing.

Underlying geology has substantial influence on the type of land-cover change that occurs within an area. In Pasture 6, the average percentage of areas classified as "no change" for the three members of the Blanca formation (tb-u, tb-m, and tb-l) is 41.5%, considerably lower than the average of 61.5% for the remaining geologic units. The volcaniclastic conglomerate and breccia composition of the Blanca formation have potentially made it more susceptible to erosion from overgrazing in comparison with the surrounding igneous and metamorphic units, and therefore more active in terms of land-cover change in the post-grazing period. The high degree of land-cover change activity in Pasture 23 is likely attributable to the instability of the Monterey shale unit (tm) that underlies the majority of the pasture area. Dibblee (2001) describes the Monterey unit as 'somewhat crumbly, weakly resistant to erosion, forms many landslides.'

Although a basic knowledge of underlying geology is invaluable for this type of analysis, there can be considerable variation in land-cover change within a single geologic unit. Only two geologic units appear in more than one of the three pastures chosen for this further analysis, the Monterey shale formation (tm) and the Prisoner's Harbor member of the Santa Cruz Island volcanics (tva-p), and their behaviour varies between the two pastures. The tm unit drops from almost 90% "no change" in Pasture 7 to 53.5% "no change" in Pasture 23, while the tva-p unit "no change" percentage rises slightly from Pasture 7 to Pasture 23. For the Monterey shale, some of this difference may be attributable to the orientation of the unit's bedding in Pasture 23, making it more susceptible to failure in this area. These results indicate that although differences in geology do have an impact on land-cover change trajectories in a region, geologic information alone is insufficient to accurately predict land-cover change activity.

The effect of differences in slope and aspect on land-cover change was also examined and, again, its impact varied to some extent with pasture. In Pastures 6 and 7, differences in slope and aspect had essentially no impact on land-cover change classification. This was unexpected given the extreme variation these variables within the pasture areas and field observations of the strong influence of aspect on different vegetation types. Pasture 23, which is the least stable geologically of the three pastures, did show some interesting relationships between slope, aspect and land-cover change classification. In Pasture 23, the amount of land classified as "un-modelled" increased with increasing slope. This can be attributed to the instability of the underlying Monterey shale and the increased likelihood of landslides and other abrupt land-cover changes in steeply sloping areas. With respect to aspect, the highest percentage of "no change" land in Pasture 23 was found in north-facing areas and the lowest in south-facing areas. This may be related to the only other notable aspect-driven difference in Pasture 23; south-facing areas were much more likely to be classified with decreasing concave down curves then areas facing other directions. This has been discussed earlier and is likely attributable to a particular vegetation community that occupies these south-facing areas.

7 Conclusions

A method for modelling land cover change was developed for Santa Cruz Island in the post-grazing period of 1985–2002 using a combination of SMA and time series trend analysis. The island has responded to the removal of the sheep population in various ways, with the most prominent recovery occurring in heavily grazed pastures. Historic grazing intensity and underlying geology were the most important factors in land cover change classification, with slope and aspect playing a much more limited role. With the exception of grazing intensity, island-wide generalizations about the impact of underlying factors on land cover change were unsuccessful. Although underlying geology was often an important factor for driving land cover change, this was not always the case. The magnitude and type of change within the same geologic unit could also differ considerably across the island. Similar situations were found for slope and aspect. Reasons for the localized importance of these factors and their true overall relationship with land cover change are still not well understood. In contrast, historic grazing intensity and land cover change are clearly related, highlighting the importance of obtaining land use information in a study of this nature. The complexity of land cover change on Santa Cruz Island suggests that methods developed in previously published studies, which generally focus on overall change and linear regression curves, would not be able to isolate important but subtle differences in land cover change found across the island.

References

Brumbaugh, R. W. 1980. Recent geomorphic and vegetal dynamics on Santa Cruz Island, California. D. M. Power (ed.), *The California Channel Islands*. Proceedings of a multidisciplinary symposium. Santa Barbara Museum of Natural History, Santa Barbara, CA, pp. 139–158.

Dibblee, T. W. 2001. Geologic Map of Western Santa Cruz Island, Santa Barbara, CA. *Dibblee Geological Foundation, Map #DF-77*.

Dibblee, T. W., Jr. 1982. Geology of the Channel Islands, southern California. D. L. Fife and J. A. Minch (eds.), *Geology and Mineral Wealth of the California Transverse Ranges*. Mason Hill Volume, South Coast Geological Society, Annual Symposium and Guidebook 10, Santa Ana, CA, pp. 27–40.

Dregne, H. E. 2002. Land degradation in the drylands. *Arid Land Research and Management*, Vol. 16, pp. 99–132.

Dunkle, M. B. 1950. *Plant Ecology of the Channel Islands of California*. University of Southern California Press. Allan Hancock Pacific Expeditions, Los Angeles, CA. November 30, Vol. 13, No. 3.

Flügel, W. A., Märker, M., Moretti, S., Rodolfi, G. and Sidrochuk, A. 2003. Integrating geographical information systems, remote ground truthing and modeling approaches for regional erosion classification of semi-arid catchments in South Africa. *Hydrological Processes*, Vol. 17, pp. 929–942.

Furby, S. L. and Campbell, N. A. 2001. Calibrating images from different dates to 'like-value' digital counts. *Remote Sensing of the Environment*, Vol. 77, pp. 186–196.

Haboudane, D., Bonn, F., Royer, A., Sommer, S. and Mehl, W. 2002. Land degradation and erosion risk mapping by fusion of spectrally-based information and digital geomorphic attributes. *International Journal of Remote Sensing*, Vol. 23, No. 18, pp. 3795–3820.

Hill, J., Hostert, P., Tsiourlis, G., Kasapidis, P., Udelhoven, T. and Diemer, C. 1998. Monitoring 20 years of increased grazing impact on the Greek island of Crete with earth observation satellites. *Journal of Arid Environments*, Vol. 39, pp. 165–178.

Hill, J. and Schutt, B. 2000. Mapping complex patterns of erosion and stability in dry Mediterranean ecosystems. *Remote Sensing of Environment*, Vol. 74, pp. 557–569.

Hochschild, V., Märker, M., Rodolfi, G. and Staudenrausch, H. 2003. Delineation of erosion classes in semi-arid southern African grasslands using vegetation indices from optical remote sensing data. *Hydrological Processes*, Vol. 17, pp. 917–928.

Hostert, P., Roder, A. and Hill, J. 2003a. Coupling spectral unmixing and trend analysis for monitoring of long-term vegetation dynamics in Mediterranean rangelands. *Remote Sensing of Environment*, Vol. 87, pp. 183–197.

Hostert, P., Röder, A., Hill, J., Udelhoven, T. and Tsiourlis, G. 2003b. Retrospective studies of grazing-induced land degradation: a case study in central Crete, Greece. *International Journal of Remote Sensing*, Vol. 24, No. 20, pp. 4019–4034.

Junak, S., Ayers, T., Scott, R., Wilken, D. and Young, D. 1995. *A Flora of Santa Cruz Island*. Santa Barbara Botanic Garden, Santa Barbara, CA. 397 pp.

Lawrence, R. L. and Ripple, W. J. 1999. Calculating Change Curves for Multitemporal Satellite Imagery: Mount St. Helens 1980–1995. *Remote Sensing of Environment*, Vol. 67, pp. 309–319.

Martínez-Casasnovas, J. A. 2003. A spatial information technology approach for the mapping and quantification of gully erosion. *Catena*, Vol. 50, pp. 293–308.

Metternicht, G. I. and Fermont, A. 1998. Estimating erosion surface features by linear mixture modeling. *Remote Sensing of Environment*, Vol. 64, pp. 254–265.

Peterson, S. and Stow, D. A. 2003. Using multiple image endmember spectral mixture analysis to study chaparral regrowth in southern California. *International Journal of Remote Sensing*, Vol. 24, No. 22, pp. 4481–4504.

Redman, C. L. 1999. *Human Impact on Ancient Environments*. The University of Arizona Press, Tucson.

Riaño, D., Chuvieco, E., Ustin, S., Zomer, R., Dennison, P., Roberts, D., and Salas, J. 2002. Assessment of the vegetation regeneration after fire through the multitemporal analysis of AVIRIS images in the Santa Monica Mountains. *Remote Sensing of Environment*, Vol. 79, pp. 60–71.

Ricotta, C, Avena, G. C., Olsen, E., Ramsey, D. and Winn, D. S. 1998. Monitoring the landscape stability of Mediterranean vegetation in relation to fire with a fractal algorithm. *Journal of Remote Sensing*, Vol. 19, No. 5, pp. 871–881.

Roberts, D. A., Smith, M. O. and Adams, J. B. 1993. Green vegetation, non-photosynthetic vegetation, and soils in AVIRIS data. *Remote Sensing of Environment*, Vol. 44, pp. 117–126.

Schuyler, P. 2003. Control of feral sheep (*Ovis aries*) on Santa Cruz Island, California. F. G. Hochberg (ed.), *Third California Islands Symposium – Recent Advances in Research on the California Islands*. Santa Barbara Museum of Natural History, Santa Barbara, CA, pp. 443–452.

Shoshany, M. 2002. Landscape fragmentation and soil cover changes on south- and north-facing slopes during ecosystem recovery: an analysis from multi-date air photographs. *Geomorphology*, Vol. 45, pp. 3–20.

Smith, M. O., Ustin, S. L., Adams, J. B. and Gillespie, A. R. 1990. Vegetation in deserts: A Regional Measure of Abundance from Multispectral Images. *Remote Sensing of Environment*, Vol. 31, pp. 1–26.

US Bureau of Census, Census of Agriculture. 1870. 9th Census of US, v.2, Schedule of agricultural recapitulation, Santa Barbara County (microfilm). California State Library, Sacramento, CA.

Van Vuren, D. 1981. *The Feral Sheep of Santa Cruz Island: Status, Impacts, and Management Recommendations*. Report to the Nature Conservancy, Arlington, VA.

Chapter 6
Decision Support Systems for Water Resources Management in Dudhi and Bewas Watersheds, Madhya Pradesh, India

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Abstract In recent years, the concept of watershed management has grown rapidly due to the importance of water as an increasingly precious natural resource that is, at the same time, very difficult to manage within the overall development of any nation. Watersheds integrate many physical, biological, social and economic processes and information. Water resource management is a continuous process requiring attention at various levels because of its inherent nature and the extent of interventions being made at various levels and scales. Small-scale interventions, at the village level, are mainly for soil and water conservation and fulfil the requirements of a small community. It is essential to generate biophysical information that can be used to generate scenarios, which in turn can help in local-level planning and management of land and water resources in the watersheds. The present study demonstrates the methodology for development of a decision support system for planning a sustainable watershed management programme at village level which can be used for sustainable root level planning for development, implementation, monitoring and evaluation of watershed management programmes in semi-arid regions.

Keywords Decision support system, soil and water conservation, participatory, and community

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1 Introduction

In India, integrated watershed management has been adopted as a part of the National Water Policy 2002 for the conservation of natural resources. Recently, greater emphasis has been placed on ensuring that local-level users participate in the planning and management of the natural resources at the watershed level. Although the intention is in place, the mechanism to achieve this goal is inadequate. It is imperative that new tools be provided to handle the complexities of the integrated watershed management philosophy in a scientific manner. At the same time, it is equally important to ensure that these new technologies be disseminated through highly user-friendly interfaces to help planners in reaching the appropriate decisions.

The study demonstrates the use of hydrological modeling for generating information and scenarios for possible manmade interventions, which would be highly beneficial for community participation as well as for the effective handling of the integrated watershed management approach.

Decision support systems (DSSs) and GIS-model linkages have become a new area of research in watershed management programmes in India and therefore this study attempts to develop a participatory DSS for watershed management in semi-arid regions.

2 The Decision Support System (DSS) Approach

Decision support systems are defined as computer-based information systems designed to support decision-makers interactively in thinking and making decisions about relatively unstructured problems. Traditionally, DSSs have three major components: a database, a model base and a user interface as depicted in Fig. 1.

GIS (Geographical Information System) is a general purpose technology for handling geographic data in digital form, with the ability to pre-process data into a form suitable for analysis, to support analysis and modeling directly, and to

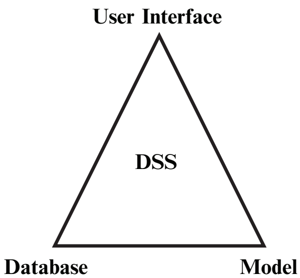


Fig. 1 Components of DSS

post-process results (Goodchild, 1993). After the models are run, the resulting output can be written onto the database for later display via the user interface, in tabular, chart or map form. For planning purposes, this ability to dynamically change information, forecast and perform sensitivity analysis is essential.

In a GIS, information about the spatial characteristics of a geographic area can be stored to account for different types of data (e.g., soil type, elevation and land use). Both GIS and DSS have been widely used in natural resource management. Watkins and McKinney (1995) presented a review on DSS in water resources; and Goodchild et al. (1996) described a comprehensive study of GIS in water resources and environmental engineering. Singh and Fiorentino (1996) gave a comprehensive review of GIS in hydrology.

The SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998; Srinivasan et al., 1998) model has been selected for the present study. The SWAT model is a combination of the SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990), GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) (Leonard et al., 1987), and ROTO (Routing Outputs to Outlet) (Arnold et al., 1995) models, and hence it is able to model both the hydrology and water quality of a watershed (ibid). The model is reported to be able to operate on both a raster and sub-watershed (hydrologic response unit) basis (ibid). In addition, the model is linked to GIS packages like GRASS (Geographic Resources Analysis Support System) via the SWAT-GRASS interface (Srinivasan and Arnold, 1993) and ARC-View through the SWAT-ARC View interface (Diluzio et al., 1997), thus easing the task of data input and output display.

This is done by building interfaces that interact with existing models intercepting its input and output and using them as layer databases in the system.

3 The Study Area

In the present study the Dudhi and Bewas watersheds (Fig. 2), located in central India in the State of Madhya Pradesh, have been selected for detailed study. The catchment area of Dudhi watershed covers 5,989 km^2 and represents a third-order drainage network in a part of Begamganj Tehsil of Raisen district of Madhya Pradesh. It is bordered by northern latitudes 23°24' to 23°27' and eastern longitudes 78°32' to 78°37' and lies on the Survey of India Toposheet No. 55 I/11.

Bewas watershed is also located in a part of Begamganj Tehsil of Raisen district of Madhya Pradesh bordered by northern latitudes 23°23' to 23°26' and eastern longitudes 78°32' to 78°34' which lies on the Survey of India Toposheet No. 55 I/11. This watershed is adjacent to Dudhi watershed and its geographical areas cover 7,554 km^2.

The failure of monsoons and their erratic behaviour results in the depletion of surface storage. As a result, dependence on groundwater resources becomes inevitable. Soil erosion plays a prominent role, which is adversely affecting fertility of the agricultural lands.

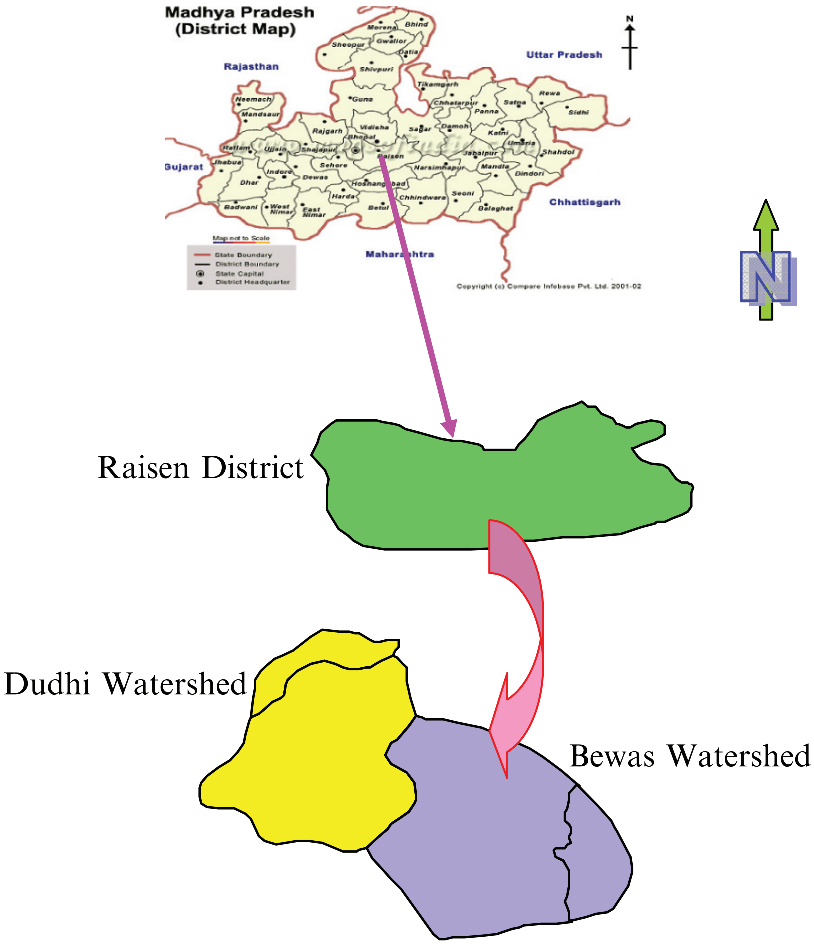


Fig. 2 Location map of the study area

4 Methodology

A Digital Elevation Model (DEM), as a digital representation of the continuous variation of relief over space, consists of a sampled array of elevations for ground positions that are normally spaced at regular intervals. The DEM is presented in Fig. 3. A map file consists of soil and land-use data, being the sources of information consisting of digitized maps with soil texture and land-cover attributes. The process of extracting data from map sources has been divided into two sections: (i) topography-related data using a DEM file, and (ii) soil type and land-cover data using a map file.

Prior to the DEM utilization, a drainage watershed conditioning process should be done to prepare the file for data extraction. This involves processing the elevation data in order to create a depressionless DEM. Depressions present a significant

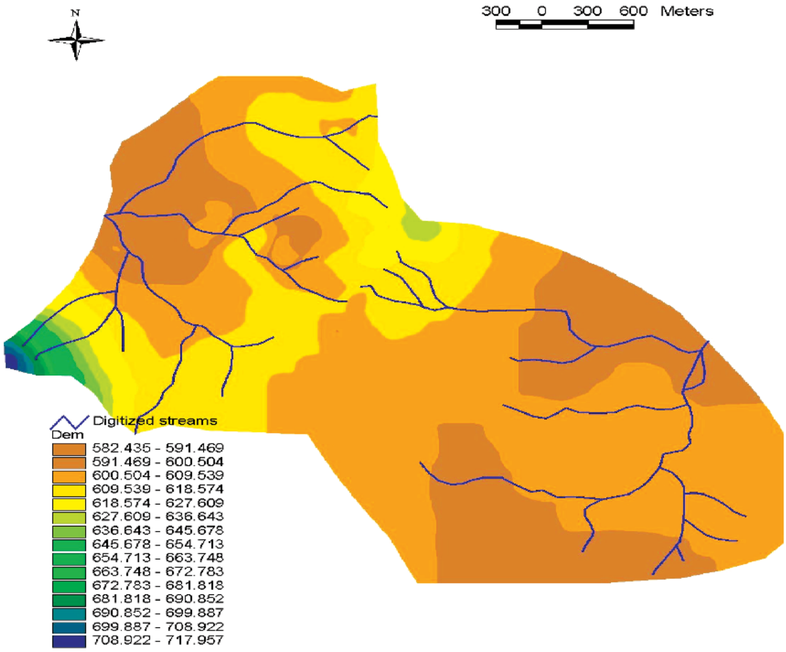


Fig. 3 Digital elevation model

problem in flow prediction models for two reasons. First, depressions in DEMs are often data errors introduced during the DEM interpolation process. Secondly, depressions serve to confuse flow direction models because they must be filled before flow can continue. During the same process, the flow direction and flow accumulation values are generated for each DEM element.

For the DEM extraction, the calculations are performed in two steps. For the flow direction and receiving cells, the DEM elements that intersect the borders of each cell in the grid are used. Using the direction and flow accumulation attributes from the DEM file, the direction of the element with the highest drainage value that intersects one of the four borders of the grid cell is assigned as the flow direction for that cell. With this flow direction, extending a straight line from the middle point of the cell provides the identification of the receiving one.

The second step is to calculate the land slope using the elevation attribute from the DEM file. In this case the elevation values of the DEM elements falling inside a grid cell are averaged and then subtracted from the minimum elevation. In order to obtain the land slope, the representative length of the cell then divides the average value. At this point, the default values for slope shape and slope length are captured for each grid cell. For the variables that depend on soil type and land-use information, another process is activated that browses the layer file looking for the intersection with every cell in the grid, calculating the area for each attribute (i.e. soil type) and the percentage with respect to the total area of the cell.

4.1 Modeling Approaches

4.1.1 Delineation of Watershed

Using the DEM grid and then removing any depression started watershed delineation. Then drainage network was delineated with a threshold value of 100 as it was found to be optimum for defining minimum numbers of cells to start delineating a stream. After the drainage network was delineated, the Dudhi and Bewas watershed boundary themes were added to the view and overlaid on the drainage network (Fig. 4).

The outlet point for delineating each watershed was selected by adding or deleting point(s) on the main stream intersecting the watershed boundary. Then subwatersheds were delineated (Fig. 5) to generate watershed maps for the Dudhi and Bewas watersheds.

The numbers of watersheds delineated for different sub-watersheds are presented in Table 1.

4.1.2 Scenario Generation

A SWAT hydrological model has been run using nine years of daily weather data (1994–2002) for the Dudhi watershed. Three scenarios (Fig. 6) have been run on the basis of the possible changes in the land-use pattern in the watershed (Table 2).

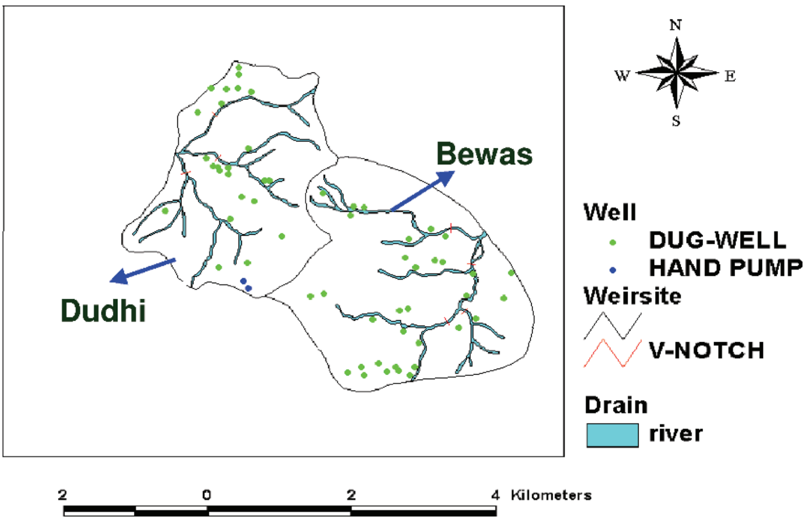


Fig. 4 Drainage network of the study area

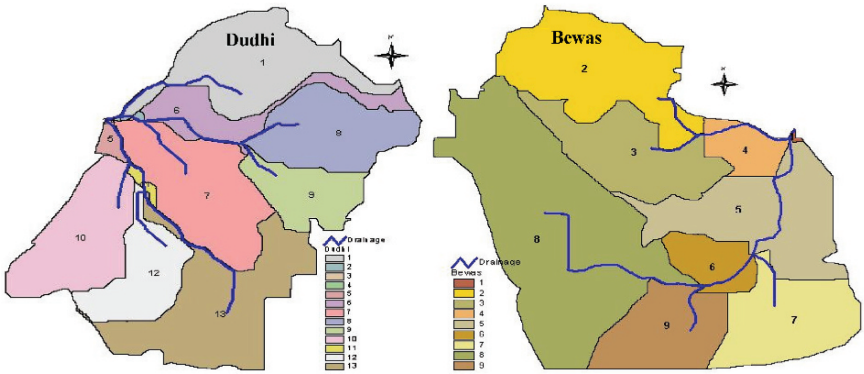


Fig. 5 Sub-watersheds of Dudhi and Bewas watersheds

Table 1 Details of various scenarios run on Dudhi micro-watershed

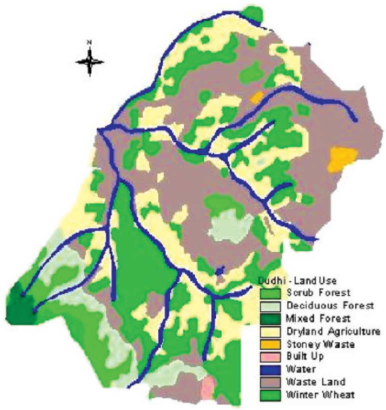
	Area in % Scenario 1 (Baseline)	Scenario 2 Wasteland to forest	Scenario 3 Forest to agriculture
Water	7.13	7.13	7.13
Stony waste	0.72	0.72	0.72
Urban	0.30	0.70	0.70
Agriculture (dryland)	21.63	21.63	29.41
Scrub forest	4.66	4.66	4.66
Deciduous forest	6.64	6.64	Nil
Mixed forest	1.14	36.02	Nil
Waste land	34.88	Nil	34.88
Winter wheat	22.92	22.92	22.92

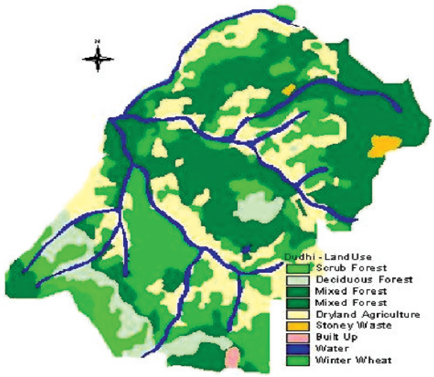
The summary outputs on the identified water balance components are presented in Fig. 6 for all the scenarios.

5 Results

The components of the water balance of the SWAT model outputs (surface runoff; total water yield consisting of surface runoff, lateral flow and base flow; soil water recharge and actual evapotranspiration) are presented in Fig. 7 for all the scenarios.

Scenario 2 shows a reduction in surface runoff by about 29% of the surface runoff in the baseline Scenario 1 and in water yield up to 12%. The actual evapotranspiration over the total watershed has increased by 19% of the baseline scenario.





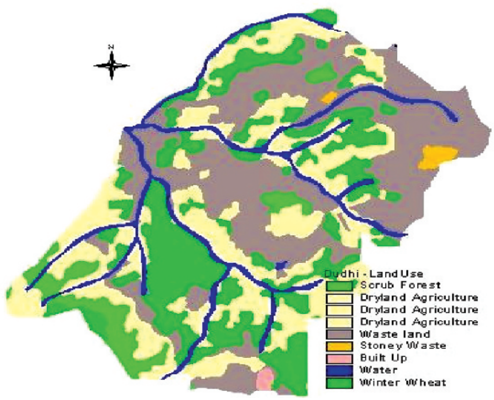


Fig. 6a Baseline land-use scenario 1
Fig. 6b Baseline land-use scenario 2
Fig. 6c Land-use scenario 3

Table 2 Water balance components

Average annual over 4 years (mm)	Rain (mm)	Surface runoff	Water yield	Soil water recharge	Actual ET	Lateral flow
Scenario 1	1196.0	263.33	507.97	235.68	582.4	8.68
Scenario 2	1196.0	186.98	447.12	253.89	695.4	6.27
Scenario 3	1196.0	272.43	551.69	270.36	562.80	8.92

The increased evapotranspiration can result in depletion of the available moisture in the soil profile, which in turn will induce higher infiltration. Similarly, in Scenario 3, the surface runoff has increased by about 4% and there has also been an increase in the water yield by about 8%. The actual evapotranspiration over the whole watershed has reduced by about 4%.

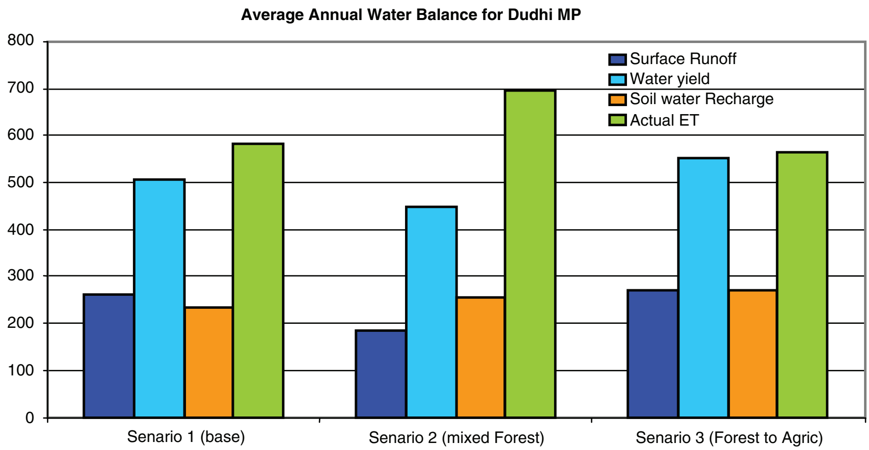


Fig. 7 Water balance components under different land-use scenarios for Dudhi watershed

The present study is intended to demonstrate the capabilities of the hydrological modeling framework to generate various scenarios in consultation with the local communities and to evaluate the same at local level as well as at level of drainage system and thereby assure the sustainability of such actions. Such a framework, once implemented, can serve as a very comprehensive platform for the planning and management of drylands in semi-arid regions.

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References

Arnold, J. G., Williams, J. R., Nicks, A. D. and Sammons, N. B. 1990. SWRRB: A basin scale simulation model for soil and water resources management. College Station, Tex.: Texas A&M University Press.

Arnold, J. G., Williams, J. R. and Maidment, D. R. 1995. A continuous-time watershed sediment routing model for large basins. *ASCE J. Hydr. Eng*.

Arnold, J. G., Srinivasan, R., Muttiah, R. S. and Williams, J. R. 1998. Large area hydrologic modeling and assessment Part I: model development. *J. Am. Water Resour. Assoc.*, Vol 34, No. 1, pp. 73–89.
Diluzio, M., Srinivasan, R. and Arnold, J. G. 1997. *An Integrated User Interface for SWAT Using ArcView and Avenue*. Presented at the August 1997 Annual International Meeting of ASAE in Minneapolis. Paper No. 972235.
Goodchild, M. F. 1993. Data models and data quality: Problems and prospects. M. F. Goodchild, B. O. Parks and L. T. Steyaert (eds.), *Environmental Modeling with GIS*. Oxford University Press, Oxford, pp. ———.
Goodchild, M. F., Steyaert, L. T., Parks, B. O., Johnston C., Maidment D., Crane, M. and Glendening, S. 1996. GIS and environmental Modeling: Progress and research issues. M. F. Goodchild, L. T. Steyaert, B. O. Parks, C. Johnston, D. Maidment, M. Crane and S. Glendening (eds.), GIS World Publication, Fort Collins, Collins, CO.
Leonard, R. A., Knisel, W. G. and Still, D. A. 1987. GLEAMS: Groundwater loading effects on agricultural management systems. *Trans. ASAE* 30(5):1403–1428.
Singh, V. P. and Fiorentino, M. 1996. *Geographical Information Systems in Hydrology*. Kluwer, Dordrecht.
Srinivasan, R. and Arnold, J. G. 1993. Integration of a basin scale water quality model with GIS. *Water Resources Bulletin*.
Srinivasan, R., Ramanarayanan, T. S., Arnold, J. G., Bednarz, S. T. 1998. Large area hydrologic modeling and assessment Part II: model application. *J. Am. Water Resour. Assoc.*, Vol 34, No. 1, February, pp. 91–101.
Watkins, D. W. and Mckinney, D. C. 1995. Recent developments associated with decision support systems in water resources. *Rev. Geophys*. (Supplement), July, pp. 941–948.
Williams, J. R., Nicks, A. D. and Arnold, J. G. 1985. SWRRB, A simulator for water resources in rural basins. *ASCE J. Hydrol. Eng*. 111(6):970–986.

Bibliography

Andriole, S. J. 1989. *Handbook of Decision Support Systems*. Tab Books, Blue Ridge Summit, Pennsylvania, PA.
Arnold, J. G., Allen, P. M. and Bernhardt, G. 1993. A comprehensive surface-groundwater flow model. *Journal of Hydrology*, Vol. 142, pp. 47–69.
Black, P. A. 1991. *Watershed Hydrology*. Prentice-Hall Advance Reference Series.
Burrough , P. A. 1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Oxford University Press, Oxford.
Chow, V. T. 1964. *Handbook of Applied Hydrology*. McGraw-Hill, New York.
Danial, R. O. 2005. *A thesis of the degree master of applied Science on decision support system for rural water supply in the Nilgiris district of South India*. McMaster University, Hamilton, Canada.
Gosain, A. K. and Rao, S. 2001. SDSS for land and water management. *Proceedings of GIS Technologies for Sustainable Development at Local Level*. New Delhi.
Loucks, D. P. and Costa, J. R. da 1991. *Decision Support Systems Water Resources Planning*. NATO ASI series. Springer, Berlin.
Rao, S. and Gosain, A. K. 2001. The district Almanac characterization tool. *Proceedings of GIS Technologies for Sustainable Development at Local Level*. New Delhi.

Chapter 7
Soil Indicators of Rangeland Degradation in a Semi-arid Communal District in South Africa

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Abstract Rangeland degradation is a major threat to sustainable livestock production in South Africa. The changes in aboveground vegetation have mainly been used to describe rangeland degradation, but little research has been carried-out to assess the extent of soil degradation, particularly in communally managed grazing lands. The objective of this study is to provide some baseline reference indicators of soil quality and changes at three communal managed grazing sites (Austrey, Southey and Tseoge) in the Bophirima District in the North-West Province. This on-going study forms part of the Desert Margins Program (DMP) in South Africa. Soils from benchmark plots (grazed and adjacent ungrazed exclosure) were monitored for indicators such as pH, organic carbon and phosphorus, dehydrogenase, β-glucosidase and acid phosphatase in 2005 and 2006. The soils are predominantly sandy (±95%) with low fertility (organic carbon ranging between 0.06% to 0.10%, and phosphorus from 6.3 to 8.66 mg kg^{-1} irrespective of grazing or exclusion). At all sites, there were few significant differences between grazed and ungrazed plots for soil chemical properties, or for enzymes activities, but the sites did differ. The results were presented to and discussed with community members during workshops to raise awareness on soil degradation. At this early stage, it was difficult to detect significant trends of soil properties resulting from grazing management. Long-term monitoring and further indicators are required for a thorough assessment of soil properties responses. Furthermore, as land (soil) degradation is not only about the land, but also about people, a multi/interdisciplinary approach should be followed in analyzing soil degradation issues in these areas.

Keywords Range degradation, grazing management, communal sites, capacity-building

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1 Introduction

Drylands occupy 41% of the Earth's land surface and are home to more than 2 billion people. About 10–20% of the world drylands (mainly pasture or rangelands) are already degraded (Millennium Assessment, 2005). In South Africa, drylands represent approximately 91% of the land area (Table 1). Roughly 80% of the land is used for agriculture, but only 13.5% is considered arable. Two main land tenure systems (namely, commercial and communal, which represent 70% and 14%, respectively, of the land surface) exist in South Africa (Hoffman and Ashwell, 2001).

Desertification, which is a serious form of land degradation, affects all land use types in South Africa. For centuries people have been concerned about overgrazing, soil erosion and invasive alien plants (Hoffman and Ashwell, 2001). South Africa ratified the United Nations Convention to Combat Desertification (UNCCD) in 1997, and thereby committed to developing and implementing a long-term strategy to address issues related to desertification (DEAT, 2004). A prerequisite for tackling land degradation is a concise definition and assessment of the status and extent of the problem. A national audit of land degradation was conducted in order to provide a scientific basis for decision-making about land degradation (Hoffman and Ashwell, 2001). This audit drew on the expertise of more that 450 agricultural technicians, extension officers and land users and provided the first synthesis of land degradation in South Africa (Hoffman et al., 1999; Hoffman and Ashwell, 2001). Land degradation (soil, vegetation and combined degradation) was found to be more of a problem in the communal than in the commercial districts (Hoffman and Ashwell, 2001). However, these findings have been criticized for lack of scientific rigor, and an objective, systematic and spatially explicit measure of land degradation has been stressed (Wessels et al., 2004).

Grazing lands (rangelands) occupy approximately 80% of the land surface and constitute the most dominant land use type (Hoffman and Ashwell, 2001). Over the past decades, large areas of rangeland have been degraded as a result of combined effects of population growth, poverty, poor grazing practices (overgrazing and overstocking), incorrect use of fire and climate change. Communal rangelands (nearly 14% of the land surface) are viewed as degraded because of continuous

Table 1 Percentage of land area in each aridity zone in South Africa

Aridity zone	Hyper-arid	Arid	Semi-arid	Dry sub-humid	Humid
MAP/PET	<0.05	0.05–0.2	0.2–0.5	0.5–0.65	>0.65
% South Africa	8%	47%	39%	5%	1%
			Affected drylands		

From Hoffman and Ashwell, 2001. MAP: mean annual precipitation; PET: potential evapotranspiration grazing at high stocking rates. However, there is still debate about the appropriate definitions of degradation and overgrazing in communal rangelands (Vetter et al., 2006). The main forms of rangeland degradation are shifts from palatable to unpalatable species, loss of plant cover, invasion of alien plants and bush encroachment (Fig. 1). The impact of degradation on soil properties has received little attention, mainly in terms of soil quality. Snyman and du Preez (2005), for instance, stressed the need to assess soil responses to overgrazing and rangeland degradation in order to develop suitable grazing practices.

Sustainable use of grazing lands requires management strategies that do not compromise the capacity of the soil to function (Liebig et al., 2006). Ongoing assessment of the quality of soil resource is vital to maintain the sustainability of agriculture (Doran and Safley, 1997). Soil quality is defined there as 'the capacity of a kind of soil to function within ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health'. Indicators of soil quality are necessary to help land managers identify degradation areas and help to make management decisions for sustainable land use.

2 The Desert Margins Program (DMP): Turning Adversity into Opportunity

The ongoing study reported here forms part of long-term monitoring under the Desert Margins Program (DMP) research in South Africa. The DMP is a collaborative initiative to support research activities related to desertification in western, eastern and southern Africa. The overall objective is to arrest land degradation in Africa's desert margins through demonstration and capacity-building activities. The broader objectives are:

- Develop a better understanding of the causes, extent, severity and physical processes of land degradation in traditional crop, tree and livestock production systems in the desert margins, and the impact, relative importance and relationships between natural and human factors.
- Document and evaluate with the participation of farmers, non-governmental organizations and national agricultural research systems, current indigenous soil, water, nutrient, vegetation and livestock management practices for arresting land degradation, and identify socio-economic constraints to the adoption of improved management practices.
- Develop and foster improved and integrated soil, water, nutrient, vegetation and livestock management technologies and policies to achieve greater productivity of crop, trees and animals and to enhance food security, income generation and ecosystem resilience in the desert margins.
- Evaluate the impact and assist in designing policies, programmes and institutional options that influence incentives for farmers and communities to adopt improved resource management practices.

- Promote more efficient drought-management policies and strategies.
- Enhance the institutional capacity of countries participating in the DMP to undertake land degradation research and the extension of improved technologies, particularly to multidisciplinary and participative socio-economic research.
- Facilitate the exchange of technologies and information among farmers, communities, scientists, development practitioners and policy-makers.
- Use climate change scenarios to predict shifts in resource bases and incorporate these into land use planning strategies (Koala and Tabo, 2004).

The DMP in South Africa aims to conserve and restore biodiversity in the desert margins through sustainable utilization, and specifically to develop strategies to enhance ecosystem function and sustainable use in arid and semi-arid areas that are degraded and have reduced biodiversity associated with human and climate impact.

3 Objective of the Study

Long-term monitoring is essential to provide reliable information of changes or trends in the functional status or quality of soil and to help land managers to identify degradation areas. The objectives of the study were to provide baseline reference indicators of soil condition and associated changes resulting from management, to raise awareness about land degradation and sustainable management practices, and to serve as benchmark sites for long-term monitoring of land use and management effects.

4 Study Sites and Methods

The experimental sites were located in the Western Bophirima District in the North-West Province in South Africa (Fig. 2). Conducted in 2005 and 2006, the study forms part of ongoing long-term monitoring. The climate is semi-arid, with an annual rainfall between 200 and 400 mm, of which 80% falls in the summer (October–March) and 20% in the winter (April–September) (Mangold et al., 2002). The vegetation in the area is classified as the savanna biome, and consists of the Kalahari thornveld and shrub bushveld vegetation types. At each of three communally managed grazing sites (Austrey, Southey and Tseoge; Fig. 1), benchmarks were erected and grazed, and adjacent exclosure plots measuring $110 \times 20\,m^2$ each were established in 2001 at Austrey and 2003 at Southey and Tseoge. Each plot was divided into three subplots, considered as replicates for sampling purposes, because there were no replicates per plots. Samples (10) were collected from each subplot at a depth of 0–20 cm, mixed thoroughly with dead coarse organic materials and stones removed to get a composite sample. Samples were analyzed for organic carbon (OC), pH, P-Bray 1 and the activity of dehydrogenase (DHA), β-glucosidase and acid phosphatase (ACP).

Fig. 1 Loss of plant cover and bush encroachment on a communal managed grazing land in the Bophirima District, North-West Province

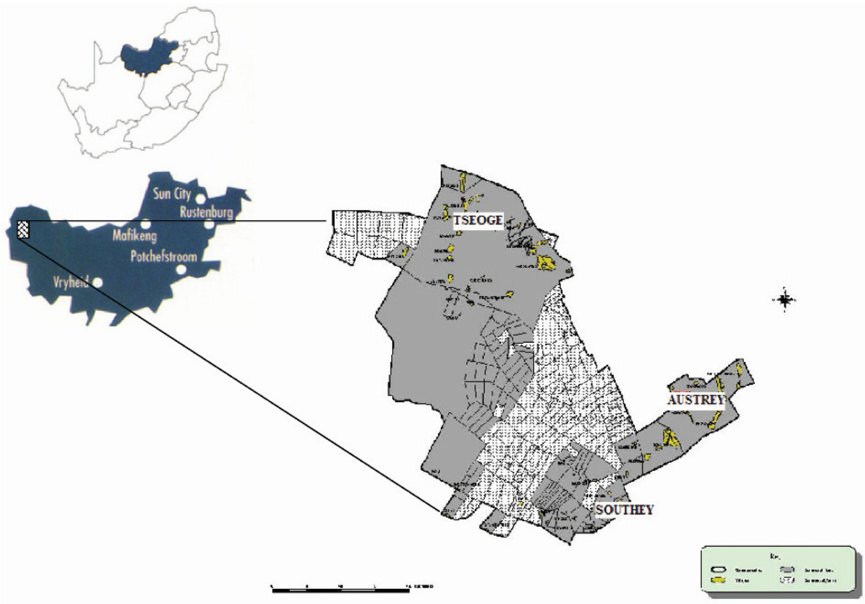

Fig. 2 Location of the study sites

5 Results

5.1 Soil Chemical Properties

At the Austrey site the soil was moderately acidic (pH 5.52), with low phosphorus (6.3 mg kg^{-1}) and organic carbon (0.10%). There were no statistically significant differences of soil pH, phosphorus and organic carbon between the grazed and ungrazed exclosure, respectively, in 2005 and in 2006. Phosphorus was significantly lower in 2006 in the grazed as well as the ungrazed plot. Soil organic carbon was significantly higher in 2006 compared to 2005 in the grazed plot. At the Southey site, soil pH averaged 5.55, phosphorus was 8.55 mg kg^{-1} and total organic carbon was 0.10%. Soil phosphorus was not statistically different between the grazed (GR) and ungrazed exclosure (UNG) both in 2005 and in 2006. Soil organic carbon was not statistically different between GR and UNG plots in 2005, but it was in 2006. It was significantly higher in 2006 in the grazed plot only, compared to 2005. At the Tseoge site, the average soil pH was 7.11, while phosphorus was 8.66 mg kg^{-1} and organic carbon was 0.06%. Soil phosphorus was statistically different between GR and UNG in 2005, but not in 2006. In the grazed plot, P-Bray 1 was not significantly different between 2005 and 2006, although lower in 2006. Soil organic carbon was not different between GR and UNG both in 2005 and in 2006. There was no difference between 2005 and 2006, respectively, in the grazed and ungrazed plot (Fig. 3).

6 Enzymes Activities

The activities of soil enzymes in both the grazed and ungrazed plots in 2005 and 2006 are given in Fig. 4. At the Austrey site, there was no significant difference between GR and UNG for the activities of DHA in both 2005 and 2006. The activity of DHA was significantly lower in GR and UNG in 2006. β-glucosidase activity was not statistically different between GR and UNG in 2005, but was in 2006. It was similar in the grazed plot over the two years, but significantly different for the ungrazed plots. Acid phosphatase showed significant difference between GR and UNG in 2005, but not in 2006. The activity of ACP was significantly lower in 2006, compared to 2005. At the Southey site, the activity of DHA was significantly different between GR and UNG in 2005, but not in 2006. Furthermore, DHA was significantly lower in 2006 in both the grazed and ungrazed plots, compared to 2005. There were no significant differences for the activity of β-glucosidase between GR and UNG in both years and within a plot between years. The activity of ACP was not different between GR and UNG in both 2005 and 2006, but it was significant over the two years at the grazed plot. At the Tseoge site, DHA showed no significant difference in activity between GR and UNG in 2005 and 2006, but it was significant between 2005 and 2006 in the grazed plots only. The activity of β-glucosidase was

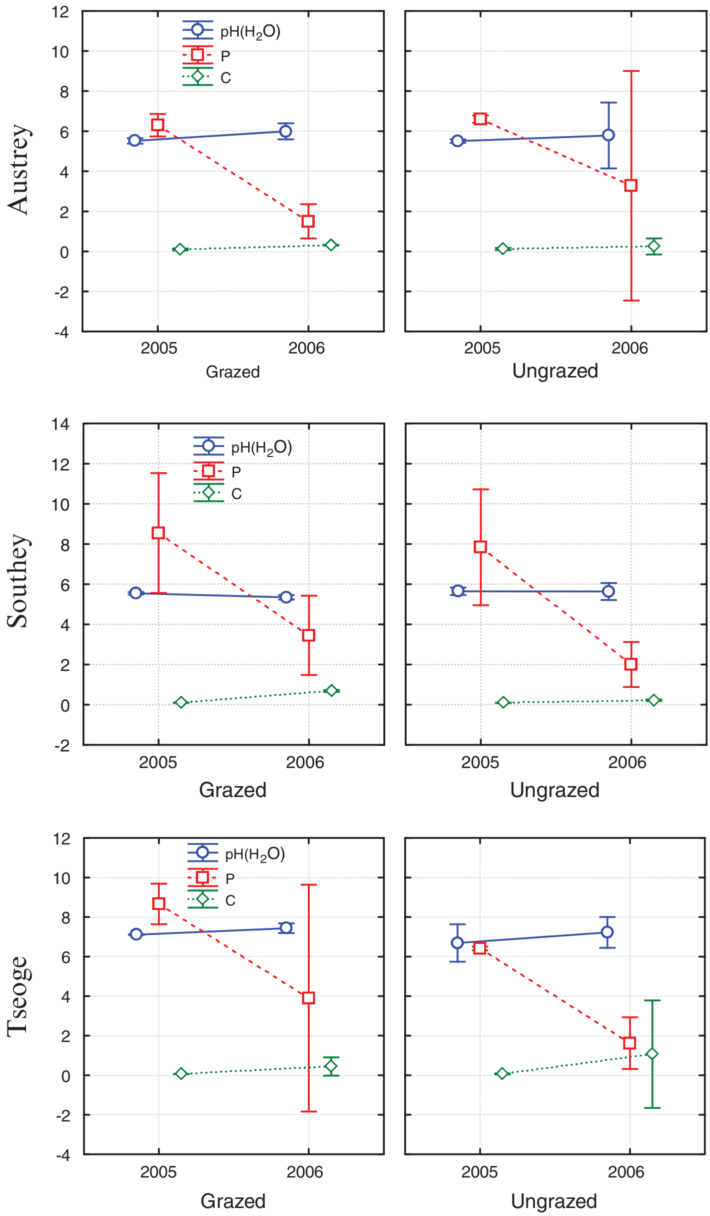

Fig. 3 Soil chemical properties in grazed and ungrazed plots in 2005 and 2006

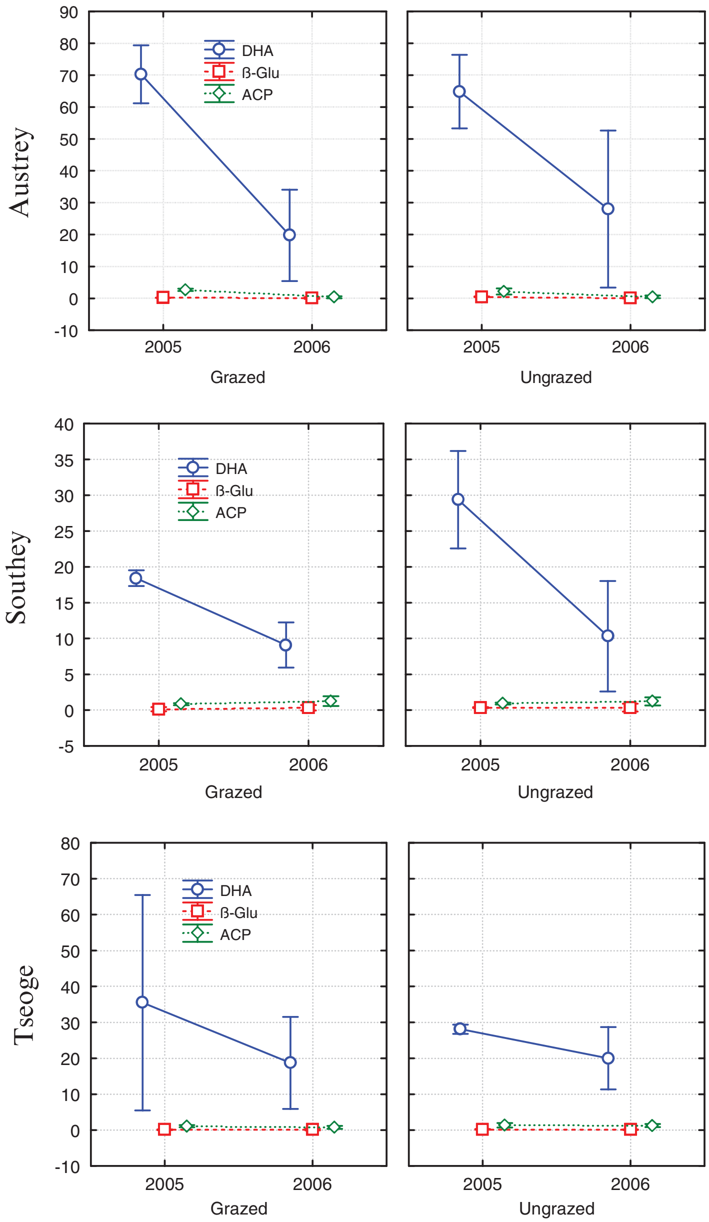

Fig. 4 Soil enzymes activities in grazed and ungrazed plots in 2005 and 2006

not significantly affected by GR nor by UNG in 2005, but was in 2006. There was no difference between the GR plots in 2005 and 2006, but the UGR plots showed significant difference over the two-year period. The activity of ACP was significantly affected by grazing exclusion in 2005, but not in 2006. There were no significant differences in the activity of ACP between GR plots and UNG plots in both years.

7 Conclusions

A major feature of the soils at the three sites (Fig. 5) was their general low fertility (low organic carbon and phosphorus), irrespective of grazing or exclusion. At this early stage, it was difficult to detect significant changes on soil properties resulting from grazing management at the three sites. The characterization of soil condition, however, is crucial as it constitutes a baseline reference in time that could help land users with management and decision-making in the future. Workshops, information and demonstration days were held at the three communal sites (Fig. 6), results were discussed with land users to raise awareness about soil degradation and the relationships between vegetation condition and rangeland health and productivity.

Evaluation of grazing management's effects on soil requires decades before measurable differences can be detected; hence, long-term monitoring is of the utmost importance and further indicator are needed. However, biophysical indicator monitoring is one aspect only of a complex and multifaceted problem that of land

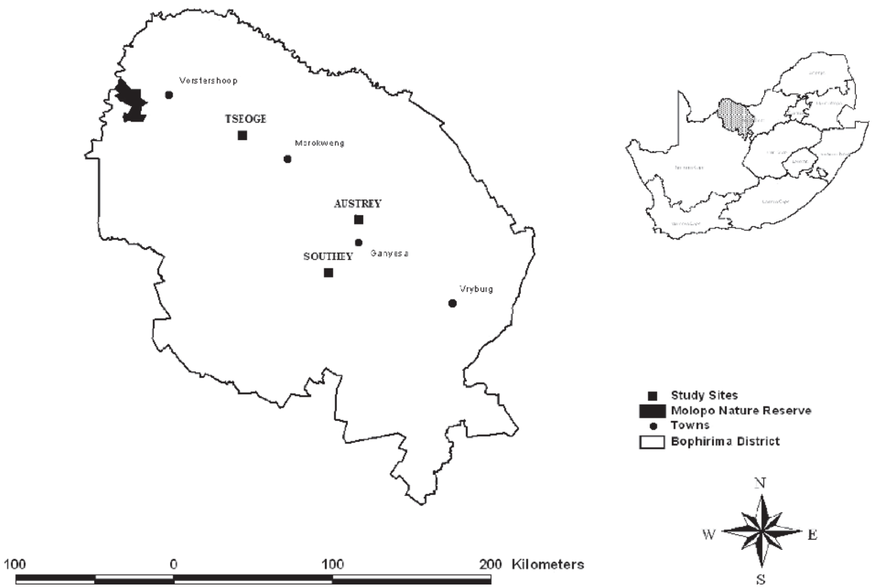

Fig. 5 Location of the three study sites

Fig. 6 Participation, capacity-building, knowledge exchange and demonstrations are important in analyzing and combating land degradation

degradation. Land degradation is not only about the land, but also about people. The driving forces (which are very often deeply rooted in the socio-economic and policy history of communities) behind their actions on the land are determinants to consider in a multi/interdisciplinary approach (biophysical, socio-economic, policy issues) in addressing the problem of land (soil) degradation, particularly in poor and formerly disadvantaged communities. These results are in line with South Africa's NAP of the UNCCD, and at the provincial level provide information on trends in the environment as part of the *State of the Environment Report* (SOER).

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References

DEAT. 2004. *Combating Land Degradation to Alleviate Rural Poverty*, National Action Programme, Department of Environmental Affairs and Tourism (DEAT), Pretoria, South Africa.

Doran, J. W. and Safley, M. 1997. Defining and assessing soil health and sustainable productivity. Pankhurst, C. E., Doube, B. M., Gupta, V. V. S. R. (Eds.), *Biological Indicators of Soil Quality*. CABI, Wallingford, pp. 1–28.

Hoffman, M. T., Todd, S., Ntshona, Z. and Turner, S. 1999. *Land Degradation in South Africa*. Prepared for Department of Environmental Affairs and Tourism, Pretoria, South Africa.

Hoffman, M. T. and Ashwell, A. 2001. *Nature Divided: Land Degradation in South Africa*. University of Cape Town Press, Cape Town.

Koala, S. and Tabo, R. 2004. *Turning Adversity into Opportunity: The Desert Margins Program–Towards Sustainable Management of the Desert Margins of Sub-Saharan Africa*. Project Document 2002–2008. Patancheru, Andhra Pradesh, ICRISAT.

Liebig, M. A., Gross, J. R., Kronber, S. L., Hanson, J. D., Frank, A. B. and Phillips, R. L. 2006. Soil response to long-term grazing in the northern Great Plains of North America. *Agriculture, Ecosystems and Environment*, Vol. 115, pp. 270–276.

Mangold, S., Kalule-Sabiti, M. and Walmsley, J. 2002. *State of the Environment Report 2002*: *North West Province, South Africa*. North-West Province Department of Agriculture, Conservation and Environment.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Desertification Synthesis*. World Resources Institute, Washington, DC.

Snyman, H. A. and du Preez, C. C. 2005. Rangeland degradation in a semi-arid South Africa, II: Influence on soil quality. *Journal of Arid Environments*, Vol. 60, pp. 483–507.

Vetter, S., Goqwana, W. M., Bond, W. J. and Trollope, W. W. 2006. Effects of land tenure, geology and topography on vegetation and soils of two grassland types in South Africa. *African Journal of Range and Forage Science*, Vol. 23, pp. 13–27.

Wessels, K. J., Prince, S. D., Frost, P. E. and van Zyl, D. 2004. Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. *Remote Sensing of Environment*, Vol. 91, pp. 47–67.

Acronyms

ACP:	acid phosphatase
AfNet:	African Network for soil biology and fertility
CIAT:	International Center for Tropical Agriculture
DEAT:	Department of Environmental Affairs and Tourism
DHA:	dehydrogenase
DMP:	Desert Margins Programme
NAP:	National Action Programme
OC:	Organic carbon
TSBF:	Tropical Soil Biology and Fertility
UNCCD:	United Nations Convention to Combat Desertification
β-glu:	β-glucosidase

Chapter 8
Monitoring Drylands Ecosystem Dynamics for Sustainable Development Policies: The Keita Experience

Vieri Tarchiani, Andrea Di Vecchia, Lorenzo Genesio and Federica Sorani

Abstract The Keita Valley in Niger covers an area of about 4,800 km^2 of plateaux with rocky slopes and valleys forming a complex system of watersheds moulded by strong winds and water erosion.

The Keita Rural Development Project began in 1982. Its main objective was to reduce food insecurity in an arid region in danger of environmental collapse. The project proposed to increase food security while combating desertification through the reduction of soil erosion and reforestation in this large area.

More than 20 years of soil conservation and land reclamation interventions make Keita an open-air laboratory for the study of desertification dynamics and land reclamation activities. The availability of long series of environmental and socio-economic data and information allows for ecosystem monitoring through indicators based both on field data and model output. This extraordinary situation, almost unique in the Sahel, provides the opportunity not only to model the behaviour of natural vegetation during the re-colonization of degraded lands but also to evaluate the impact on populations and production systems. Observing dynamics in the Keita Valley helps to extrapolate the potential evolution of environmental behaviour in arid and semi-arid ecosystems.

Environmental monitoring in Keita has a dual target in planning support at national and local levels. The former supports the definition of national policies and actions plans to combat desertification and land reclamation while the latter, according to the decentralization process that Niger has initiated in natural resource management, sustains local authorities in territorial planning.

Keywords Keita Rural Development Project, ecosystem monitoring, land reclamation, desertification, agro-ecosystem dynamics

IBIMET-CNR, Fondazione per il Clima e la Sostenibilità, Florence, Italy

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

1 Introduction

The Sahel covers the area between the Sahara and the Sudan, from Senegal to Chad, and receives about 250–500 mm summer rainfall (Wezel and Rath, 2002). In spite of some local exceptions, this area is characterized by semi-desert grassland, scrubs and wooded grasslands in which *Acacia spp*. play a dominant role. Although the area has been inhabited for at least 9,000 years, only in recent decades has the overexploitation of soils – closely linked to population growth and limited and irregular rainfall as a consequence of global change – caused soil exhaustion and lowered productivity. Climate changes and soil overexploitation are resulting in a rapid and often irreversible degradation of the natural resources. This is particularly true for vegetation and soil because the lack of alternative sources of income and the primitive agricultural techniques lead to non-sustainable exploitation (Le Houérou, 1996).

During the 1980s, different Sahel countries began to increase the number of projects focusing on land reclamation and reforestation but were generally limited to local situations. The impact of such scattered initiatives has not always been appreciable, not least because forest restoration initiatives were not planned for the long term and faced rapid degradation. This is the reason why a proper evaluation of a project's success requires long-term monitoring activities. In contrast, the Keita experience – the Ader Doutchi Maggia Rural Development Project, Keita NIGER – is one of the longest lasting projects thanks to the results achieved; it has also been the subject of many scientific studies.

Generally, experience in the Sahel until now has shown that there is no widely accepted approach to managing the arid and semi-arid ecosystems. Ideas and theories on integrated management of agro-ecosystems are still evolving and have not yet matured into a commonly shared strategy. Moreover, specific issues on arid ecosystems are not widely addressed; for example, important knowledge gaps exist of such arid Sahel species as *Acacia spp*., their growth dynamics (Gourlay, 1995), production (carbon sequestration, wood and non-wood) and interaction with crops (Bremann and Kessler, 1995). The sustainable management of arid and semi-arid lands should be based on the understanding of such dynamics.

2 The Keita Ecosystem

The Keita *area* is located in the centre of the Republic of Niger and covers an area of more than 4,860 km^2 characterized by plateaux with rocky slopes and valleys forming a complex system of watersheds exposed to strong winds and water erosion. The Sahelian climate with an average temperature of about 29°C, a short rainy season (June–September) and a yearly average rainfall between 400–500 mm represents one of the most limiting factors. The diagram of monthly average rainfall and temperature is shown in Fig. 1.

Between 1960 and 1990, a decrease in yearly average rainfall was observed particularly during the month of August, with a latitude shift of 30 km from northeast to southwest.

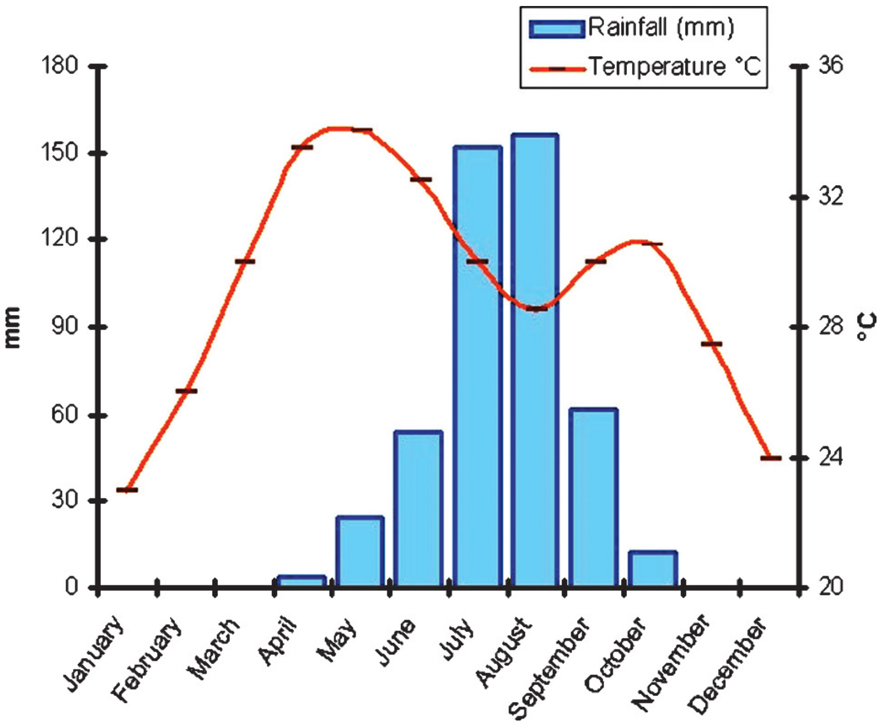

Fig. 1 Average climatic data for Keita

The decade between the two recent great droughts in 1973 and 1984 represents a line of demarcation between two different environmental and socio-economic systems. A negative synergistic process, which seemed irrepressible, struck the ecosystem, bringing it close to breaking point – crop production fell and herds were decimated. In 1984, the area seemed destined again to become a zone of low population density and few future prospects, as it was at the beginning of the century.

The Keita Valley has always represented a boundary of the Sahara Desert that allowed for the development of a multiethnic community composed of communities from southern regions and nomads from the north. Thus the total population increased from 65,000 inhabitants in 1962 to 230,000 in 2003.

3 The Keita Project

The Ader Doutchi Maggia Rural Development Project (PDR-ADM), known as the Keita Project, was launched in 1982 within the framework of the Italian Initiative for the Sahel, whose aim was to reduce food insecurity. It became operational in 1984 and since then has been active throughout the three phases, which ended in 2003. The main objective was to increase food security over a very large area while combating desertification through the reduction of soil erosion and reforestation (FAO, 1995b).

A new initiative (Fond Local de Développement de l'Ader Doutchi Maggia, FLD-ADM) began in 2006 with the objective to complete existing involvement, fund local investments and transfer management and property to local institutions and organizations.

The PDR-ADM operated in:

- Reclamation of plateaux and abandoned lands in the valleys for agricultural and pastoral purposes
- Reforestation of slopes, of the *koris* banks and dunes
- Creation of wind breaks and forest areas
- Control of the water flow in the *koris* by banks consolidation and small dams

Simultaneously, the project has also addressed social and economic development by building schools, medical centres, wells and roads, and providing technical assistance and financial support for the creation of new economic activities.

The main interventions of PDR-ADM from 1984 to 2005 are shown in Table 1 (KeitaLAB, 2006).

Table 1 PDR-ADM interventions until 2005

Interventions	
Reclamation and improvement of agricultural and pasture lands, reforestation and dune fixation	34,483 ha
Trees planted	18,648,000
Road construction	313 km
Drilled wells	5
Excavated wells	708
Rural buildings	28,000 m^2
Small dams	40
Dams	2
Weirs	251

More than 20 years of soil conservation and reclamation involvement makes Keita an open-air laboratory where it is possible to carry out studies on the environmental and socio-economic impact of actions in order to combat desertification. The availability of long-term environmental data and information concerning the age and typology of intervention enables the development of specific environmental analysis and indicators based on data rather than models. This extraordinary situation provides the opportunity not only to evaluate the impact of PDR-ADM actions but also to model the behaviour of natural vegetation (trees and herbaceous plants) during the recolonization of degraded lands while fostering future development and potentialities.

4 Agro-Ecosystem Monitoring in Keita

While the PDR-ADM focused on land management, it did not fully consider environmental monitoring. Consequently, from 1995 on many initiatives were conceived and begun to fill this monitoring deficit. CASE-IBIMET institutions have been involved in Keita for more than ten years. Keita has been chosen as the privileged environment to help to answer questions in the fields of scientific research and development cooperation in the drylands, such as:

- Are climatic changes definitive or are they the expression of cyclic phenomena?
- What kind of pressure can natural resources sustain in these areas? How and in how much time could this pressure be modified?
- What kinds of new relationships could be created between humans, the economy and the environment in the future?
- What techniques are the most appropriate in order to recover degraded environmental resources and to preserve those at risk?
- How can this recovery be achieved in an efficient and economically profitable way? What are the sustainability guarantees of these interventions?
- How can true partnerships be achieved when carrying out rural development programmes?

The agro-ecosystem monitoring initiatives being carried out in Keita are:

- 1995–1997: The Projet d'Evaluation des Interventions de Conservation et de Récupération de l'Environnement (PEICRE) – Italian Cooperation – built an Information System on Keita in order to evaluate and monitor interventions.
- 1997: Keita is identified by ROSELT (Réseau d'Observatoires et de Surveillance Ecologique à Long Terme) as one of the priority places in Niger for desertification monitoring.
- 1999–2000: Realization of an Information System to Sustain Evaluation Analysis and Planning; FAO-Italian Cooperation-CeSIA.
- 2001: Launch of Keita Observatory through the Projet d'Appui à la Formation et d'Assistance en Gestion de l'Environnement (PAFAGE) – Italian Cooperation.
- 2002: IBIMET-CNR studies in the context of three major United Nations conventions (UNCCD, CBD, UNFCCC) on Keitas potential regarding carbon sequestration.
- 2006: Launch of KeitaLAB, IBIMET-CNR and the Climate and Sustainability Foundation (FCS).

KeitaLAB was launched in early 2006, during the International Year of Deserts and Desertification, which represents the right context to valorise and diffuse the Keita experience in combating desertification. KeitaLAB aims to preserve, emphasize and consolidate the knowledge heritage coming from the synergy between a successful cooperation programme and the exceptional engagement of Italian scientific institutions. In this context, the union between International Cooperation and scientific research in drylands makes Keita unique in the Sahel. That is why, in this area, global interest topics, represented by United Nation conventions (UNFCCC, UNCCD and CBD), integrate with sustainable development according to Johannesburg Summit recommendations.

The main objectives of the initiative are:

- To deepen the analysis of PDR-ADM impact on sustainable development combating and desertification and to valorize project results
- To analyze territorial economic and productivity dynamics and potentiality and to evaluate their impact and sustainability
- To support planning for the protection and valorization of territorial resources
- To consolidate knowledge and facilitate access to other scientific institutions
- To promote new economic dimensions and international cooperation topics, such as the CDM (Clean Development Mechanisms)
- To promote activities and projects in order to emphasize Keita's international dimension and its role in the Niger context

KeitaLAB is sponsored by IBIMET-CNR (Institute of Bio-meteorology) and FCS (Climate and Sustainability Foundation). Working activities being developed within the partnership include:

- The PDR-ADM
- The Ministère de l'Hydraulique, de l'Environnement et de la Lutte contre la Désertification of Niger
- The Turin Polytechnic University
- The IUAV (Venice Architecture University Institute)

Agro-ecosystem monitoring began in Keita in 1995 with the PEICRE project. The results of ten years of activities are valorized by KeitaLAB both at the scientific level and planning support level.

As regards planning in Niger, territorial resources management is ascribed to local authorities (communes), thanks to decentralization, and PDR-ADM is transferring project interventions to the same local authorities.

To strengthen this process, communes benefit from assistance (technical and training) and tools (databases and information products) for the definition and implementation of resource management plans.

5 Results

Achieved results can be organized into scientific and planning support results. At the scientific level, agro-ecosystem dynamics have been studied so as to understand the impact of project activities in relation to climate change and human pressure. Furthermore, changes in land productivity have also been studied in order to assess the impact of the project on the socio-economic dimension. From the planning point of view, the territory has been analyzed in order to identify areas at risk and those displaying best performances and potentialities.

5.1 Agro-Ecosystem Dynamics

The impact of PDR-ADM interventions on the environment has been monitored by a multi-temporal analysis of land cover.[1] Changes in land cover are the result of synergies of different factors (climate change, interventions of PDR-ADM and demographic pressure). The environmental status prior to the beginning of the project testifies to the negative impact of climate and anthropogenic pressure on ecosystems. In 1962, the slopes of the highlands were forested, but in 1972 some signs of degradation became evident, and by 1984 the forest had completely disappeared. Between 1984 and 2002, there has been a progressive recovery of the natural vegetation (Fig. 2).

In approximate terms, the diachronic land cover study revealed that between 1984 and 2002 woodlands increased by more than 300% (from 10,000 ha in 1984 to 45,000 ha in 2002) against a 30% reduction in the shrubby steppes. This trend is also supported, in addition to the PDR-ADM intervention, by the gradual increase in rainfall, which was recorded from the 1990s.

Although the same dynamics are observed in the whole Sahelian part of Niger, this trend has achieved such results in Keita only because of the PDR-ADM intervention and the control of human pressure on natural resources. In addition to wood natural vegetation recovery, there has also been an evident increase of agricultural surfaces (about 80%) resulting from the substitution of large grassland areas (decreased about 70%) and of PDR-ADM land reclamation interventions (about 12,000 ha). These data confirm that the trend of natural vegetation recolonization is reduced by the increase of human pressure.

In particular, valley and glacis are exposed to higher agricultural pressure, and the trend is towards the spread of croplands. This occurs in three ways: first, by restoring degraded lands; secondly, by reclaming of grasslands; and lastly, by clearing woody vegetation. The first method, supported by PDR-ADM, concerns the slopes of the Keita Valley and also the sandy dunes of the eastern plateaux. Land reclamation of grasslands has been driven by demographic pressure especially in the Keita and Insafari valleys. Woody vegetation clearing happens especially in the secondary valleys, where demographic pressure before 1984 was low but greatly increased subsequently. On the other hand, woody vegetation restoration involves large areas on the slopes and also in the valleys as gallery forests (Fig. 3). This trend on the slopes is particularly interesting where it is not due directly to project interventions (plantation in trenches) because it shows the effectiveness of the watershed approach and water management on plateaux and slopes.

Cropland degradation is also observed due mostly to wind erosion and sand accumulation. It provides evidence that desertification is still active, even though PDR-ADM interventions has reduced its effects. In this context, monitoring the territory in ways that could indicate a reactivation of desertification is very important, especially during this phase when the environment is slowly recovering equilibrium.

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[1] Land cover classification is expressed by the Land Cover Classification System (LCCS) standards of FAO-Africover.

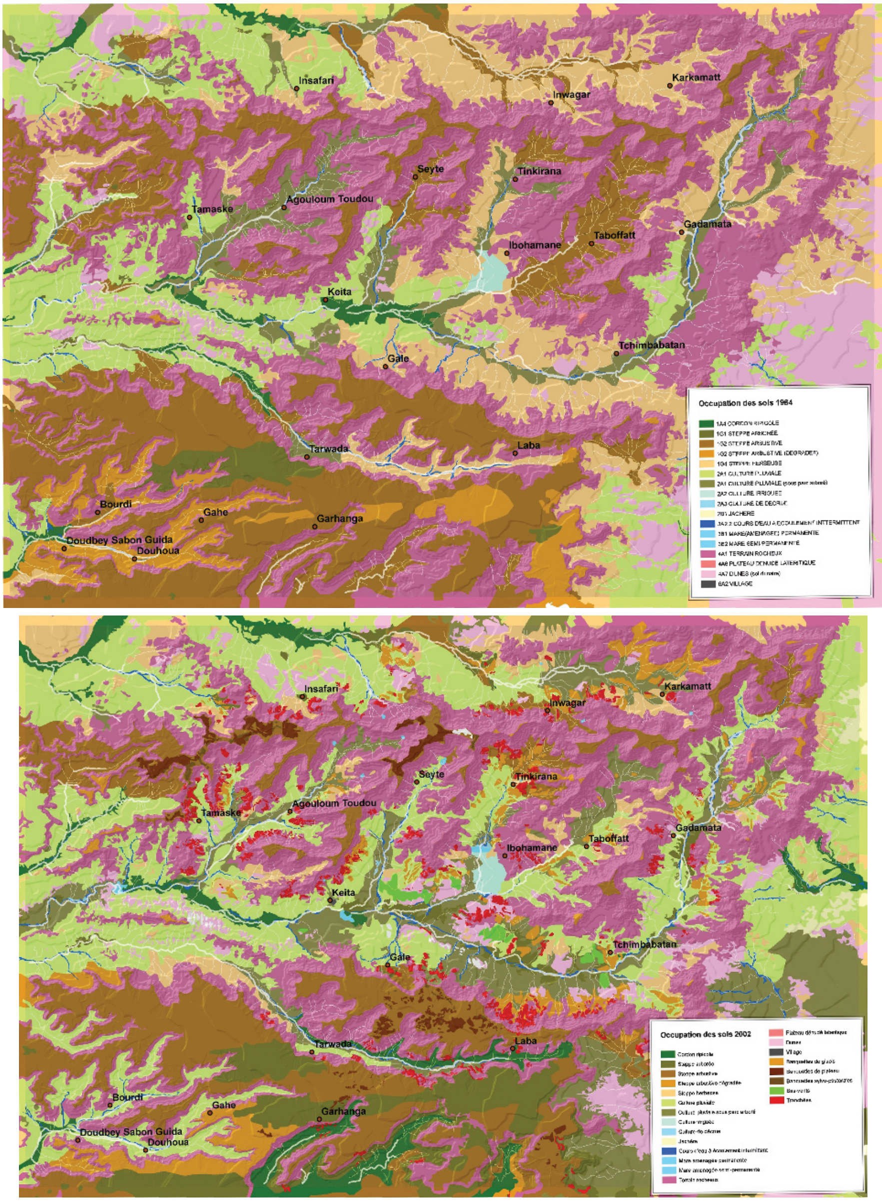

Fig. 2 Keita Valley, land cover in 1984 and 2002 (with PDR-ADM interventions) – Interpretation of Landsat image

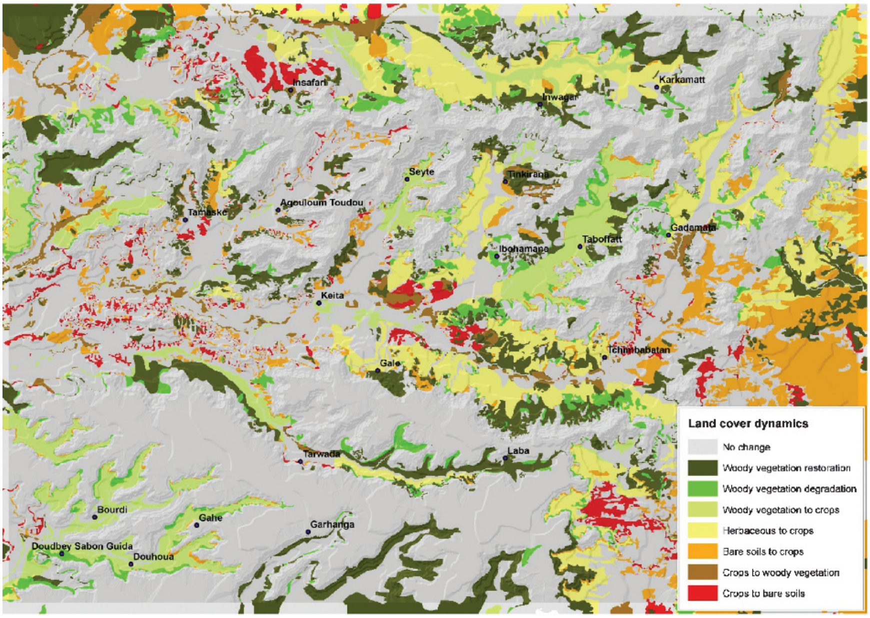

Fig. 3 Land cover dynamics between 1984 and 2002

5.2 *Improvement of Land Productivity*

Pressure from population growth is currently one of the main factors of desertification; consequently, the classic environmental approach to combating desertification is doomed to failure if it is not combined with actions to reduce this pressure through the creation and diversification of sources of income for the population.

Productivity is assessed by considering the main products contributing to the population's livelihood: agriculture, forestry and livestock. Regarding agriculture, only rainfed cereals have been considered and in the case of plantations, only block cereals such as *tranchées* and *banquettes* are analyzed.

In 2003 the entire project area produced about 40,000 t of wood compared to production in 1984 of about 17,000 t, with a variation of 133%. The availability of leaf biomass has also increased by about 57%.

In 1984 cereal production was about 39,000 t, while in 2003 it reached 55,000 t.[2] With these variations, pressure on natural resources also strongly increased–generally more than production, as demonstrated by population and livestock growth of about 50% during the period.

[2] Reduction coefficient of 0.85 is applied to agricultural production to account for losses due to accidental factors.

5.3 Monitoring Application for Planning

Monitoring activities on territorial resources are useful not only for scientific research but also for the planning and management of these resources at national and local levels. Analyses for planning support at the local level have been carried out on the basis of territorial units (UTE) that correspond to sub-basins. Analysis on rainfed agriculture reveals that, for the entire area, 89% of potential croplands are already exploited and 23 out of 77 UTE attain 100%. Nevertheless, cereal production is not sufficient to satisfy population cereal needs. Cash crops are becoming extremely important in their contribution to household incomes.

The forestry sector, which had completely disappeared in 1984, is regaining importance. Monitoring analysis shows that existing woodlands have sustainable production but that the amount satisfies only 69% of the population's needs (Fig. 4).

The breeding sector evaluates yearly production of dry biomass at about 80,000 t (41% herbaceous, 27% crop residues and 32% foliar). The rate of satisfaction of needs in terms of livestock changes according to the morphology and land use of the UTE, is generally in deficit for 37 UTE, of which 18 have a rate <50%.

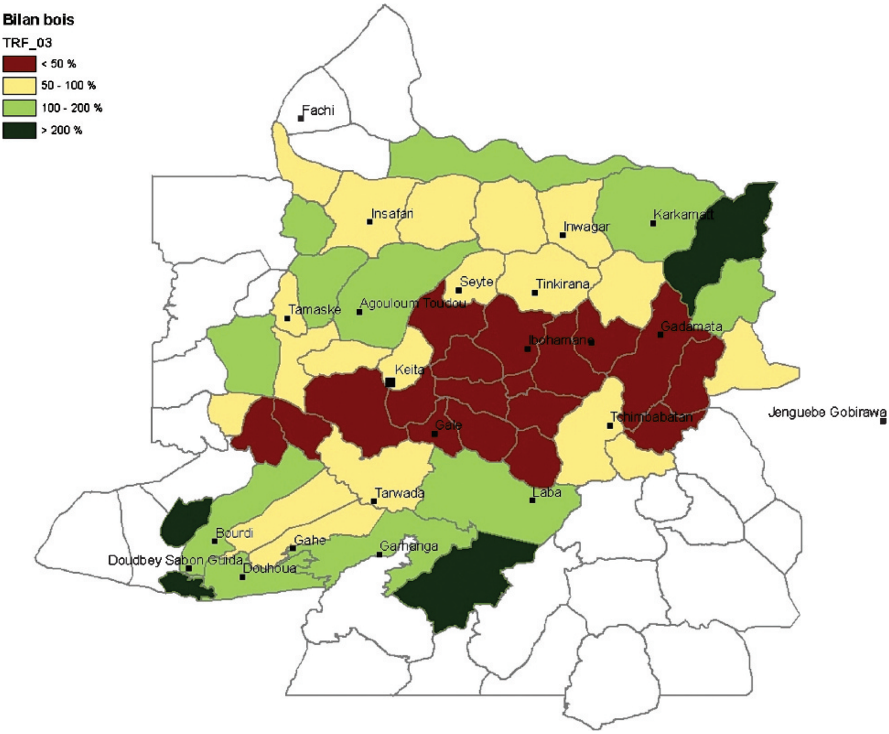

Fig. 4 Satisfaction of population's need for firewood by sustainable exploitation

One of the main results of the Keita Observatory was the realization of an Environmental Information System (SIE-Keita). Its main objective was to establish an information base that would be useful in planning and monitoring the impact of desertification control and rural development actions.

In fact SIE-Keita is designed to respond to requests at both the institutional and the technical level in terms of thematic information for monitoring and planning. The former involves the decision-making level (Ministry of Environment), which addresses natural resource management, while the latter concerns the technical-scientific level in terms of monitoring agro-ecosystem dynamics and the assessment of development sustainability.

To play this dual role, the system is intended to be easily accessible for all users both at central and local levels. In a national context, where telecommunications still present structural limitations, the critical step not only involves ensuring that SIE-Keita does not remain a mere technological tool that is difficult to exploit but that a simplified version of SIE-Keita on CD-Rom be extracted. This version is conceived for use at the level of decentralized services, as well as for other actors involved in the environmental field of planning and natural resource management. To ensure that every user can access geographical information, the system is based on flexible, user-friendly software (Visual Keita), which allows users to display and query available data (Fig. 5).

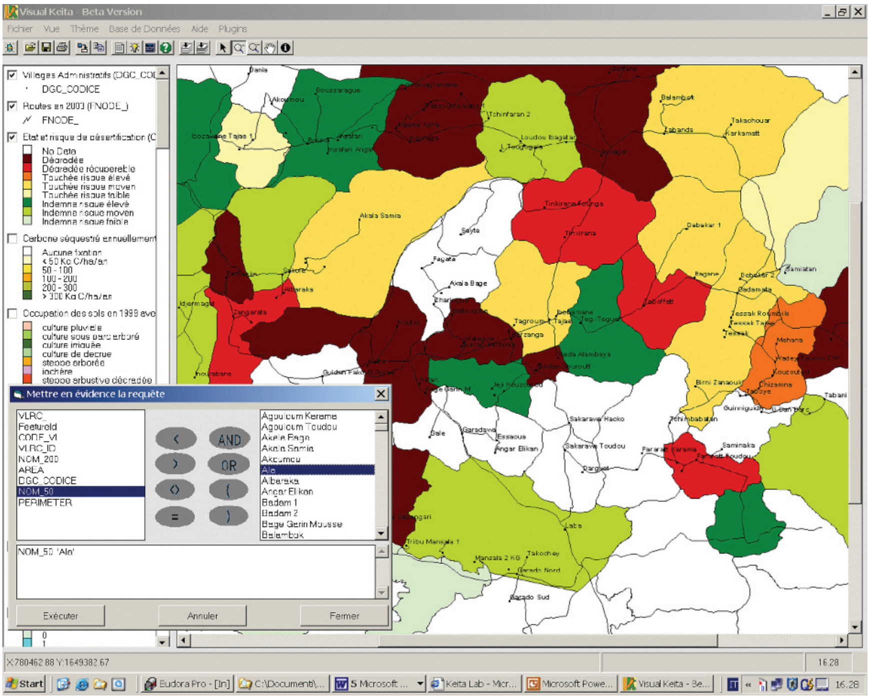

Fig. 5 Visual Keita

6 Conclusions

Twenty years of PDR-ADM interventions have enabled the natural and production systems to recover and stabilize. For this reason, Keita became an example in the Sahel, one of the more interesting and dynamic economic poles of the country and attractive to neighbouring populations.

Notwithstanding the efforts and undeniable results of PDR-ADM, the traditional rainfed production systems are reaching saturation point and the ecosystems are suffering from human pressure. The PDR-ADM approach was designed to effect the rapid recovery of a degraded environment close to physical collapse. For the sake of ecological equilibrium, a new strategy is required that places priority on the socio-economic dimension and developes alternative sources of income.

At the level of national policies and action plans, important lessons have been learned from the Keita experience: land reclamation and conservation practices for agricultural activities are very important but not sufficient to assure a perspective of development and a balance between population needs and production.

Furthermore, recovery of degraded territory requires that projects last for decades and not only years. Keita proved that the recovery phase – to regain prior environmental balance – demands twice the length of time taken for the degradation process. Moreover, it also proves that prevention is by far less costly than reclamation.

It is unlikely that, at the present rate of population growth, food security and a sustainable future can be assured in the Sahelian areas by agricultural activities alone. Considering that the income produced by rainfed agriculture is not sufficient, the promotion of initiatives aimed at strengthening local economic systems by diversification of production is necessary.

Future interventions to combat desertification need to join land conservation and rehabilitation practices with specific actions aimed to develop new income generation scenarios in order to assure the sustainability and success of the interventions in the long term.

Finally, greater knowledge of non-conventional production should be a starting point to identify new and suitable approaches aimed at valorizing any possible *means* capable of generating new sources of income with low environmental impact. Trees are a good example because they are an important source of income for the local population and because traditionally they have multiple uses. In addition to the underestimated contribution of secondary products (i.e. leaves, fruits) to the domestic budget, trees are used for wood and other commercial products (i.e. gum), and given the possibilities of the Kyoto Protocol in terms of reforestation and carbon credit, trade could be considerable in the coming years.

At the local level the transfer to local administration of territorial management requires transferring the knowledge necessary for the sustainable exploitation of resources and the definition of development plans.

The commitment of PDR-ADM and its partners in support of Keita *communities* for territorial management constitutes a step forward and an example in decentralization and the sustainable exploitation of resources.

References

Breman, H. and Kessler, J. J. 1995. *Woody Plants in Agro-Ecosystems of Semi-Arid Regions with an Emphasis on the Sahelian Countries*. Springer, Berlin.

———. 1995b. *The Keita Integrated Rural Development Project*. Food and Agriculture Organization of the United Nations, Rome.

Gourlay, I. D. 1995. The definition of seasonal growth zones in some African Acacia species – A review, *International Association of Wood Anatomists Journal*, Vol. 16, pp. 353–359.

KeitaLAB. 2006. IBIMET-CNR, FCS. http://www.ibimet.cnr.it/Case/keita/index.php

Le Houérou, H. N. 1996. Climate change, drought and desertification. *Journal of Arid Environments*, Vol. 34, pp. 133–185.

Wezel, A. and Rath, T. 2002. Resource conservation strategies in agro-ecosystems of semi-arid West Africa. *Journal of Arid Environments*, Vol. 51, pp. 383–400.

Bibliography

Di Vecchia, A., Genesio, L., Mazzoni, S., Miglietta, F., Vaccari, F. P. and Maracchi, G. 2002. *Keita Integrated Project: An Appropriate Model for Sustainable Development*. Biometeorology Institute, Florence.

FAO. 1995a. *Role of Forestry in Combating Desertification*, FAO Conservation Guides – 21. Food and Agriculture Organization of the United Nations, Rome.

PAFAGE. 2004. *Visual Keita*. Coopération Italienne-Ministère de l'Hydraulique, de l'Environnement et de la Lutte contre la Désertification, République du Niger. Projet d'Appui à la Formation et d'Assistance en Gestion de l'Environnement.

Reij, C. and Steeds, D. 2003. *Success Stories in Africa's Dry Lands: Supporting Advocates and Answering Sceptics*. CIS/Centre for International Cooperation, Vrije Universiteit, Amsterdam.

Session IV
Sustainable Land Use and Agriculture

Session Chair: Dr. Mekhlis Suleimenov
Rapporteur: Prof. Sayyed Ahang Kowsar

Synthesis of Presentations

A. Dr. Ronald Bellefontaine, CIRAD-Foret, France, reported on a very low-cost method of tree propagation, the process of 'root suckering and ground layering'. It is technically and rapidly practicable by poor populations and may be very beneficial to increase their standard of living and to combat desertification. These vegetative propagation techniques have important advantages, including low cost, reduced hole-digging and subsequent erosion, as well as the reproduction of trees with farmer-preferred physical characteristics. Before the total disappearance of the remaining vegetation, the induction of suckering (ground layering) by slightly wounding the roots (branches) at the right time is less expensive than re-planting. These forms of asexual regeneration have not been sufficiently considered up to now. He displayed vivid photos of his trials in different countries from the Mediterranean region to tropical Africa. Usually suckers develop roots down to 5–10 cm, but there are two exceptions at 80 cm. For two other species, amazingly 81 m suckers were also reported. More than 875 species have been identified and published.

He noted the following research priorities:

- To find the best time(s) of the year in each country when the success of this technique is more assured and to document the conditions under which suckers and layers can later become independent of the mother tree
- To experiment the root cuttings method, especially the respect of plant polarity
- To record the traditional knowledge and to start local case studies on key indigenous species which show this ability

B. Dr. Asamoah Larbi, ICARDA, Syria, discussed the critical situation of insufficient forage for a growing population of livestock in Central and West Asia and North Africa. Overgrazing has caused land degradation and loss of biodiversity in these regions. Development of improved indigenous forage legumes with high protein content and yield, and the potential to enhance soil fertility, are the objectives of this research project. The cooperation of ICARDA scientists and national partners has resulted in the identification and release of high-yielding, nutritious legumes, particularly vetches (*Vicia spp.*) and *Lathyrus spp.*, suitable for grazing, hay making, and harvesting at maturity for seed and straw. Forage legumes germplasm improvement for increased production and productivity was emphasized.

C. Mr. Humberto Alves Barbosa, FUNCEME (Fundação Cearense de Meteorologia e Recursos Hidricos), Brazil, linked sustainable indices and climate variability in the state of Ceará, northeastern Brazil. Fluctuations of sea-surface temperature in the tropical Pacific (Ni2o 3.4 index) and Atlantic (Dipole index) were linked to drought and high rainfall occurrences. He found that total seasonal maize and bean production is inversely correlated with Ni2o 3.4 and Atlantic Dipole indices. Year-to-year averaged February–April sea-surface temperature fluctuations explain about 50% of the inter-annual variability in maize and bean production over the rainy season. Variation of +0.5°C from a 30-year mean indicates drought, while –0.5°C indicates a rainy season.

D. Dr. Abule Ebro, Adami Tulu Agricultural Research Center, Ethiopia, discussed the conflicts in the Awash Valley of Ethiopia since 1960 between the pastoralists, who want to graze their herds, and the conservationists, who prefer protection of the wildlife habitat. The conflict, aggravated by drought, has threatened the co-existence of Afar and Kereyu graziers, park and plantations, and resulted in rangeland deterioration. This degradation has caused bush encroachment on grasslands. Improvement in livestock marketing and animal fattening is a direct approach for increasing the income of the graziers. As diversification is thought to improve the well-being of the affected pastoralists, the following activities have been foreseen for their benefits: apiculture, palm leaf processing, fish farming, ecotourism, and handicraft, establishment of saving and credit groups, and increasing social services.

E. Dr. Mohammed Karrou, INRA, Morocco, was concerned that some of the very precious rainfall in the drylands of Morocco is wasted through evaporation and runoff. Insufficient and unreliable rainfall, drought and low diversification of crops have resulted in natural resource degradation, low production and low water-use efficiency. Improving water-use efficiency through the implementation of appropriate technologies may lead to poverty mitigation. Soil and water conservation (straw management) and soil fertility improvement (including legumes in rotation) are recommended. Timely cropping is a strategy for having a weed-free stand, and maturing earlier than the warm spring weather impedes growth of small-grained cereals. Planting of better adapted trees, shrubs and aromatic and medicinal crops, along with water harvesting, is advised. Commitment and willingness of farmers, extension agents and government is essential for the success of such undertakings.

F. Ms. Zhang Qian, Peking University, China, presented policy analysis in grassland management of Xilingol Prefecture, Inner Mongolia. The Livestock and Grassland Double-Contract Responsibility System (LGDCRS) has been implemented since 1984, which is based on the Clementsian Succession Theory and property right theory. The LGDCRS aims to help herders to keep their livestock population below the carrying capacity of their pasture inorder to maintain sustainable livestock breeding when they have long-term usufruct of rangeland.

However, in its 20 years of operation the LGDCRS has fallen short of its goals. Moreover, six years of implementing Fencing Grassland and Moving Users policy (FGMU) has also failed to restore the degraded rangelands. According to the field study, three problems encountered in the implementation of LGDCRS and FGMU in Xilingol Perfecture have caused the failure of these policies.

1. Neglect of the character of the grassland ecosystem.
2. Three defects in implementation (non-operational standard of carrying capacity, lack of the expected external preconditions, and the expanding gap between the rich and the poor) changed the livestock breeding depending on natural rangeland into high-investment production.
3. The very high cost of FGMU.

G. Ms. Nagwa Hassan Elnwishy, Suez Canal University, Egypt, advocated fish farming for combating desertification in the Sinaitic Peninsula. In a laboratory experiment she showed that raising fish and using the fish pond water for irrigation is a viable alternative to the traditional farming usual in deserts. The fish pond water had higher nitrogen and organic matter content than the well water used for irrigation. Her study proved that tilapia fish (*Oreochromis niloticus*) performs equally well in groundwater and natural open waters. Soil quality is improved by irrigating with fish pond water. The added income from such enterprises decreases over-exploitation of natural resources and thus reduces land degradation.

Species and variety trials with other fish species in water with different salinity levels, and salt-tolerant plants, such as the date palm, are recommended to be planted and irrigated with the fish pond water.

H. Mr. Lugman Mohamedein Mohamed, Forest National Corporation, the Sudan, discussed assessment of *Acacia seyal* management as a means of degraded dryland rehabilitation in the Sudan. Large-scale mechanized farms are expanding at the expense of *Acacia seyal* forests. Overpopulation, poverty, war, overgrazing and migration have led to deforestation, deterioration of forest cover, and environmental degradation that is the manifestation of desertification. In harmony with government efforts to implement the National Action Programme to Combat Desertification, cooperation of the local communities was requested. Particular attention in this ongoing study is paid to identification of different varieties of this valuable tree. Forest inventory is made by measuring breast height diameter and height of trees, the parameters used in estimating the volume of each trunk. The socio-economic survey examines the local participation in managing and rehabilitating the vegetative cover, and their willingness to engage in forest management for their own well-being. This study identifies which of the following four methods delivers the best results:

1. Forest protection with the very strict governmental control
2. Government and individual participation in forest management
3. Contract agreement between the government and the people
4. Collaborative forest management through partnership between the government and local communities

I. Mr. Raddaoui Boubaker, Office de l'Elevage et des Paturages (OEP), Tunisia, stated that the organizational culture of learning transparency and accountability is essential in monitoring the success or failure of a project. Recovery of a degraded rangeland has been achieved through fodder shrub planting and complementary activities of public awareness and training addressed to the local agro-pastoral communities in the Kasserine, Tunisia. Participatory monitoring tools, integrated with remote sensing data and GIS, were used at specific sites in the framework of Tunisian National Action Plan to Combat Desertification to evaluate the impact on the environment and the local community's life. Biophysical outcomes and social impacts will be measured by certain indices. Preliminary results show that plantation of fodder shrubs have a positive impact on the degraded rangeland reclamation. However, the overall success of the project depends entirely on the active involvement of the local farmers and breeders.

The following research priorities were identified:

a. Identification of other plants that may be propagated using the same method; finding the best time(s) of the year when the success of the treatment is more assured; application of growth hormones for initiation of root growth in difficult cases.
b. As some of the C4 grasses, such as *Panicum antidotale* Retz., are potential N-fixers and they tolerate heat and drought, their identification and improvement is suggested. Alfalfa, with its very long roots (10 m), is a valuable fodder that maybe planted with spate irrigation in very deep soils. Fodder trees, such as *Acacia salicina* Lindl., offer a potential stock for drylands facing recurrent droughts; this tree also provides pollen and nectar for honeybees in the fall and the winter.
c. Introducing soil and plant parameters in the model is necessary to predict the yield more accurately. As most of the soils in northeastern Brazil cover rock, and therefore water remains in the rooting zone, the improved model may be used to estimate the area of spate-irrigated farm fields based on the amount of flood-producing rainfall, thus "riding the variability curve".
d. Participation of the locals in genetic resource conservation and biodiversity protection; rangeland productivity determination, and effect of management in yield enhancement; domestic and export marketing information; collection of traditional knowledge in weed control, rangeland yield assessment, and range plant evaluation; finding the not-so-obvious causes of land degradation and possible ways for their prevention and remediation; water harvesting for spate irrigation and the artificial recharge of groundwater.
e. Identification and/or breeding of drought- and salt-resistant small-grained cereals; developing wheat and barley with exceptionally long roots; spate irrigation of cereals in rotation with annual and perennial fodder legumes; soil-building through spate irrigation along with the artificial recharge of groundwater.
f. Reinstitution of nomadism for the herders, along with the provision of water and fuelwood on their treks through water conservation methods, particularly spate irrigation and the artificial recharge of groundwater.

g. Species and variety trials with fish and shrimp, with water of different salinity levels, are recommended. Salt-tolerant plants, such as the date palm, may be irrigated with the fish pond water.
h. Variety and provenance trials, pruning and thinning studies, fertility experiments, and advanced forest management research projects may contribute to an increase in yield and enhancement of gum arabic.
i. Spate irrigation of fodder shrubs, along with the species trial of fodder trees in the water spreaders, will bring more forage and better protection of the fragile soil.

Assessment of the Human Development Index (HDI) at certain intervals (e.g., 5 years) is a more accurate method of measuring the impact of reclamation activities.

Since the main aim of all of the desertification control activities is the provision of better living conditions for desert-dwellers, indeed for all human beings, inclusion of HDI assessment in the project is strongly recommended.

Session IV
Sustainable Land Use and Agriculture

Chapter 1
Vegetative Propagation at Low Cost: A Method to Restore Degraded Lands

Ronald Bellefontaine[1] **and Michel Malagnoux**[2]

Abstract Many multipurpose woody plants in arid and semi-arid zones are endangered species. The natural or induced vegetative propagation (NIVP) of these species can be very beneficial in reversing this trend so as to increase the living standards of impoverished populations, control erosion and combat desertification. Different species can propagate thanks to rhizomes, runners, suckers or rooting of living branches that are in contact with the soil – terrestrial layering. This NIVP alternative to plantation is currently being investigated in different countries from the Mediterranean region to tropical Africa. Some of the trial results carried out in Tunisia, Togo, Niger and Burkina Faso are discussed. Generally speaking, this method, which does not disturb the soil, is well adapted to the restoration and protection of degraded lands against erosion and desertification.

Traditional knowledge in NIVP should also be considered. For instance, in Mauritania, hedgerows are gradually created by planting *Balanites aegyptiaca* while maintaining a large distance between the rows. By watering the length of the row, it induces the roots to grow mainly along these lines and produce root suckers that form the hedgerow.

In order to regenerate a degraded woodlot, and prior to the complete removal of the remaining vegetation, suckering is induced by slightly wounding the roots. This is carried out at a specific time and has been shown to be less expensive than replanting. This process may take longer, but it is the most cost-effective, time-effective (availability of workers just before the rainy season), and erosion control-effective (less soil disturbance) method. These forms of asexual regeneration have not been sufficiently considered to date.

Keywords Vegetative propagation, ligneous species, terrestrial layering, genetic variability

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1 Introduction

Sexual reproduction is fundamental as it ensures genetic variability. Today, assorted data on the conservation, dormancy, pre-treatments and seed germination of Mediterranean ligneous species are available. However, trees also exhibit vegetative reproduction.

Rational exploitation of forests results in the establishment of an inventory of available resources and its dynamic prior to and following thinnings. An analysis of the results of these two successive inventories conclusively proves that we should clearly question among those that undergo regeneration the proportion emanating from vegetative multiplication,[1] vegetative propagation[2] and natural sowing. In fact, it is often difficult in the forest to distinguish between a plant that has been sown or vegetatively propagated, which influences the inventories where all forms of regeneration are erroneously grouped together under the term "natural seeding" or "regrowth" – despite the fact that we note that for certain species and in certain sites, the trees' origin may exhibit more vegetative than sexual reproduction.

Thus, in the Mediterranean region, it is easy to recognize that forests of holly or evergreen oak (*Quercus ilex*) are often derived from NIVP (Table 1). As regards cork oak (*Q. suber*) in northwestern Tunisia, Hasnaoui (1991) counted from 127 to 228 root suckers in $30 \times 100\,m^2$ plots. These root suckers possess various dimensions (height and diameter) and ages, and their emergence, following a clean cut of adult individuals, is spaced out over a period of five years or more. Along the length of water courses, regular flooding results in certain forest species opting for asexual behaviour as a complement to sexual reproduction; this can occur only because of flooding or the hydromorphic environment (Deiller et al., 2003). As regards *Populus tremuloides*, Bella (1986) demonstrated that sexual reproduction is very low but that the density of root suckers one year following exploitation can range from 55,000 to 200,000 stems per ha in Canada.

2 Examples of Vegetative Multiplication and Propagation

2.1 Stem Sprouts and Reiterates

Let's recall that a stump sprout develops on an anatomic structure of the *stem* (that is, the stump). A sprout – whether in the crown, on the trunk (adventitious shoots on the trunk), a stump, a low branch (air layer) or a root (root sucker) – is a young

[1] The term "vegetative multiplication" used in this paper corresponds to: stump sprouts, subterranean lignous tubercules (or lignotubers), terrestrial layers, root suckers and cuttings from root segments. In fact, the first two do not always stem from vegetative multiplication in the strictest sense (Section 3).

[2] The term "natural or induced vegetative propagation" (NIVP) will be used here to refer to the root suckers, terrestrial layers and cuttings from root segments (CRS).

Table 1 Behaviour of 15 Mediterranean species (native and introduced) as an example

Genus and species	Family	Species known root suckering (with any other information)	Species known for abundant root suckering	Other forms of vegetative multiplication (except tissue cloning, stem or leaf cuttings, grafting, *in vitro* cultivation)
Acacia saligna (Labill.) H. Wendl. (e.g. *A. cyanophylla*)	*Mimosaceae*	Watkins (1960); Min. Agr. Réf. Agr. (1978); Nat. Ac. Sc. (1980); Baumer (1983)	Boudy (1950); Metro et Sauvage (1955); Marcar et al. (1995); Dommergues et al. (1999): dune fixation	
Arbutus unedo L.	*Ericaceae*			Mesléard et Lepart (1989): **LT**; Lopez-Soria and Castell (1992): **LT** or heap of subterranean buds; Del Tredici (2001): **LT** or S**RC**; Blanc (2003): form of ligneous **BP**
Argania spinosa Skeels	*Sapotaceae*	M'Hirit et al. (1998)	Maillet (1987)	
Atriplex canescens James	*Chenopodiaceae*	Baumer (1983)		
Balanites aegyptiaca (L.) Del. (e.g. *B. ziziphoides* Mildbr. et Schlechter)	*Balanitaceae*	Nat. Ac. Pr. (1983); Szolnoki (1985); Parkan et al. (1988); Booth et Wickens (1988); Icraf (1992); Catinot (1994); Alexandre (2002); Chevallier (2003); Project CSFD (2004)	Baumer (1983); Booth and Wickens (1988); Hall and Walker (1991); Hines and Eckman (1993): **RS** at considerable distances from the trunk	Poupon (1980): **RS** Hines and Eckman (1993): **RC**; Alexandre (2002): **RC** are envisageables
Erica arborea L.	*Ericaceae*			Mesléard et Lepart (1989): from **LT**; Lopez-Soria et Castell (1992): **LT** or heap of subterranean buds.
Ficus carica L.	*Moraceae*			Caraglio (1986): basal and periphery reiteration at the point de contact of the stalks with the soil; Lieutaghi (2004): **TL**

(continued)

Table 1 (continued)

Genus and species	Family	Species known root suckering (with any other information)	Species known for abundant root suckering	Other forms of vegetative multiplication (except tissue cloning, stem or leaf cuttings, grafting, *in vitro* cultivation)
Ilex canariensis Poir.	*Aquifoliaceae*		Fernandez-Palacios and Arévalo (1998).	
Laurus nobilis L.	*Lauraceae*	Jacamon (1992)	Lieutaghi (2004).	Lieutaghi (2004): **TL**
Nerium oleander L.	*Apocynaceae*		Lieutaghi (2004).	Blanc (2003): basal sprouts; Lieutaghi (2004): **TL**
Pistacia lentiscus L	*Sapindaceae*	Lieutaghi (2004)		Lopez-Soria and Castell (1992): **LT** or heaps of subterrannean buds.
Populus euphratica Oliv.	*Salicaceae*	Iqbal Sheikh and Hafeez (1977); Nat. Ac. Pr. (1983); Chaturvedi (1997)	Troup (1921): **RS** following a fire; Metro et Sauvage (1955); Sharma et al. (1999).	
Quercus ilex L.	*Fagaceae*	Lavauden (1942); Guinier et al. (1947); Cochet (1959); Louni (1994): **RS** up to an advanced age.	Pardé and Pardé (1938); Boudy (1950): **RS** quickly self-sufficient following exploitation or fire; Jacamon (1984); Lieutaghi (2004).	Lopez-Soria and Castell (1992): sprout from the root crown or from the base of the trunk; Blanc (2003): on steep slopes, originating from a **BP**, multiple trunks embracing the support.
Quercus suber Kotschy	*Fagaceae*	Pardé and Pardé (1938); Boudy (1950): **RS** extremely exceptional, following a fire; Jacamon (1984).	Hasnaoui (1991) **RS**; Peyre (1999): RS with vigour following a fire.	Del Tredici (2001): SRC or LT.
Tamarix aphylla (L.) Karst (e.g. *T. articulata* Vahl.; *T. orientalis* Forssk.)	*Tamaricaceae*			Booth and Wickens (1988): from branches swept by water.

Note: RC = root cuttings; RS = root suckering; TL/AL = terrestrial layers/aerial layers; BP = basal plateau; SRC = sprouts from root collar; LT = lignotuber. The bibliographic references cited above can be accessed: http://www.secheresse.info/article.php3?id_article = 2344. The 15 examples above were chosen among other examples taken from 'Pour de nombreux ligneux, la reproduction sexuée n'est pas la seule voie: analyse de 875 cas', *Sécheresse*, No. 3E, Dec. 2005 (In French).

tree growing on an "old" tree. At the beginning of its life, a tree always possesses one architectural unit; over time other architectural units spring from the first "by growing from each other". The tree continues to accumulate additional units by reiteration. The majority of plants form colonies in this way and certain ligneous colonies are sometimes quite vast and older than 10,000 years. These clones display clonal colony[3] behaviour. Plants (annuals and perennials) live for the most part in colonies; probably no more than 20% of plants live as a sole architectural unit among the total number of plant species (Hallé, 1999).

2.2 Terrestrial and Aerial Layers

A terrestrial layer originates from *stems or branches* in contact with the soil, on which roots neo-form. In drylands, the natural terrestrial layers are often still attached to the mother-tree. The artificial aerial layers are not discussed here, despite the fact that this form of vegetative multiplication is inexpensive (Harivel et al., 2006).

2.3 Suckers, Stolons and Rhizomes

A sucker is a stem that first appears on the *root*, which is often a shallow root, whether the root is in or above the soil (still connected to the stump or not). One should not confuse suckers with sprouts that develop on rhizomes. The *rhizome* (as with the *stolon*) is a cauline structure (*stem*) with nodes and inter-nodes. The suckers, as opposed to *cuttings (from a branch)*, benefit from the effect of the stump through their root system, which constitutes, vis-à-vis the neo-formed cauline stem, an incredible reservoir of trophic substances; the influence of endogenous phytoregulators should not be underestimated. This *source* of non-negligible reserves allows for the seasonal regeneration of new individuals. The root suckering ability varies considerably and depends on the environmental conditions (sites, seasons, etc.), the ontogenesis, and the genetic identity of individuals – with marked differences between species and *clones* at the intraspecific level (Bellefontaine and Monteuuis, 2002). In general, root suckers develop from shallow roots situated at a depth of a few centimetres (0.1 to 5–10 cm). However, in Gabès (Tunisia), Chaieb (1992) noted that *Prosopis stephaniana* regenerates almost exclusively by root suckering. Moreover, its root profile presents a particularity in that the suckers appear at an unexpected depth (0.6 and 1 m). In the moving sands of Mauritania, root suckers of *Balanites aegyptiaca* appear (sometimes in bundles) at the same depths that become visible when they are loosened by the wind (M. Malagnoux, 2006, personal communication).

[3] Colony-seeking: that lives in colonies and reproduces by vegetative multiplication in those areas fixed by the founding colony.

2.4 Ligno-Tubers

Even though ligno-tubers are well known among *Eucalyptus spp*., they also occur among other species (Table 1). Hence, among examples of regeneration observed during two years in Burkina Faso on 50 × 20 m plots that were repeated five times, the following was observed: young plants mostly came from root suckers in the case of *Boswellia dalzielli* (98%) and *Bombax costatum* (94%), but only 14% for *Afzelia africana*. This species *reproduces* by subterranean ligno-tubers in 86% of cases, while *Pterocarpus erinaceus* almost only adopts the latter behaviour (99.8%). In the case of these four species, sexual reproduction after two years is excessively low (Ouedraogo et al., 2006).

2.5 Cuttings of Root Segments (CRS)

Cuttings of root segments (CRS) are used to multiply certain decorative and fruit shrubs, such as *Rubus spp*. (raspberries). For are species that do not graft easily, the duplication by CRS of a selected phenotype are fairly common in Europe. However, CRS fundamentally differentiate themselves from *root suckers* by the fact that the separation of the vegetative fragment occurs, contrary to the root sucker, before the neo-formation of the buds that develop on the stem. This is understandably confusing because the root bud can appear naturally, for example, when clayey or marly soils become desiccated and start to crack, which brings about the rupture of roots and their individualization (Bellefontaine and Monteuuis, 2002).

International literature on root suckering reveals the many tests that are carried out with CRS. Johansson and Lundh (1988) worked on CRS of an average diameter of 10 mm of *P. tremula* aged from 10 and 15 years under greenhouse conditions placed in the soil at various depths. The best results regarding the number of root suckers after 83 days were obtained from repositioned segments at a depth of 4 and 6 cm and at a temperature of 25°C. The number of root suckers obtained increased with light intensity. In France, tests with wild cherry (*Prunus avium*) enabled the comparison with CRS of various diameters placed horizontally (without access to light) or vertically with the extremity emerging from the compost. It was the latter, a diameter greater than 15 mm, that gave the best results. For the wild cherry, it seems that the proximal pole[4] of the CRS needs light for the cauline part of the root sucker to emerge. It is fundamental that the distal pole[5] is placed in a low position (in the compost) and the proximal pole at a higher position in order to respect the polarity (LeBouler et al., 2001). However, in Tunisia, the stems that we can see on the root suckers of *Quercus suber* in general develop on the distal side, while the

[4] Proximal: structure or organ close to the point of fixation of the mother-plant (*Oxford Dictionary of Plant Sciences*, 2004).

[5] Distal: pole situated at a distance from the point of fixation, towards the extremity during growth.

new roots appear on the proximal side. Tunisian researchers were able to bring the two vascular systems together (root and cauline systems) by reducing the size of the explant (N. Souayah, 2005, personal communication). It appears that polarity should also be respected in CRS but requires further complementary studies.

3 Behaviour of Ligneous Species with Respect to the Deterioration of Environmental Conditions

The resilience of many ligneous species when environmental conditions deteriorate can be explained by their capacity (at least in certain periods of their life) to produce various reiterates. This capacity to fragment vegetatively is assimilated by a certain number of searchers as a form of adaptation to an environment subjected to repetitive bush fires, recurrent droughts, overgrazing, etc. This competition for the use of space forces ligneous species to develop several types of behaviour. We have attempted to provide a number of definitions for these phenomena that reveal behavioural types of regeneration, survival and augmentation of the photosynthetic surface of the canopy (Bellefontaine, 2005b). Vegetative multiplication implies that a plant can be multiplied and reproduced in several other examples *without calling on classic mechanisms of sexual reproduction and, in addition, these clones can become autonomous* in relation to the mother-plant. Plants are normally capable of fragmenting. If there is no fragmentation, then there is no vegetative multiplication. A number of species produce stump sprouts that develop their own autonomous root system around the mother-plant. In the case of other species, the sprouts use only the root system of the stump; hence, in the latter case there is no sexual reproduction or autonomy. Can we therefore assimilate these sprouts to vegetative multiplication? The same applies in the case of the root suckers; it is rare for those found in the drylands rapidly to become self-sustaining and develop their own root system. Other species do not acquire this independence and remain attached to the mother-plant at least during the period of our observations, which were admittedly fragmentary (Bellefontaine, 2005b). The emerging root sucker lives as a saprophyte on the mother-plant for a certain period of time before freeing itself as it feeds from other parts of the plant.

Detachment from the mother-plant at an early stage, and often under hot and humid conditions, occurs naturally by autonecrosis of the carrying root (upstream from the point of insertion of the root sucker – Jacq et al., 2005), by the action of termites (Bationo et al., 2005), etc.

For temperate species, there is little information concerning the detachment of root suckers, and even less for terrestrial layers. Thus with Chinese sumac (*Ailanthus glandulosa*) in France, the actual root system of the floriferous root suckers practically does not develop (which prevents the root sucker from detaching). On the case of sterile root suckers (non-floriferous), however, a root system specific to the root sucker develops in parallel – we note an auto-amputation. This is produced upstream from the root sucker on the mother-root which allows this type of more vigorous root sucker to detach (Clair-Maczulajtys, 1985).

Plants therefore adopt various behaviours and often in reaction to stress: the further we move away from the shores of the humid tropical forest towards Sahelian zones; the more we move from Mediterranean regions towards temperate and boreal zones; the more we reach altitudinal and latitudinal limits of the geographic zones of species; the more we go from the interior of the country towards the coast blown by the winds; the more we leave the land to descend towards the main river bed – the more we make any of these moves, the more we notice that ligneous species adopt other behavioural types in reaction to an environment that is increasingly hostile. The boreal resinous often have terrestrial layers and fewer root suckers, while the hardwood of hot semi-arid zones tend to produce root suckers.

Some species or genotypes are able to produce root suckers, while others cannot. Certain species are resistant to artificial layering but not to root suckering. Others undergo root suckering without stump sprouting and vice versa.

The NIVP occurs only at a certain ontogenic stage. Before this stage – in the natural state – there are never any root suckers. During the life of a plant, root suckering occurs only at certain stages. Certain cells will lose their totipotency early on (e.g., the pith) and will no longer be able to differentiate. On the other hand, the parenchyma cells, because of their position, will keep their totipotency throughout the existence of an organ. They will appear when they are subjected to a random event with respect to trophic and hormonal levels, and correlations of inhibition.

Habitat fragmentation of tree populations can lead to very important consequences from the point of view of species conservation, notably for clonal species that possess mechanisms of auto-incompatibility. This absence of genetic variability in certain isolated populations can result in a loss of the sexual reproduction mechanism. A study was carried out in which 568 leaf samples of *Santalum insulare* from ten Polynesian islands were analyzed to measure the degree of clonality of these over-exploited residual populations: 58% of trees analyzed are ramets[6] (Lhuillier, 2006). Residual Australian populations from five sites of *S. lanceolatum* are formed from one clone and recruitment only occurs by NIVP (Warburton et al., 2000).

4 Recent Results Obtained in Various African Countries

In Africa and especially in the Mediterranean zone, scientific experience in this field is very limited. In Tunisia, root suckering is studied in the laboratory with the help of CRS. Nsibi (2005) analyzed the development of cork oak root suckers over three years in two plots at Melloula and Ain Serja: in the first site, the number of root suckers increased by 5% in the second year and remained stable thereafter (from 212 to 224 root suckers/ha), while in Ain Serja it regressed by 15% in three years (from 102 to 85 root suckers/ha). The success of CRS varies with the nature of

[6]Ramet: An individual of a clone (as a consequence, it comes from an ortet or original plant).

the substrate (perlite is recommended), the period of the year (it multiplies in June rather than in December), and most of all, with the age of the mother-plant. In fact, by removing the roots from trees aged: 1, 10, 20, 50 and 100 years, in June (on perlite), root development occurs by 97%, 68%, 58%, 37% and 13% with CRS, respectively. In an earlier test, the best rates reached 87%, with ten root suckers with CRS of 30 cm in length and 0.5–2 cm in diameter for the CRS removed in June on one year-old cork oaks. The hormonal treatment had benefited the number of sprouts, notably among the older individuals (Nsibi et al., 2003).

A high proportion of root suckers of *Balanites aegyptiaca* were revealed at Toufedet and In Tounine in the Algerian Sahara. The predominance of NIVP appears to be linked to species adaptation to desertification of the environment. In the Sahara, climatic conditions do not enable seed germination to occur in certain years of drought and favours root suckering. Moreover, animal husbandry does not seem to lead to significant damage; the root suckers are not destroyed by animal grazing or trampling, as occurs in the Sahel (CSFD, 2004).

In Togo the rate of root suckering observed in 74 plots for *Isoberlinia doka* and *I. tomentosa* are high in the fields and fallows (56% and 83%, respectively), while in the forest these rates are relatively lower (35% and 39%). Regeneration by sowing represents 32%, the sprout stumps 10.6%, and root suckers 57.4% (Dourma et al., 2006).

In Uganda root suckering is used to improve the hectare density of ligneous medicinal trees threatened with extinction. After sectioning the shallow roots of *Spathodea campanulata*, we obtain 100% of root suckers on the distal extremity (on the part of the root separated from the mother-tree) with root neo-formations.

Other species (*Melia azedarach*) do not produce distal root suckers but only proximal suckers on the part of the root still connected to the mother-plant. As regards *Harungana madagascariensis*, it colonizes the dense forest by terrestrial layers emanating from root suckers: in the first instance, the filiform stems of the root suckers move towards the light of the canopy. When they fall to the ground, they behave like terrestrial layers. On the latter, newly established and instable axes appear (Meunier et al., 2006).

In Burkina Faso and in Niger, *Guiera senegalensis* and *Combretum micranthum* have been studied (Bationo et al., 2005). Following germination, the survival of the natural seeding is often compromised by climatic uncertainty. But the branches of older trees in continuous contact with the soil frequently take root during the short rainy season. The plagiotropic branches accentuate this phenomenon, notably on steep slopes. The role of root suckering has yet to be determined for these two species and is currently being studied in Senegal.

5 Traditional Knowledge and Know-How

Until now, in terms of NIVP, traditional knowledge and know-how of the population have hardly been investigated. In Burkina Faso, Niger, northern Cameroon and Uganda, investigations have enabled certain techniques to be updated, though they still require verification. Within populations, species that have a potential for root suckering and terrestrial layering seem to be quite well-known by certain people.

In Mauritania a practical example of traditional know-how consists of the establishment of live fences made with *Balanites aegyptiaca*. Trees are planted a good distance apart along the line of the hedge. This can also be established from pre-existing trees. This is followed by a repeated and directional watering starting from the base of the tree in the direction of the future hedge so as to initiate its appearance and direct the roots towards the required direction. The root suckers will then naturally appear according to these lines (Meimine Ould Salek, 2006, personal communication).

6 Vegetative Propagation of a Number of Mediterranean Species

Table 1 indicates certain behavioural types of Mediterranean species (root suckers, terrestrial layers, lignotubers, etc.), of which only 15 species are shown. The complete table can be accessed on-line, at http://www.secheresse.info/article.php3?id_article = 2344 (in French).

7 Future Research to Undertake

At this stage it is more reasonable to observe what is first occurring on the structural plan – for example, how does colonisation by root suckers occur? – before studying issues of totipotency and cell dedifferentiation; it is more reasonable to carry out more in-depth studies (cytology, genetics) on root tissue and the first primordia in order to determine when and how the plant passes from a root structure to a stem structure. In our view, priority resides in NIVP observation and the possibility of benefiting with the least cost. The main research gaps in this field were cited in a recent article (Bellefontaine, 2005a). Three studies have been prioritized: the detachment of root suckers/terrestrial layers, the polarity of cuttings of root segments, and the study of ontogenesis and induction.

7.1 Detachment Leading to Autonomy

There is only very limited data on the upstream auto-necrosis from the point of insertion of a terrestrial layer on a branch or a root sucker on a root of the mother-tree or ortet (Section 3). This amputation results in fragmentation of the clone into several autonomous elements (or ramets). At an early or a later stage, though no one actually knows to this day, these reiterates can produce their own root system, which is more-or-less independent. The possibility of progressive and early auto-severance has a determinant importance in terms of forest management comprising clonal species that can favour the process of incompatibility.

7.2 Polarity

As for CRS, it seems that polarity must be respected, since results seem to be contradictory or specific only to certain species (Section 2).

7.3 Ontogenesis and Induction

Trees are not able to reproduce asexually during every moment throughout its life cycle (this is also the case for sexual reproduction). Depending on their age and the season, certain organs (shallow roots, stump, taproot) are richer or poorer in reserves than others. We need to interact with the plant so as to release the trophic reserves at the *right time* if we want to obtain root suckers. It requires careful study of the optimal conditions for induction or for the appearance of root suckers and terrestrial layers. This capability varies according to the physiological age of the organism and its ontogenetic stage: At which stage of their development is induction best adapted? Which type of induction proves to be the most effective and the least costly?

8 How Can NIVP Be Used to Restore Fallow and Degraded Lands?

8.1 Induced Terrestrial Layering

Various interventions, such as partially snapping off branches and placing them in contact with the soil and the covering of plagiotropic branches, can stimulate terrestrial layering on the condition that it respects the ontogenesis and the season. Judging by early empirical observations, it would be interesting to experiment with the induction of terrestrial layering by digging up the earth (with the help of a simple hoe) – a very economical mode of regeneration in terms of investment of work time. These are simple techniques compared to others, such as artificial sowing and plantations. This is the most easily reproducible method for local populations.

8.2 Induction of Root Suckering

The induction of root suckering is employed by populations in Burkina Faso on *Faidherbia albida* (Harivel et al., 2006) and in Mauritania on *Balanites aegyptiaca* (Section 5). Tests in Uganda (Meunier et al., 2006) show the potential of this method (Section 4). Shallow roots of root sucker species should be cut or injured. Nonetheless, it is important to respect the calendar for each species (in terms of ontogenesis and season).

8.3 Cuttings of Root Segments

This method, which has not been widely developed, is reproducible by rural populations especially to increase the number of trees with different multiple-uses (pharmacopoeia, fruits, complementary incomes, etc.), to create forage orchards for use in the case of scarcity, to combat erosion, and to enrich a fallow. CRS can be very useful to ensure reproducibility of the same ligneous forage species containing a high concentration of nitrogen. Thanks to bacteria, two groups of trees – the leguminous and the actinorhizian plants – can fix free atmospheric nitrogen in the soil and foliage. In the case of other ligneous species, associations of fungi (endo- or ecto-mycorhizes) are indispensable. Seed sowing without these mycorhizes ends in failure. The use of CRS is likely to prevent this pitfall. This is an added advantage of the NIVP not previously cited (Bellefontaine et al., 2000).

9 Conclusions

For certain species the study of forest dynamics is distorted if foresters continue to overlook sexual reproduction. It is vital to "master" all forms of regeneration, particularly those that are least expensive and those that have a better chance of success in the long term. In the presence of species that regenerate vegetatively, it is important for the manager to be able to distinguish between the number of juveniles emanating from NIVP and those coming from sowing, as well as the maximal distance from the mother-tree at which the ramets can propagate, in order to manage genetic variability through exploitation by cutting.

Genetic derivation in a forest is all the more important if the population of the species is small. In a situation with increased clearings and only a small number of trees with the same genetic heritage, genetic derivation can induce random changes in the frequency of the alleles. The isolation of a population therefore behaves as an accelerator of evolution. Natural selection that acts by increasing the frequency of alleles transmitted by individuals renders them more apt for survival, and undoubtedly NIVP in a given environment, as in the case of drought or repeated fires.

To conclude, for certain species, and depending on the sites and their ontogenic stage, NIVP is far more important than first believed. The studies recommended in this report will undoubtedly be useful to reinvent a new sylviculture in the face of looming climate change.

Fig. 1 Numerous reiterations on a stem of *Combretum micranthum* lying at 400 mm of annual rains in Tientiergou, Niger (Photo: S. Karim)

Fig. 2 A group of terrestrial layers of *Combretum micranthum* uprooted after excavation of the root system in Tientiergou, Niger (Photo: S. Karim)

Fig. 3 Two aerial layers rooted (3 weeks old) on a stem and a branch of *Solanecio mannii* in Uganda (Photo: Q. Meunier)

Fig. 4 *Balanites aegyptiaca* with root suckers close to the mother-tree in Burkina Faso (Photo: A. Harivel)

Fig. 5 After 4 months in the nursery, we note the neo-formed roots on two root segment cuttings of *Quercus suber* in Tunisia (Photo: R. Nsibi)

Fig. 6 To the right of the cut, we can distinguish distal root suckers of *Spathodea campanulata* (Photo: Q. Meunier)

References

Bationo, B. A., Karim, S., Bellefontaine, R., Saadou, M., Guinko, S. and Ichaou, A. 2005. Le marcottage par couchage et buttage de la partie apicale des branches, technique économique de régénération de certains ligneux tropicaux. *Sécheresse,* Vol. 1E, No. 3, décembre. http://www.secheresse.info/article.php3?id_article = 2342

Bella, I. E. 1986. Logging practices and subsequent development of Aspen Stands in East-Central Saskatchewan. *The Forestry Chronicle*, Vol. 62, No. 2, pp. 81–83.

Bellefontaine, R. 2005a. Régénération naturelle à faible coût dans le cadre de l'aménagement forestier en zones tropicales sèches en Afrique. *Institut des Sciences de l'Environnement, Université du Québec, Montréal. Revue électronique VertigO*, Vol. 6, No. 2, pp. 1–15. http://www.vertigo.uqam.ca/vol6no2/framerevue.html

———. 2005b. Pour de nombreux ligneux, la reproduction sexuée n'est pas la seule voie: analyse de 875 cas – Texte introductif, tableau et bibliographie. *Sécheresse*, Vol. 1, No. 3, December. http://www.secheresse.info/article.php3?id_article = 2344

Bellefontaine, R., Edelin, C., Ichaou, A., du Laurens, D., Monsarrat, A. and Loquai, C. 2000. Le drageonnage, alternative aux semis et aux plantations de ligneux dans les zones semi-arides: Protocole de recherches. *Revue Sécheresse*, Vol. 11, No. 4, pp. 221–226.

Bellefontaine, R. and Monteuuis, O. 2002. Le drageonnage des arbres hors forêt: un moyen pour revégétaliser partiellement les zones arides et semi-arides sahéliennes? pp. 135–148. In: *Multiplication végétative des ligneux forestiers, fruitiers et ornementaux: 3ème rencontre du groupe de la Sainte Catherine*, Orléans, 22–24/11/2000, M. Verger, H. LeBouler (eds.), CD-Rom CIRAD-INRA, CIRAD, Montpellier.

Chaieb, M. 1992. Biologie et comportement écologique du *Prosopis stephaniana* (M.B.) Kunth, à la limite Ouest de son aire de répartition (cas du site de Gabès). *Forêt méditerranéenne*, Vol. 13, No. 2, pp. 85–89.

Clair-Maczulajtys, D. 1985. *Quelques aspects de la biologie de l'Ailanthus altissima (Mill.) Swingle*. Etude de la double stratégie de reproduction par graines et par drageonnement en relation avec les métabolites de réserve. Thèse, Université Paris VII.

CSFD, 2004. *Impact des pratiques humaines sur la conservation et la gestion in situ des ressources génétiques forestières: Cas d'Acacia tortilis raddiana et de Balanites aegyptiaca*. Comité Scientifique Français de lutte contre la Désertification (CFSD – Agropolis) et CIRAD-forêt, Montpellier, France.

Deiller, A. F., Walter, J. M. N. and Trémolières, M. 2003. Regeneration strategies in a temperate hardwood floodplain forest of the Upper Rhine: Sexual versus vegetative reproduction of woody species. *Forest Ecology and Management*, Vol. 180, pp. 215–222.

Dourma, M., Guelly, K. A., Kokou, K., Batawila, K., Walla, K., Bellefontaine, R. and Akpagana, M. 2006. Importance de la multiplication végétative par drageonnage d'*Isoberlinia spp*. dans les formations soudaniennes du Togo. *Bois et Forêts des Tropiques*, Vol. 289, pp. 49–57.

Hallé, F. 1999. *Eloge de la plante. Pour une nouvelle biologie*. Editions Seuil, Paris.

Harivel, A., Bellefontaine, R. and Boly, O. 2006. Essais de multiplication végétative à faible coût de huit espèces forestières (Burkina Faso). *Bois Forêts des Tropiques*, Vol. 288, pp. 39–50.

Hasnaoui, B. 1991. Régénération naturelle par rejets de souche et par drageonnement d'une suberaie dans le Nord-Ouest de la Tunisie. *Ecologia Mediterranea*, Vol. 17, pp. 79–87.

Jacq, F., Hladik, A. and Bellefontaine, R. 2005. Dynamique d'un arbre introduit à Mayotte, *Litsea glutinosa* (Lauraceae): une espèce envahissante ? *Revue d'Ecologie*, Vol. 60, pp. 21–32.

Johansson, T. and Lundh, J-E. 1988. Sucker production from root cuttings of *Populus tremula* in relation to growing conditions. *Scandinavian Journal of Forest Research*, Vol. 3, pp. 75–82.

LeBouler, H., Rondouin, M., Le Bouler, M. and Verger, M. 2001. Accélérer la diffusion de matériel forestier de reboisement issu du programme d'amélioration du merisier. *Multiplication végétative des ligneux forestiers, fruitiers et ornementaux: 3ème rencontre du groupe de la Sainte Catherine*, Orléans, 22–24/11/2000. M. Verger and H. LeBouler (eds.), CD-Rom CIRAD-INRA, CIRAD, Montpellier.

Lhuillier, E. 2006. *Diversité génétique de Santalum insulare, espèce forestière de Polynésie Française. Implications pour sa conservation*. Mémoire de stage, Master Pro II, Univ. Pierre et Marie Curie, Paris.

Meunier, Q., Bellefontaine, R. and Boffa, J. M. 2006. Développement durable et gestion viable par la maîtrise de la régénération des écosystèmes ligneux en Afrique. Cas du *Spathodea campanulata* en Ouganda. *Institut des Sciences de l'Environnement, Université du Québec, Montréal. Revue électronique VertigO*, Vol. 7, No. 2. http://www.vertigo.uqam.ca/

Nsibi, R. 2005. *Sénescence et rajeunissement des subéraies de Tabarka – Ain Draham avec approches écologiques et biotechnologiques*. Thèse, Univ. Tunis II, Fac. Sc. Tunis.

Nsibi, R., Souayah, N., Khouja, M. L., Khaldi, A., Rejeb, M. N. and Bouzid, S. 2003. Le drageonnement expérimental du chêne liège (*Quercus suber* L., *Fagaceae*). Effets de l'âge et des conditions de culture. *International Journal of Tropical Ecology and Geography* (*Geo-Eco-Trop*.), Vol. 27, No. 1–2, pp. 29–32.

Ouedraogo, A., Thiombiano, A., Hahn-Hadjali, K. and Guinko, S. 2006. Diagnostic de régression de 4 espèces ligneuses en zone soudanienne du Burkina Faso. *Sécheresse*, Vol. 17, No. 2.

Warburton, C. L., James, E. A., Fripp, Y. J., Trueman, S. J. and Wallace, H. M. 2000. Clonality and sexual reproductive failure in remnant populations of *Santalum lanceolatum* (Santalaceae). *Biological Conservation*, Vol. 96, pp. 45–54.

Chapter 2
Linking Sustainable Indices and Climate Variability in the State of Ceará, Northeast Brazil

Humberto A. Barbosa

Abstract The underlying source of climate variability affecting the Ceará rain-fed agricultural production in Northeast Brazil is the interrelated global-scale fluctuations of sea-surface temperature (SST) in the tropical Pacific and Atlantic regions. Despite the elevated skill in seasonal climate forecasts for rainfall in Ceará, models linking SST anomalies (SSTAs) in the tropical Pacific (Niño 3.4 index) and Atlantic (Dipole index) regions to crop production are not well developed. The results of this study show that clear connections among episodes of drought patterns and maize and bean production and yields over the rainy season result from seasonally changing SSTAs. Total seasonal maize and bean production are inversely correlated with Niño 3.4 and Atlantic Dipole indices, while maize and bean yields are directly correlated with Niño 3.4 and Atlantic Dipole indices but inversely correlated with maize and bean yields averaged from February to April. Year-to-year averaged February–April SSTA fluctuations explain about half the interannual variability in maize and bean production over the rainy season. There were two fluctuation shifts (from 1974 to 1981 and from 1984 to 1997, with a transition during 1982–1983) of the maize and crop production and yields that were largely in-phase with seasonal SSTAs. However, the magnitude and duration of extreme El Niño-Southern Oscillation (ENSO) and Atlantic Dipole effects on Ceará crop production and yields indicated by the vulnerability index offers some strong policy warnings.

Keywords Climate variability, fluctuations, El Niño, vulnerability index, Ceará state, grain production

1 Introduction

The rain-fed agricultural production in Northeast Brazil has experienced persistent drought episodes during the last three decades of the 20th century. However, it is necessary to assess the vulnerability of its agricultural production to precipitation

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variability due to interrelated global-scale fluctuations of sea-surface temperature (SST) in the tropical Pacific and Atlantic Oceans. Most of the evidence presented by recent studies on the influence of a strong El Niño-Southern Oscillation (ENSO) event on agricultural climate of Northeast Brazil is qualitatively similar to those on southern Africa. The large variations in rainfall, which cause either drought or (flooding), lead to either a decrease or an increase in crop production in this region, which are associated with the El Niño (drought) and La Niña (flooding) episodes. In many cases, however, there is a joint effect between the influence of a positive El Niño SST anomaly and a positive gradient (SST North Atlantic warmer than South Atlantic), which tends to decrease rainfall dramatically during the austral summer and autumn in the region (Alves and Repelli, 1992). While several drought spells were recorded over this region in recent history, drought in the 20th century has been unprecedented for its severity. Throughout the recorded history of occurrence of drought (meteorological) over this region, there were three drought occurrences in the 17th century, 11 in the 18th century, and 12 in the 19th and 20th centuries. It seems that in the past the environment was more resilient to climatic variations.

One of the greatest sources of uncertainty in current climate variability research is how future decision-makers on various scales, from individuals to organizations to societies, will respond to future climate fluctuations and the attendant impact on agriculture in the arid and semi-arid tropical regions. Yet these uncertainties have already been impacted by land degradation due to growing population pressures. Despite the high skill in seasonal climate forecasts for rainfall in Ceará (Sun et al., 2005), models linking SST anomalies (SSTAs) in the tropical Pacific (Niño 3.4 index) and Atlantic (Dipole index) regions to crop production are not well developed. However, simulations of the impact of climate change using crop models suggest that projected changes in precipitation and warmer temperatures will undoubtedly impact the agricultural sector in the northeast region (IPCC, 2001). The global agricultural model of Rosenzweig and Parry (1994) identifies this region as suffering yield impact and is among the most severe in the world. In addition, the impact of extreme changes in weather (e.g., a series of drought years) is likely to cause environmental and social stress in a number of localities in the region. For the assessment of the effects of climate change on Ceará, which is already having difficulty coping with environmental stress, climate change resulting in an increasing imbalance in water demand, water supply and agricultural production would also show tendencies after 2005 (Krol et al., 2006). To model the impact of climate variability on grain production in the region, research must be conducted, based on the knowledge of climate and agriculture data currently available, and then examined in view of connections between ENSO and crop production. Conversely, the use of climate-agriculture information and seasonal modeling forecasts in agriculture may also offer agricultural decision-makers the opportunity to mitigate unwanted impact. However, efforts to foster the use of regional climate models based on ENSO in agriculture forecasts require adequate simulation and prediction of responses to uncertain climate scenarios (Phillips et al., 2001).

In Northeast Brazil recent findings from satellite images (Barbosa, 2004, 2006; Barbosa et al., 2006) reveal a consistent upward trend in vegetation density for the period 1984–1990 and a downward trend for the period 1991–1998, but demonstrate that such short-term vegetation changes, with a period of 7–8 years, were associated with episodes of unusually wet (years of La Niña activity) and dry (years of El Ninõ activity) climate oscillations. Trends in global SST patterns explain the recent period of desiccation in the Sahel but do not present an exact explanation for rainfall in particular years. More strikingly, trends in tropical SST patterns on multi-year to decadal timescales explain the Sahelian desiccation during the last three decades of the 20th century but do not provide an exact explanation for rainfall in individual years after 1970 (Nobre and Shukla, 1996). Although the challenge remains in confronting climate variability for a range of locally specific climate impacts, the understanding of the causes of this variability is still unfolding. Understanding the impact of the occurrence of extreme weather and climate events on the rain-fed agricultural production in Northeast Brazil is crucial to establishing an effective and comprehensive monitoring and early warning system as one component of an effective drought preparedness plan. An ideal area of study is the state of Ceará in Northeast Brazil, which is already experiencing significant climate variability. This study, building on findings of previous studies of the impact of rainfall variability crop production and yields in the state of Ceará, carries the analysis of this impact one step further to evaluate connections between SST variability and the attendant impact on its crop agriculture.

2 Study Area

The state of Ceará is the geographic focus of this study (Fig. 1). It located in the northeastern region of Brazil (Nordeste) known as an anomalous area within the equatorial zone because, in contrast to other areas such as those located in the Amazon or central equatorial Africa, this state has a semi-arid tropical climate. This semi-arid zone comprises approximately two-thirds of the northeastern region (4–16°S and 33–46°W), which is subject to extreme climate variability and recurrent drought. The main rainy season in the region has an annual average of less than 600 mm, which is typically concentrated between February and April. The interannual precipitation variability is very high, usually around ±40% from the long-term annual average (IBGE, 1993). These fluctuations have motivated numerous studies that collectively documented the high spatial and temporal variability in the region's precipitation due to both large-scale oceanic forces (i.e., region-global SST anomalies and its distribution) and atmospheric circulation patterns (Hastenrath and Heller, 1977). During strong El Niño conditions, precipitation tends to decrease (causing drought) in the state. On the other hand, the strong La Ninã conditions have the opposite effect (causing flood). Because the high frequency and intensity of El Niño years have increased rapidly since the late 1990s, a repeat of such drought episodes may have severe consequences not only for the region's fragile ecosystems but also for the region's

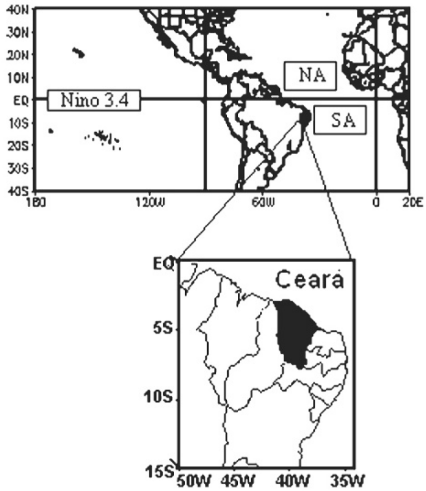

Fig. 1 Location of the state of Ceará in Northeast Brazil, Niño 3.4 and Atlantic Dipole regions (NA – SA)

seasonal grain production. The great drought of 1958, for instance, forced 10 million people to emigrate from the region (Namias, 1972). After 1958, droughts continued to have severe impact, but consequences like death casualties have been avoided by policy responses. Nonetheless, as the El Niño drought of 1998 demonstrated, the vulnerability of the rural population remains critically high. In the state of Ceará, around 95% of the state territory (147,000 km^2) is classified as semi-arid. The majority of the state's rural population, mostly rain-fed farmers, lies beneath the poverty line and is extremely vulnerable to drought (Chimelli et al., 2002).

Overall agricultural land use in the Brazilian semi-arid ecosystem is characterized by smallholder crop production and extensive livestock farming. Smallholders in the region produce about 70% of the grain supplying the market-based agriculture, including maize, beans and manioc. Approximately 90% of all agricultural areas are smaller than 100 ha, but together they cover only about 30% of the total agricultural production area (IBGE, 1993). Since the 1950s, the agricultural community in the state of Ceará has undergone profound changes, including the growth of small farms but also the development of the precarious occupation of land, causing the impoverishment of small farmers, who face increasing difficulty to access land. These changes have also aggravated the conditions for the social reproduction of this community. In contrast, in the northeast of Ceará, the agricultural community produces cash crops, such as cashew, cotton, fruits and vegetables, involving various irrigation projects along the Jaguaribe River.

3 Data and Methodology

The raw data employed as agricultural observations include the total monthly maize and bean production (t) and yields (kg/ha) from 180 municipalities throughout Ceará. Total monthly SSTAs utilized as a climate indicator were delimited by the latitudes

170–120°W and longitudes 5°S–5°N (Niño-3.4 region), and also by the gradient between tropical Atlantic North (5–25°N) and South Atlantic (5–25°S) (known as the Atlantic Dipole index). Agriculture and climate time series were compiled from digital records. The former are available on the databases of the FUNCEME and the latter were obtained from a file of the Comprehensive Atmospheric Ocean Data Set (COADS) for 1971–2000. The COADS file has data of monthly averages in grade points of 1° × 1° latitude-longitude for 1971–2000. Total monthly data are averaged from February to April.

To assess the behaviour of maize and bean production and yields in response to SSTA fluctuations in the study area, the Vulnerability Index (VI) was designated. To measure the variation at the same rate and scale, the variables in question have deviated from the maximum and minimum values from the long-term record. This index allows a direct comparison among the different variables in question for a given period. It is calculated using the following equation,

$$VI_j = [(DEV_j - DEVmin) / (DEVmax - DEVmin)]*100,$$

which DEV represents the deviation that is employed as a measure of variability relative to mean value. It is calculated as the difference between the variable in question for the current time step and the long-term mean for a given period

$$(DEV_j = \text{variable value}_j - \text{variable value}_{mean}),$$

and DEVmax and DEVmin are measured from the long-term record for a given period and j represents the index of the current time step. DEV represents the deviation that is employed as a measure of variability relative to mean value. The VI is measured in percentage (%) and varies between 0% and 100%. It effectively reflects how close the VI of the current period is in relation to the long-term minimum and maximum VI. In addition, the linear correlation was applied among the variables utilized.

4 Results

The averaged trimester deviations of maize and bean production from monthly values (February–April) on Ceará for 1971–2000 are displayed in Fig. 2. The anomaly cycles of maize and bean production vary substantially during the last three decades of the 20th century (Fig. 2a). The amplitude of these cycles has increased rapidly by 37% since 1983. This result is particularly striking in relation to the increasing level of maize and bean production in the study area. Nevertheless, the most dramatic decline in maize and bean production occurs before 1981, with concomitant increase in maize and bean yields (Fig. 2b).

Over the entire period, the frequency distribution of anomaly for the bean production (bean yields) is in phase with the distribution of maize production

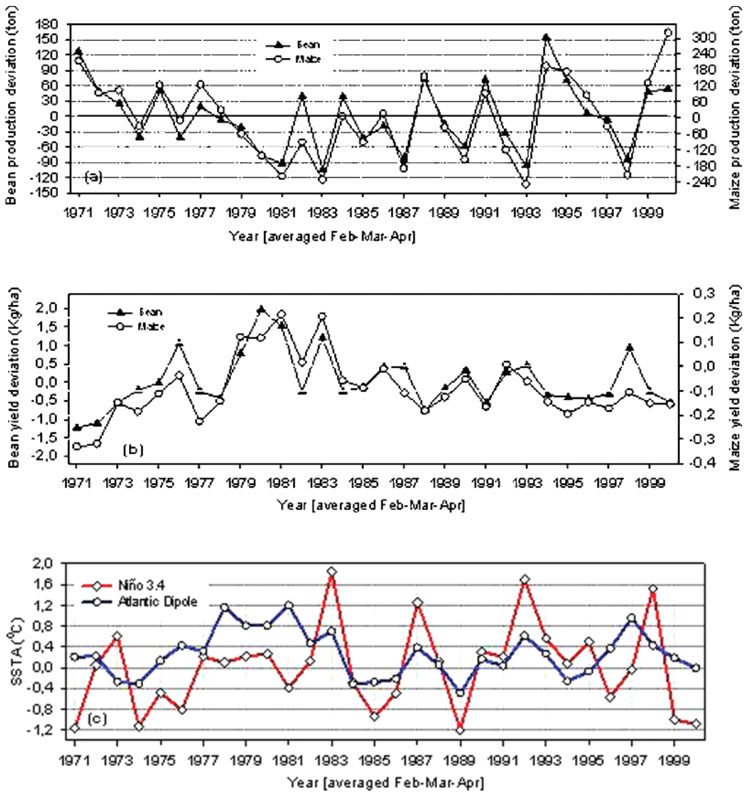

Fig. 2 Normalized deviations (anomaly). (a) Maize and crop production (t), (b) Maize and crop yields (kg/ha), and (c) SST (°C) in Niño 3.4 and Atlantic dipole regions for the period 1971–2000, state of Ceará

(maize yields), but in less magnitude. As indicated in Fig. 2c, there is significant connection between SSTA climate patterns and crop production in Ceará during the rainy season. Despite the year-to-year changes, coherency between extreme SSTAs and crop production and the strength of the correlation is relatively weak (average of r = −0.42, n = 30). Of particular interest is the decline in maize and bean production beginning in 1971 with concomitant increased maize and bean yields that has continued through 1981, with only slight relief in 1975 and 1977. These results provide the basis for linking seasonally changing SSTAs in Ninõ 3.4 and Atlantic Dipole regions directly to bean and maize production in the rainy season, when over half of the interannual change in crop production on Ceará is explained by changes in SSTAs. More substantively, changes in maize and bean production for the averaged February–April crop year are closely contemporaneous with well-known droughts, specifically 1972, 1979, 1980, 1981, 1982, 1983, 1990, 1992 and 1998. In particular, the drought of 1982–1983, +1.85°C and +0.47°C deviations in the Niño 3.4 and Atlantic Dipole regions steadily decrease the maize and bean production by more than 135 t, while the maize and bean yields steadily increased by more than 1.5 kg/ha. The drought's impact on bean production on Ceará has striking similarities to that for maize but differs in that the bean crop is planted and harvested earlier than maize in the rainy season, and it can also substitute partially for bean plantings in drought years. Although increasing in its overall economic importance, maize is still the second most important food staple for most of people in Ceará.

Results in Fig. 3 illustrate the vulnerability of bean production and yield in response to SSTA variability as expressed by the vulnerability index (VI). This index was able to capture the agricultural drought in response to changing in SSTAs. The larger VI for climate (Niño 3.4 plus Atlantic Dipole SSTAs), the stronger is the drought agricultural severity, which is indicated by the smaller VI for crop production. In this study, when the VI for SSTAs is generally close to the long-term maximum of 160% during 1971–2000, there are severe drought agricultural conditions (a VI of 0%). In particular, in the period 1971–1973, the value of VI for bean production decreased sharply from +89% to +49% while the bean yield increased from +0.1% to 21% and the value for VI climate varies from moderate humid conditions (+42%) to normal conditions (73%). It is interesting to note that the time series of VI associated with bean production and yield show distinct differences in the early 1970s, the late 1970s, the late 1980s and the late 1990s. Separating the fluctuations of VI from varying lengths and intensities, the period 1977–1983 clearly saw the worst agricultural drought of the last three decades of the 20th century. The period 1984–1989 was optimal in terms of agricultural production, interrupted only by the intense agricultural drought of 1987. Total seasonal maize and bean production are inversely correlated with Niño 3.4 ($r = -0.49$ and $r = -0.36$, $n = 30$, $p < 0.05$) and Atlantic Dipole indices ($r = -0.42$ and $r = -0.41$, $n = 30$, $p < 0.05$), while maize and bean yields are directly correlated with Niño 3.4 ($r = +0.32$ and $r = +0.34$, $n = +30$, $p < 0.05$) and Atlantic Dipole indices ($r = +0.32$ and $r = +0.46$, $n = 30$, $p < 0.05$), but inversely related with maize and bean yields ($r = -0.67$ and $r = -0.74$, $n = 30$, $p < 0.05$) averaged from February to April.

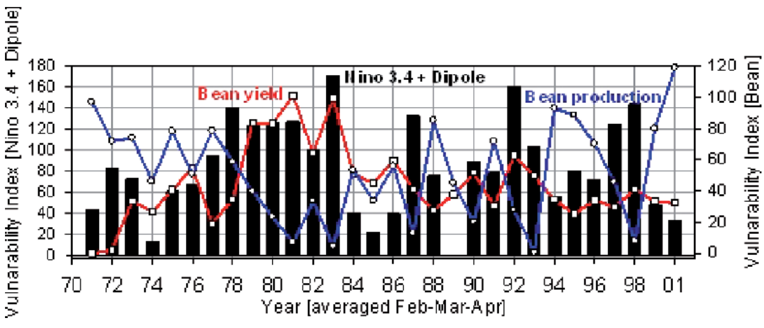

Fig. 3 Vulnerability Index (VI). (a) Bean production (t), (b) Bean yield (kg/ha), and (c) Niño 3.4 plus Atlantic dipole SSTA (°C)

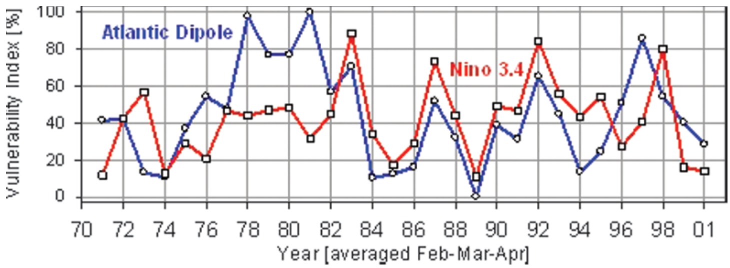

Fig. 4 Vulnerability Index (VI). Niño 3.4 SSTA (°C) and Atlantic dipole SSTA (°C)

As suggested by Fig. 4, seasonal changes associated with VI for Niño 3.4 and Atlantic Dipole SSTA regions show distinct differences from the early 1970s to the late 1970s and from the late 1980s to the mid-1990s, with a transition during 1982–1983. Prior to 1982–1983, year-to-year changes in bean production and yields are primarily associated with North Atlantic SSTA variability (a positive gradient – North Atlantic warmer than South Atlantic – leads to a decrease in precipitation in the state) that is often, but not always, reduced by La Ninã variability (a cold ENSO variability – La Niña conditions – which leads to an increase in precipitation on the state). After 1982–1983, year-to-year changes in bean production and yield reflect the influence of seasonally changing SST associated with ENSO variability (an El Niño and a La Ninã variability) that is irregularity amplified (reduced) by North Atlantic variability (South Atlantic variability – a negative gradient – North Atlantic cooler than South Atlantic that leads to an increase in precipitation in the state). These large fluctuations associated with VI for Niño 3.4 (VI values close to 0% [or 100%] lead to a La Niña [or an El Niño]) and Atlantic Dipole (VI values close to 0% [or 100%] lead to a negative gradient [or a positive gradient]) vary almost in-phase for 1985–1997, apart from 1998–2000, when the two VIs are out-of-phase. The warm phase of the North Atlantic beginning around 1977 is readily associated with the agricultural drought beginning in 1977. The worst drought occurred in 1983 (a VI of 160%) in the period from 1971 to 2000, which was strongly affected by persistent anomalous warming SST in the North Atlantic Ocean beginning in 1977. Despite the droughts, the increase in bean production between 1984 and 2000 is striking. Severe droughts (1987, 1992 and 1998) alternated with relatively humid years (1985, 1989 and 1995). This indicates that recovery of rain-fed agricultural production from persistent droughts has been enhanced since about 1983. Moreover, these long-term fluctuations were in-phase with global climate variability, specifically ENSO and the North Atlantic variability. Therefore, the vulnerability of rain-fed agricultural production in Ceará to changing SSTAs and its recoverability after persistent droughts suggest that the long-term rain-fed agricultural production in Ceará may be predictable.

The wavelet spectral analyses applied to the annual rainfall totals over Ceará for 1961–2003 show intense wave signals between 2.3 and 18.3 years (Fig. 5c). Fig. 5a exhibits the annual rainfall fluctuations in Ceará, which are not constant in

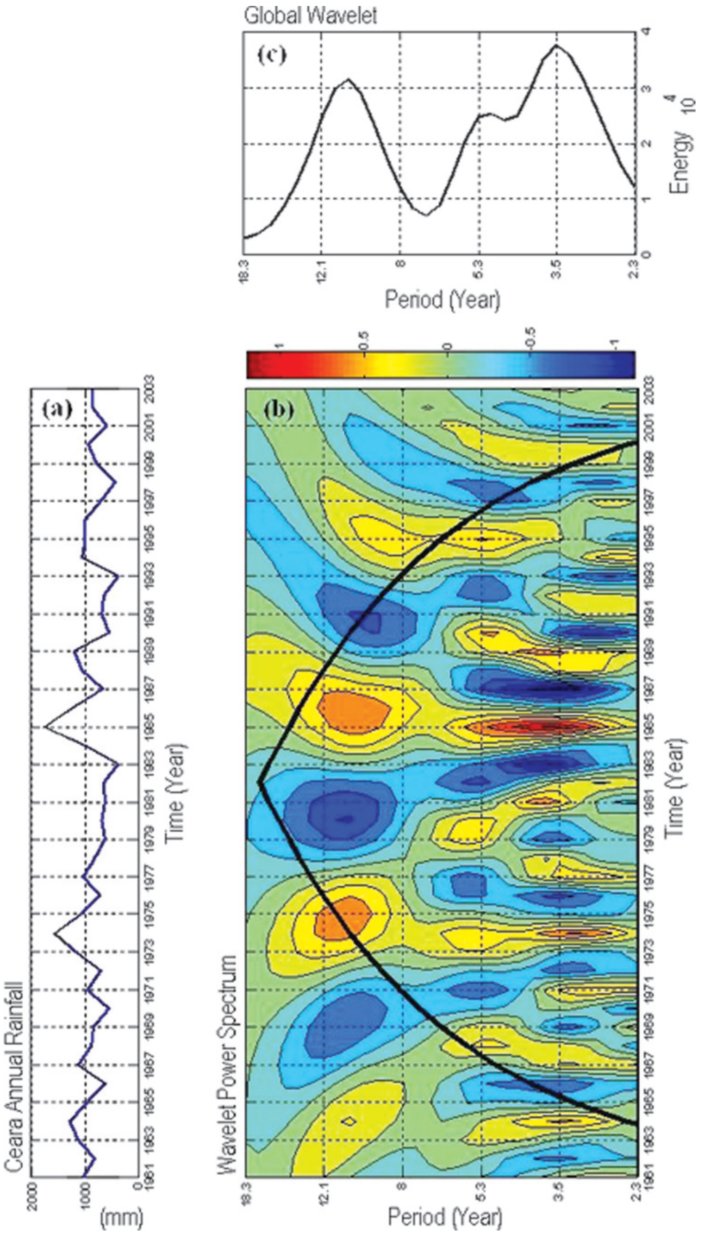

Fig. 5 (a) Ceará annual rainfall. (b) The wavelet power spectrum; black contour is the 95% significance level. (c) The global wavelet power spectrum

amplitude or period throughout the years. Fig. 5b illustrates the distribution of Morlet wavelet coefficients, which are delimited by the cone-shaped solid lines with the shaded areas below subject to a significance level of 95%. The shaded areas are chosen so that positive isopleths (red color) correspond to humid years and negative isopleths (blue color) represent drought years. And zero isopleths correspond to sudden change line. During 1974–1986, the low-frequency wave signals between 8 and 18 year periods are strong. According to Fig. 5b, during 1983–1989, it is clearly the high-frequency wave signals with period 2.5–5.3-year periods, which are strong, too. It is apparent that periods with high-frequency wave signals show lower VIs for both crop and Ocean SST indices, as shown in the Fig. 3. Therefore, the Morlet wavelet and vulnerability index analyses show that both interannual and/or interdecadal oscillations are recorded in the rainfall and agricultural production patterns of Ceará. As such, the ENSO and PDO are likely responsible for the high- and low-frequency wave signals, respectively.

5 Conclusion

In conclusion, rain-fed agricultural production in Ceará varied substantially in the last three decades of the 20th century, primarily due to changes in the tropical North Atlantic and ENSO variability. Prior to 1982–1983, year-to-year changes in maize and bean production and yields were primarily associated with tropical North Atlantic SSTAs, which were often, but not always, reduced by La Ninã variability. From 1982–1983, year-to-year changes in agricultural production and yields reflected the influence of seasonally changing SST associated with ENSO variability. Therefore, these oscillations may provide an important means of understanding and predicting long-term patterns of rain-fed agricultural production on the state.

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References

Alves, J. M. B. and Repelli, C. A. 1992. A variabilidade pluviométrica no setor norte do nordeste e os eventos El Niño-Oscilação Sul (ENOS). *Revista Brasileira de Meteorologia*, São Paulo, Vol. 7, No. 2, pp. 83–92. (In Portuguese.)

Barbosa, H. A. 2006. Interannual variability of vegetation dynamics in the semi-arid Northeast region of Brazil and its relationship to ENSO events. 8th International Conference on Southern Hemisphere Meteorology and Oceanography, 24–28 April, Foz de Iguaçu.

Barbosa, H. A. 2004. *Vegetation Dynamics over the Northeast Region of Brazil and Their Connections with Climate Variability during the Last Two Decades of the Twentieth Century*. Doctoral degree dissertation in Soil Water, and Environmental Science at the University of Arizona, Tucson, Arizona.

Barbosa, H., Huete, A. and Baethgen, W. E. 2006. A 20-year study of NDVI variability over the Northeast Region of Brazil. *Journal of Arid Environments*, Vol. 67, pp. 288–307.

Chimelli, A. B., Mutter, C. Z. and Ropelewsk, C. 2002. Climate fluctuations, demography and development: insights and opportunities for Northeast Brazil. *Journal of International Affairs*, Vol. 56, pp. 213–234.

Hastenrath, S. and Heller, L. 1977. Dynamics of climate hazards in northeast Brazil. Quart. *Journal of the Royal Meteorological Society*, Vol. 103, pp. 77–92.

IBGE (Instituto Brasileiro de Geografia e Estatística). 1993. *Recursos naturais e meio ambiente: uma visao do Brasil*. Departamento de Recursos Naturais e Estudos Ambientais, IBGE, Brasilia.

IPCC (Intergovernmental Panel in Climate Change). 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability*, McCarthy J. J., Canziani O. F., Leary N. A., Dokken D. J. and White K. S. (eds.), Geneva (See http://www.grida.no/climate/ipcc_tar/, accessed 23 August 2006.)

Krol, M., Jaeger, A., Bronstert, A. and Guintner, A. 2006. Integrated modeling of climate, water, soil, agricultural an d socio-economic processes: A general introduction of the methodology and some exemplary results from the semi-arid north-east of Brazil. *Journal of Hydrology.*

Namias, J. 1972. Influence of northern hemisphere general circulation on drought in northeast Brazil. *Tellus*, Vol. 24, pp. 336–342.

Nobre, P. and Shukla, J. 1996. Variations of sea surface temperature, wind stress and rainfall over the tropical Atlantic and South America. *Journal of Climate*, Vol. 9, pp. 2464–2479.

Phillips, J. G., Makaudze, E. and Unganai, L. 2001. Current and potential use of climate forecasts for resource-poor farmers in Zimbabwe. American Society of Agronomy Special Publication No. 63, *Impacts of El Nino and Climate Variability on Agriculture*. American Society of Agronomy, Madison, WI, pp. 87–100.

Rosenzweig, C. and Parry, M. L. 1994. Potential impacts of climate change on world food supply. *Nature*, Vol. 367, pp. 133–138.

Sun, L., Ferran Moncunill, D., Li, H., Divino Moura, A. and de Assis de Souza Filho, F. 2005. Climate downscaling over Nordeste Brazil using NCEP RSM97. *Journal of Climate*, Vol. 18, No. 4, pp. 551–567.

Chapter 3
Conservation of Biodiversity of Nigerian Drylands

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Abstract A large proportion of Nigerian drylands is characterized by sandy undulating topography. The sandy soil is usually low in organic matter, nitrogen and phosphorus, and degrades rapidly under conditions of intensive rainfall. When over-used, denuded patches may appear as the sand becomes mobile and windblown.

The rainfall regimes are characterized by high concentrations in a few months, intermittence and violent storms. Thus, the drylands are prone to recurrent depletion of soil and shallow groundwater resources that are capable of disrupting the low resilience of the natural ecosystems.

Crop and livestock production are the predominant land uses and they form an integral part of the farming system. Fuel wood alone accounts for 95% of the wood requirement of the people in the drylands. Drought and desertification, accentuated by climate change, constitute the major and most important environmental problems in the drylands of Nigeria. Intensive land use as human and livestock populations increase adds problems of deforestation, air and water pollution, municipal and industrial waste, biodiversity loss and pest infestation. Efforts to protect the environment include establishment of protected areas, such as national parks, game reserves, forest reserves and shelterbelts. A National Biodiversity Strategy and Action Plan has also been put in place to map out the strategies and guidelines for environmental management and conservation of biodiversity of Nigerian drylands.

Keywords Desertification, drylands, Nigeria, biodiversity, conservation

1 Introduction

It is estimated that drylands occupy 41% of the Earth's land area, 70% of which are degraded and are inhabited by over 2 billion people worldwide (UNCCD, 1996). Drylands are generally subject to climate regimes that are not highly favourable to

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crop production. Low total rainfall and high variability in rainfall patterns present difficult challenges for growing crops. The degradation of drylands is due mainly to climatic variability and unsustainable human activities. It involves the loss of biological and economic productivity and ecosystem goods and services, caused by soil erosion, deterioration of the physical, chemical, biological and economic properties of soil and the long-term loss of natural vegetation (Dupuy et al., 2002)

Desertification is the major environmental problem for Nigerian drylands. Desertification undermines the goal of sustainable development by increasing poverty, poor health, malnutrition, impaired child development and susceptibility to disease. Nigeria has concluded the process of the preparation of its National Action Plan (NAP) to combat desertification.

This paper highlights Nigeria's efforts to ensure conservation of biodiversity and sustainable development in the drylands.

2 Extent of Nigerian Drylands

The drylands of Nigeria form an undulating plain at a general elevation of about 450–700 m, lie approximately within latitudes 10°N and 14°N of the Equator, and comprise Adamawa, Bauchi, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, Yobe and Zamfara states of Nigeria. The total human population in Nigerian drylands is estimated at 33.5 million, with an average population density of 158 person/km^2.

3 Drylands Environment

Average annual rainfall in the drylands of Nigeria varies from less than 250 mm in the northeast to about 750 mm in the south, but it is unreliable in many parts. Unpredictability and unreliability characterize the pattern of rainfall. As in other arid and semi-arid areas of the world, it is not just the total amount of rainfall that is important but the timing and distribution. In this respect, the pattern of rainfall in the region is highly variable in spatial and temporal dimensions, with an interannual variability of 15–20%. In addition to high interannual variability, the rainfall regimes of the drylands of Nigeria are characterized by high concentration in a few months, intermittence and violent storms. Thus, the drylands are by nature prone to recurrent and sometimes intense and persistent periods of drought.

The high water deficit associated with this zone has compelled individuals, private companies and the three tiers of government (local, state and federal) to explore and exploit groundwater resources, which is more available than surface water in the zone. Currently, the extraction of groundwater through bore holes and hand-dug wells is tapping one or more of the aquifers underlying the area. However, the general fear is that over-pumping of groundwater is causing the water table of the area to fall (Folorunso, personal communication).

3.1 Soil

Soils in most parts of the drylands are sandy, well-drained and low in soil organic matter content. They are therefore characterized by low water-holding capacity. The only exception to this observation is the fadama soil, which is fine-textured with higher organic matter content and relatively higher water-holding capacity.

3.2 Temperature

The mean annual temperature ranges between 17°C and 32°C, although high temperatures of up to 42°C occur during April/May. In December/January, low temperatures of around 5°C are experienced.

3.3 Flora and Fauna Diversity

Climate of the zone supports mostly savanna vegetation. Thus, apart from some relic forests on low-lying ground around the southern boundary, the whole zone is covered by savanna vegetation consisting of Sudan and Sahel savanna with the density of trees and other plants decreasing as one moves northwards. Typical species are the trees *Sclerocarya birrea, Combretum glutinosum, Albizzia chevalier* and *Piliostigma reticulatum*; while the shrubs include *Guiera senegalensis, Randia nilotica* and *Cassia singueana*. A number of species typical of the grass-dominated Sahel savanna, such as *Balanites aegyptiaca, Adansonia digitata* and *Acacia senegal*, also occur in this zone. The striking *Acacia seyal*, with its varied-coloured powdery bark, forms pure communities on low-lying ground. In a quantitative study of the ecology of the Acacias on Borno and Yobe states, Sanusi and Okali (1995) found that of the 12 species of Acacia encountered, *Acacia albida* alone occurred on a wide range of habitats and soil types. Most of the other species exhibited some preference for particular habitats or soil types, e.g. *A. laeta, A. Senegal* and *A. tortilis* occurred on deep aeolian dunes and sandy plains, while *A. seyal* and *A. nilotica* occurred on low-lying sites with clayey soils and liable to flooding.

Typical species of relict forests in the drylands include *Lophira alata, Terminalia glaucescens, Daniellia oliveri, Hymenocardia acida, Vitex doniana, Detarium senegalense* and *Afzelia africana*. Riparian forests are present on the fringes of the flood plains of the Hadejia Nguru wetlands and harbour tree species such as the mahogany *Khaya senegalansis* ebony (*Diospyros mespiliformes*), *Tamarindus indica* and *Ficus spp*. Common wildlife species include hartebeest (*Alcaphalus busephalus*) and wart hog (*Phacochoerus aethiopica*). Small mammals in the savanna zone include a large variety of rodents. Species range from the multimammate mouse (*Mastomys natalensis*) and gerbils (*Tatera valida* and *Taterillus gracilis*) to larger animals, such as the porcupine (*Hystrix cristata*). Common carnivores of the savanna include the Egyptian mongoose (*Herpestes ichneumon*), jackal (*Canis adjustus*) and white-tailed mongoose (*Ichneumia albicauda*). Avian biodiversity in Nigeria is discussed in Ezealor (2002). Typical bird species, which inhabit the savanna regions of Nigeria, include the bulbiols, francolins (*Francolinus spp*), bustards (*Eupodontis spp*), bee eaters (*Merops spp*), and starlings (*Hamprotornis spp*) (FORMECU, 1998). The high diversity and population of birds in the Hadejia-Nguru wetlands have had both national and international recognition. During the 1997 winter survey, 324,510 water-related birds were counted in the wetlands (Polet et al., 1997). This large number of birds is attracted by the various habitats found within the wetlands (Okali and Bdliya, 1997, 1998). In the Nigerian savanna, reptiles such as snakes, lizards and turtles are common. Species such as alligators and crocodiles are found along rivers and in many wetlands, freshwater lakes and swamps.

The diversity of insect life has been found to be high especially in the Hadejia-Nguru wetlands (Molta, 1997). Records show that about 14 insect species found in the wetlands are not documented in the list of the biodiversity of aquatic fauna of Nigeria by Egborge (1993). Insects like bees provide honey abundantly and thus make honey collection a source of income for many households.

3.4 Land Use Practices

Eighty percent of the population in Nigerian drylands lives in rural communities. The area has 8.24 million ha of arable land, of which 3.57 million ha are under cultivation. In addition, there are 685,047 ha of fadama land, which can be irrigated, indicating that the irrigation potential of the area is quite substantial. Agriculture is the mainstay of the economy of the area. Millet, sorghum and wheat cultivation are predominant in arid and semi-arid sub-zones, while sorghum, maize, cotton, legumes and rice feature prominently in the sub-humid zone. Large quantities of tomatoes, onions, pepper, carrots and other vegetables are also grown as sole crops. Agro-forestry systems practised in the zone include scattered farm trees, boundary tree planting, homestead gardens, woodlots, shelterbelts, as silvo-pastoral or agro-silvo-pastoral systems.

Livestock production is a prominent part of the zone's farming system. The zone is an important producer of livestock, which include approximately 10 million cattle, 615 million goats, 13 million sheep, 34 million poultry, 475,000 donkeys, 460,000 rabbits, 253,000 pigs, 65,000 horses and 54,000 camels (Folorunso, personal communication). Open, free-range land made-up of natural pasture is the primary source of animal feed, particularly for large stock and small ruminants. The open woodland and the tree/shrub savanna provide the most important grazing areas. There are grazing reserves covering a total land area of over 1.2 million ha. The area of forest reserves is estimated at 2.4 million ha. There are also some exotic tree species in plantations, woodlots, shelterbelts and amenity planting covering over 12,000 ha.

Surface water resources of Nigeria's drylands comprise four major rivers – Rima, Kadunna, Kano and Hadeija – and their tributaries, as well as reservoirs and lakes. Over 32,000 fishermen are engaged in both artisanal fishing and aquaculture with a yield potential estimated at 157,000 metric tonnes of fish annually.

3.5 Threats to Biodiversity

Ecological and environmental problems of the drylands of Nigeria are similar to those of other arid regions of the world. Drought and desertification accentuated by climate change constitute the major and most important environmental problems. Others include deforestation, air pollution, water pollution, municipal and industrial wastes, and pest infestation. The direct and indirect causes of these ecological and environmental problems, as well as their negative impact on the dryland ecosystems of Nigeria, are summarized in Table 1.

Increases in rural population places additional pressure on natural habitats and plant and animal species. In order to meet the demands for food and other products, large areas of the natural habitat are converted to cropland and grazing land, which has a negative impact on the diversity and populations of indigenous species. In areas where particular species, such as trees, medicinal plants, wild fruits and other non-timber forest products, are harvested unsustainably, not only are these species lost but also a myriad of associated plants, insects, fungi, etc. that require these specific hosts to meet their own ecological requirements for survival.

There is also the problem of genetic erosion when the best and most vigorous trees are selectively logged, leaving the stunted and deformed to produce. Overexploitation due to local demand and export has also caused many dryland species to become endangered. Such species include *Borassus aethiopum, Combretum spp, Detarium macrocarpum, Dialium guineense, Hyphaene thebaica* and *Pterocarpus erinaceus*. Likewise, the cultivation of some indigenous crop species has been abandoned for exotic species, leading to genetic impoverishment and near -extinction of such indigenous species as *Oryza glaberrinna*, *Digitaria exilis,* and indigenous guinea corn (*Sorghum spp. gbyam*) and indigenous millet (*Pennisetum spp, Dauro*) are no longer grown in their native range in Sokoto, Katsina, Jigawa and Kano states.

Many aquatic species have very particular requirements of water quality, flow and seasonality, all factors that are undergoing anthropogenically induced changes in the drylands. Pollution from industrial areas, mining and agricultural runoff are impacting the water quality of rivers and streams. Some rivers and streams have even dried up with consequent loss of biodiversity. Soil erosion is a rampant problem in the zone and also adds more than normal levels of silt to some bodies of water, such as Lake Chad, with negative effects on some aquatic species.

The impact of habitat modification on wildlife composition and population mainly accounts for the low wildlife species diversity that is now characteristic of Nigerian drylands.

Table 1 Major environmental problems of the drylands of Nigeria, their causes and their impact on the ecosystem (from Anon, 2002)

Environmental problem	Direct cause(s)	Indirect cause(s)	Negative impact on ecosystem
Drought	Sunspot phenomenon causing drought	Indiscriminate felling of trees	• Reduced vegetal cover • Increased soil erosion • Reduced soil productivity
Deforestation	Agricultural expansion, urban expansion, fuel wood gathering, forest fires, overgrazing, improper resources management, pest infestation, mechanized land clearing	Population pressure, upstream damming, poverty, lack of alternative fuel, distortion of forest product prices, open access to land	• Reduced forest coverage • Increased concentration of greenhouse gases • Reduced soil stability
Desertification (land degradation)	Excavations for road or building constructions, poor irrigation practices resulting in floods, water-logging, increased salinity and inappropriate agricultural practices	Natural geology, geomorphology and soils, upstream dams, poor dam designs and operation, careless mechanical farming, deforestation, weak sanctions	• Reduced soil productivity • Increased level of poverty • Increased incidence of health-related problems • Increased level of greenhouse gases
Air pollution	Emission of polluting gases from industrial plants, obsolete industrial processes or equipment, unspent fumes from engines of vehicles	Weak enforcement of anti-pollution laws or regulations, inadequate E.I.A. study or wrong approval of some weak solutions	• Distorted hydrological balance • Global warning • Increased incidence of water-borne health problems
Water pollution	Inadequate waste treatment, lack of drains, spills and leaks, obsolete industrial processes and equipment	Weak enforcement of laws and regulations	• Reduced availability of good quality water for domestic and agricultural purpose

4 Conservation Actions

To reconcile environmental conservation in the drylands with sustainable development and the sustainable use of biodiversity, protected areas and institutional frameworks have been put in place.

4.1 Establishment of Protected Areas

In situ conservation stands, including managed forest reserves, game reserves (e.g. Lame/Burra, Kogin Kano, Kamaku and Kwiambana), national parks (Yankari, Chad Basin and Gashaka-Gumti), and a Ramsar site (Hadejia-Nguru wetlands), have been established in the zone with a view to conserving the flora and fauna resources. Nigeria has a number of globally important ecological areas in the drylands, but only one has so far received international conservation attention – Hadejia-Nguru wetlands Ramsar site.

Hadejia-Nguru wetlands is a flood plain complex on the southern edge of the Sahel savanna in northeastern Nigeria. This area has long been noted for its importance to both breeding and wintering water birds passing through. It is also known to harbour at least 89 species of freshwater fish and many savanna animals. The wetlands also provide sanctuary for some endangered tree species, as well as other endemic plant species. Prior to its designation as a Ramsar site, the area was under threat from (i) water diversions and flooding due to poor management of dams constructed upstream, (ii) livestock grazing pressure and (iii) agricultural expansion.

4.2 Institutional Framework and Capacity-building

The Nigerian Government has put in place the institutional framework and initiated research projects to tackle the problems of environmental degradation and biodiversity loss in Nigerian drylands. Foremost in these steps is perhaps the articulation of a National Conservation Strategy in 1986, followed by a Natural Resources Conservation Action Plan in 1992 (NARESCON, 1992). The latter document focused on of drought and desertification, which afflict the country's drylands. Specifically, among other measures, the Action Plan recommended the establishment of more forest reserves and grazing reserves in the zone in order to protect the flora and fauna. It also recommended greater support for research to deal with various aspects of the problem.

A Shelterbelt Research Station at Kano, and a Savanna Research Station in Zaria and a Northeast Arid Zone Research Station at Damasek in Maiduguri – all outstations of Forestry Research Institute of Nigeria, Ibadan – have been established to conduct the afforestation and rehabilitation of degraded areas in the drylands. The predominance of harsh weather conditions during the dry season (Harmattan), the unreliability of the rainfall, and the prevailing high moisture deficit (annual amount of evaporation exceeds the annual rainfall) all severely constrain agricultural practices. Shelterbelts (which are long rows of trees planted across the direction of the prevailing winds) have been established in many parts (Kano, Sokoto, Bauchi and Borno states) as a means of ameliorating the harsh weather conditions. It has been observed that shelterbelts do influence soil moisture storage on the lee side as against the windward side and improve grain and groundnut yield (Onyewuotu, 1985; Ujah, 1985).

In collaboration with the University of Maiduguri, the government has established the Centre for Arid Zone Studies (CAZS) to carry out comprehensive studies on dryland ecology, hydrology, agricultural and livestock production and soil and water conservation.

Fuelwood alone accounts for 95% of the total wood requirements of the zone. Considering the devastating effects of deforestation on biodiversity and the environment, a Solar Energy Research Centre has been established at Usman Dan Fodio University, Sokoto, to promote solar energy and non-fossil fuel research and their applications to agriculture and rural community development. Specifically included are projects related to the development of technologies for alternate forms of energy (solar, wind and geothermal) and those dealing with the substitution of critical sources of energy by renewable energy sources and forms (agricultural and forestry products and residues and biomass)

Nigeria is a signatory to several treaties and international conventions, including the UN Convention on Biological Diversity (CBD) and the UN Convention on Combating Desertification (UNCCD). This government is committed to conserving its natural resources.

5 Conclusion

An agro-ecological analysis of dryland and farmland degradation in Nigeria showed low organic matter content, low chemical status, deficit supply of nitrogen and phosphorus, and very low water table. Some of these deficiencies could be remedied through fertilization, composting of crop residues, post-harvest ploughing to conserve residual moisture and reduce wind erosion, and establishment of shelterbelts. Agroforestry practices using nitrogen-fixing species, such as *Falderbia, Acacia albida* and other tree species with reverse defoliation, protects the soil in the dry season. In areas with low water tables, *Acacia senegal* has shown very promising results. The carrying capacity of the drylands is directly related to rainfall, which is highly variable. It is therefore necessary that human population numbers be kept within environmental carrying capacity. A higher productivity and sustainable development could be achieved in Nigerian drylands through higher input and more technology in farming. Fodder and fuel subsidies are needed to take the pressure off natural vegetation, while monitoring species distribution and ecosystem behaviour and functions, protecting the wetlands, relatively undisturbed forest and woodlands, and rehabilitating vegetation all would contribute to conserving Nigerian dryland biodiversity. It is also necessary to establish more protected areas to cover vegetation types currently not being covered in the existing network of protected areas in the zone.

References

Anon. 2002. *Training Module for Ecosystem Management in Nigeria*. Federal Ministry of Environment, Food and Agriculture Organization of the United Nations (FAO), Abuja, Nigeria.

Dupuy, A., Lee, C. and Schaaf, T. 2002. Combating desertification: Freshwater resources and rehabilitation of degraded areas in the drylands. *Proceedings of the International Seminar on Desertification, N'Djamana, Chad, 30 October–4 November 2000*. UNESCO, Paris.

Egborge, A. B. M. 1993. *Biodiversity of Aquatic Fauna of Nigeria*. Barika Enterprises Suleja, Nigeria.

Ezealor, A. U. (ed.). 2002. *Critical Sites for Biodiversity Conservation in Nigeria*. Nigerian Conservation Foundation, Lagos.

FMoE. 2003. *National Biodiversity Strategy and Action Plan*. Federal Ministry of Environment, Abuja, Nigeria.

FORMECU. 1998. *Area Summary of Dominant Vegetation and Hand Use Classes for 1976/78 and 1993/95*. Geomatics/Forestry Management Evaluation & Coordinating Unit, Ibadan, Nigeria.

Molta, M. 1997. Insects and small mammals biodiversity survey of the Hadejia-Nguru Wetlands Conservation Project Area, North-Eastern Nigeria. *Biodiversity of the Hadejia-Nguru Wetlands: Report of a Survey*, Okali, D. U. U. and Bdliya, H. H. (eds.). IUCN/HNWCP (Hadejia-Nguru Wetlands Conservation Project), Nigeria.

Okali, D. U. U. and Bdliya, H. H. (eds.). 1997. *Biodiversity of the Hadejia-Nguru Wetlands: Report of a Survey*. IUCN/HNWCP, Nigeria.

———. 1998. *Guidelines for Wise Use of the Hadejia-Nguru Wetlands*. IUCN/HNWCP (Hadejia-Nguru Wetlands Conservation Project), Nigeria.

Onyewuotu, L. O. Z. 1985. Establishment consideration for optimum spacing of shelterbelts in the Sahel and Sudan zones of Nigeria. *The Challenging Character of the Nigeria Forest Resources and the Implications for Future Development*, Proceedings Annual Conference, Forestry Association of Nigeria, J. A. Okojie and O. O. Okoro (eds.), pp. 32–38.

Polet, G., Isalo, S. Dutse, Akinsola, O. A and Garba, Boyi, M. 1997. The survey of water fowls and water related Birds of the Hadejia-Nguru wetlands Nigeria. *Biodiversity of the Hadeija-Nguru Wetland: Report* of a Survey, D. U. U. Okali and H. H. Blidiya (eds.). IUCN/HNWCP.

Sanusi, S. S. and Okali, D. U. U. 1995. Ecology of Acacias in Borno and Yobe States. *Annals of Borno*, Vol. 11–12, pp. 154–157.

Ujah, J. E. 1985. Soil moisture studies with millet, groundnut and cowpea under sheltered and unsheltered farmlands in the semi arid zone (Dambatta Kano State) of Nigeria. *The Changing Character of Nigeria Forest Resources and the Implications for Future Development*. Proceedings Annual Conference, Forestry Association of Nigeria. J. A Okojie and O. O. Okoro (eds.), pp. 39–47.

UNCCD. 1996. *United Nations Convention to Combat Desertification*. United Nations, New York. (See http://www.unccd.int/convention/ratif/doeif.php, Accessed 1 September 2006.)

Chapter 4
Impact of Land Use Conflict on Livelihood and Range Condition in the Awash Valley of Ethiopia

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Abstract Since 1960 rangelands in the Awash Valley of Ethiopia have been subject to competing claims: wildlife conservation, development to generate revenue for the state, and the use of the valley by pastoralists. This conflict, aggravated by drought, is a frequent occurrence between Afar and Kereyu pastoralists, the conservation, park and state plantations and has threatened the co-existence of the communities and the park, resulting in range deterioration. Studies were undertaken to examine options for livelihood diversification and to identify entry points for range improvement through consultation with key stakeholders, reviews of documents, and field data collection. Though livestock production is the major source of livelihood, local communities have undergone changes in terms of their livelihood. The percentage of bare ground varied between 4% and 25%, with many spots without any vegetation and the proportion of forbs ranging between 3% and 44%. The area is bush encroached and the range has degraded, thus decreasing the conservation value of the area for ecotourism. The options for livelihood diversification, rangeland improvements and future research needs are outlined.

Keywords Conflict, pastoralists, rangelands, livelihood diversification, livestock

1 Introduction

The majority of the world's pastoralists are in Africa (55%), Asia (29%), the Americas (15%) and Australia (10%) (Child et al., 1984), and there are more than 25 million people in sub-Saharan Africa (SSA) for whom pastoralism is not only a system of livestock production but also a way of life (Lane, 1998). The majority

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of the pastoralists in Ethiopia consist of Somali, Borana and Afar communities, and the rangelands are estimated to cover 61–67% of the country. Livestock is the sole source of livelihood, accounting for more than 60% of the household revenue, and livestock production is almost totally dependent on native pasture and woody plants (Zinash et al., 1998). In addition, there are many other resources, including sites suitable for archaeological and socio-anthropological studies (e.g., *Lucy* in the Middle Awash). In the study districts – Awash-Fantale (Afar community) and Kereyu-Fantale (Oromo community) located in the Upper Awash and part of the Middle Awash Valley of Ethiopia – from the 1960s a substantial portion of the fertile land of the pastoralists was given to Awash National Park (ANP), state-owned sugar plantations, and other agricultural enterprises. Land losses are due to annexation, and the diminished size is further aggravated by continuous drought, population pressure and migration. Therefore, the problems associated with the carrying capacity of the Awash Basin are likely to become increasingly serious, further compounding the challenges of co-existence not only between the different pastoral groups but also between the pastoral communities and the state or private investment ventures, as well as the ANP (Mudris, 1998). The maximum productivity of an ecosystem is constrained in the drylands mainly because of the lack of precipitation. Accordingly, the rangeland improvement measures should go hand in hand with improving the livelihood of the pastoralists. Various interventions were undertaken both by NGOs (CARE-ETHIOPIA) and government institutions (Ethiopian Wildlife Conservation Organization) to develop the ANP and its surroundings. However, the prevailing use of resources has given rise to conflicts among the multiple users. The decline of key natural resources calls for a holistic and integrated approach to promote collaborative resource use and a sustainable management system. Accordingly, studies were undertaken examine options for livelihood diversification and to identify entry points for rangeland improvements.

2 The Study Area and Methodology

The study districts are located adjacent to each other in the southern part of the northeastern rift valley of Ethiopia (Fig. 1). The long-term annual rainfall averages 550 m, but is highly variable. The main rainy season is from July to September, and the shorter rainy season is from February to April. The mean minimum and maximum temperatures are 17.4°C and 32.7°C, respectively. Up until the early 1950s, the dominant inhabitants in Kereyu-Fantale district were the Kereyu. The Ittu tribal group, which moved there in the early 1950s from western Harareghe because of competition within their tribe as well as with the Issa tribal group, falls within the same ethnic group and lives in the same district as the Kereyu. The Afar are one of the largest pastoral groups in Ethiopia, inhabiting the vast rangelands of northeastern Ethiopia, most of the middle and almost the entire lower Awash Valley. They have, however, lost access to much of their land due to irrigation (Mudris, 1998). The Ittu are

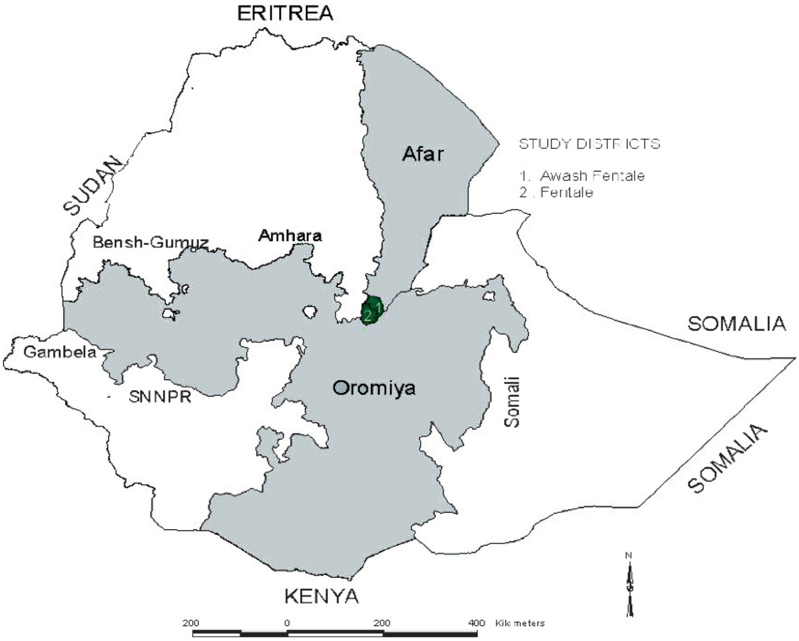

Fig. 1 The location of the study districts in Ethiopia

generally involved in crop production, while the Kereyu practice pastoralism, crop production, charcoal and firewood-making, as well as off-farm employment. The Afar exercise off-farm employment, charcoal and firewood-making and some cropping activities (Mudris, 1998). The human populations of the Kereyu-Fantale and Awash-Fantale districts are estimated to be 74,932 and 21,442, respectively (CSA, 2000). The ANP was established as a strict conservation area in which all forms of human land use were prohibited. The park legally covers an area of around 752 km^2. According to UNESCO (1964), the justification for the choice of the ANP rested on its extraordinary features from both a physiographic and a geological point of view. The establishment of the ANP required the resettlement of the people and their livestock, and it also coincided with the establishment of the sugar cane plantation, which left few alternatives to the local community (Mudris, 1998).

The study procedures included a review of policy literature and a Participatory Rural Appraisal (PRA) technique supplemented by a structured questionnaire/interview. For the assessment study of rangeland condition, sites were selected from within the ANP (20) and the grazing lands bordering the park, which were further stratified into those on the Oromo side (8), Afar side (10) and on traditionally improved pastoral grazing lands, locally called *Kalo* (6), although the latter areas legally belong to the ANP. Parameters on the herbaceous, soil and woody vegetation layers were also collected.

3 Major Findings

3.1 Perceptions of the Communities and Other Stakeholders

According to the participants in the PRA, the pastoralists of the study area have undergone many changes as a result of external influences and internal dynamics. The effect of the former, such as the introduction of development schemes, has been a change in the pastoral land use system and a reduction in the available grazing lands. Most of the development interventions seem to reveal that there was no community partnership in the decision-making process. Community representatives from Kereyu argue that they had three ecologically differentiated zones: Ona Ganna (wet season grazing zone from the beginning of June to mid-September), Ona Bona (moderately dry season grazing land from mid-September to December), and Ona Birra (dry season grazing land from January to April). Similarly, the Afar traditionally sub-divide their grazing land into *Alta* (mountainous, rocky area used for wet season grazing) and *Kalo* (swampy, marshy area located around river banks and mainly used in the dry season). However, this traditional practice of rangeland management is diminishing. According to the Karayu community, they are left with only the Ona Gana ecological zone. The case of the Afar is by no means different and because of that they currently spend the whole year in plains in fear of the emerging conflicts against other ethnic groups in these bordering highland areas. As a result, they are frequently exposed flood and displacement. In addition, in the past, both pastoral groups used to rest and burn their grazing land where grass was abundant as rangeland improvement measures. The participants in the PRA from Benti-Mogissa PA argue that several roads, covering short distances and mainly used to water their livestock during the dry season, are totally closed by the ANP. Currently, the local communities have access to only one road, which takes long hours from their locality to reach the Awash River. Accordingly, many people from the local community, especially those in Kereyu-Fantale (i.e., Gelcha Village), are forced to use water contaminated with factory waste. The competition for scarce resources by different pastoral communities escalates to conflict. Consequently, the Oromo and Afar communities who enjoyed friendship, *jalla* in peaceful times, now come into severe conflict. In addition to the loss of human lives and animal-raiding, conflict has far-reaching consequences for the rural economy, the daily livelihood of the people and the under-utilization of grazing lands around borders (no man's land).

Livestock production is the major source of livelihood. However, the system has become increasingly unstable due to minor climatic events. In the study area, a recent drought of 2001–2002 saw the average holding livestock drop from 60 to 26 for Afar and from 26 to 11 head of cattle per household for Oromos between 2001 and 2003, respectively. Drought resulted in 58% of cattle losses during this crisis period. Sheep mortality was 38% and 34% for Afar and Oromo, respectively. Goat mortality was 29% and 38% for Afar and Oromo, respectively. Camel mortality was 29% and 10% for Afar and Oromos, respectively. Consequently, people are becoming poorer, outward-looking and more involved in non-pastoral activities. Improving human welfare should focus on creating a virtuous cycle based on more timely livestock sales, alternative investment of revenues, and sustainable economic diversification. Strengthening and restoration of traditional management needs the full participation and willingness of all stakeholders working in the area, including the political and administrative units. It is also equally important to incorporate risk management planning in projects/programmes undertaken by government and non-governmental organizations. Mobility is an inherent strategy of the pastoralists to optimize means of livelihood in a heterogeneous landscape with a precarious climate. According to PRA, 75% of Oromo and 98% of Afar pastoralists move their livestock from place to place in search of food and water. However, 90% of the Oromo and 60% of the Afar pointed out that mobility as a strategy has been causing concern for the security of their animals and their own lives, death of animals *en route*, incidence of disease and predators. The shrinking of natural resources further resulted in change of livestock species composition (species change). By contrast, the Afar are mainly dependent on camels. Crop production is the second major source of livelihood particularly on the Oromo side. The outstanding reason for starting crop production is to increase income (for both Afar and Oromo). Irrigation-based cultivation is more common in the Afar communities, while the majority of Oromo respondents depend on rain-fed agriculture.

3.2 Options for Livelihood Diversification

1. Dairy marketing: The household interview indicated that sales of cow milk, cheese and butter and camel milk are important sources of household income to the Afar (50%) and Kereyu (33%), as compared to sales of other animal products. Women and children do most of the activities, and women control sales. CARE-Awash has also started organizing a Dairy Marketing Women Group in Awash.
2. Fattening group: The fattening project, facilitated by CARE-Awash, is one option.
3. Saving and credit groups: Simply providing a means to create village-level savings and credit cooperatives could help have some resources outside the livestock sector.
4. Beekeeping (apiculture).
5. Palm leaf processing.
6. Community game practices and hunting license: The pastoralists (53% and 76% of Oromo and Afar, respectively) indicated that predators have killed their animals in the past ten years. The major wildlife threat to the Afar is lion (37%), followed by hyena (26%). The Oromo pastoralists ranked hyena (84%) and fox (13%) as big threats. Having realized that hunting has benefits, the Afar community in Boloita and residents along Bulga River have started to conserve wild animals, including oryx, and the community has declared the area a “no hunting zone”.

7. Ecotourism and community-based tourism.
8. Aquatic resource development and harvest.
9. Handicrafts: All the above activities must be strengthened through exchange tours, focused training, provision of timely market information and access, provision of inputs, and awareness creation.
10. Increasing social service to the community: According to survey results, the educational level of the Afar community is very low (16% for young and 11% for adult Afar and 25% for young and 8% for adult Oromo, which is below the national average). Education increases the chance of pastoral children to lead a different lifestyle (employment) and reduce population pressure in the area. Improving other social services, like health, construction of roads, marketing centres and water points, is essential. Government organizations and NGOs, though limited in scope, are doing their share. Consequently, the involvement of state-owned and private farms in community development could reach a wider audience and build positive relationships between state development and pastoral communities.

3.3 Policy Issues

Since the early 1900s, Ethiopia's grazing lands have been regarded as state property. Later, the 1975 land reform proclamation resulted in the establishment of a Pastoral Association in pastoral areas, and pastoralist sedenterization and state farm development were the central objectives. The proclamation was *inter alia* accompanied by a substantial removal of grazing areas from pastoralist control, causing a significant loss of critical grazing areas, the decline of pastoral livelihoods, and increased pressure on the remaining rangeland. In the absence of a pastoral land use policy, and empowerment of the pastoral traditional management council, more and more land will be lost, which will pose a serious threat to the pastoral livelihood. Similarly, environmental and biodiversity conservation policy was not effective enough in addressing biodiversity conservation. The lack of significant and consistent policy in terms of tourism development is also a concern. However, there are opportunities for development. The recent Wildlife Policy objective is to preserve, manage and sustainably utilize Ethiopia's wildlife resources for social and economic development and for the integrity of the biosphere. In addition, the draft stated that communities stand to play a far greater role in conservation and also to benefit from hunting and park revenues, which seems to acknowledge community participation in the management of parks. An equally important policy arena is tourist sector development. Although modern tourism commenced in Ethiopia in the early 1960s, when tourism was formally recognized as an economic sector, there were no significant and consistent policy changes in the sector. As a result, Ethiopia lost many opportunities in foreign exchange earnings. The policy should consistently review the possibility of having cultural tourism, hotel expansion, custom duties, knowledgeable tour operators, Internet, and mobile telephone services.

3.4 Rangeland Condition

3.4.1 Rangeland Sites within the Park

In all the rangeland sites, except the Awash riverine vegetation sites, the dominant grass species was *Chrsopogon plumolosus* (17–75%). Almost all the farm animals and many wild animal species, birds, rodents and insects, are dependent on grasses as a source of food (Oudtshoorn, 1999). Accordingly, a look at the percentage of grass, non-grass species and bare ground can be used as an indicator of the condition of the rangeland. A high percentage of bare ground and non-grass species (except for some legumes) indicates that the condition of the rangeland has deteriorated. Accordingly, the percentage of grasses, non-grasses and bare ground varied between 45–91%, 3–21% and 4–25%, respectively. The DM (dry matter) yield of grass varied between 334 and 728 kg ha^{-1}, with a corresponding grazing capacity of 9.83–4.51 ha GU^{-1}. When the production of grass is low, the amount of land required to produce a sufficient amount of grass to sustain a grazer unit (an animal) will be more. The woody vegetation density (plants ha^{-1}) varied between 88 and 2,767, while the Evapotranspiraton Tree Equivalent (ETTE) value, defined as the leaf volume equivalent of a 1.5 m single-stemmed tree, ranged between 531 and 12,042 ha^{-1}. Furthermore, these woody plants, particularly *A. senegal* and *A. nubica,* are the main encroacher plant suppressing grass production.

3.4.2 Rangeland Sites on the Oromo Side

Except at Kara and Kolbayu, *Chrysopogon plumolosus* was the dominant grass (14–83%). The percentage of grasses, non-grasses and bare ground varied between 45–90%, 3–44% and 4–21%, respectively. The grass DM was generally low (Figs. 2 a,b), ranging from 216 to 384.3 kg ha^{-1}, and the grazing capacity (GC) ranged between 11.6 and 21.9 ha TLU^{-1}. The density of woody vegetation (plants ha^{-1}) ranged between 1,880 and 4,500, while that of ETTE between 3,259 and 17,280 ha^{-1}. Furthermore, these woody plants (mainly *A. senegal* and *A. nubica*) are also the main woody plants suppressing grass production.

3.4.3 Rangeland Sites on the Afar Side

The dominant grass species varied among sites: *Tetrapogon cenchrifrmis* (26%), *Trajus berteronianus* (14–24%), *Paspalm* (32%) and *Chrysopogon plumolosus* (22–68%). The percentage of grasses, non-grasses and bare ground varied between 36–94%, 6–55% and 3–14%, respectively. The DM yield of grass varied between 200 (Samayu) and 340 kg ha^{-1} (Madala), with a corresponding GC of 24 ha^{-1} TLU^{-1} (Samayu) and 13.5 ha TLU^{-1} (Madala). The woody vegetation density (plants/ha) varied between 669 and 2,167 and ETTE 2,484–16,544/ha^{-1}. The major encroaching woody plants are species of Acacia and *Grewia tenax*.

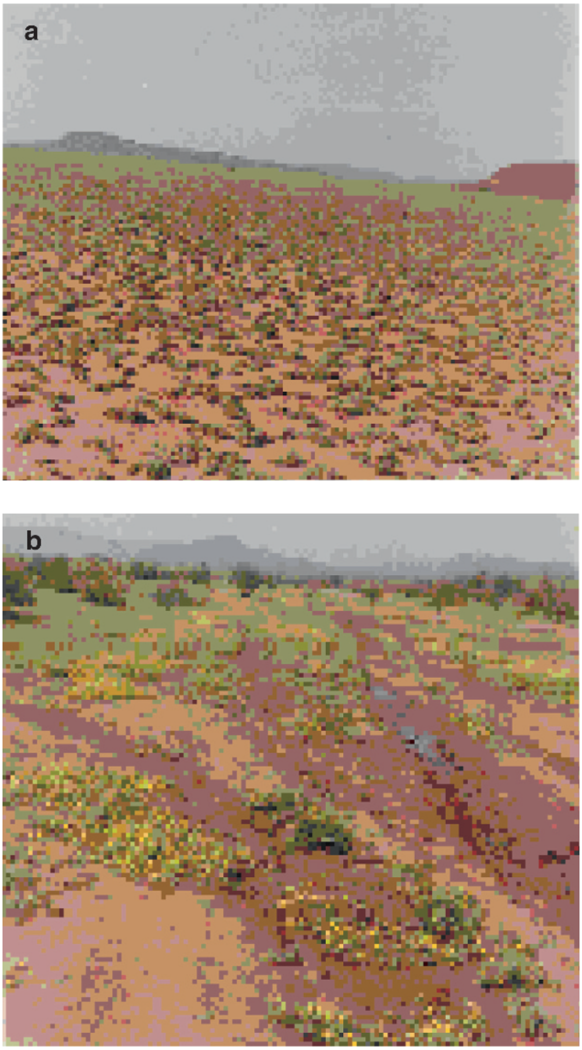

Fig. 2 The condition of the grazing lands in different sites

3.4.4 Traditionally Improved Protected Grazing Land, *Kalo*

Traditionally improved protected grazing lands are those grazing lands found on the side of the Oromo pastoralists, which are protected from grazers for one main rainy season or more. The dominant grass species was *Chrysopogon plumolosus* (34–77%), and these rangeland sites, in general, have high percentage of grasses (88.5–92.2%), low percentage of non-grass species (1.3–6.9%) and bare ground (1.9–10.3%)

(Figs. 3 a, b). The grass DM yield (355–830 kg ha^{-1}) and grazing capacity (5.5–12.9 ha TLU^{-1}) was highest at the *kalo*. The woody vegetation density was (1,750–3,900 plants ha^{-1}) and that of ETTE (3,211–5,767 ha^{-1}). *A. nubica* is the encroacher woody plant. The results of this study indicate that, given proper management like resting the grazing land, the rangeland can bounce back remarkably well.

Fig. 3 Traditional *kalos* improved by Community, CARE and GTF joint effort

3.4.5 Rangeland and Wildlife

The area is bush encroached with few woody plants, notably *A. senegal*, *A. nubica*, and *A. mellifera*. Community members (100% of Afar and 79% of Kereyu) replied that, compared with the past, their grazing land is bush encroached. This implies that a multi-species area gradually is changing to an area dominated by a few species, which decreases the conservation value of the area and, in turn, impacts the type and number of wild animals. The livestock and wildlife in the study area interact in many ways, such as grazing competition, soil/pasture degradation, disease transmission and crop raiding.

3.5 Options for Improvement of Rangeland Resources

Several possible interventions have been proposed that can be implemented by the community and the park administration along with other stakeholders in the area. The use of non-range feed resources (such as cane tops, molasses and crop residues) must be promoted. Where appropriate, forage and fodder bank development are options for reducing pressure on grazing resources.

Rangeland rehabilitation is an expensive venture; consequently, efforts should focus on key grazing resources. Communities must play the lead role in identifying the location of the key resources that require rehabilitation. Depending on the extent of land degradation, the most economical method of reclaiming deteriorated key grazing lands is through the use of methods not requiring planting of the desirable species (reseeding). The reclamation can therefore be conducted through the control of unwanted plants, concentrating moisture or harvesting precipitation, and/or grazing land management. When moderate rangeland deterioration occurs, the withdrawal of grazing animals may contribute to rangeland recovery depending on the availability of adequate seed reserves and rainfall. In extreme cases, radical rangeland reclamation measures, such as oversowing/re-seeding, are required, and the grass species to be used for range seeding should be the native varieties. CARE-Awash can play a vital role here. To obtain best results, land improvement should be combined and coordinated with grazing management techniques and the livestock market. One of the issues that must be controlled in rangeland management of the ANP is unplanned burning of the rangelands. Currently the park is not as attractive to tourists and visitors as it should be and therefore requires improvement. Because of interference by the community, and illegal marketing (contraband) common in the Awash area, many roads there are not actually essential for the development of the wildlife industry in the area. Rather, they decrease the available land for grazing. Furthermore, the physical location of the ANP, close to a highway carrying heavy traffic, exposes the wild animals to the risk of poachers and vehicular accidents. The condition of the roads in the park needs improvement, as some of them are either closed or covered by vegetation. There must also be a reliable and thorough assessment of resources. Bush encroachment is one of the problems in the study districts, notably in Awash-Fantale and the ANP. Bush encroachment is an example of an agricultural problem that is also a biodiversity problem – reduced agricultural productivity occurs because of the low value of thorn trees to livestock. The bush encroachment problem on the side of Afar pastoralists is more severe than on the side of the Oromo pastoralists. The control can be accompanied by mechanical thinning followed by goat/camel browsing (mainly in the Awash-Fantale district). In such control, the primary focus should be on protecting those open grasslands so that they are not encroached upon by bushes. Therefore, one option for controlling bush encroachment in the park could be mechanical thinning (reducing the number). Furthermore, unwanted plants, like *Perthineum*, *Calotropis procera*, and *Cryptostegia grandiflora,* are invading the rangelands, and appropriate control measures must be devised. Water development programmes should distinguish between water for human, calf and other livestock uses. The shortage of water is more severe for the Oromo pastoralists than for the neighbouring Afar pastoralists. Both communities greatly appreciate the contributions made by government organizations and NGOs operating in the study area in terms of water development activities. Capacity-building with regard to human resources, facilities for rangelands, and wildlife in particular, while creating a favourable working environment, needs strong emphasis at the community level, in the concerned offices and the ANP. Solutions to the problems in the study area are possible through collaboration between all parties involved. Currently, the Regional Government of Oromiya and the Ministry of Federal Affairs of Ethiopia are trying to assist the pastoral communities with funding obtained from international sources and the Federal Government of Ethiopia. These relationships will help to formulate rangeland policies based on solid scientific and indigenous knowledge systems that can improve the condition of the rangelands. Moreover, an appropriate system of technology transfer must be developed.

3.6 Suggestions to Improve the Relation between the ANP and the Community

The very fact that the Awash National Park (ANP) is located at the junction between two neighbouring, and at times conflicting, pastoral communities with a shortage of grazing land for their animals has made the problem more critical. The people's struggle for daily survival means the notion of "tomorrow" plays virtually no part in their reality. The ANP should be a partner in pastoral development, and the development and implementation of effective strategies require innovative ideas that emanate from the community, the park administration and other stakeholders. It is better for the ANP to work *outside* to improve the situation *inside*. There has been a realization that relying solely on protected areas to conserve biodiversity is insufficient. In such situations, community participation creates a better working environment for the ANP to manage wildlife in and around the park. There must be effective two-way communication, which is key to success as it builds trust and respect. Wherever possible it is vital that community members be given an opportunity to be part of the action through employment in the park and other state development ventures. The ANP should also work more on spreading the message of sustainable utilization, and should actively look for methods of promoting sustainable utilization of renewable natural resources in the pastoral communities. For example, soil erosion is one problem and the ANP can consciously try to combat soil erosion in the pastoral areas by helping the community along this line. The ANP can also focus on transforming potential and real problems into opportunities. For example, bush encroachment is one major problem in the park. This problem can be transformed into potential opportunity such that the harvested woody materials can be made available to the neighbouring communities on a controlled basis, thereby giving pastoral women access to firewood. Environmental education also needs much emphasis in the Awash area (e.g., for school children).

3.7 Future Directions of Drylands Research

The research to be undertaken in the drylands should have an agro-ecological, production system, multidisciplinary, participatory, gender-sensitive and demand-driven nature. It should include:

1. Development of mechanisms by which the communities are involved in wildlife and other genetic resources conservation, and mechanisms of sharing benefits with the community.
2. Determination of the loss of biodiversity and genetic dilution and mechanisms of genetic resource conservation and policy options.
3. Looking for possible ways of income diversification.
4. The productivity of the rangeland (herbaceous and woody) and the effect of interacting factors on rangeland vegetation.
5. The formulation of land use policy that also incorporates co-management of resources.
6. Livestock marketing opportunities that link the pastoral communities with the domestic and export market.
7. Possible ways of range improvement, bush and unwanted-plant control methods that take into account the knowledge within the community.
8. Evaluation of sustainability, efficiency and impact of intervention activities.
9. The ecological and social impact of drought.
10. A study on the impact of resource use and neighbouring pastoral conflicts on the status of the rangelands.
11. Identification, quantification and characterization of genetic resources.
12. Effect of different land use/land cover systems on socio-economic and ecological characteristics.
13. Identify and document the indigenous knowledge of the community with regard to parameters or variables used in rangeland condition assessment and rangeland condition rating systems, usage of different plant species and others.

14. Develop an information base on the level of encroachment of desertification and factors causing desertification and development of intervention methods.
15. Study the possible causes, intensity and extent of land degradation and their interactive effect with possible solutions.

References

Child, R. D., Heady, H. F., Peterson, W. C. and Piper, R. D. 1984. *Arid and Semi-arid Lands: Sustainable Use and Management in Developing Countries*. Winrock International, Morrilton.

CSA. 2000. *Statistical Abstracts*. Addis Ababa, Ethiopia.

Lane, C. R. (ed.) 1998. *Custodians of the Commons. Pastoral land tenure in East and West Africa.* UNRISD-IIED, Earthscan Publ., London.

Mudris, A.M. 1998. *Resource Deprivation and Socio-economic Changes among Pastoral Households: The Case of Kereyu and Ittu Pastoralists in the Middle Awash Valley of Ethiopia*. M.S. thesis, Agricultural University of Norway.

UNESCO. 1964. Saving the wildlife of Ethiopia. Recommendations of UNESCO mission. *Oryx*, Vol. 7, pp. 247–250.

Zinash, S., Tesfaye, K., Azage, T. and Osuji, P. (eds.) 1998. Livestock Early Warning System for East Africa)-TAMU (Texas A&M University) and EARO (Ethiopian Agricultural Research Organization). *Proceedings of the National Workshop on Early Warning System and Monitoring Livestock Nutrition and Health, 4 February*. Addis Ababa, Ethiopia. GL-CRSP/ LEWS-TAMU and EARO, Addis Ababa, Ethiopia.

Chapter 5
The Control of Sandstorms in Inner Mongolia

Jiang Gaoming

Abstract The frequent occurrence of sandstorms in northern China in recent years has had an immediate bearing upon the ecological degeneration of grasslands in Inner Mongolia. The long-term exploitation by humans of the primordial ecosystems has led to the degradation of the sandy grasslands. In this respect, human infringement is the predominant reason followed by natural retrogression. Hence, in order to tame the sandstorm scourge, the pressure on the depleted ecosystems from livestock grazing should be eased in such a way that native vegetation is restored while large areas of grasslands may be revived by natural processes in their normal evolutionary course. This article discusses the formative reasons behind the sandstorms, approaches harnessed to tackle the scourge, and the constructive roles played by forests and other natural factors.

Keywords Sandstorms, Inner Mongolia, grasslands, livestock grazing, ecological management

1 Where Does the Material Basis of Sandstorms in the Chinese Territory Come From?

On this question, the research community has yet to reach consensus (Qui Xinfa et al., 2001; Wang Shigong et al., 1996). According to satellite-relayed remote-sensing data released from the State Meteorological Center, about 66% of the dust material comes from Mongolia or places further north or northwest. Another batch of data from CAS-hosted wind-tunnel experiments indicate that 60% of the sandy dust originates from Chinese pasture lands, while 20% are blown from our country's transitional areas sandwiched between farming and herding regions. What conditions would we find in an on-the-spot investigation? According to our surveys, following the 2002 spate of sandstorms about 0.2–1 cm of the topsoil in the

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grasslands of Xilingol League, Inner Mongolia, was lost. The figure was 3–21 cm in Hunshandak Sands. A number of other individual cases we observed were really appalling. For example, on 2 May 2001, a gust of wind blowing over 1,300 ha of farmland in Baiyinxile resulted in the loss of all the wheat seeds, chemical fertilizer and 8 cm-thick topsoil, which was blown away without a trace. Where did the grains in the topsoil fall?

Heavy lumps and nodules in the topsoil fell on the spot to bury herdsmen's dwellings, sheep fences and highways. Nobody can deny that the lighter material floating in the air was transported far away, resulting in the sandstorm.

One of the menacing developments now under way before our eyes is the large-scale drive towards ecological depletion now inflicting our arid or semi-arid grasslands. According to our dynamic monitoring and observation data, the land desertification rate in China during the 1970s was 1,560 km^2 per year; this figure reached 2,100 km^2 during the 1980s, 2,460 km^2 during the first five years of the 1990s, and 3,436 km^2 over the last five years. From these figures we can recognize the on-going momentum of this menacing threat, which is looming larger and larger. The sandstorm is the most directly related environmental disaster caused by the ecological depletion of the sandy grasslands (Shu Wen and Jiang Gaoming, 2002). Over the last century, China has been hit by almost 70 sandstorms. During the first 30–40 years of the 20th century, a sandstorm occurred on average every three years, though the situation has worsened in the last decade or so. For example, in the 1960s and 1970s, a sandstorm would occur every two years, but one occurred every year in the 1990s. Very rapidly, the figure increased to 12 spells of dusty weather in 2000, and a total of 18 spells of dusty weather were seen in northern China in 2001, including a severe sandstorm lasting for a continuous 41 days. During the period 18–21 March 2002, most areas in northern China experienced the most ferocious dusty weather since the start of the 20th century, sweeping over an area of up to 1.4 million km^2. The inflicted area was so wide that all regions in the country north of the Yangtze Valley were ravaged to various degrees by the scourge. In recent years, the calamitous sandstorms have caused huge economic losses in China. To harness them, the national authorities have spent considerable sums, with expenditure growing steadily every year. However, even if we admit that in the short term 33% of the sandy dust originates from within Chinese territory, we have no reason to feel complacent even if this is true because large-scale ecological degradation is currently underway in arid or semi-arid areas of the Chinese hinterland. It is impossible for us to harness the ominous development occurring in the Republic of Mongolia and, as a matter of fact, the latter's ecological depletion is much less grave than ours.

2 Is the Sandstorm a "Natural Calamity" or a "Man-Made Disaster"?

First of all, we begin by presenting a brief analysis of changes in six environmental factors capable of supporting an ecosystem's normal performance:

- There is no change in sunlight.
- Temperature fluctuates within normal margins.
- There is no discernible change in atmospheric content of oxygen.
- There is an observable increase in the atmospheric content of CO_2 (from 290 ppm before the advent of the Industrial Revolution to 350 ppm at the present-day level).
- Moisture has changed considerably (such as in the three-year-long drought from 1999 to 2001), but annual precipitation remains normal on the whole, while in some years the rainfall increased slightly. For example, the annual precipitation in 2002 was heavier than in past years. In an arid or semi-arid area, water is the main restrictive factor for plant growth. However, even in harsh conditions, natural vegetation can survive, as it is a result of the long-term evolution of the biosphere. As plant growth is still thriving under favourable climatic conditions, why does plant growth seem to go from bad to worse with each passing year?
- Both the soil and its mineral content have undergone radical change: the material circulation in nature has been interrupted and suspended by human infringement, leading to aggravated soil erosion. The topsoil layer in the grasslands, in which the native vegetation used to take root, is 100 cm thick at most. (In many places, it is less than 10 cm thick.) Beneath this layer, sands are as deep as several hundred metres. It is evident that the 100 cm-thick topsoil layer is crucially significant in the survival of the whole ecosystem. The grasses, meadows, shrubs and thickets blanket the topsoil and protect it from being blown away. When they disappear or are ravaged by irrational human-induced exploitation, the topsoil's compact texture loosens, disintegrates and eventually transforms into sandy dust that makes its way through the air to Beijing and even across the Pacific Ocean.

Therefore, we do not endorse the view that the degeneration of sandy grassland is caused by the worsening climate, although some scholars believe that the ongoing trend of global change intensifies aridity in some places. Two other facts can explain this situation. The first point concerns the depleted grasslands in the eastern part of Hulun Buir League and Xilingol League in Inner Mongolia: the thickness of the topsoil has eroded to less than 20 cm or so and a few Mongolian gazelles live there. In sharp contrast, on the opposite side of the national border in the Republic of Mongolia, the topsoil is 100 cm thick and tens of thousand roe deer (*Capreolus capreolus*) are seen roaming on the steppe. If the arid climate is to be blamed, then the grasslands on the Mongolian side should show greater devastation due to their location further north in the hinterland. The second point concerns the 10 km-wide belts on the Sino-Russian and Sino-Mongolian borderlines: the 100 cm thickness of the topsoil is still preserved at the level observed during the 1950s. This fact refutes the following two viewpoints: 1. the arid climate leads to the impaired growth of the grass; 2. without the livestock's overgrazing, the grasslands cannot do well. It is well known that no livestock are allowed to graze along the boundary between the two countries.

From these assumptions, we might conclude that the primary reason for grassland ecosystem degradation is the exploding population,[4] i.e. the appearance of sandstorms is caused by human activity and could be interpreted as a “warning” or a form of “vengeance” from nature. Since the founding of the People’s Republic in 1949, the Xilingol League’s population has grown from 205,000 to 920,000, a net increase of 348% (IMP, 1996). In the wake of the population increase, and the insatiable demand for better material and living conditions, the number of domestic livestock has witnessed a dramatic increase from 1.6 million to 23 million heads, a net increase of 1338%. In this way, the foraging pressure on the grasslands has increased so rapidly that it will soon exceed the bearable limits of the whole grassland ecosystem. The average pasture area available to support the survival of one standard sheep has dropped from 5.13 to 0.467 ha. This means that the net grazing pressure on the grasslands has increased up to 950%. Another contributing factor is the change in lifestyle of the resident community, and its related policy orientation. The nomadic lifestyle has been replaced by the many fixed settlements; this is in addition to desired objects of modernity longed for by the local herdsmen to improve their quality of life. This leads to the ongoing trend of grassland depletion – from bad to worse. The working mechanism for this process is as follows: after a long, tedious and famine-prone winter, the livestock scramble to the budding grass in early spring, at a sensitive juncture when the herbages’ photosynthetic organs begin their initial growth. The amount of the forage consumed by the livestock is less than 1% of the ecosystem’s grazing potential. If the grazing livestock numbers are reduced, then the ravage caused in early spring may be absorbed by nature itself. If grazing activity occurs throughout the grassland, the latter would be too suppressed to grow. Year after year, a malignant cycle forms.

3 Do “Humans Force the Sands to Retreat” or Are “Both Humans and Sands Withdrawing”?

During the 1950s a slogan heard everywhere in China called the people to embark on a march towards the desert. At that time, the Chinese people were high-spirited and rallied to start their heroic expedition to conquer the deserts by wielding their spades and hoes. Now, half a century later, it seems that the deserts were far more powerful than we imagined, since nothing significant remaining from the drive except for a few successful harnessing models achieved by pouring in handsome investments. Today’s recklessness and unbridled sandstorms provide convincing proof of this. It is obvious that we are engaged in combating desertification without respite. Yet, to our great regret, the struggle so far not only has failed to stem the scourge but has seen desertification accelerate. The swelling population is one of the driving factors behind this ominous development (Ci Longjun and Liu Yuping, 2000). Hence, the key to containing the worsening momentum of this degeneration lies in the self-regulation of the population itself. The survival of and solution for human development in the future provides the permanent cure, and other measures constitute only temporary solutions to alleviate the symptoms of the scourge. In other words, to harness those "diehard areas" that do not react to any harnessing measures, the best method would be "human withdrawal", which reduces human infringement and allows nature to repair the depleted ecosystem. Even in ancient desert areas, the *laissez faire* attitude would not necessarily create more damage; for example, the Gobi Desert has a natural "protective shield" blanketing its surface. If we do not interfere with this "shell", then the topsoil is protected and prevented from blowing away. In essence, we must treat the desert properly. The natural condition of grasslands and sandy steppes is better than those in deserts such that a retreat of the human inhabitants would result in greater vegetation restoration.

Hence, human withdrawal is conducive to the "shrinkage of deserts", or at least it is effective in "stemming the advancing momentum of deserts". How can we reap the maximal returns from this move? This is a question that requires more detailed and focused research from scholars and government departments. A strategy of encirclement and transfer of native residents or *ex-situ* development has in fact been carried out in the Inner Mongolia Autonomous Region. This approach helps in the revival of the native vegetation. However, new questions arise, such as: How are the transferred communities of local residents settled elsewhere? Will they cause new damage on unspoiled grasslands? All these issues must be treated in a secure and reliable way.

4 Does Ecological Revival Depend on Natural Forces or Human Intervention?

Britain was the world's first industrialized country and the first country to taste the bitter fruit of ecological devastation. Today, it has revived abandoned wastelands caused by mining activities (mainly coal mining) into thriving ecosystems, and through further planning programmes it has transformed them into world-renowned scenic sites in the countryside. One of the reasons for this success lies in ecological revival that takes advantage of natural processes (Bradshaw, 2000). Such an approach might be understood as simply "a man-made encirclement". This is based on the premise that no soil erosion occurs, various vegetative forms (such as seeds, spores, fruits, germinated roots or geminated buds) might settle and reproduce in a way that is free from any external interference. Clearly, the practice of planting a solitary arboreal species such as poplar on a natural meadow should be opposed. This would constitute an artificial invasion of the grassland and would undoubtedly be detrimental to the revival of a grassy ecosystem (such as the disturbance of water circulation in an ecosystem). There are many successful examples to demonstrate ecosystem revival by natural forces. For instance, during 1991–1999, 4,356 households from the native population were removed from the mountainous areas of Yanqing County in a northern suburb of Beijing Municipality, thus reducing the local population in these areas from 60,000 to

30,000. The population pressure on the woodland in the county was thus greatly mitigated. At present, the forest coverage of the county is up from 30% to more than 70%. One of the restrictive factors hampering the afforestation effort lies in firewood collection by the local population, which is equal to 1.3 ha of the mountain slope per capita on average. Another example can be found in Hong Kong, where over the past 40 years all farming activities in a hilly district were prohibited; the natural restoration led to a lush and green plantation covered by forests. In the Xilingol Xilin Gol League of Inner Mongolia, in a desolate and saliferous beach land area deserted by nearby herdsmen, we conducted an experiment involving the encirclement of 2,670 ha of grassland; the herbal plants achieved overall restoration in the first year (with herbal coverage up to 100%) and the height of grass reached more than 80 cm. The output in the second year was especially rewarding and spectacular: the height of the grass measured up to 1.43 m and the fresh forage harvest attained a record 79.5 t per ha, while the natural germination rate of two-year-old elm seedlings was 321 saplings per m^2. The depleted vegetation became fully restored to 1960s levels. The nature of the vegetation also changed under protection: before the experiment, the vegetation in fixed sandy dunes were mainly dominated by *Artemisia frigid*, *Cleistogens squarrosa* and *Carex duriuscula*; with protection this changed to *Agropyron michnoi*, *Kochia prostrate*, etc. The dominant species of vegetation in the lowland changed from *Chenopodium glaucum* and *Chenopodium acuminatum* to *Leymus chinensis* and *Elymus dahuricus*, etc., which are considered to be the best forage species for animals. Furthermore, the number of plant species in the samples increased after being protected for only two years, with 121% in protected areas and 74% on average in intermittent protected areas in all habitats. It is impossible for humans to nurture an equivalent development pattern for the rehabilitation of a depleted grassy ecosystem. Another example is the 670 ha heartland of the protected biosphere reserve in Saihan Wula in Bairin Right Banner under the jurisdiction of Chifeng City. Following the removal of some 100 permanent residential centres of nomadic herdsmen, the barren sandy wasteland changed its originally desolate state of damaged vegetation, resulting in overall ecological rehabilitation in the first year. All these examples prove that ecological revival, with the aid of natural forces, should involve the most immediate, most economical and most effective approach with the least risk.

In their struggle against sandstorms, some people have adopted an attitude that takes advantage of the natural forces but does not remove human interference. With regard to the grassy ecosystem, we tend to spend large sums of money to stem the degenerative process, but our efforts thereby are concentrated on treating only the symptoms and not the scourge itself. Moreover, the harnessing drive will not be successful without taking into consideration the destructive factors in the decaying ecosystem, and without the participation of the local people. Instead, this could lead to a time delay needed to seize comprehensive control of the scourge. We must remain highly vigilant over the so-called project for ecological construction under the banner of "ecological revival", which actually has the opposite effect leading to "ecological destruction", although people may contribute to this without being aware of their actions due the lack of knowledge of the processes involved.

5 Means of "Nurturing the Land Through the Land Itself" and Environmentally Friendly Residential Centres

In the course of harnessing the degraded sandy grasslands, a model of "nurturing the land through the land itself" was developed. This approach is essentially concentrated on raising the efficiency of land use with help from up-to-date technology so as to improve the material conditions and quality of life of the local inhabitants. In this way, a greater amount of land resources are laid idle in order to allow them to recuperate and nurture themselves through a natural process. Thus, the degraded ecosystems become rejuvenated in the vast pastureland (J. Gaoming, 2001, 2003). The approach is both simple and effective: in a few places where the supply of water, electricity, fertilizers, transportation access and agronomic techniques are available, demonstration projects are created and their production and lifestyle are reshaped accordingly. The remainder of the vast degenerated land resources is closed to livestock grazing and fuel collection in order to facilitate the natural revival of the native vegetation. This step is followed by upgrading the areas to natural reserve status under administrative protection. The ratio of the two portions might be set to 1:100. The reason for such a low ratio is because, at present, a depleted ecosystem has very low productivity. For example, the fresh biomass production rate for a degenerated meadow is 450–1,500 kg per ha. After technical treatment, the figure might rise to 90,000 kg per ha. The scientific grounds for the approach is that intensified exploitation of a land tract fully supplied with water and manure would not cause degeneration. In China proper, for example, the farming civilization so far has lasted for more than 5,000 years without any indication of fading. The reason is that land resources there have produced nothing degenerative.

The key to the approach of "nurturing the land through the land itself" lies in its nurturing aspect. This implies that:

1. Soil erosion must be prevented.
2. Soil salinization caused by underground water has to be removed (if these two processes are not ensured, the nurturing itself will be spoiled and lead to the creation of a man-made wasteland).
3. The soil must be nourished by manure or fertilizers so that it can support sustainable exploitation.

In line with the current scientific approach, it is quite possible for us to achieve the three steps listed above. The approach on large-scale acreage is to allow the grassy ecosystem to rest and develop its strength for vegetation succession to take place, which is free of human interference. The returns are both enormous and rewarding. Taking our experimental plot as an example, the annual harvest of dried hay is 10,000 t, at a price of 0.4 yuan per 1 kg; the income from this single item (the hay) is roughly more than 4 million yuan, while the actual input is 160,000 yuan for building the enclosure fences and includes less than 10,000 yuan in security fees. In terms of the re-settlement of the herdsmen, the key lies in financial support. This issue seems to be the most important, and therefore we must look further into the related policies. For example, the degraded grasslands in the Alxa Banner of Inner Mongolia account for more than 80% of the area and are home to about 15,000 households of native herdsmen covering a population of 62,000 inhabitants. If the latter's livelihood is completely left to the above approach, spending would be 150 million yuan per year (averaging 10,000 yuan for each household). Of course, this is quite likely to be regarded as the worst thing to do by some people. Conversely, the Banner has a land area of about 270,000 km^2, equivalent to three Jiangsu Provinces in eastern China. The expenditure on it is worthwhile as it is considered to be a sensitive prairie 'noted for its ecological fragility it exerts direct impacts on the Yellow River mainstream, Hexi Corridor, Yinchuan Plain, Hetao Plain and the whole land mass of northwest China, north China or even the south of the Yangtze River will be influenced by it.' If we did not regret investing as much as 100 million yuan for the implementation of so-called ecological construction projects in the past, then we should be equally generous today at this critical juncture.

As regards the resettlement of the native herdsmen, our expectation is to spend a large sum of money on the 1% of the land resources and on the economic prosperity of the residential communities by helping them form an industrial chain, an intensive trade or new market of animal husbandry, involving forage grass plantation, superb strain cultivation, livestock-rearing in a fenced enclosure, mechanized procedures for forage harvesting, storage, transport, milking, beef and mutton production, re-transport, urban consumption of meat and so on. If the local herdsmen can obtain such benefits, a massive "ecological exodus" might be prevented. Scientifically, it would not be difficult to realize a thriving ecosystem on a small stretch of land. The difficulty lies in producing products with highly proliferated values. For example, a large amount of top-quality forage grown by the CAS (Chinese Academy of Sciences) scientists in Zhenglan Banner under the Xilingol League in Inner Mongolia encountered obstacles to the sale. Consequently, various priority actions such as funds for ecological harnessing (including sand dune fixation and afforestation projects), disaster relief, allotments for ecological remedies, various social donations or contributions and funds granted by the national, regional and local authorities tend to lean towards ecologically depleted areas in the drive to boost urban development in small cities and towns. They may be used to resolve various practical issues, such as water supply, electricity, telecommunication networks, transport systems, educational infrastructure and improvements in living standards of local residents, leading to less environmental devastation. The current state of the herding areas is such that there are considerable funds for the transformation of reclaimed farmlands into their original vegetation but few for grass planting. Such an unconventional policy must be corrected in time or else grassland depletion will be aggravated even further. By transforming the existing pattern of interrelated interests and functions of land use, the local residents can take the initiative and participate in the drive towards ecological harnessing. In this way, they can reverse their role, changing it from "misappropriating" nature into becoming the protector of their ecological setting. Herein lies the key to the success of our efforts.

6 Recommendations for Stopping Sandstorms and Initiating Sustainable Dryland Management in Inner Mongolia

Sixty billion yuan has been invested in projects to control the sandstorms that are hitting northeastern China. Tree-planting projects have also been running for 30 years across northern China. But why have they not worked? More important still: What will work? To answer these questions, let us first consider the difference between trees and grass. Ecologists look at vegetation in terms of its quantity and the area it covers. In China's deserts and grasslands, grass is by far the most common form of vegetation, followed by scrub and then trees. On the Xilingol grasslands, for example, trees account for only 0.87% of the total vegetation. The current strategy – to plant trees to counteract problems caused by a lack of grass – contradicts principles of ecological management. In fact, our repeated calls for change have now resulted in more attention being paid to scrub vegetation. Scientists agree that millions of years ago these areas were once covered with trees, but that is the distant past – no amount of spending will bring back ancient forests. In fact, grass is much more effective than trees at stopping sandstorms and does not necessarily require planting. By simply protecting the grasslands, they will grow. Trees use up groundwater, while grass uses only rainwater. Grass is denser and fixes the soil in place; it also keeps the ground moist by retaining precipitation, with the result that no dust is blown away – something trees cannot do. Secondly, we need to consider where our sandstorm control efforts are being focused. Currently, our work is concentrated on areas that are easy to reach and monitor, that is, regions that are accessible by road. Large sums of money have been spent with some good results, but we seem to ignore the very remote, ecologically degraded areas that are less accessible yet have greater responsibility for sandstorms. I once asked a local forestry official why he was not using aerial sowing techniques to rehabilitate these areas. His answer was simple, 'Who would notice?' Current schemes are designed to be seen by the officials who approve their funding. Do not get too excited by those recovered grasslands and forests you see along the highways; they only cover 10% of the total affected area. The other 90% continues to cause sandstorms. Thirdly, we need to look at the relationship between humans and nature. Arid and semi-arid areas can support only one or two people per km^2. In China, the population density in these areas is over ten people per km^2. The original inhabitants were nomadic, and moved in search of grass and water, allowing the grasslands to recover. But now they have settled, increasing the pressure on the environment – and inevitably damaging it. Measures are needed to move this scattered population into towns and cities; funds for ecological management should be used to this end. Fourthly, we must reconsider the relationship between ecological management and poverty relief. Sandstorms are caused by the consumption of grass by livestock, by the clearing of grasslands for crops and by deforestation. At present, sandstorm control programmes have little regard for the lives of local people. The money currently spent brings them scant benefit, and only helps those that receive the funding directly.

My rough calculations show that spending on major sandstorm control projects amounts to around 326 yuan (US$42) per *mu* (666.67 m^2). This works out to almost 500,000 yuan (around US$64,705) per household in the south of Inner Mongolia. If as little as one-tenth of that figure were actually spent on getting the locals to give up their livestock and to plant trees, there would be no danger of sandstorms and the locals would be financially better off – at present, none of this funding reaches them and most struggle to earn 10,000 yuan (US$1,294) per year. A fortune has been spent in one part of Inner Mongolia on restoring the grasslands, but no one can come up with the 10,000 yuan needed to protect it. Finally, we need to question the relationship between China's eastern and western provinces. At present, much of China's livestock is located in the west of the country, in ecologically vulnerable areas such as Inner Mongolia, Xinjiang and Tibet. Ideally, these animals would eat straw, which is a by-product of agriculture, but straw is found in the east, in such provinces as Shandong, Henan and Hebei, which have a far greater production capacity for animal fodder than the grasslands – 50–100 times greater in fact. This hampers the development of livestock farming. Straw in the east is simply burned, while degraded ecosystems in the west struggle to support livestock. The largest source of income for the west is funding for reforestation and environmental protection projects, with highly marked-up animal products coming second. These products cost 5–10 times as much to produce than they would in agricultural areas with better conditions. China's west should not develop its animal farming further, or sooner or later the grasslands will be grazed bare, leaving the rest of the country to pick up the bill for its recovery.

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References

Bradshaw, A. 2000. The use of natural processes in reclamation advantages and difficulties. *Lanscape and Urban Planning*, Vol. 51, pp. 89–100.

Gaoming, J. 2001. How to start in the restoration of the depleted ecosystem in Hunshandak Sands? *Chinese Youth Daily*, 25 July, p. 11.

IMP. 1996. *Compiling Committee of the Annals of the Xilin Gol League in Inner Mongolia*. Hohhot, Mongolia, Inner Mongolian Press.

Longjun, C. and Yuping, L. 2000. Population increases driving impact on desertification. *Resources and the Environment in Arid Areas*, Vol. 14, pp. 28–33.

———. 2003. Counter measures for rehabilitation of the depleted ecosystem in Hunshandak Sands. *China's S&T Forum*, Vol. 3, pp. 13–15.

McNaughton, S. J. 1990. Grazing as an optimization process: Grass-regulate relationships in the Serengeti. *The American Naturalist*, Vol. 113, pp. 691–703.

Shigong, W., Guangrong, D. and Debao, Y. 1996. A preliminary research on the sandstorm's changing trend in North China. *Journal of Natural Calamities*, No.5, pp. 86–94.

Ware, H. 1997. Desertification and population: Sub-Saharan. H. G. Michael. (ed.), *Environment Degradation in and Around Arid Land*. Boulder, CO, Westview, pp. 124–234.

Wen, S. and Gaoming, J. 2002. When will the green net trap the ‘Yellow Dragon?’ *Newton’s Scientific World*, No.7, pp. 28–30.

Xinfa, Q., Yan, Z. and Qilong, M. 2001. The sandstorm’s distributive patterns in time and space, its sources and motion routes in China. *Acta Geographica*, Vol. 56, pp. 316–322.

Chapter 6
Desertification Control for Sustainable Land Use in the Cholistan Desert, Pakistan

Muhammad Akram, Muhammad Akram Kahlown and Zamir Ahmed Soomro

Abstract The area of Cholistan Desert is 2.6 million ha. The desert measures 480 km in length and between 32 and 192 km in breadth. Human and livestock population in the desert is 0.1 and 2.0 million, respectively. There is no river or canal flowing through the desert area, which has a hyper-arid climate. The main land use in the area is livestock rearing. Agricultural farming is not practiced due to unavailability of irrigation water and low rainfall. More than 81% of the desert is under small and big sand dunes, while 19% consists of alluvial flats and sand hummocks. The area is affected by severe to very severe desertification due to poor vegetation cover, severe wind erosion and very severe soil salinity. The grazing of livestock is uncontrolled, so, the pastures are overgrazed. The Pakistan Council of Research in Water Resources (PCRWR) has converted the severe desertified land into productive land as a model on more than 100 ha at Dingarh Cholistan through sand dune fixation and stabilization by mechanical and vegetative means. Although once desertified, the area is now under forest trees, orchard of grafted *zizyphus* and date palm, fodder crops and grassland grown with collected rainwater and saline groundwater. Now the area is fully secured from desertification and its micro-climate has been transformed into pleasant and friendly environment.

Keywords Cholistan desert, desertification, integrated water management, irrigation, crop yield

1 Introduction

The total area of Pakistan is 79.6 million ha, of which 70 million ha arid and semi-arid climate, while about 41 million ha are arid, including 11 million ha of deserts. The main deserts in the country are the Thar, Cholistan, Thal and Chagi-Kharan. These deserts suffer from severe to very severe desertification due to over- and

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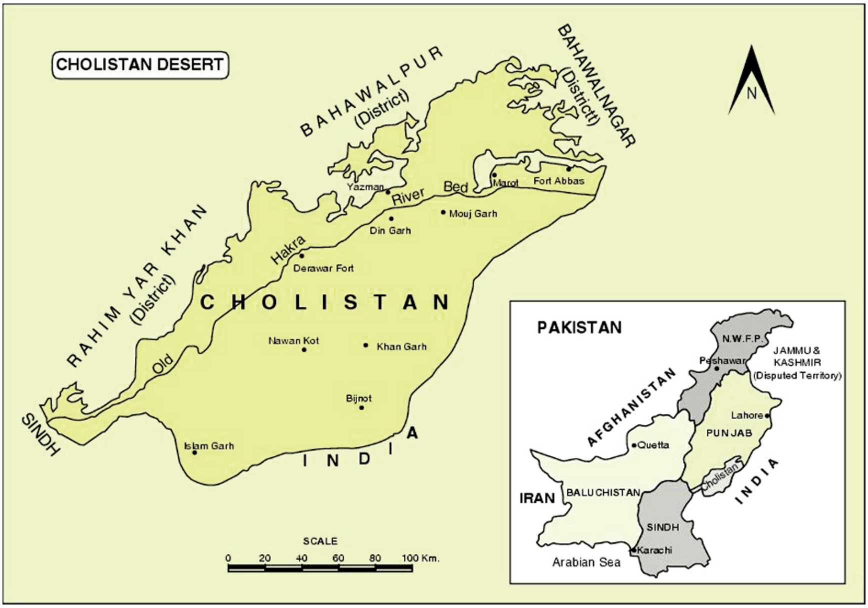
Pakistan Council of Research in Water Resources, Pakistan

mis-utilization of land, water and vegetation resources without any scientific planning and management.

The Cholistan is a vast sandy desert spread over about 26,000 km^2. It is located between latitudes 27° 42′ and 29° N and longitudes 69° 57′ 32″ and 72° 52′ 30″ E. The length of the desert is about 480 km and breadth ranges between 32 and 192 km. The two parts of the Cholistan are called the Smaller Cholistan and the Greater Cholistan. The smaller Cholistan in the north consists of alluvial flats and low sand ridges, whereas the Greater Cholistan in the south is covered with of big sand dunes. The location of the Cholistan Desert is shown on the map of Pakistan (Fig. 1). The main source of good quality water in the desert is rainfall. The groundwater in the major part of the desert is highly saline. The mean annual rainfall in the desert is low, variable and erratic. Most of the rainfall is received in the months of July, August and September, during monsoon season. The annual rainfall varies between 100 and 250 mm. About 1.13 million ha of the Cholistan is covered with large sand dunes with rolling to moderate topography. The extent of sandy soils is 0.95 million ha, which are nearly level to gently sloping with hummocks. These soils are deep to very deep, excessively drained, calcareous and coarse textured. The loamy soils are in the valleys between dunes in both parts of the Cholistan. The extent of these soils is only 0.06 million ha making 2% of the desert. The alluvial flats in the Smaller Cholistan consist mostly of fine textured clayey soils. These soils are mostly level, shallow to moderately deep, poorly drained, calcareous and saline-sodic. The extent of these soils is 0.442 million ha, making up 17% of the



Cholistan. The vegetation in the Cholistan is mostly xerophytic and halophytic, consisting of bushes, grasses, shrubs and some very drought-resistant trees. The land is not used for agriculture farming due to the hyper-arid climate, low rainfall, topography and unavailability of irrigation water. The main land use in the area is livestock grazing, which is a major source of income for the local people. Drinking water for human and livestock population is not sufficiently available. As a result, livestock production is not as successful as it might be. Due to the unavailability of drinking water for the entire year, people migrate from the area along with their animals canal-irrigated areas in search of water. They remain there until the next rainy season.

2 Status of Desertification

Desertification in the Cholistan Desert is due to degradation of soil and vegetation cover caused by various factors. Soil and vegetative degradation are factors to each other. Soil degradation processes are phenomena that cause a decrease in the quality of soils to produce crops or useful plants. The main desertification processes seen in the Cholistan Desert are: water scarcity, low rainfall, poor vegetation cover, wind erosion, soil salinity and very poor physical properties of soil, e.g. porosity, permeability, and crusting. Climate is also one of the major contributors to desertification in the Cholistan Desert. Dryness of atmosphere, sporadic and erratic rainfall, and a high rate of evaporation cause reduction in growth vegetation cover. As a result, bare soil is easily affected by wind erosion, which causes land degradation that leads to desertification. The extent and severity of desertification in the Cholistan is given in Table 1.

Table 1 Extent and severity of desertification in the Cholistan

Desertification Class	Extent (ha)	%age	Causes
Moderate	58,700	2.0	Moderate sand migration due to wind erosion, vegetation cover above 30% and less than 50%, moderate soil salinity and hyper-arid climate.
Severe	2,079,400	81	Vegetation cover less than 30%. Area under big sand dunes, small sand ridges and hummocks, severe wind erosion and hyper-arid climate.
Very severe	441,900	17	No vegetation cover or vegetation cover less than 10%, saline-sodic impervious fine textured soils, pH more than 9.0, very hard soils, non porous and very poorly drained soils.
Total	2,580,000	100.00	

3 Desertification Control Measures

3.1 Management of Water Resources

The Pakistan Council of Research in Water Resources conducted research on a rainwater harvesting system and identified the potential of runoff to be more than 350 million m^3 from an average annual rainfall of 160 mm in normal rainy years to develop water sources. Arrangements for rainwater harvesting and collection have been made in 92 reservoirs, each with a storage capacity of 15,000 m^3 for drinking by the human and livestock populations. To harvest and collect all estimated potential quantity of rain runoff, 21,000 such reservoirs would be needed. The water requirement for human and livestock consumption is 0.1 million m^3 and 2.0 million m^3, respectively, ill Rainfall Cholistan is about 7.0 million m^3, while the remaining annual rain runoff of 343 million m^3, after meeting drinking water requirements, can be made available for farming of precious vegetables and fruit trees in the Cholistan to develop more economic resources to upgrade the socio-economic status of the community.

3.2 Integrated Water Management of Resources

A network of water resources has been established by the PCRWR in the Cholistan Desert by developing 92 specially designed reservoirs at appropriate locations, normally 10–15 km apart with water storage capacity of 15,000 m^3 (4.0 million gallons), yielding a total of 1.35 million m^3 (368 million gallons) from all reservoirs annually. Twenty specially designed deep tubewells have been installed by the PCRWR with an annual discharge of about 7.0 million m^3 (1,405 million gallons) in the Cholistan Desert, where groundwater is usable for drinking by humans and livestock. Two Reverse Osmosis Plants have been installed to desalinize highly saline groundwater with desalination capacity of 0.01 million m^3 annually for human and livestock drinking. The developed water sources have been distributed throughout the Cholistan, taking into consideration the human and livestock populations in order to meet their drinking water requirements (the overall drinking water requirements annually for humans and livestock is about 7.0 million m^3 – 1,681 million gallons). Water sources have in fact been developed to provide more than 8.4 million m^3 (1,800 million gallons) of water annually. Now drinking water in the desert is available throughout the year. As a result of water source development, human and livestock migration due to water shortages has stopped and has saved the annual loss of 6 billion rupees caused by the reduction in livestock production due to mortality, disease, reduction in meat and milk as well as damage to crops in canal-irrigated areas. Furthermore, the microclimate around the reservoirs has also become welcoming to wildlife. Birds and other wildlife can now be frequently seen around the reservoirs and new and greater numbers of vegetation species have also been identified.

Table 2 The survival and growth data of trees

Age (months)	Zizyphus			Acacia			Eucalyptus			Tamarix		
	Survival %	Height (cm)	Canopy cover (cm)	Survival %	Height (cm)	Canopy cover (cm)	Survival %	Height (cm)	Canopy cover (cm)	Survival %	Height (cm)	Canopy cover (cm)
6	84	37	–	77	57	–	86	53	–	72	35	–
8	57	49	–	75	61	–	83	66	–	60	55	–
12	51	59	–	73	80	–	82	84	–	53	71	–
22	43	104	51	68	115	100	82	129	80	53	96	82
25	43	118	82	66	131	126	80	149	101	53	106	112
Average	56	73	27	72	89	45	83	96	36	58	73	39

3.3 Sand Dune Fixation and Stabilization by Afforestation

Desertification in Pakistan is rapidly reducing capacity in dry areas for producing human and livestock food, timber, fuelwood and other utilities. Desertification of sandy deserts in the country has gained momentum due to wind erosion, timely efforts are required to halt its damage. The main cause of wind erosion, in the desert is poor vegetation, cover resulting from overgrazing by livestock. Migrating sand is advancing towards irrigated lands adjacent to the desert periphery and threatening their utility for crop production. The sand particles move progressively with the prevailing winds and encroach upon valuable range and agricultural lands, rendering them useless and causing abandonment of human settlements, roads, irrigation systems and other valuable structures. Wind erosion becomes a serious problem particularly during the summer months and dry periods, when soils are exposed to strong winds due to the absence of vegetation cover. Livestock grazing is the major land use in these deserts. Grazing is uncontrolled, which results in overgrazing that continues to decrease the vegetative cover. Stabilization of sand dunes with perennial vegetation cover is the only sustainable way to halt sand migration towards irrigated fertile lands, and to avoid their abandonment and to produce timber, fuelwood and forage for livestock. This will rehabilitate desertified land and protect it and the surrounding area against desertification. The stabilization of mobile sand can be achieved by prohibiting free livestock grazing and by re-vegetation with drought-resistant species of afforestation trees, grasses and shrubs. At Dingarh shifting sand had been fixed by micro-barrier fences in a checkerboard form before plantation to create an environment for successful growth of plants. There micro-fences for dune fixation had prevented the movement of sand for long enough to enable natural and planted vegetation to become established. Alternative irrigation with rainwater and saline water helped the plants to grow fast, thereby playing an important role in developing good vegetative cover to protect bare soil from wind erosion. Perennial tree species, such as *Acacia*, *Tamarix*, *Zizyphus*, *Parkinsonia*, *Prosopis*, *Ampliceps* and *Eucalyptus*, were used to develop excellent vegetation cover on the mobile sandy area affected with wind erosion. The survival and growth data of trees is shown in Table 2.

The canopy cover in the wind-erosion-affected area before and after plantation of tree species with intervals of 5–12 years was measured, data for vegetation canopy is given in Table 3.

Canopy cover before plantation was between 10% and 32% among the 11 traverses. Five years after plantation, the canopy cover improved between 75% and 98%. After 12 years, the vegetation canopy was between 73% and 93%. The same area that once had poor vegetation cover before the start of desertification control activities now has excellent vegetation cover. The area is free from wind erosion. The tree species created a favourable environment for the growth of other natural vegetation species and acted as windbreaks to protect the soil surface against strong winds. The area under this plantation is completely stabilized and is beautifully green – a botanical garden in the desert.

Table 3 Canopy cover in the wind-erosion-affected area before and after plantation of tree species: Data for vegetation canopy

	Canopy cover in percentage										
Traverse No.	1	2	3	4	5	6	7	8	9	10	11
Before fencing and plantation	10	14	15	22	18	25	32	26	27	27	20
After 5 years	85	75	90	96	96	93	90	98	92	95	90
After 12 years	87	75	89	86	74	87	93	83	73	89	81

3.4 Rangeland Development

The overgrazed area devoid of vegetation was converted into good rangeland by fencing and prohibiting free livestock grazing, as well as by introducing different species of trees, bushes and grasses. The comparison of vegetation species with number of plants in the natural grazing land and controlled grazing land per 25 m^2 is given in Table 4. In the developed area, there were 11 species observed and in the natural grazing area there were six. There were more species of palatable grasses and bushes in the developed area, while in the area free to natural grazing, non-palatable species of vegetation were dominant.

3.5 Grassland Development

Dry biomass of cultivated grasses under saline water irrigation and natural grazing land at Dingarh with carrying capacity of each is shown in Table 5.

Natural grazing land produced 1,141 kg of dry biomass of palatable vegetation per hectare, while cultivated grasses under saline water irrigation – namely, *Cenchrus ciliarus*, *Panicum antidotale*, *Lasurus sindicus*, *Napier bajra* (wild millet) – produced dry palatable biomass of 15,012 kg, 12,407 kg, 18,274 kg, and 38,780 kg per ha, respectively. The carrying capacity of natural grazing land per hectare is 1.25 sheep, whereas fodder grasses cultivated under saline water irrigation had dry biomass 10–35 times more per hectare than natural grazing land. It indicated that if desert lands are properly seeded with the best grasses and irrigated even with saline water, the carrying capacity for livestock can be enhanced 10–35 times that of the natural grazing land of desert.

3.6 Introduction of Orchard Plants

An orchard of date palm, grafted *ber* and local *ber* has been developed successfully at Dingarh in the Cholistan Desert. The area of the orchard is about 10 ha, with of

Table 4 Comparison of vegetation species in controlled and natural grazing areas

		Controlled grazing area						Natural grazing area							
		Sites						Sites							
		1	2	3	4	5	6	7	1	2	3	4	5	6	7
S. No.	Name of species	No. of plants						Natural grazing area							
1.	*Cenchrus* (Dhaman)	16	3	–	10	3	6	–	–	–	–	–	–	–	–
2.	*Sindicus* (gorkha)	–	1	8	6	6	7	26	–	–	–	1	1	1	–
3.	*Eleusine* (Chimber)	–	60	32	–	80	150	–	–	–	–	–	1	–	–
4.	*Cymbopogan* (Khavi)	–	3	35	6	23	16	2	–	–	9	10	26	4	8
5.	*Calligonum* (phog)	–	3	–	1	1	–	–	–	1	1	1	–	–	–
6.	*Haloxlon* (lana)	–	–	–	–	–	5	18	–	–	–	–	–	–	–
7.	*Dipteregium* (lathia)	1	1	–	1	–	–	–	1	–	12	22	6	2	–
8.	*Aerua jawanica* (bui)	–	–	–	–	–	–	–	1	1	–	–	–	–	–
9.	*Mohabat Booti*	–	–	–	–	–	–	10	–	–	–	–	–	–	–
10.	*Atriplex*	1	1	–	–	–	–	–	–	–	–	–	–	–	–
11.	*Aristida depressa* (lumb)	–	–	–	–	–	–	16	–	–	–	–	–	–	–
Total:		18	72	75	24	113	184	72	2	2	22	34	34	7	8

2 ha of dates, 3 ha of grafted *Zizyphus* and 5 ha of local *ber*. The source of irrigation is rainwater collected in the reservoirs, as well as groundwater pumped by a turbine pump. The quality of groundwater is moderately to highly saline. Therefore, irrigation of orchard plants uses in the early stage, for one year, rainwater followed by irrigation applied alternatively with saline water and rainwater. The soils of the area are sandy and well drained. The local *Zizyphus* and grafted *Zizyphus* that were planted are bearing fruit, while dates are growing well and will bear fruit after another two years.

3.7 Growing of Salt-tolerant Crops with Saline Water Irrigation

The yield from barley and mustard crops irrigated with highly saline groundwater were lower than yields from these crops with irrigation of good quality river water. The crop yield from per hectare of different blocks is given in Table 6. The salinity environment around the root zone of the plants reduced their vegetative and root growth. As a result, the plants remained stunted and produced less yield than under non-saline conditions. The yield is classed as good to poor. The good and moderate

Table 5 Dry biomass of cultivated grasses with associated carrying capacity

		Carrying capacity per year			
Grass species	Dry biomass (kg)	Camel	Goat	Sheep	Cattle
Cenchrus ciliaris	15,012	2	14	16	3
Panicum antidotale	12,407	1	11	14	3
Lasurus sindicus	18,274	2	17	20	4
Wild millet	38,780	4	35	42	9
Natural grazing land	1,141	–	1.25	1.25	–

Table 6 Yield of crops per hectare of each block

Block and plot no.	Crop grown	No. of plants (m^2)	Height of plants (cm)	No. of tillers/ branches	No. of pods/No. of grains per plant	Yield per/ha (kg)
1	Barley	22	48	8	30	205
2	Barley	45	92	28	62	609
3	Barley	40	81	23	49	593
4	Barley	24	51	11	33	228
5	Barley	18	39	7	27	185
6	Barley	33	61	14	42	383
1	Mustard	11	70	10	125	124
2	Mustard	24	103	18	186	317
3	Mustard	5	60	6	80	111
4	Mustard	11	75	8	113	158
5	Mustard	30	135	25	295	418

yields from barley and mustard crops occurred where the soils were well drained, and at a level with adequate availability of moisture to the seeds for germination and growth. Poor yields of barley and mustard occurred where soils were poorly drained and germination of seeds was less. To obtain a good yield of crops using saline water irrigation, it is essential to select rapid percolating soils and precision-levelled fields to avoid adverse effects of salt found in saline water on seed germination and subsequent growth. Crop yields using saline water irrigation also depend on the salt tolerance of each crop, management practices, application of fertilizers, addition of manures and amendments, as well as the environment in which the crop has been grown.

4 Conclusion

To control desertification in desertified areas for sustainable production it is necessary to adopt an integrated approach for the better utilization of available local water, land and plant resources scientifically.

Bibliography

Akram, M., Abdullah, M., and Khan, A. D. 1990. Management of resources in deserts for their development. *Proceedings of National Seminar on Water Resources Development and its Management in Arid Areas*, 6–8 Oct 1990 at PCRWR, Quetta, Pakistan, pp. 44–51.

Akram, M., Abdullah, M., and Majeed, A. 1991. Role of surface and ground saline water for agriculture development in Cholistan desert. *Proceedings of the National Seminar of the People's Participation in the Management of Resources in Arid Lands*, 11–13 November 1990, Bahawalpur, Pakistan, pp. 53–60.

Akram, M. and Abdullah, M. 1990. Wind erosion and sand dune stabilization in the Cholistan desert. *Proceedings of the International Symposium on Applied Soil Physics in Stress Environments*, 22–26 January 1989. PARC, Islamabad, Pakistan, pp. 323–334.

Akram, M., Malik, M. K., Khan, W. A., Sheikh, B. A. and Khan, A. D. 1996. Transformation of sand dunes in to forest and grassland: A Geographical case study of Cholistan desert. *Journal of Pure and Applied Sciences*, Vol. 15, No. 2, pp. 27–38.

Akram, M. and Chandio, B. A. 1998. Conjunctive use of rainwater and saline groundwater for desertification control in Pakistan through agro-forestry and range management. *Journal of Arid Land Studie*s, Vol. 7S, pp. 161–164.

Akram, M. and Sheikh, B. A. 1999. Desertification, its issues and control achievements during the 20th century in Pakistan: *Proceedings of the National Workshop on Water Resources Achievements and Issues in 20th Century and Challenges in the Next Millennium*, 28–30 June, 1999, Islamabad.

Chapter 7
Policy Analysis in Grassland Management of Xilingol Prefecture, Inner Mongolia

Zhang Qian and Li Wenjun

Abstract According to Clementsian succession theory and the property rights theory, grasslands could be used in a sustainable way because the herders would control their livestock population within its carrying capacity to protect grassland when they have long-term usufruct of their grasslands. However, the 20-year implementation of the policy of Livestock and Grassland Double-Contract Responsibility System (LGDCRS) in Xilingol Prefecture based on these two theories indicates that this mechanism does not work well. Moreover, the six-year implementation of the policy of Fencing Grassland and Moving Users (FGMU) also falls short of its objective to restore degraded grasslands by stopping grazing seasonally or even annually. Based on a review of the development of dominant theories on grassland management, as well as 22 interviews in different banners in Xilingol Prefecture, three problems in the implementation of LGDCRS and FGMU in Xilingol Prefecture were analyzed: (i) neglect of characteristics of the grassland ecosystem; (ii) three defects in implementation: non-operational standard of carrying capacity, lack of expected external preconditions, and the expanding gap between rich and poor; and (iii) huge cost of FGMU policy. Due to these problems, the designed goals of these two policies, including the control of grassland degradation and the development of livestock breeding, cannot be achieved.

Keywords Grassland management, Livestock breeding, equilibrium ecosystem theory, carrying capacity

1 Introduction

As part of desertification process, grassland degradation has attracted much attention from the Chinese Government and scholars abroad, especially after the frequent and widespread sandstorms in spring 2001. The process of grassland degradation and its reasons have been analyzed from the perspectives of ecology (e.g. Clements, 1916; Holling, 1973; Westoby et al., 1989; Li, 1990, 1997; Zhang, 1995), economics (e.g.

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Liu, 1990; Zhang, 2002; Ning Baoying, 2004; Dalintai and Alatengbagena, 2005), and the social institutions and cultural context (Hardin, 1968; Humphrey and Sneath, 1999; Sneath, 2000; Williams, 2002; Enkhee, 2003) by many scholars around the world. Livestock breeding, the main livelihood of the Mongolian people, has played an important and reciprocal role in terms of grassland health for thousands of years. Correspondingly, the people living in this environment have formed their specific lifestyle and culture. However, the property rights arrangements of livestock and grasslands have changed nine times following the establishment of the People's Republic of China in 1949 (Williams, 2002). They have had great impact on livestock breeding, and consequently exerted great influence on grassland health.

Among these changes, the implementation of Livestock and Grassland Double-Contracted Responsibility System (LGDCRS) from 1984 was the most important change to livestock breeding because it had totally changed the herders' lifestyle from nomadism to settlement. The main objective of the policy was to develop animal husbandry (BAHIM, 2000: 245) and protect grassland (Zhou, 1984). However, policy implementation over 20 years revealed that the goals were not achieved: the degraded grassland was expanding and for most herders their living conditions did not improve. According to the comparison of data from 1984 and 1999 conducted by Kang and Xu (2004), the proportion of degraded grassland occupying available grassland had expanded from 48.6% in 1984 to 64% in 1999, the vegetation coverage decreased from 35% to 27.2%, and average biomass production per hectare decreased from 509 kg to 320 kg. Correspondingly, the carrying capacity of the available grassland fell from 25 million standard sheep units[1] (SSU) in the 1960s to 10.4 million in 2003 (Kang and Xu, 2004). Meanwhile, herders' income from livestock breeding increased slowly but then fell after 1999. During the period from 1998 to 2002, the disposable income of the urban residents of the whole country increased by 8.6% per year, and was equal to 3.8% for farmers living in agricultural areas but decreased by 1.9% for herders living in pastoral areas in Inner Mongolia (Dalintai, 2006).

These results not only impede economic development in Inner Mongolia but also threaten the ecological health of the whole country. Since 2001, in order to combat grassland degradation, the local government carried out a policy called 'Fencing Grassland and Moving Users (FGMU) with support from the central government. However, the trend 'improved on some sites but degraded on a large scale" (MOA, 2006) and the difficulty in livestock breeding did not change at all. To achieve sustainable development in pastoral area, it is necessary to rethink LGDCRS and FGMU policies, including its theoretical bases and practical implementation. Only in this way can we understand the roots for grassland degradation and the stagnant development of animal husbandry in Inner Mongolia, and consequently the reasons for the problems behind these policies.

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[1] Standard Sheep Unit (SSU) is a hypothetical animal and considered to be equal to one mature ewe of approximately 50 kg with a lamb younger than a half year, and having 1.8 kg standard hay per day. (www.chinaforage.com/standard/zaixuliang.htm, accessed June 2007). In the following calculation on carrying capacity in this paper, one cattle equals to five SSU based on the food requirement.

2 Literature Review

2.1 Equilibrium Ecosystem or Non-equilibrium Ecosystem in Dryland Grassland

During the last 30 years, a debate on the sources and types of dynamic behaviour driving ecological systems has been developed with a special focus on grassland management in drylands (Sullivan and Rohde, 2002). This debate focuses on the most suitable theory to be used in drylands management: equilibrium ecosystem theory or non-equilibrium ecosystem theory. The equilibrium ecosystem theory is developed on the basis of Clementsian succession theory, which is defined by a given ecological site where there is typical and continuous vegetation composition – the climax vegetation is in equilibrium with a given climate and soil conditions. Moreover, grassland degradation is defined as the status of grassland deviating from the climax vegetation to a large degree under the influence of human activities, such as grazing, reclamation and firewood collection (Li, 1990). Based on this theory, the goal of grassland management is to maintain the balance between the livestock population and biomass productivity by adopting a conservative grazing strategy (Bartels et al., 1990). This was precisely the objective of LGDCRS and FGMU implementation in Inner Mongolia: they were to protect the grassland by controlling the amount of livestock grazing on the grassland.

Arid environments – which typically experience rainfall with a greater than 33% interannual coefficient of variation – are so dominated by variability that they can be distinguished from equilibrium systems (Illius and O'Connor, 1999). Large fluctuations in primary productivity associated with low and erratic precipitation regimes are hypothesized to prevent herbivore populations from effectively tracking forage availability and thereby minimize negative feedbacks between grazing intensity and vegetation dynamics (Ellis and Swift, 1988). This kind of system, which is more vulnerable to external disturbances, was called a non-equilibrium ecosystem (Briske et al., 2005). Based on this, the opportunistic strategy of livestock breeding was proposed. Using this theory, many new range ecologists are trying to determine the extent to which rangeland degradation (including desertification) is caused by livestock overgrazing and the extent to which it is a result of a natural waxing and waning process of rangeland in response to rainfall (and thus is not "degradation" at all) (Ho, 2001).

2.2 Property Rights Theory and the Development of Neo-institutional Economics

Based on the mechanism of "tragedy of commons" described by Hardin (1968), the notion of common property seems extremely risky in terms of grassland protection. Through the privatization of grassland, where the owners of land and animals are the same person (Humphrey and Sneath, 1999; Williams, 2002), the herders would bear all costs due to degradation of the grassland, which would encourage the rational use of grassland. This is another reason for LGDCRS implementation aimed at encouraging herders to protect their own grassland mainly by controlling livestock population (Li et al., 1993), as well as encouraging herders to work harder by initiating livestock breeding. This is the main content of the property rights theory.

The development of neo-institutional economics (NIE) has greatly influenced classical property rights theory and can be summed up by two aspects. One aspect is *homo oeconomicus*, defined in NIE as bounded rationality (Simon, 1957) rather than complete rationality in classical economics. The other aspect is that transaction costs exits and are not zero. Moreover, in any given location, common property status does not necessarily lead to, nor does it suffice to explain, the event of resource depletion (Williams, 2002: 73). In fact, the legal framework of land property rights was not as important as some economic factors. Whenever the conditions supporting production had been achieved, and thus improved agricultural production and natural resources management, the question of whether the land was private or collective was no longer important (ibid.).

3 Case Study and Methodology

3.1 Case Study Area

Xilingol Prefecture is located north of China and northeast of Inner Mongolia (Figs. 1, 2). It is bounded by 111°59′E and 120°E longitude and 42°32′N and 46°41′N latitude. In Xilingol Prefecture, the available grassland is equal to 17.8 million ha and occupies 90.6% of the natural grassland. The representative type of grassland is typical *stipa* steppe. Meadow steppe and semi-desert steppe can also be found. During the 47 years from 1949 to 1995, Xilingol Prefecture had provided 43.4 million livestock, 1.7 million t of meat, 0.4 million t of wool, 8,700 t of cashmere, 5,500 t of camel hair, 46.3 million pieces of hide and 1.7 million of milk to the national market, and the total production value was US $1.5 billion (Qi et al., 2002: P28).

3.2 Methodology

Based on the accumulated knowledge of several field studies in Xilingol Prefecture, it was decided to conduct fieldwork (April, 2006) in different places in Xilingol Prefecture so as to gain a comprehensive understanding of the herders' lifestyle and production. Twenty-two herders from three different zones participated in interviews (Fig. 1). The main banners where interviews were conducted include East

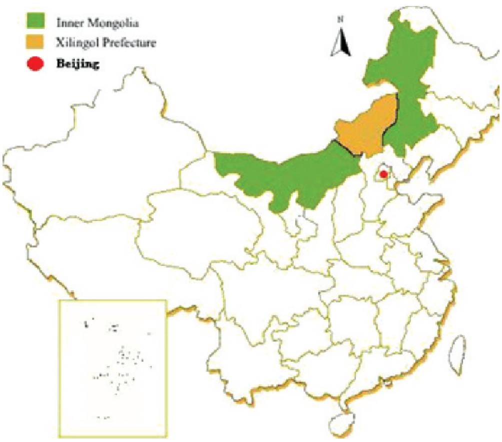

Fig. 1 Location of Xilingol Prefecture in China

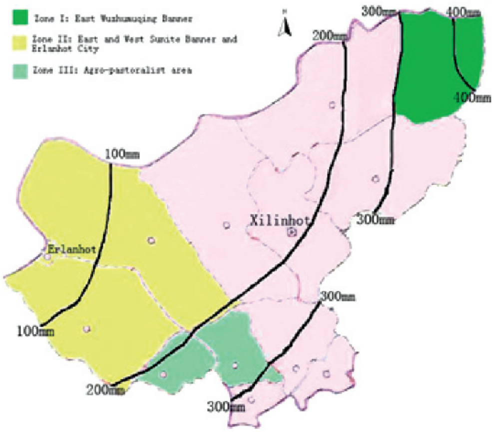

Fig. 2 Zonation in Xilingol Prefecture (from WBIM, 2006)

Wuzhumuqing Banner (Zone I), East Sunite Banner and West Sunite Banner (Zone II), Zhenglan Banner, Sanggendalai Town and Zheng Xiangbai Banner (Zone III).

Considering the distance of each herder's household, the first interviewees were stochastically selected close to the road network. The interviewee was then asked to recommend another herder's family according to our needs. In order to increase the representative level of interviewees, we attempted to cover the different income levels of the interviewees through recommendations by herders. Taking into consideration livestock population and household net income, the widest representative level of interviewees was found in East Sunite Banner, and lowest in Zheng Xiangbai

Banner. Interviewees in East Wuzhumuqing Banner represented the most averagely distributed herders.

The interviews adopted a method using a semi-structured questionnaire that covered asset items, the cost and benefit of livestock breeding (in 2005), living expenditures, and their viewpoints on LGDCRS and FGMU policy. The Cost-Benefit Analysis (CBA) tool was mainly used in the analysis of herders' livestock breeding.

4 Findings

According to the CBA of the present status of livestock breeding in Xilongol Prefecture, it was found that the problems with the LGDCRS and FGMU polices could be summed up in three aspects that make it impossible to achieve the designed goals of these two policies, including the control of grassland degradation and the development of livestock breeding.

4.1 Neglecting the Characters of Grassland Ecosystem in Policy-making

The annual precipitation in most of Xilingol Prefecture is less than 300 mm. And the variability of rainfall was above 30%, and thus it was a typical non-equilibrium grassland ecosystem (Dalintai, 2004). It means that the abiotic factors are exerting much more influence on ecosystem than the livestock. However, the unified LGDCRS and FGMU implementation of grassland management in Xilingol Prefecture has always paid less attention on abiotic factors than livestock population, which has compelled herders to cope with the variety of primary productivity of natural grassland, high risk of natural disasters and decline of the multi-functions of grassland ecosystem individually as stated below. Therefore, the herders have no capability to develop animal husbandry continuously and protect grassland at the same time, which are the goals of LGDCRS and FGMU policies.

4.1.1 Variety of Primary Productivity in a Non-equilibrium Ecosystem

According to the definition of a non-equilibrium ecosystem by Ellis (1994), and our survey data, the grassland ecosystem in East and West Sunite Banner is typically a non-equilibrium ecosystem, while the grassland in East Wuzhumuqing Banner is comparatively in equilibrium because its annual rainfall is over 300 mm (Fig. 1). The different ecosystems have exerted a great influence on the cost composition of the two sites. Erridunbater from East Wuzhumuqing Banner and Chai Liansuo from East Sunite Banner were selected (Fig. 2) for a comparative study of their cost

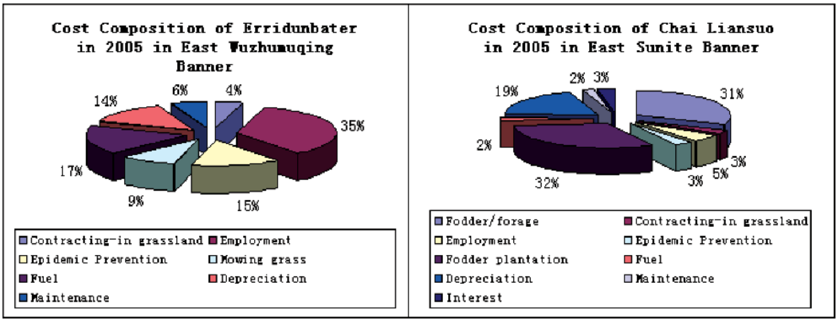

Fig. 3 The comparison of cost composition of two herders from two banners

composition. They have a similar livestock population: one is 765 SSUs and the other is 850 SSUs. First, the biggest difference can be seen in the fodder/forage cost. In Erridunbater, they did not buy any fodder/forage in 2005, but in Chai Liansuo 31% of total cost was spent on it (Fig. 3). Secondly, in Erridunbater, hay was extracted from the natural grasslands, while in Chai Liansuo they needed to plant fodder/forage to compensate for the shortage of animal feed. The cost of mowing grass from natural grassland was 9% of Erridunbater's total cost, including payment for labour and the expenditure on the machinery. However, the cost of fodder plantation was 32% of Chai Liansuo's total cost. Clearly, these results reveal the difference in abiotic factors between the two places. As a result, the net household income in Erridunbater is over 11 times greater than that in Chai Liansuo, even though the latter has 85 SSUs more than the former.

4.1.2 High Risk of Natural Disasters but Slow Recovery in Livestock Breeding

The potentially high risk of natural disasters and slow recovery in livestock population is the most important cause of bankruptcy for the herder. Many natural disasters threaten the development of animal husbandry, including drought, blizzard, sandstorm and locust plague. This is made worse by the fact that the cycle of livestock breeding is much slower compared with cropping cultivation. The frequent natural disasters increase the non-equilibrium relationship between rainfall variation and livestock population. Table 1 shows an example of the recovery of livestock population following a natural disaster. Supposing the population of productive ewes decreased from 100 to 50 after a blizzard in year t, there are three assumptions: (i) the gender proportion of newborn lambs is 1:1; (ii) the first lamb of a productive ewe is born after the ewe is 2 years old; and (iii) all the male lambs are sold off. As shown in Table 1, the population of productive ewes will not recover until the year $t+4$.

Table 1 The slow recovery of productive ewe population after a natural disaster

Year	Productive Ewes	Female lambs	Male lambs	Ewe of 1-year old	Sold sheep	Reserved sheep
t	50	0	0	0	0	50
t +1	50	25	25	0	25	75
t +2	50	25	25	25	25	100
t +3	75	37.5	37.5	25	37.5	137.5
t +4	100	50	50	37.5	50	187.5

4.1.3 Abandonment of the Multi-functions of Grassland Ecosystem

In addition to the function of supporting animal husbandry, the grassland ecosystem has many other ecological functions, including: providing a habitat for wild animals, such as wolves and Mongolian gazelle (*Procapra gutturosa*); protecting cities from sandstorms; adjusting climate; and preserving biodiversity. However, the implementation of LGDCRS distributed grassland to the herders as simple productive capital but neglected the other ecological functions of the grassland ecosystem. Following LGDCRS, a herder, Enhebatu, noted that Mongolian gazelle and wolf numbers had decreased because fences blocked their movement. As a result, the economic function could not be maintained without the protection of *all* these ecological functions.

4.2 The Fatal Defects in LGDCRS Implementation

The privatization of livestock and grassland usufruct has definitely encouraged herders to work harder in animal husbandry because they have a residual claimant right for the income from their livestock. However, there are three fatal defects in LGDCRS implementation, making it impossible to achieve the goals of LGDCRS. Herders have become more dependent on the unsteady quality and quantity of natural resources and spent increasing amounts on livestock breeding due to the decrease in herders' cooperation. Meanwhile, the government has lost control of livestock population growth in the implementation of LGDCRS.

4.2.1 Unpractical Standard of Carrying Capacity

According to the data from the interviews, there is a vast difference in the carrying capacity of the various banners, or even in different Sumus within one banner. Moreover, the carrying capacity also varies according to the changing annual precipitation on each site. However, the present carrying capacity standard is simply the relationship of the livestock's fodder requirement to the grassland area but not to the biomass production as it is defined. Chai Liansuo, one of our interviewees in East Sunite Banner, suggested that grassland with fences or grazing rotation could support as much as double the standard carrying capacity regardless of whether the biomass productivity could double due to the fence or rotation. Therefore, in practice, carrying capacity has lost its significance.

Moreover, it seems that herders never think of the carrying capacity standard as scientific. For example, the three interviewees in East Wuzhumuqing Banner all thought that they could acquire more livestock without grassland degradation because of their experience in animal husbandry. However, herders in the other three western banners are obliged to buy huge amounts of fodder/forage to maintain their livestock populations even if they are below the carrying capacity standard. The livestock population was maintained principally because of the herder's ability to buy fodder/forage and the anticipated future development when climate conditions improved. The carrying capacity standard was hardly considered when herders made decisions about the livestock populations.

4.2.2 Increasing Productive Cost and Decreasing Social Services

In addition to the great increase in fodder/forage cost due to the ecosystem characteristics as stated above, there are two more reasons causing the increase of productive cost following LGDCRS implementation. On the one hand, cooperation – as an important method to save productive cost in livestock breeding – lost its role after LGRCRS implementation when livestock breeding was based on household units, especially in the western banners of Xilingol Prefecture. On the other hand, herders cannot escape displacement from natural disasters but can only reduce the consequences of disasters by investing in infrastructures and buying more fodder and forage. Moreover, herders cannot sell off their livestock products at reasonable prices. According to data in our field survey, most of the interviewees are selling their livestock products to "wild traders" and are not transporting and selling their products directly to local markets. Therefore, most of the products sold were sold at prices set by the traders with some bargaining by herders. Herders explained that prices would be lower if they transported their livestock products directly to the city because the living sheep would have to be sold quickly, thereby forcing them into a weak negotiating position.

As far as the social services are concerned, many of the prior social services provided during the collective period were cancelled during LGDCRS implementation but without reasonable substitution. 'Everything needs to be bought', as Enhebatu, one interviewee in East Wuzhumuqing Banner, complained. Compared with 'moving schools on horse' and the union of collective health care during the collective period, the cost of education and health care has increased dramatically, which has bankrupted a number of herders.

4.2.3 Expanding Gap between the Rich and the Poor

Settled livestock grazing following the distribution of livestock and grassland to individual herder households made the herder increasingly dependent on the quality

Table 2 Comparison of household net income from livestock breeding in different banners in 2005 (Unit: USD)

	East Wuzhumuqing Banner	East Sunite Banner	West Sunite Banner	Zheng Xiangbai Banner	Dairy cattle breeding village
Max	9,426	8,489	1,548	4,659	−2,596
Min	6,685	−6,288	93	4,013	−3,026

and quantity of their natural resources. The increasing gap between the rich and the poor has hindered cooperation between rich and poor herders, which consequently hampers grassland protection – the basis of an integrated ecosystem – and prevented the poor from developing animal husbandry.

The comparison of net income from livestock breeding is shown in Table 2. The highest net income from livestock breeding was found in East Wuzhumuqing Banner and the lowest was found in East Sunite Banner. According to fieldwork data, herders in East Wuzhumuqing Banner developed livestock breeding in the traditional way with different forms of cooperation among the herders. However, natural disasters and limited natural resources restricted cooperation between the herders in East Sunite Banner, where herders did not invest in developing similar cooperation because they were struggling to maintain their livestock populations and find ways to compensate their loss in animal husbandry. The poorer herders were in a weakened position to negotiate and cooperate on equal terms with the wealthier herders. Moreover, they were deprived of the chance for development because their productive capital, such as forage and ewes, was taken away by the renters to pay back the loans.

4.3 Unsustainable Implementation of FGMU Policy

Until the end of 2004, the central government had invested US $154 million to combat grassland degradation in Xilingol Prefecture (Weng, 2005), which, in terms of grassland protection, was a huge investment. On average, this was equal to US $38.5 million per year from 2001 to 2004. However, according to the official criteria for ecological compensation and actions to halt grazing in the grassland area, the total amount of the ecological compensation was US $71.7 million in 2004, which was almost twice the practical government budget.

To reduce the deficit between the practical budget and the ecological compensation criteria, the government and herders undertook different measures. For example, local government officials decreased the amount of ecological compensation paid to the herders. According to data from the interviews, herders, especially those who moved out of the grassland and switched activities to breed dairy cattle, did not get the expected amount of compensation. Moreover, none of the promises made by the government, such as the support of health care, education and compensation, were realized. According to herders, the ecological compensation paid to the majority of the interviewed herders was the amount calculated based on stopping seasonal grazing equal to US $1.1 per ha, regardless of whether grazing was stopped annually by the adoption of pen-raising or immigration to villages breeding dairy cattle. Indeed, ecological compensation promised by the government for stopping annual grazing should have been 345 kg old stock grain per ha, which was about US $43 per ha. In fact, in order to compensate for the shortage of fodder and forage, the herders surreptitiously graze their livestock at night during the cessation of grazing. The most common measure was for herders to buy increasing quantities of fodder and forage from outside sources. In short, the implementation of the FGMU policy was not sustainable for all the stakeholders because of the dishonest activities of some of the herders due to fund shortages, despite the enormous funds already disbursed.

5 Conclusion

Based on the above analysis of the theoretical bases and present status of the implementation of the LGDCRS and FGMU policies, we found that the problems encountered with these policies have made it impossible to achieve the goals, for three reasons. First of all, the ecological basis of the LGDCRS and FGMU policies – the equilibrium ecosystem theory – is not suitable for most of the grassland in Xilongol Prefecture because it is a non-equilibrium ecosystem where annual precipitation is below 300 mm. The variety of fodder/forage, the high risk of natural disasters coupled with slow recovery, and the declining economic function of the grassland ecosystem have made it difficult for the herders to conduct livestock breeding based on the working unit at the individual household level. Secondly, the non-operationality of the carrying capacity standard resulted in the governments losing its capacity to control the livestock population to protect grassland. In addition, increasing production and living costs have made it difficult for herders to make their living solely through livestock breeding. Moreover, the expanding gap between the rich and the poor has made it difficult for herders to cooperate, and they have become increasingly isolated from each other. Finally, the huge cost of the FGMU ensured that effective implementation was impossible.

Therefore, the goals of these two policies – protecting grassland and developing livestock breeding – cannot be achieved because of the integrated effects of the three problems mentioned above. Meanwhile, the continuous drought, which has lasted almost seven years, has also devalued the implementation of these policies, the FGMU policy in particular. One interviewee in East Sunite said that he could not herd sheep anyway, even though there was no policy to cease seasonal grazing, because of the lack of rain and therefore of grass. To help the herder combat drought, it may be useful and feasible in Xilingol Prefecture, the methods that promote small-scale cooperation between herders so as to decrease their productive cost and maximize the prices of livestock products by selling them to the correct market.

References

Bartels, G. B., Norton, B. E. and Perrier, G. K. 1990. *The Applicability of the Carrying Capacity Concept to Africa*. Comment on PDN Paper 29b by de Leeuw and Tothill. Pastoral Development Network. Paper No. 30e, Overseas Development Institute, London.

Bureau of Animal Husbandry of Inner Mongolia (BAHIM). 2000. *The History of Animal Husbandry Development of Inner Mongolia*. People's Publishing House of Inner Mongolia, Huhhot, Mongolia. (In Chinese.)

Clements, F. E. 1916. *Plant Succession: An Analysis of the Development of Vegetation*. Carnegie Institute of Washington Publication No. 242. Washington, DC, pp. 1–512

Briske, D. D. Fuhlendorf, S. D. and Smeins, F. E. 2005. State-and-transition models, thresholds, and rangeland health: A synthesis of ecological concepts and perspectives. *Rangeland Ecology and Management*, Vol. 58, No. 1, pp. 1–10

Dalintai, A. 2004. Grassland ecology and economic framework in pastoral area. Aorenqi (ed.), *Institutional Changes and Nomadism Culture*. Inner Mongolia People's Publishing House, Huhhot, Mongolia.

Dalintai, A. 2005. Rethinking the grassland desertification. *The Journal of Guizhou*, *Finance and Economics University*, Vol. 3, pp. 46–50. (In Chinese.)

———. 2006. *Project Proposal for the Ford Foundation*. (Internal material, unpublished)

Hardin, G. 1968. The tragedy of the commons. *Science*, Vol. 162, pp. 1243–1248.

Ho, P. 2001. Rangeland degradation in north china revisited? A preliminary statistical analysis to validate non-equilibrium range ecology. *The Journal of Development Studies*, Vol. 37, No. 3, pp. 99–133.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, Vol. 4, pp. 1–23.

Humphrey, C. and Sneath, D. 1999. *The End of Nomadism? – Society, State and the Environment in Inner Asia*. Duke University Press, Durham, NC.

Illius, A. W. and O'Connor, T. G. 1999. On the relevance of nonequilibrium concepts to arid and semiarid grazing systems. *Ecological Applications*, Vol. 9, pp. 798–813.

Enkhee, J. 2003. A historical retrospect on grassland desertification: Cultural dimension of development. *Journal of Inner Mongolia University (Humanities and Social Sciences)*, Vol. 35, No. 2, pp. 3–9. (In Chinese.)

James, E. E. and Swift, D. M. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. *Journal of Range Management*, Vol. 41, No. 6, pp. 450–459.

Kang, A. and Xu, J. 2004. The consideration of ecological restoration in pastoral grassland. *Research on Irrigation Works Development*, Vol. 4, No. 12, pp. 35–1239, (in Chinese,)

Li, B. 1990. *Grassland in China*. Science Press, Beijing, pp. 234–235. (In Chinese.)

———. 1997. The grassland degradation in North China and its countermeasures. *Chinese Journal of Agricultural Science*, Vol. 30, No. 6, pp. 1–9. (in Chinese.)

Li, O., Ma, R. and James R. S. 1993. Changes in the Nomadic Pattern and its Impact on the Inner Mongolian Steppe Grasslands Ecosystem. *Nomadic People*. Vol. 33, No. 66

Liu, Y. 1990. Economic Reform and the Livestock Pasture Imbalance in Pastoral Areas of China. In: J. Longworth (ed.) *The Wool Industry in China*. Australian Inkata Press, Victoria, pp. 93–105.

Ministry of Agriculture (MOA). 2006. *The Strategy of Prata Industry Sustainable Development.* (http://nc.people.com.cn/GB/61159/4378886.html, Accessed June 5, 2006).

Ning Baoying, Fan Shengyue and Zhao Chengzhang. 2004. Study on the social and economic causes for natural grassland degradation and sustainable countermeasures for utilization: A case in Sunan County. *China Population, Resources and Environment*, Vol. 14, No. 2, pp. 94–98. (In Chinese.)

Qi, B. et al. 2002. *The History of Livestock Breeding in Xilingol Prefecture*. Inner Mongolia People's Publishing House, Huhhot, Mongolia.

Simon, H. 1957. *Administrative Behavior*. (2nd ed.). Macmillan, New York.

Sullivan, S. and Rohde, R. 2002. On non-equilibrium in arid and semi-arid grazing systems. *Journal of Biogeography*, Vol. 29, pp. 1595–1618.

Weather Bureau of Inner Mongolia (WBIM). 2006. *Inner Mongolia Climate Bulletin* (2005). WBIM, China. (In Chinese.)

Weng, H. 2005. The Blooming Tropaeolum: Travel in Xilingol Grassland of Inner Mongolia. *Environmental Economy*, Vol. 21, No. 9, pp. 48–49, (In Chinese.).

Westoby, M., Walder, B. and Noy-Meir, I. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*, Vol. 42, No. 4, pp. 266–274.

Williams, D. M. 2002. *Beyond Great Walls: Environment, Identity, and Development on the Chinese Grasslands of Inner Mongolia*. Stanford University Press, Palo Alto.

Zhang Zihe. 1995. Discussion of the result of grassland degradation and its reasons. *Pratacultural Science*, Vol. 12, pp. 4–5. (In Chinese.)

Zhang, Q. and Li, W. 2002. Benefit evaluation of stockbreeding in Xilingol Biosphere Reserve. Han, N., Jiang, G. and Li, W. (eds.), *Management of Degraded Ecosystems in Xilingol Biosphere Reserve*. Qinghua University Press, Beijing. (In Chinese.)

Zhou, H. 1984. The implication of the fixation of grassland usufruct. *Red Flag*, Vol. 10, (In Chinese.)

Chapter 8
Combating Desertification through Fish Farming

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Abstract For many years the relationship between fish farming and agriculture has been built on recycling the discharged water from the cultivated fields into the aquaculture systems. This discharged water was sometimes full of pesticides and chemicals that were hazardous to both fish and humans. But the proposed integrated aquaculture and agriculture system is to work in the opposite direction: the drainage water of the aquaculture is recycled for agriculture. In this case, no pesticides or hazards are transferred to the fish and, at the same time, plants are irrigated with naturally fertilized water, which has very limited chances of negative impact on the environment or human health.

The study revealed no significant difference ($P > 0.05$) between tilapia fish (*Oreochromis niloticus*) reared on groundwater and fish grown in the natural open waters, whether in growth rates, total protein or total phosphorus content. The organic matter, total Nitrogen and NH_3 were significantly increased in the drainage water as compared with the supplied water. Irrigating the soil with the drainage water of fish ponds significantly enhanced soil quality, indicated by an increase in organic matter and total nitrogen, and reduced soil salinity.

It was concluded that combating desertification can be made effective through integrative fish farming in arid and semi-arid areas with the presence of brackish groundwater. Moreover, not only will it protect lands from degradation and improve their quality, but it will also utilize neglected natural resources in creating a productive community.

Keywords Desertification, fish farming, groundwater and soil quality

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1 Introduction

The Gabal El-Maghara is located in the north of the Sinai in Egypt. It occupies a very dry area of ≈1,500 km^2, where the mean annual rain fall is 45–90 mm and available groundwater is around 2,500 ppm (Guindy, 2000). Moreover, the area is very remote and threatened with desertification. So, in an attempt to save the area from land degradation, this study was based on experimentation in the application of an Integrated Fish Culture and Agriculture System. The study aimed to test the efficiency of using the area's groundwater in fish culture, and to test the significance of the fish drainage water in terms of concentration of organic matter (COD), Nitrogen (N), Phosphorus (P) and Potassium (K), which are used as soil fertilizers. Furthermore, the effectiveness of irrigating plants with this drainage water was also tested. Based on the final results, the experimental system would ultimately be expanded at a larger scale in the area. Any observations or obstacles encountered during the test should be considered when actually implementing the system.

2 Materials and Methods

2.1 Collecting Materials

Soil and groundwater of the Gabal El-Maghara area were transferred to the laboratory as well as 100 tilapia fry (*Oreochromis niloticus*). For 50 days, 1.3 ± 0.3 g fish were reared in an aquarium with a stock rate of 611 tilapia fish/m^3 using the transferred groundwater. Oxygen was maintained in the aquarium by aeration pumps, and water temperature was adjusted to 30°C by water heaters. Fish were fed on 40% protein pellets for 30 days, five times a day, and then later fed on 30% protein. Feeding rate was 10% of fish *wet* weight three times a day (Eurell et al., 1978). The rate was reduced to 3% of fish weight after a month of rearing (GAFRD, 2002). Fenugreek (*Trigonella foenum-graecum*), wheat (*Triticum Aestivum*), egyptian clover (*Trifolium alexandrium*) and broad beans (*Vicia Faba*) were planted in 24 plastic pots containing the transferred soil. Twelve pots were irrigated with the drainage water from the fish aquarium and 12 were directly irrigated with the groundwater. Analysis of the reared fish, ground and supplied water, treated and untreated soil, and planted crops was conducted at the end of 50 days. The experiment was carried out as described below.

2.1.1 Analysis of Fish

Total protein content was measured by a total protein kit described by Henry (1964); the phosphorus content was determined by an inorganic phosphorus kit, according to the method described by Fiske and Subbarow (1925). Total protein in the reared fish was compared with other fish of the same size and sex caught from the natural aquatic ecosystem.

2.1.2 Analysis of Water and Soil

Supplied water (groundwater), drainage water and soil were analyzed for EC (Richards, 1954), pH (Page et al., 1982), total N (Black et al., 1965), total P (Black et al., 1965), total K (Jackson, 1967) and total NH_3 (Page et al., 1982), determined in water and soil, while COD (Richards, 1954) was determined in water. Available N (Black et al., 1965), available P (Olsen et al., 1954), available K (Jackson, 1967), and total organic matter (OM%) were determined in soil.

2.1.3 Analysis of Plants

Tissues of stems and leaves of the planted crops were analyzed and determined for total N content (Jackson, 1967), total P (Black et al., 1965) and total K (Jackson, 1967).

2.1.4 Statistical Analysis

Data were tested by multivariate ANOVA (Wilks' Lambda) at ($P < 0.05$) using the SPSS 13.0, 2004 statistical program.

2.2 Results

No abnormal behaviour was observed in fish during the rearing period. No external diseases were detected. Fish survival rate was 90% within 50 days. The final weight was 17.35 ± 0.98.

Germination rate and growth were relatively higher in the tested crops irrigated with the drainage water of fish against the crops irrigated with the groundwater in all species. Rates were 82 against 59%, 8 against 4%, 74 against 53%, and 73 against 53% in fenugreek, wheat, Egyptian clover and broad beans, respectively.

2.2.1 Analysis of Fish

No significant difference in total protein or total phosphorus between caught fish and cultured fish was found, while a significant intercept ($P > 0.05$) was found between protein and phosphorus content in fish. Total protein content average was 3.4 ± 0.05 and 3.35 ± 0.1 g/100 gm, which is equivalent to 19.023% and 18.723% in the cultured fish and the caught fish, respectively (Fig. 1). Total phosphorus content average was 0.197 ± 0.004 and 0.20 ± 0.005 ppm, which is equivalent to 1.101% and 1.121% of cultured fish and caught fish weight, respectively (Fig. 2).

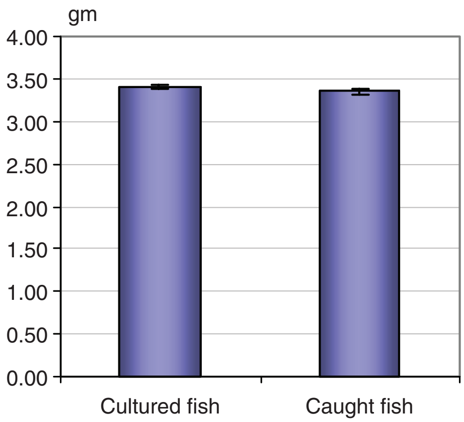

Fig. 1 Total content of protein

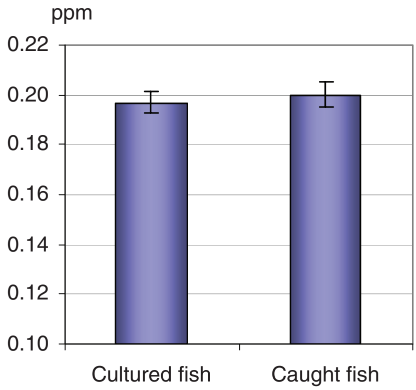

Fig. 2 Total content of phosphorus

2.2.2 Analysis of Ground and Drainage Water

The general result of the water analysis showed a significant difference between supplied water and drainage water. Results indicate a significant increase in organic matter, total N, and NH_3 in the drainage water as compared with the groundwater, while changes detected in the other parameters were not significant.

COD, N, and NH_3 were higher in the drainage water tank in the groundwater by 62.405%, 177.33% and 320.6%, respectively. Meanwhile, total P and total K were lower by 0.995% and 36.3%, respectively. EC of the groundwater was found to be 2.573 ± 0.002 psu. (See Figs. 3 and 4).

2.2.3 Analysis of Soil

In total, results revealed a significant change in soil parameters after treatment with the drainage water compared with the soil treated with groundwater. The change varied from one crop to the other – this variation was significantly affected by the

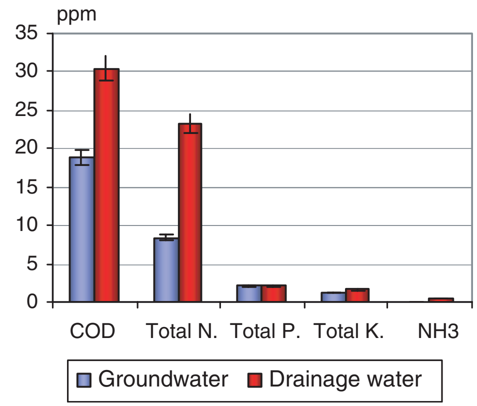

Fig. 3 Differences of some parameters between ground and drainage water parameters

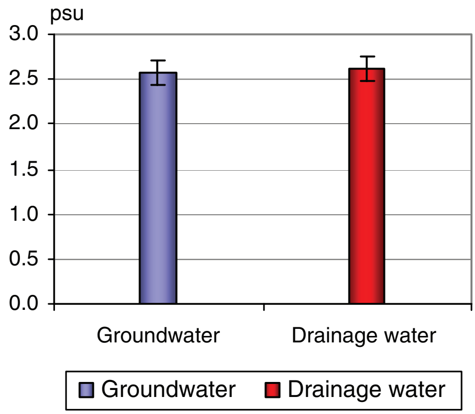

Fig. 4 Differences of E.C. between ground and drainage water parameters

type of each planted crop. In general, an increase in soil quality was found after treatment with the drainage water from the fish aquarium – total organic matter (OM%) was significantly increased in the soil of the four crop species treated with the drainage water. OM% increased from 0.08% in the untreated soil to 0.157%, 0.15%, 0.153%, and 0.133% in the soil with fenugreek, wheat, Egyptian clover, and broad beans, respectively. Against 0.107%, 0.107%, 0.073%, and 0.073% in the same order of crops irrigated directly with the groundwater (Fig. 5).

Salinity was significantly reduced in the soil of all four species in both treatments – salinity was reduced from 5.555 ± 0.093 psu in the untreated soil to 3.654 ± 0.01, 3.718 ± 0.004, 5.184 ± 0.002 and 4.672 ± 0.004 psu in fenugreek, wheat, Egyptian clover and broad beans, respectively, in the soil treated with the drainage water, while it was reduced to 5.082 ± 0.008, 5.139 ± 0.019, 5.248 ± 0.004, and 5.069 ± 0.006 psu in the same order in the soil treated with the groundwater.

Total N was significantly increased in the soil of all four species treated with the drainage water, unlike the soil treated with the groundwater, where no significant change was found. Total N was raised from 1806.67 ± 2.186 ppm to 2008.1 ± 3.9, 2003.67 ± 3.18, 1970.33 ± 30.17, and 5374.00 ± 31.13 ppm in fenugreek, wheat, Egyptian clover and broad beans, respectively (Fig. 5).

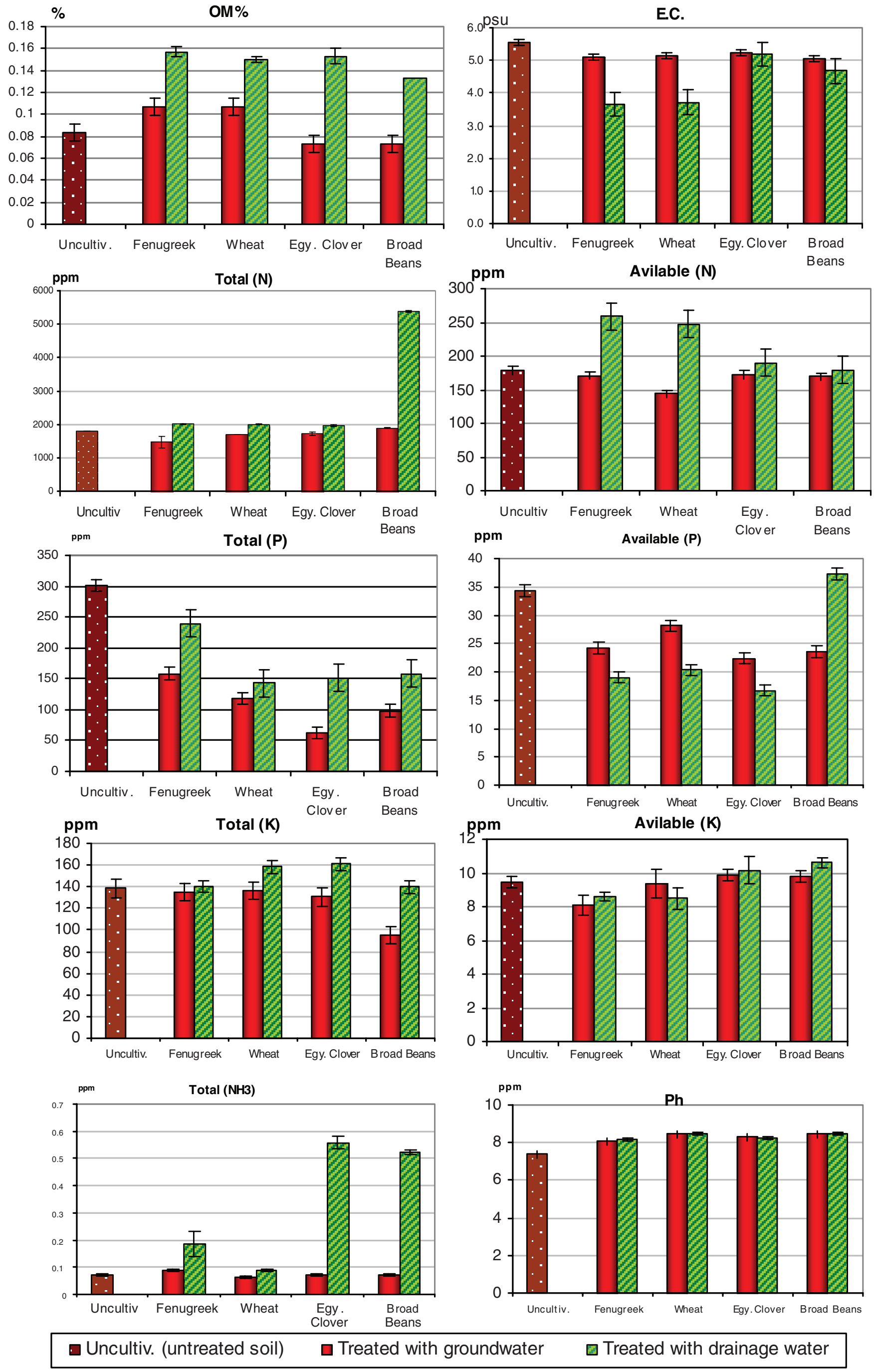

Fig. 5 Differences between soil parameters treated with groundwater and drainage water

Meanwhile, available N was significantly increased ($P<0.05$) in the soil of the species irrigated with the drainage water, unlike the soil irrigated with the groundwater, where a reduction was observed. Available N was changed from 178.6 ± .03 ppm in the untreated soil to 259.4 ± 2.05, 247.38 ± 1.85, 189.8 ± 2.6 and 179.34 ± 1.2 ppm in the soil treated with the drainage water with fenugreek, wheat, Egyptian clover and broad beans, respectively.

Total P and available P were significantly changed in the soil. A reduction in the soil of all species in both treatments compared with the untreated soil was found (Fig. 5). However, total P was higher in soil irrigated with the drainage water compared with the one irrigated with groundwater. Total P was reduced in the soil treated with the drainage water from 301.600 ppm to 158.200 ± 04, 118.033 ± 0.66, 62.867 ± 0.296 and 97.867 ± 0.33 with fenugreek, wheat, Egyptian clover and broad beans, respectively, while it was reduced in the soil treated with the groundwater to 239.300 ± 0.577, 142.667 ± 0.819, 151.300 ± 0.577 and 158.533 ± 033 in the same order (Fig. 5). Available P was also significantly reduced in the soil of the three species treated with the drainage water, and it was reduced in all species treated with groundwater – available P decreased from 34.34 ± 2.14 ppm in the untreated soil to 19.05 ± 0.55, 20.34 ± 037, 16.7 ± 0.35 in the soil treated with the drainage water with fenugreek, wheat and Egyptian clover, respectively, while it increased in the soil of broad bean to 37.27 ± 0.44 ppm. Against a reduction to 24.23 ± 2.05, 28.14 ± 0.81, 22.37 ± 1.37, and 23.16 ± 0.28 in fenugreek, wheat, Egyptian clover, and broad beans, respectively, in the soil treated with the groundwater.

Total K increased in the soil of all species treated with the drainage water compared with the untreated soil, unlike the one treated with the groundwater in which a decrease in all species was found (Fig. 5). It increased from 138.33 ppm in the untreated soil to 140.07 ± 0.64, 158.33 ± 6.84, 161.10 ± 0.06, and 140.03 ± 0.03 ppm in the soil treated with the drainage water in fenugreek, wheat, Egyptian clover, and broad beans, respectively, while it insignificantly decreased to 135.03 ± 1.98, 136.10 ± 0.49, 130.37 ±0.32, and 95.07 ±4.56 ppm in the soil treated with the groundwater in the crops in the same order. Available K changed in all species in both treatments compared with the uncultivated soil (Fig. 5).

Total NH_3 was significantly increased in the soil treated with the drainage water compared with the soil treated with the ground water and the uncultivated soil as shown in Fig. 5. It was raised from 0.073 ± 0.003 ppm in the untreated soil to 0.187 ± 0.047, 0.089 ± 0.005, 0.557 ± 0.023, and 0.523 ± 0.009 ppm with fenugreek, wheat, Egyptian clover and broad beans, respectively. Meanwhile, it changed insignificantly in the soil treated with groundwater to 0.087 ± 0.02, 0.063 ± 0.003, 0.070 ± 0.06, and 0.071 ± 0.005 ppm with wheat, Egyptian clover, and broad beans, respectively.

2.2.4 Analysis of Plants

Results in total indicated a significant difference between crops irrigated with the drainage water and crops irrigated with groundwater. Results showed a significant interaction between tested parameters and a significant difference between crops in their response towards the change of treatment. However, total N, P and K were higher in all plants irrigated with the drainage water compared with the same plant species irrigated with the groundwater (Fig. 6). Total N was higher by 12.6, 34.06, 55.8, and 46.06% in fenugreek, wheat, Egyptian clover, and broad beans, respectively. Total content of P increased by 40.9, 21.2 and 50.5% in wheat, and broad beans, respectively, while it decreased by 19.98% in fenugreek (Fig. 6). Total K was

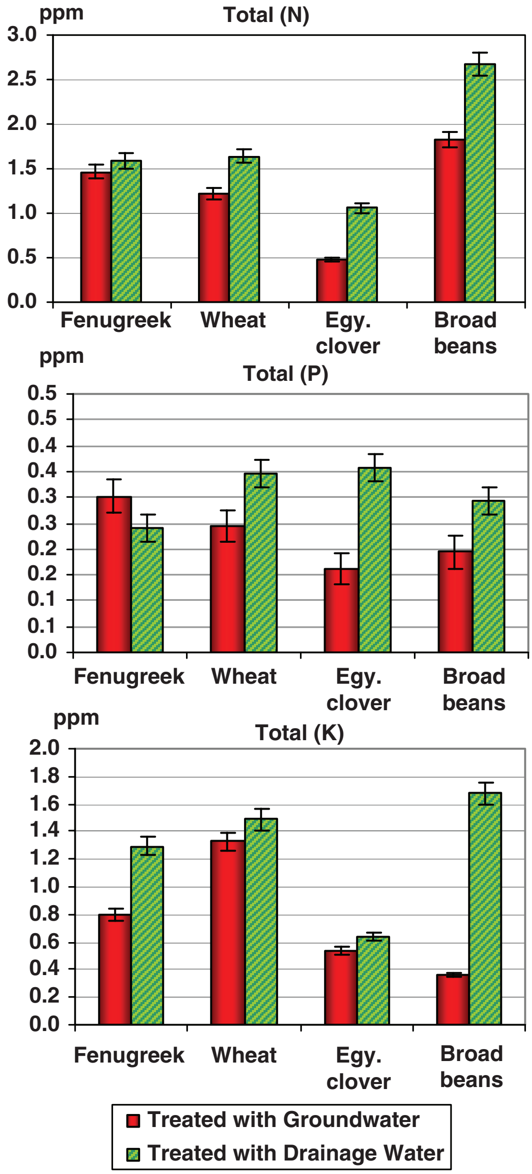

Fig. 6 Effect of treatment with groundwater and drainage water on total content of N, P, and K in tested plants

higher by 61.67%, 11.78%, 19.26% and 91.2% in fenugreek, wheat, Egyptian clover and broad beans, respectively (Fig. 6).

3 Discussion

The normal growth rate of fish is 0.1–0.5 (Mohammed et al., 2004), the normal survival rate of fry < 5 g is 70–90% depending on the handling process (ibid.), and the normal average of total protein is (15–30%) of fish weight (Abdel-Hameed, 1994), ≈19.2% in tilapia as reported by Mohammed et al. (2004), and less than 10% phosphorus. Results revealed that the tested parameters of fish are in the normal averages, which indicate normal response to feeding and normal adaptation to the used aquatic environment.

The severely low germination rate of wheat is probably caused by the salinity of the soil and/or the low quality of seeds stored and/or the late planting time; Abdel-Azeem et al. (1989) reported that late planting of wheat seeds reduce its germination to 30%. It is suggested that wheat seeds tolerant to high salinity be used when the experiment is applied in a real situation. New Egyptian species, like Kharchia, Sakha 8 and Sakha 93, were identified as the most salt-tolerant genotypes – tolerant up to 10,880 ppm (El-Hendawy et al., 2005).

However, the visual indication obtained from the germination rates is that the use of drainage water influenced the germination process and that it provided the soil with mostly acceptable amounts of nutrients needed for growth. Yet this could be an additional cause; sensitivity to salinity, storage conditions, water requirements and/or time of plantation might all be additional factors responsible for these differences. All these factors should be considered and observed by agriculturists when the system is applied in a real situation. However, for the purposes of this study, even though the result of the germination rate is not high in most of the plants, it is still an initial indicator regarding the effect of the only variable factor, which is the type of water supply.

3.1 Water Analysis

The increase in COD of drainage water is mostly due to the decomposition of fish fæces, urea and food remains. The increase is expected to be higher where fish are reared in ponds where algae and phytoplankton exist. El-Gamal (2001) confirmed the absence of sources of fish diseases in groundwater, and the presence of OM in the drainage water of the fish – this water is required for soils in arid areas.

The high content of NH_3 in the drainage water is mostly caused by the decomposition of NH_4 and urea to NH_3 in the warm water and high pH conditions (El-Gamal, 1992). NH_4 and urea are the original excreted substances of fish. The water temperature in the aquaria was maintained at 30°C.

$$NH_3 + H_2O \text{ -------- } O_2 \text{ -------- } > NH_4 + OH$$

$$NH_3 + H_2O \text{ -------- pH + heat --- } NH_4 + OH$$

However, the detected increase in NH_3 levels is acceptable as it lies within the normal averages of tilapia fish (0.5–1 ppm) (Mohammed et al., 2004).

As a consequence of the increase in total NH_3, total N also increased. In addition, fish excretions consisting of urea and ammonia increased by 90%. Possibly due to the contents of fish fæces as well, which contain protein residues when decomposed, N substances are released. Possibly due to the remnants of fish feeding pellets (40% and 30% protein) decomposition and amino acids when analyzed and decomposed, they form N substances (Abdel-Hameed and Mohamed, 1993).

3.2 Soil Analysis

The increase in the OM% of the soil is still beyond fertile soil values and is still described as 'very poor' according to Abdel-Azeem et al. (1989), who categorized soil fertility according to its organic matter content: very poor (0–1%); poor (1–2%); moderate (2–4%); fertile (4–8%); and very fertile (8–20%). However, a moderate value in soil considered sufficient to prevent soil degradation and maintain productivity of crops is equal to 2.5% (Hasanein, 2000).

The reduction in soil salinity is mostly due to salt consumption by crops for their growth (El-Hendawy et al., 2005) and/or their dissolution in water with the irrigation process. These values are still higher than the normal average for best growth of crops, which is 0–1,600 ppm (0–1.6 psu) (Hasanein, 2000). However, the salinity is expected to decrease with longer term treatment. According to Sameh (2005), soil is expected to be reclaimed and suitable for satisfying agricultural processes at the end of three fish productive seasons equal to around 24 months at most. However, no significant difference was found between both treatments on salinity reduction.

Total N was the highest in the soil with broad beans; this is most likely because broad beans contain Rhizobium bacteria (*Phizobium leguminosarum*) on its roots, which performs enormous nitrogen fixation in the soil (Mazhar et al., 1993). The normal average value of total N in soil ranges between 1,200 and 2,500 ppm (Hasanein, 2000). Obviously, the increase in total N content is caused by the drainage water treatment, which is highly rich in nitrogen. However, an insignificant decrease was found in total N with fenugreek, wheat and the Egyptian clover treated with the groundwater.

The reduction of available P in both treatments can be explained by the consumption of P by crops for growth. The reduction level of available P in the soil treated with the drainage water seems higher than in the soil treated with the groundwater, which is probably due to the higher consumption of P by crops from the soil treated with the drainage water where the germination and growth were higher while the drainage water contained limited quantities of P to balance the consumption, unlike the soil treated with the groundwater which had lower germination and growth ratios. However, available P values were very high in the soil as its average in soil was reported by Hasanein (2000) to low level (1.00–3.00 ppm) and medium level (4.00–7.00 ppm).

Obviously, total K did not significantly increase in the soil treated with the drainage water because it was insignificantly rich with total K, as explained previously. On the other hand, the reduction in the soil treated with the groundwater is mostly related to the crops' consumption. However, the level of available K is considered low according to Hasanein (2000), who reported that the medium level ranges between (60–120 ppm).

Therefore, in Egypt, where fish culture is only allowed on unfertile soil (Abdel-Bary, 2002), recycled drainage water from fish culture could be used as a supplementary fertilizer for poor soils. The increase in total NH_3 was obviously caused by the treatment with drainage water, which was enriched with NH_3.

3.3 Crops Analysis

The significant high content of total N and P in crops irrigated with the drainage water compared with crops irrigated with groundwater is mostly caused by the availability of N and P substances in the drainage water, unlike the groundwater, even though K was found with small amounts in the drainage water. But its high presence in fenugreek, Egyptian clover and broad beans indicates that it is effectively supporting the plants.

4 Conclusion

Combating desertification is a target in itself, but combating desertification while at the same time realizing additional benefits is a better target, and fish culture has been shown to be a good method to achieve this target. Applying fish farming in deserts cannot only improve the quality of the degraded soils in arid areas but, by facilitating its cultivation and increasing its field capacity, it can lead to its protection from degradation as well as help to improve living standards among the impoverished inhabitants in remote desert areas. Therefore, it is highly recommended that the proposed integrated fish culture and agriculture system be applied in the tested Gabal El-Maghara area, as well as in other arid areas where brackish or saline groundwater is available.

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References

Abdel-Azeem, A., Abdelaazez, N. and Taher, B. 1989. *Introduction to Crops Science*. (In Arabic.)

Abdel-Bary, M. 2002. The three nos and the future of fish farming. *Egyptian Society of Aqua Culture*, Vol. 1, pp. 6. (In Arabic.)

Abdel-Hameed, Mohamed, Eid. 1993. *Fish feeding*. Eid trading for publishing, (In Arabic.)

Abdel-Hamid, N.A.H. 1994. *Effect of some pollutants on biological aspects of Oreochromis niloticus*. M.Sc. Thesis, Faculty of Science, Zagazig University, Benha Branch, p. 198.

Black, C. A., Evans, D. D., White J. L., Ensminger, L. E. and Clark, F. E. 1965. Methods of soil analysis, Part 2: Chemical and microbiological properties. *American Society of Agronomy*, Vol. 9, pp. 1379–1400.

El-Gamal, A. A., 1992. Predation by Nile perch *Lates niloticus (L.) on Oreochromis niloticus (L.), Cyprinus carpio (L.), Mugil* sp. and its role in controlling tilapia recruitment in Egypt. *Journal of Fish Biology* 46, pp. 359–370.

El-Gamal, A., 2001. Status and development trends of aquaculture in the Near East. In: R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur (eds.) *Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20–25 February 2000*. pp. 357–376. NACA, Bangkok and FAO, Rome.

El-Hendawy, S. E., Hua, Y., Yakout, G. M., Awad, A. M., Hafez, S. E. and Schmidhalter, U. 2005. Evaluating salt tolerance of wheat genotypes using multiple parameters. *European Journal of Agronomy*, Vol. 22, pp. 243–253.

Eurell, T. E., Leuis, S. D. and Grumbles, L. C. 1978. Comparison of selected diagnostic tests for detection of *A. sepiticemia* in fish. *American Journal of Veterinary Research*, Vol. 39, pp. 1384–1386.

Fiske, C. H. and Subbarow, Y. 1925. The colorimetric determination of phosphorus. *Journal of Biological Chemistry*, Vol. 66, pp. 375–400.

GAFRD (General Authority of Fish Resources Development). 2002. *Principles of Fish Feeding in Fish Farms*. Vol. 24, No. 12. GAFRD, Cairo, (In Arabic.)

Guindy, K. A. 2000. Assessment of ground water resources in El-Maghra area, Central Sinai, Egypt. *Desert Institute Bulletin Egypt*, Vol. 50, No. 2, pp. 251–272.

Hasanein, B. M. 2000. Evaluation of some soil characteristics and fertility status in south eastern Egyptian desert (Halayib – Shalatein). *Desert Institute Bulletin Egypt*, Vol. 50, No. 1, pp. 209–224.

Henry, R. J. 1964. *Clinical Chemistry: Principles and Techniques*, Harper & Row, New York.

Jackson, M. L. 1967. *Soil Chemical Analysis*, Prentice-Hall, Englewood Cliffs, NJ.

Mazhar, M. F., Abdelraoof, S. M. and Khalail, A. N. 1993. *Beans and Crops Yields*. Book House Publisher, (In Arabic.)

Mohammed, F. O., Shreef, S. E. and Mohammed, A. M. 2004. What do we know about extrusion technique and its role in enhancing the efficiency of food pellets used in feeding fish and shrimps. *EACS*, Vol. 1, No. 22, pp. 220–222. (In Arabic.)

Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Department of Agriculture Circular (USDA)*, No. 939, United States Governmental Printing Office, Washington, DC.

Page, A. L., Miller R. H. and Keeny, D. R. 1982. Methods of soil analysis Part 2, Chemical and microbiological properties Part 2: *American Society of Agronomy*, Madison, WI pp. 1142.

Richards, L. A. 1954. Diagnosis and Improvement of Salina and Alkali Soils. *United States Department of Agriculture, Handbook* No. 60, Washington, USA.

Sameh, H. S. 2005. Intensifying fish farming. *Agricultural Journal*, Vol. 554, pp. 54–52. (In Arabic.)

Chapter 9
Participatory Monitoring and Evaluation of a Project to Combat Desertification in Drylands (*Case Study in Central Western Tunisia*)

Boubaker Raddaoui[1], Kasserine-Tunisie[2], Mongi Sghaier[2], Houcine Taamallah[2] and Mohammed Ouessar[2]

Abstract Success of projects to combat desertification is measured against their contribution to the achievement of outcomes. Monitoring and evaluation activities must increase their focus on outcomes by shifting towards better measurement of performance and more systematic monitoring. Such activities must be inspired by an organizational culture of learning, transparency and accountability.

A case study of participatory monitoring and evaluation is presented in a pilot project to combat desertification that involves the local agro-pastoral communities and is implemented by OEP (Office de l'Elevage et des Paturages) and NRD (Nucleo Ricerca Desertificazione-University of Sassari), in Feriana, Governorate of Kasserine in central western Tunisia. It aims to recover degraded rangelands by planting fodder shrubs as well as through complementary activities involving public awareness and training targeted to the local users. The approach used was based on participatory monitoring tools, associated with remote sensing data and GIS, and specific indicator tests developed by OSS-SMAP/CE to monitor the implementation of the National Action Plan (NAP) to combat desertification at the sub-national and local level in Tunisia, and to evaluate its impact on the environment and natural resources management capacity of local communities.

Appropriate indicators were adopted to check both the biophysical outcomes and their social impact. Some of the indicators used remote sensing parameters, which were assessed using an "expert" approach, while others required a direct interaction with local breeders and farmers.

Preliminary results showed that the plantation of fodder shrubs has a positive impact on soil stability, wind erosion and water runoff control, but plantation success is strictly related to climatic conditions and the appropriate involvement of the local farmers.

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The indicator 'fodder supply in period of pastoral deficit' has proved its reliability and credibility by accurately confirming that the impact of shrub plantations cannot be determined in cases where maintenance is no longer assured and the grazing ban has been lifted. The parameter 'appropriation and charge holder level' accurately indicates plantation durability and restoration techniques effectiveness. Local management capacities were measured in terms of compromises, project activities, internal conflicts, and the identification of priorities and needs of the local population; and inquiries were made concerning the socio-professional organization's reliability and representativeness. It revealed that the professional structure created by the project is still unable to ensure sufficient assistance to the population and to manage the divergent project objectives and expectations. Participatory monitoring and the evaluation of the socio-organizational capacity for managing natural resources, for collaboration, and for conflict-solving emerged as an effective tool towards strengthening local participant's capacity for land restoration techniques. It also generated some practical recommendations to be considered when implementing other development projects to combat desertification.

Keywords Participatory monitoring and evaluation, combating desertification projects, local people organization, rangeland improvement, grassroots indicators

1 Introduction

Increasing awareness among project planners and managers of the complexity and unpredictability of development projects, and the knowledge that the same approach can lead to different outcomes depending on the context, has led to greater attention being paid to the process of development projects in the last decade. A good system to obtain and analyze information based on experience during the course of project implementation so as to recognize weaknesses, adapt methods, correct the procedure if necessary, and respond more quickly to unexpected events (Mosse et al., 1998). Furthermore, local needs within the community change over time and development projects have to respond to these changes.

Monitoring and evaluating a development project, especially one claiming to operate in a participatory mode to combat desertification, is not simply a matter of looking at project activities. The relationship between the project and its partners, including the beneficiaries, must also be closely looked at. With such an approach, the partners come to understand each other better, avoid unrealistic expectations and disappointments, and make project success more likely (Reckers, 1997). Participatory monitoring and evaluation (PM&E) is an integral part of local capacity-building and institutional development. It can create a feeling of ownership among all partners and can help the local people to manage their own affairs better and thereby increase the likelihood that project-supported activities will continue after the project ends (Bayer and Waters-Bayer, 2002).

On the other hand, it could be argued that local resource users have the right to know the amount of funds allocated for different project components and its justification. This could be examined during periodic evaluations. In contrast, if a project is supporting the establishment of a private service or a cooperative or any socio-professional structure, financial monitoring should clearly be done in cooperation with both local people and the project partners, as this activity helps to strengthen local capacities and continues to support the initiative long after the end of the project.

Furthermore, in spite of knowledge and data accumulation, and the significant progress in understanding the biophysical processes underlying land degradation, very few approaches to monitoring and evaluating projects implemented to combat desertification have been undertaken that evaluate project success and supports the decision-making process in Tunisia (UNEP, 2001). Such approaches are particularly needed in the vulnerable arid regions, where the problems of land degradation are most critical and where make large investments governments, to carry out desertification mitigation activities.

This work is carried out in parallel of the trend observed among United Nations and bilateral development agencies and the European Union and non governmental organizations. It provides an opportunity to present relevant experience and results obtained by participatory monitoring and project evaluation to combat desertification implemented in semi-arid zones in Tunisia.

2 Methodological Approach

2.1 Study Area

The area considered here is the site of the development project. It is located in the sector of Skhirat (Delegation of Fariana, Governorate of Kasserine) that lies south of the western ridge and in the piedmont of Chaambi Mountain (Fig. 1).

The target area adequately represents some of the main land degradation and desertification issues typical of Tunisian territory and presents a significant example of the dramatic extent of land degradation in the rangelands reached in recent years.

2.2 Project Implemented in the Study Area (Skhirat)

The development project entitled 'Demonstrations on Strategies to Combat Desertification in Arid Lands with the Direct Involvement of Local Agro-pastoral Communities in West Central Tunisia' aims to contribute to the restoration of vegetation cover with drought-resistant perennial species in highly degraded, extensive

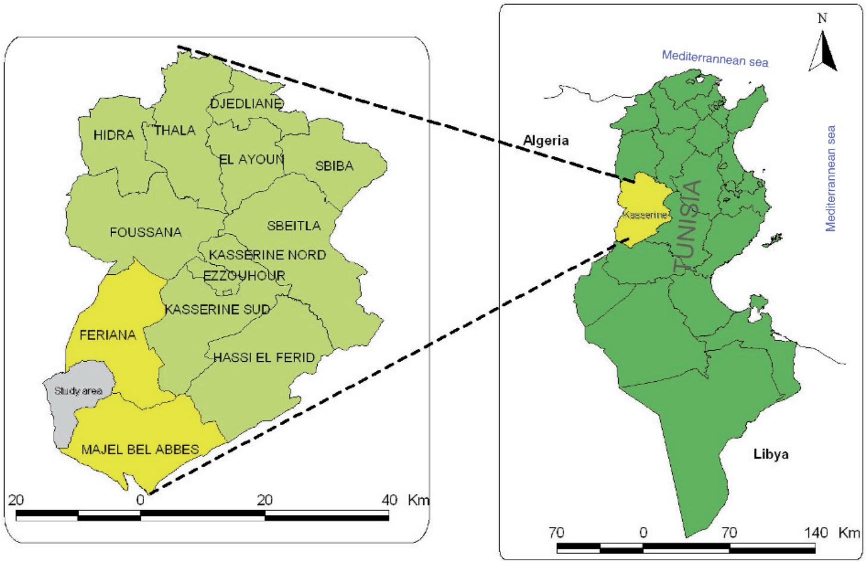


Fig. 1 Geographical location of the project

pasture land, as well as the mitigation of desertification processes through rangeland improvement and a number of rehabilitation techniques.

These objectives were consistent with the goals of the 10th quinquennial Plan for Socio-Economic Development (2002–2006), as well as with the priorities of the country assistance strategy and its National Action Plan to combat desertification. The afore mentioned objectives are to be achieved through a series of activities that are expected to obtain the following results:

- Direct intervention to restore the land by using perennial fodder shrubs and forage species
- Training activities and specific studies to strengthen local capacities and knowledge about restoration techniques
- Complementary demonstration, public awareness and information dissemination activities at local and national levels, as well as the promotion of international debate on desertification mitigation measures suitable for North African countries

2.3 Data Collection Method

Appropriate participatory tools were applied in gathering spatial information: community sketch map and transects. The project activities, baselines, inputs and outputs, and targets are collected from the annual project reports and confirmed in the field by the project beneficiaries.

2.4 Monitoring and Evaluation Tools Applied

To evaluate the impact of project activities, we have tested and applied the indicator's catalogue conceived by OSS-SMAP/CE-Tunisie (2004) with reference to the corresponding project activities and the conceptualization approach proposed by Talbi (2005). The data collected are treated in a database called 'Effort and Impact', which was developed as a platform for the various partners involved in implementing the Tunisian NAP to combat desertification (OSS-SMAP/CE-Tunisie, 2005). Project activities were monitored through the use of critical indices Normalized Difference Vegetation Index (NDVI), high resolution satellite imagery, and imagery from different sources taken at varying times to detect and discriminate changes attributed to the project.

2.5 Evaluation of Project Achieved Activities

The evaluation concerns the impact of two achieved activities: 'Fodder Shrubs Plantation and Pastoral Enrichment' and 'Socio-professional Organization', which represent the fundamental actions to mitigate land degradation and to ensure land-user organization, since they are expected to assume responsibility for operating and maintaining facilities at the local level, and feedback while enriching decisions made at policy level.

2.5.1 Fodder Shrubs Plantation and Pastoral Enrichment

This Development Activity (DA), frequently used in rural development projects, responds to drought effects mitigation by the creation of fodder reserves, pastoral enrichment and soil protection against erosion. The species used in this study include: *Acacia cyanophylla*, *Opuntia ficus* and *Atriplex nummularia*. The appropriate indicators, with their correspondent parameters, are as follows:

- **Indicator 1: Fodder supply in period of pastoral deficit**
  - *Parameter 1*: level of the plantation's exploitation
  - *Parameter 2*: the onset of the state of spontaneous vegetation
- **Indicator 2: Soil stability**
  - *Parameter 1*: state of erosion
- **Indicator 3: Plantation durability**
  - *Parameter 1*: level of appropriation or level of responsibility of the plantations.

The methodology consists of evaluating the DA's impact using the above indicators as well as the assessment of the productivity of fodder shrubs, their successful growth, and the onset of spontaneous production of vegetation cover.

2.5.2 Socio-Professional Organization of Land Users

The expected impact of this activity was seen at mid-term, in the quinquennial evaluation. In the short term, with respect to annual monitoring and evaluation, we should verify whether the conditions required to reach the expected impact have been established.

- **Indicator 1: Reliability of the socio-professional organization (SPO)**
  - *Parameter 1*: compromises management capacity
  - *Parameter 2*: DA's management capacity
  - *Parameter 3*: internal conflict management capacity
- **Indicator 2: Socio-professional organization representativeness**
  - *Parameter 1*: priorities and needs identification capacity
  - *Parameter 2*: incitement measures valorization capacity

2.5.3 Evaluation of Sustainability of Rehabilitation's Activities

According to Abbot and Guijt (1998), project sustainability can be measured using indicators that reflect the awareness-raising of local users. Such indicators were adopted in this study to evaluate the impact of the training sessions and public awareness workshops on local user groups. These groups were determined by analysis of the lists of project beneficiaries, available in the annual project reports, and triangulated and validated with relevant data offered by the socio-professional organization in the project area.

- **Indicator 1**: **Percentage of people participating in some form of land rehabilitation**
- **Indicator 2**: **Percentage of rural adults involved in the project activities**
- **Indicator 3**: **Number of beneficiaries who carry out plantation maintenance by themselves**

3 Results and Discussion

3.1 Community Sketch Map of Skhirat

The community sketch map showed where resources, problems, opportunities and project activities for remediation are located. The mapping also identified areas with specific problems (such as water shortage in Eltaifia, Ouled Abid and Ouled Brahim, erosion and gulley formation in the south, overgrazing due to overstocking everywhere in the area) or potential for improved production (e.g. predominant agricultural and livestock existing in the area for income-generation), and the project response to these issues.

3.2 Normalized Difference Vegetation Index (NDVI)

It was not possible to distinguish between dryland farming and the rangeland – whether it is rehabilitated or not, poor, fair or good since the reflectance between rainfed cropland and rangelands on the mountain and in the hills is mostly the same (Fig. 2).

3.3 Change Detection Using High Resolution Imagery

In Fig. 3 the QuickBird Satellite Image (1m of resolution) clearly distinguishes the palisades of palm leaves, constructed in the project area to stop sand encroachment, and associated with the fodder shrubs plantations. The image suggests that the project focused on rangeland improvement where native species dominated and intervened in vulnerable sites to establish fodder reserves. Protecting these plantations will control overgrazing, improve soil stability and prevent degradation.

3.4 Change Discrimination Using Different Satellite Imagery

The area units I and II indicated on the Aster image represent a sample of degraded rangeland with the bare soil subjected to water and wind erosion (Fig. 4). On the QuickBird image, the same area units were rehabilitated by the project and show a different reflectance. The ground truth has confirmed that the units are restored using *Acacia cyanophylla* and land cover is improving.

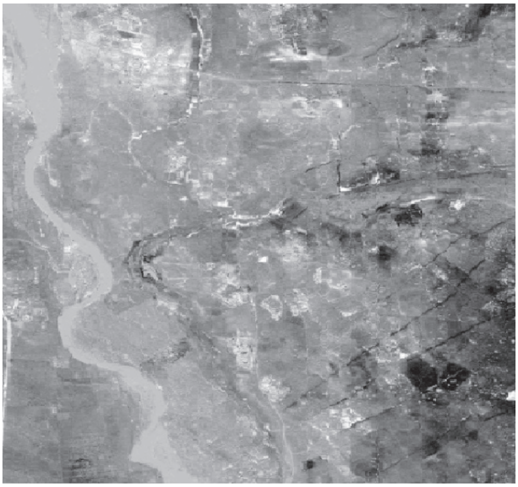


Fig. 2 NDVI QB – 1/8/2005

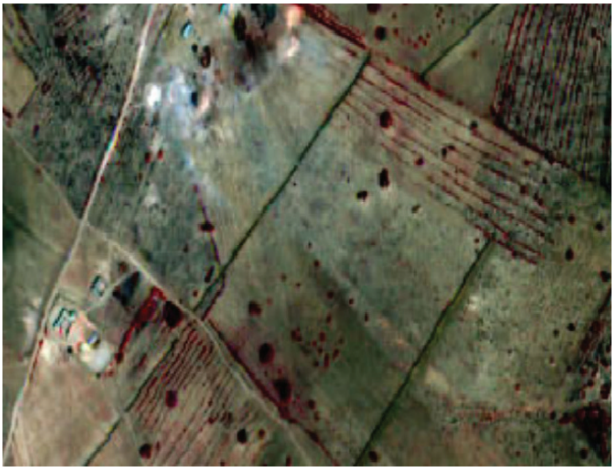


Fig. 3 High resolution image (QuickBird: 1 m)

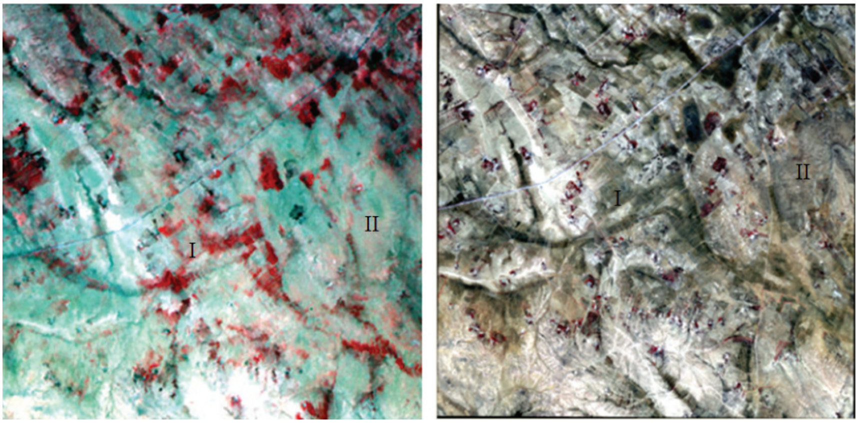


Fig. 4 Discrimination change using high resolution image

The desired state can be defined by targets that include a rehabilitation of rangeland by fodder shrub plantations to decrease the area of low infrared signal.

3.5 Evaluation of DA: Fodder Shrub Plantation and Pastoral Enrichment

Soil stability is assured wherever the plantation's growth has proved successful and when the grazing ban has been genuinely respected. Plantations on the other sites seem not to be sustained and expressed weak impact regarding soil stability (Fig. 5).

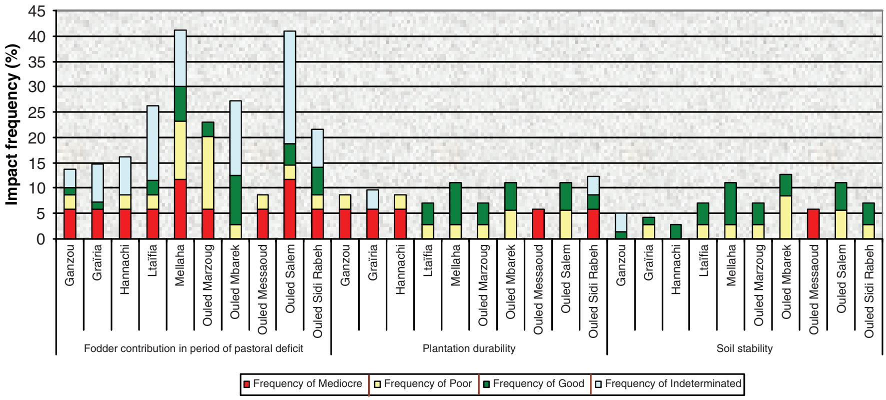


Fig. 5 Impact of the DA 'Plantation of Fodder Shrubs and Pastoral Enrichment' on soil stability and fodder contribution in period of pastoral deficit (per site)

Consequently, the soil is not well covered and is subject to erosion and degradation. These results indicate that the rehabilitation techniques (using fodder shrubs), applied to improve degraded rangeland does not achieve the same impact in the whole study area as when targeted in the project objectives.

3.5.1 Productivity and Success Rate of Shrubs Introduced

For the new plantations, two cladodes per individual will not ensure its protection against frost during winter or the prevailing dry and hot wind in summer. This explains the low growth success in the cacti introduced in 2005. The *Atriplex* has shown a high success level compared to *Acacia* due to its notable drought resistance and salt tolerance. The low success rate of *Acacia* could be attributed to irrigation water shortage, the cost of maintenance and the fact that fruit trees with their associated cash flow compete more than shrub plants. Cactus plantations provide important green biomass on the third year following plantation. It can reach 2.25 t/ha if the plantations are well maintained and/or fertilized. Growth success, expressed in terms of newly produced cladodes, is high. Plantations of 2003 have high growth success and therefore high production since they escaped frost damage.

3.5.2 The Onset Spontaneous Vegetation Cover and Production

The production of spontaneous vegetation inside parcels made up of cacti can reach 4.88 t/ha, and the cover is more important than those with *Acacia* or *Atriplex* (Figs. 6, 8). This is due to the high vegetative biomass of annual species. While biomass production of spontaneous vegetation inside the parcels of *Atriplex* do not exceed 4.2 t/ha within three years, the nature of the composition of the onset vegetation, mostly based on perennial species, provides a sign of sustainability (Fig. 7).

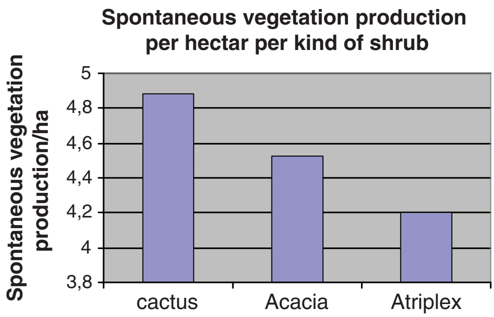


Fig. 6 Percentage of vegetation cover

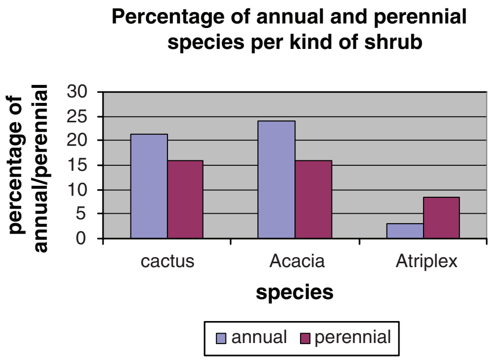


Fig. 7 Percentage of annual and perennial species

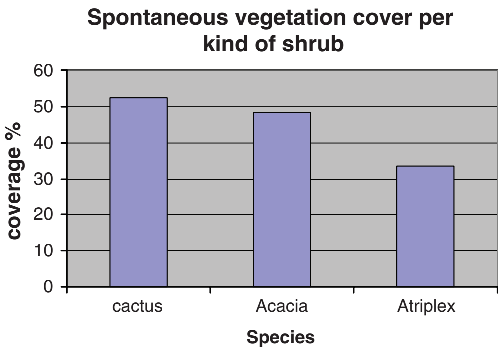


Fig. 8 Spontaneous vegetation production per kind of shrub

3.6 Evaluation of the Impact of the Socio-Professional Organization (SPO)

Measured parameters analysis (Reliability and Representativeness) shows that some of the social groups (Ouled Abderrahim) concerned with the project are not represented. The SPO's reliability, although found to be weak (10%), is the same over the whole area – apart from Ouled Merzoug due to the effective participation of this group and their background due to their participation in the stakeholder organization acquired from previous projects (Fig. 9).

The recently created SPO does not have sufficient financial means or trained staff to ensure adequate assistance to the population and to manage divergent objectives and expectations. Nevertheless, this is not a sign of project failure, as some specific training sessions oriented to both local users and SPO's members are ongoing. Moreover, if one were to look at the indicator again at the end of the project, it would reveal substantial progress even beyond expectations.

3.7 Evaluation of Project Sustainability

Indicator 1 showed that the percentage of people participating in rehabilitation activities dropped from 40% in the first year to 20% in the second year and then increased to 32% in the third year (Fig. 10). The decrease is attributed to the prolonged drought registered in 2004.

Indicator 2 proves that there is a high percentage of youth participating in land rehabilitation. Indicator 3 revealed that 20% of beneficiaries are aware of the importance of maintaining damaged plots at the end of the third year (2005). This progress can increase in the near future, even beyond expectations, if intensive training and public awareness associated with close supervision is to be addressed to local people.

3.8 Performance of the Project

The basic objectives of the project conformed to priorities of the Tunisian National Action Plan to combat desertification and the evolving policies of the Socio-economic Development Plan. In most sites, the sustainable regeneration of degraded rangeland

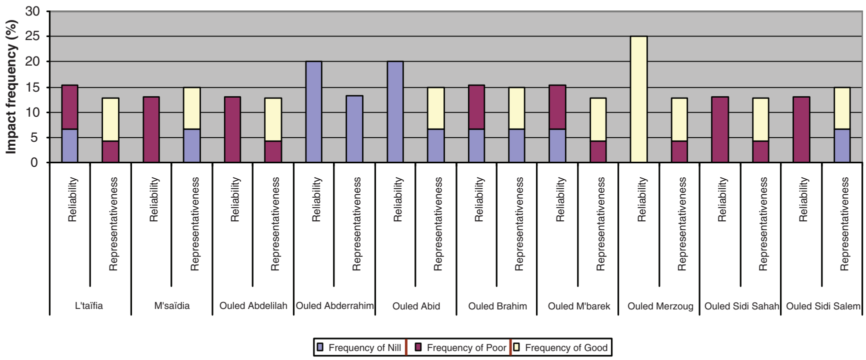


Fig. 9 Socio-professional organization impact

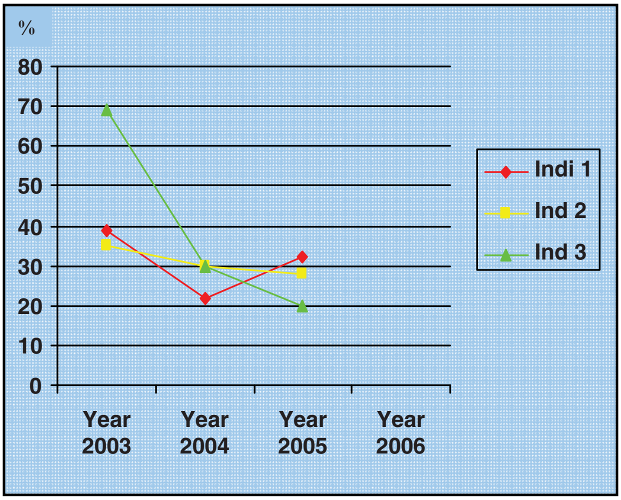


Fig. 10 Project sustainability measurement

already rehabilitated by project is being achieved. The lack of awareness on the part of beneficiaries regarding desertification risk and the limited financial capacities to support maintenance and widespread activities to prevent degradation constitute a real hindrance to attaining project objectives.

3.9 Lessons Learned

One of the lessons learned from this study, and an aspect that is usually not foreseen in project design, is that monitoring and evaluation activities could contribute to strengthening grassroots organizations. This effect, which is amply achieved through participatory monitoring and evaluation in the study area, was evaluated as an unforeseen but important outcome of the overall project.

4 Conclusion and Recommendations

Combating desertification through rangeland rehabilitation measures with the involvement of trained local agro-pastoral communities has proved successful at sites where the grazing ban has been assiduously respected. However, fodder shrub species used to improve degraded rangeland (*Opuntia ficus*, *Acacia cyanophylla*, *Atriplex nummularia*) did not show the same growth success and impact in the whole study area, as targeted in the project objectives. This relies on the participation of beneficiaries and their initiative to carry out maintenance activitie, as well as on the resistance capacity of the used species to harsh climatic conditions, especially prolonged drought and frost. Project activities need to be selectively targeted if the most disadvantaged groups are to benefit, and this should receive greater attention in later projects. Moreover, the demand for training should precede its provision, and the preferences of group members should be respected.

References

Abbot, J. and Guijt, I. 1998. C*hanging Views and Changes: Anticipatory Approaches to Monitoring the Environment*, Discussion Paper No. 2, International Institute for Environment and Development (IIED), London.

Bayer, W. and Waters-Bayer, A. 2002. *Participatory Monitoring and Evaluation (PM&E) with Pastoralists: A Review of Experiences and Annotated Bibliography*. (GT2) GmbH, Eschborn, Germany.

Mosse, D., Farrington, J. and Rew, A. 1998. *Development as Process: Concepts and Methods for Working with Complexity*. Routledge, London.

OSS-SMAP/CE – Tunisie. 2004. *Conception d'un dispositif opérationnel de suivi-évaluation au niveau sub-national et local en Tunisie: Mise en œuvre opérationnelle*. L'Observatoire du Sahara et du Sahel, Tunis.

OSS-SMAP/CE – Tunisie. 2005. *Plaquette base de données 'Efforts et Impacts*', l'Observatoire du Sahara et du Sahel, Tunis.

Reckers, U. 1997. Participatory project evaluation: Letting local people have their say. *Development in Practice*, Vol. 7, No. 3, pp.12–14.

Talbi, M. 2005. *L'opérationnalisation du dispositif de suivi évaluation du PANLCD en Tunisie*. Document de synthèse.Tunis, septembre.

UNEP. 2001. *Plan bleu. Centre d'activité régionale; Tunisie*. Nouvelle Série, Problématique et Politiques d'Environnement et de Développement Durable, UNEP, Tunisie.

Session V
Disaster and Risk Management in Drylands

Session Chair: Dr. Gertjan B. Beekman
Rapporteur: Dr. Mary Seely

Synthesis of Presentations

A. Dr. Nacif Rihani, FAO, Italy, noted that drought, often confused with aridity, is a known and accepted risk of drylands that affects both crops and livestock. Traditional livestock coping mechanisms of pastoral, agro-pastoral and mixed farming communities are deteriorating, however, and many dryland communities that rear livestock are facing chronic vulnerability. Rather than providing humanitarian aid only, droughts are best mitigated by investment in preparedness: in market integration, services and mitigation of conflict. In this paper Dr. Rihani discusses options and provides guidelines for interventions based on FAO experience. Mention is made of livestock/disaster early warning systems; types of intervention (veterinary, feed and water supply, marketing and restocking); guidelines for drought preparedness and mitigation; and further research requirements.

B. Dr. Dusan Sakulski, United Nations University, Germany, discussed the implementation of the Water Sensor Web for floods and droughts in South Africa.

The Sensor Web is a relatively new class of information systems that provides continuous, embedded monitoring. By synthesizing temporal information over large spatial areas, the Sensor Web obtains an environmental self-awareness and is literally becomes a thinking presence within the environment. The Water Sensor Web provides spatial and temporal monitoring of atmospheric, surface and groundwater. Specific portal pods provide end-user access points for the information flow both into and out of the Water Sensor Web.

In South Africa, the Water Sensor Web has been in operation since 2000. The South African Department of Water Affairs and Forestry, Department of Agriculture and South African Weather Service are the main nodes. An effort to continuously monitor, collect, store and analyze atmospheric, surface and groundwater data was synthesized through the South African National Hazard and Vulnerability ATLAS. Special attention was given to droughts and floods.

C. Dr. Ibrahim M.G Phiri, Agricultural Research and Extension Trust, Malawi, discussed the impact of changing environmental conditions on vulnerable communities of the Shire Valley, southern Malawi. He noted that, during the last two decades, the Shire Valley in southern Malawi has experienced significant changes in weather patterns, ranging from severe drought conditions in 1991–1992 to extreme flooding events with flash floods in 2000–2001. These events have had irreversible and damaging effects on crop and livestock production, and the environment. This paper presents results from studies on vulnerability and adaptation assessments that were conducted in 2004 among rural farmers in the Shire Valley, southern Malawi. The studies showed that, in responding to impacts of current climatic threats, 87.5% of farmers reduced the amount of food eaten, while 90% reduced the number of meals eaten per day. Forty percent of the farmers changed their land-use patterns and 50% changed to more adaptable crop varieties. The paper highlights the available technologies and improved production practices for vulnerable farmers and proposes key strategies for the reduction of impacts of adverse effects of climate change.

D. Dr. Braulio Lapinel Pedroso, Instituto de Meteorología, Cuba, noted that the current increase of aridity in the eastern half of Cuba, which corresponds to projections of the main scenario assessments in the region, is explained through examination of causes and repeated events of drought, including the critical event of the period 2003–2005, the most intense drought in 100 years. This drought event has impacted on the population, economy and environment. There is evidence of modifications in the regional atmospheric circulation pattern, showing statistically significant trends for magnitude of vertical movements in the troposphere, which indicates an increase of downward atmospheric flows and a decrease of upward flow, inhibiting rainfall. Capacity-building on global climate change, drought, aridity and desertification has developed the awareness of stakeholders, resulting in feasible measures that are locally adapted. Finally, recommendations are given on improving the Integrated Management System to Combat Desertification and Drought.

Conclusions

a. Aridity and drought are still a matter of confusion. Aridity is a natural phenomenon accompanied by naturally high climate variability. Drought represents the exceptional periods when conditions are considerably drier than usual. Drought is a slow onset, chronic phenomenon.
b. Adaptive strategies are essential for addressing aridity and increasing dryness in drylands. They are also essential to address other manifestations of global change in drylands. This represents risk management.

c. In contrast, coping strategies are necessary for application during the exceptional periods when drought prevails or other disasters occur. This represents disaster management.
d. Responses to droughts and other disasters usually represent media-driven short-term responses that are often inappropriate and too late. Instead, what is needed in drylands is proactive prevention based on a reliable system of information and coordination to support proactive management on all levels.
e. A key issue related to both risk management and drought and other disaster response is education of decision-makers so they can focus on and support maximizing adaptive strategies and actions and minimizing vulnerability, both essential components of living in drylands.

Session V
Disaster and Risk Management in Drylands

Chapter 1
Implementation of the Water Sensor Web for Floods and Droughts in South Africa

Dusan Sakulski

Abstract The Sensor Web is a relatively new class of information system that provides a continuous, embedded monitoring presence. By synthesizing collected temporal information over large spatial areas, the Sensor Web obtains environmental self-awareness and literally becomes a thinking presence within the environment. This new approach is transforming the way we explore, monitor and manage environments and is impacting many fields, including hydrology, agriculture and ecology, as well as disaster risk reduction.

The Water Sensor Web provides a dynamic infrastructure for the spatial and temporal monitoring of atmospheric, surface and groundwater. It is a macro-instrument that allows for the spatio-temporal understanding of an environment through coordinated efforts between multiple numbers and types of instruments that can be fixed as well as mobile. Each pod contains one or more sensors and communicates (more and more wirelessly) within the network, distributing information to the end users. Specific portal pods provide end-user access points for the information flow both into and out of the Water Sensor Web.

In South Africa Water Sensor Web is in operation since 2000. The South African Department of Water Affairs and Forestry, Department of Agriculture and South African Weather Service are the main nodes in this network. An effort to continuously monitor, collect, store and analyse an atmospheric, surface and groundwater data was synthetised through the South African National Hazard and Vulnerability ATLAS. From the user prospective special attention was made to the implementation of Water Sensor Web data and information in regards to droughts and floods. Various flood and drought related indicators have been calculated continuously collecting input data via Water Sensor Web, and utilising an Internet / Intranet as a user's front end.

Keywords Sensor Web, disaster management, drought, ATLAS

United Nations University, Institute for Environment and Human Security (UNU-EHS), Bonn, Germany

1 Introduction

The South Africa Water Sensor Web has been in operation since 2000. The South African Department of Water Affairs and Forestry, Department of Agriculture and South African Weather Service are the main nodes in this network. An effort to continuously monitor, collect, store and analyze atmospheric, surface and groundwater data are synthesized through the South African National Hazard and Vulnerability ATLAS. From the user perspective, special attention was given to the implementation of Water Sensor Web data and information with respect to droughts and floods. Various flood- and drought-related indicators have been calculated, continuously collecting input data via the Water Sensor Web and utilizing Internet/ Intranet as a user's front end.

2 Water Sensor Web

Disaster risk reduction has been officially regulated in South Africa since the promotion of the National Disaster Management Act signed by the president in February 2002. Prevention and proactivity are the major highlights of the Act. An integrated database-driven, web-enabled information system (ATLAS) is implemented to enable disaster risk managers, at all vertical levels of governance, to 'see in advance what kind of threats are on the way'. The South African Weather Service (SAWS), Department of Water Affairs and Forestry (DWAF), Satellite Application Centre (SAC) and National Disaster Management Centre (NDMC) are major institutions liked horizontally via ATLAS.

In southern Africa the most frequent disasters are water-related: droughts and floods as well as waterborne diseases. Do Exercising proactivity with regard to those disasters entails, among other things, continuously monitoring rainfall activities, both spatially and temporally. The ATLAS pages allow for seamless links to rainfall information. SAWS rainfall and storm information (Fig. 1) is refreshed every five minutes and shows spatial distribution of existing activities, as well as 30 min forecasts.

Ground radars do not cover the entire South African territory. The recently terminated project SIMAR enables spatial merging of the following rainfall data: from gauging stations, ground radars and satellite rainfall estimation. The end result is synthesized in the accumulated daily rainfall map (Fig. 2).

If intensive rainfall is imminent, it will certainly generate runoff. What is the existing situation with regard to streamflow as well as the water level in the reservoirs (dams)? DWAF's hydrology division monitors streamflow on major rivers (Fig. 3). The majority of gauging stations are linked via satellite and have a frequent data refresh rate. The user can obtain either flow or water level (heights) information (Fig. 4), or dam capacity information (Fig. 5).

To proactively monitor drought events, ATLAS links to information related to the Standardised Precipitation Index (SPI). It is a commonly accepted drought indicator that uses rainfall as input data.

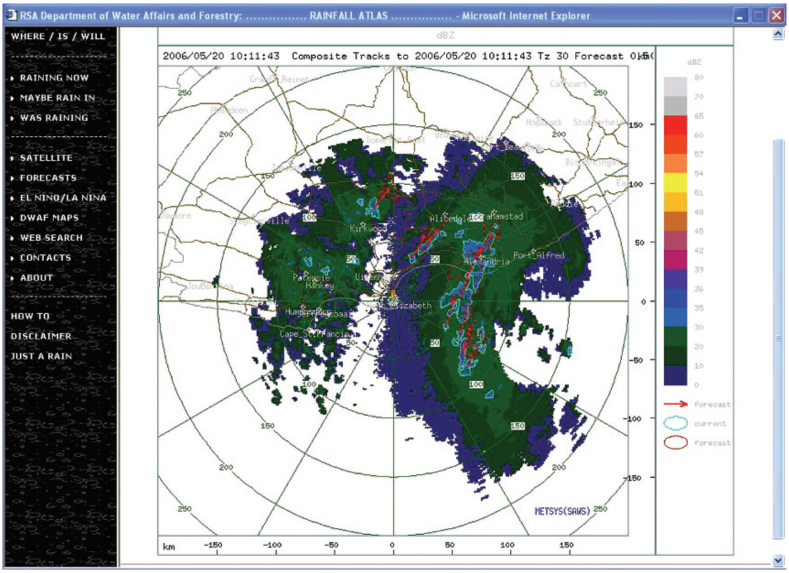


Fig. 1 SAWS weather radar rainfall and storm activities

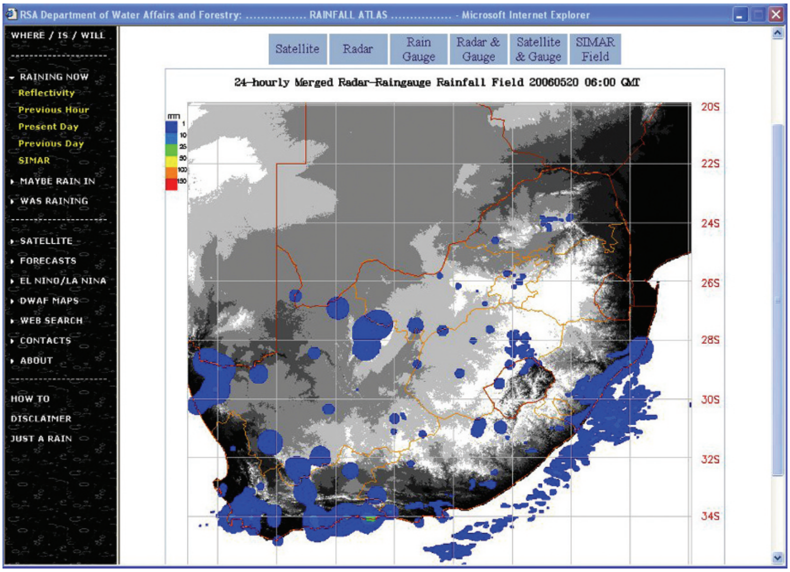


Fig. 2 SIMAR integrated rainfall information

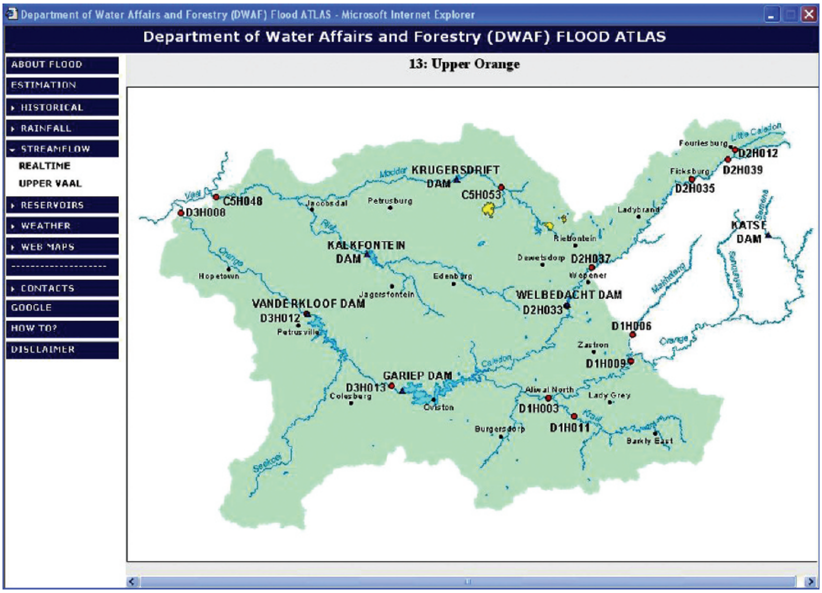


Fig. 3 River flow gauging station on major rivers in the Upper Orange catchment

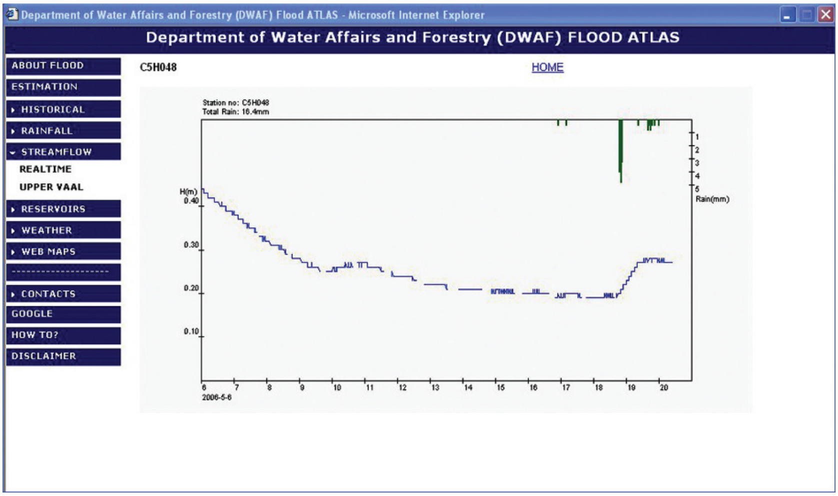
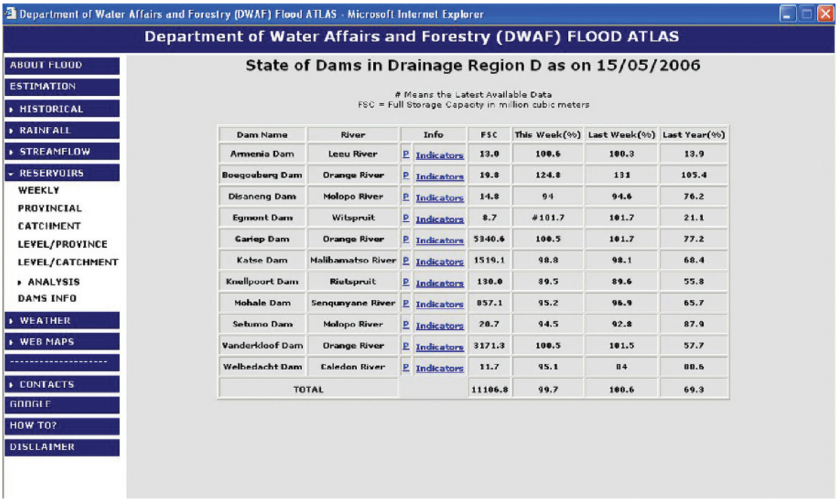


Fig. 4 River water level information

SPI is calculated for a period of 1, 3, 6, 12, 24 and 48 months, in relation to agricultural, surface water or groundwater drought. SPI can be presented spatially as a map (Fig. 6) or temporally as a graph (Fig. 7).

The South African Disaster Risk Management Authority is working very hard to improve the existing ATLAS technology. It serves as a tool to increase proactive



Department of Water Affairs and Forestry (DWAF) Flood ATLAS - Microsoft Internet Explorer

Department of Water Affairs and Forestry (DWAF) FLOOD ATLAS

ABOUT FLOOD
ESTIMATION
HISTORICAL
RAINFALL
STREAMFLOW
RESERVOIRS
WEEKLY
PROVINCIAL
CATCHMENT
LEVEL/PROVINCE
LEVEL/CATCHMENT
ANALYSIS
DAMS INFO
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WEB MAPS

CONTACTS
GOOGLE
HOW TO?
DISCLAIMER

State of Dams in Drainage Region D as on 15/05/2006

# Means the Latest Available Data
FSC = Full Storage Capacity in million cubic meters

Dam Name	River	Info		FSC	This Week(%)	Last Week(%)	Last Year(%)
Armenia Dam	Leeu River	P	Indicators	13.0	100.6	100.3	13.9
Boegoeberg Dam	Orange River	P	Indicators	19.8	124.8	131	105.4
Disaneng Dam	Molopo River	P	Indicators	14.8	94	94.6	76.2
Egmont Dam	Witspruit	P	Indicators	8.7	#101.7	101.7	21.1
Gariep Dam	Orange River	P	Indicators	5340.6	100.5	101.7	77.2
Katse Dam	Malibamatso River	P	Indicators	1519.1	98.8	98.1	68.4
Knellpoort Dam	Rietspruit	P	Indicators	130.0	89.5	89.6	55.8
Mohale Dam	Senqunyane River	P	Indicators	857.1	95.2	96.9	65.7
Setumo Dam	Molopo River	P	Indicators	20.7	94.5	92.8	87.9
Vanderkloof Dam	Orange River	P	Indicators	3171.3	100.5	101.5	57.7
Welbedacht Dam	Caledon River	P	Indicators	11.7	95.1	84	88.6
TOTAL				11106.8	99.7	100.6	69.3

Fig. 5 State of dams (reservoirs)

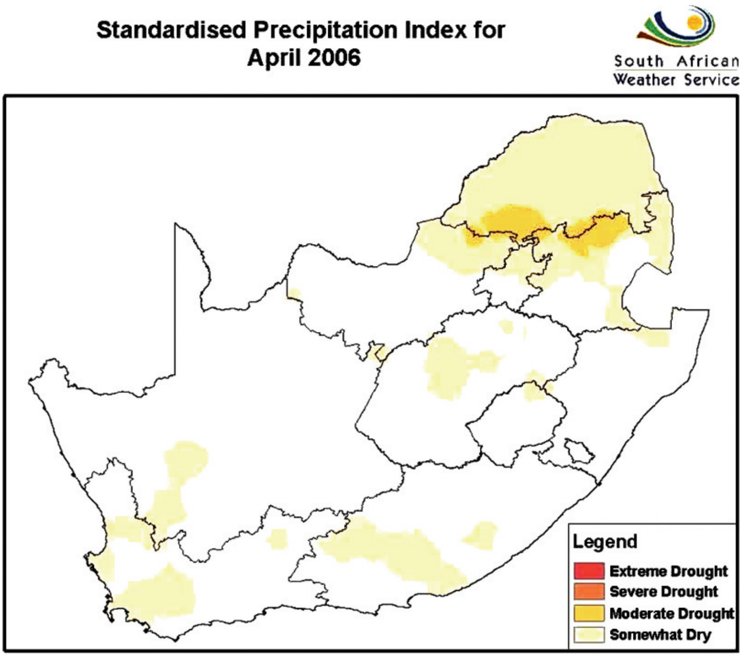

Fig. 6 SPI spatial distribution

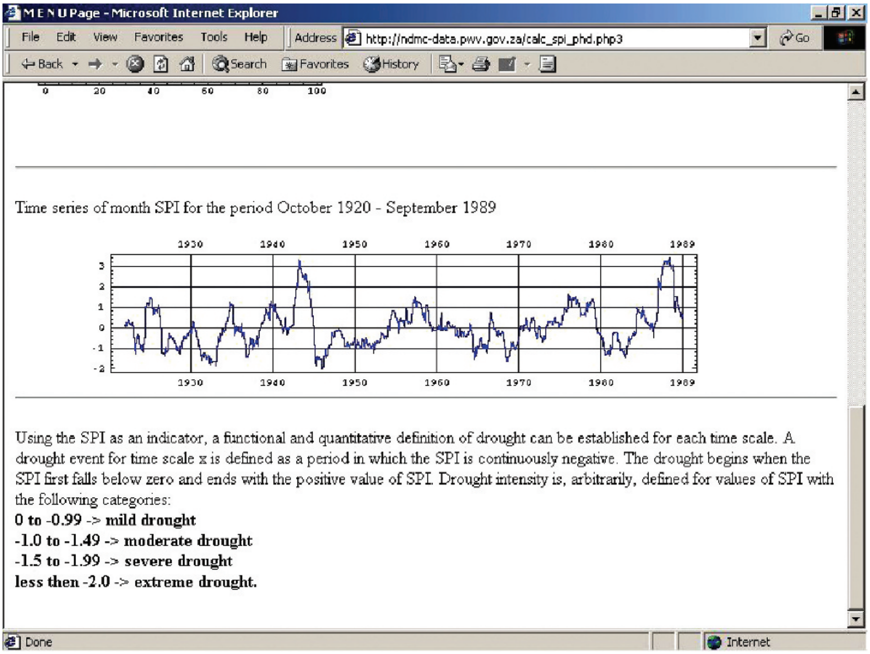

Fig. 7 SPI temporal distribution

thinking and activities to minimize the risk of natural and human-induced hazardous events.

Acknowledgements The author would like to acknowledge the following South African institutions; National Disaster Management Centre (NDMC); South African Weather Service (SAWS); Department of Water Affairs and Forestry (DWAF); Department of Agriculture (DoA); Satellite Application Centre (SAC).

Chapter 2
The Impact of Changing Environmental Conditions on Vulnerable Communities in the Shire Valley, Southern Malawi

Ibrahim M. G. Phiri[1] **and Alex R. Saka**[2]

Abstract During the last two decades, the Shire Valley in southern Malawi has experienced significant changes in weather patterns, ranging from severe drought conditions in 1991–92 to extreme flooding events with flush floods in 2000–01. These events have had irreversible and damaging effects on crop and livestock production and on the environment. This paper presents results from studies on vulnerability and adaptation assessments that were conducted in 2004 among rural farmers in the Shire Valley, southern Malawi. The studies were aimed at predicting climatic changes and their impact on crop production, and at determining the coping and adaptation strategies being used by rural farmers in order to overcome the threats posed by extremes in weather conditions. The studies predicted changes in temperature and rainfall patterns resulting from increased atmospheric carbon dioxide levels, which would in turn reduce the productivity of maize, the main staple food. The studies further showed that, in trying to address the impact of current climatic threats, 87.5% of the farmers reduced the amount of food eaten, while 90% reduced the number of meals eaten per day. The studies also showed that farmers have developed long-term adaptation strategies to overcome climate change. For example, 40% of the farmers changed their land-use patterns and 50% changed to more adaptable varieties. This paper highlights the available technologies and improved production practices for the vulnerable farmers and proposes key strategies for reducing the impact of the adverse effects of climate change on rural farmers in the Shire Valley, southern Malawi.

Keywords Climate change, Shire Valley, rainfall, drought, food security

1 Introduction

Malawi is a land-locked country in southern Africa. It lies along the African Rift Valley between latitudes 9°S and 18°S and longitudes 33°E and 36°E. It is bordered by Tanzania in the north and north-east, Mozambique in the south and the east, and

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[2]Department of Agricultural Rese.arch Services, Malawi

Zambia in the west. It is 910 km long and ranges in width from 60 to 161 km. It has a total surface area of 11.8 million ha, of which the land area is 9.4 million ha (80%) and the remaining 2.4 million ha (20%) is water, principally dominated by Lake Malawi, the third largest lake in Africa. The country is administratively divided into three regions (northern, central and southern regions), which are in turn divided into 27 districts.

Agriculture is the mainstay of the Malawi economy. It contributes about 35–40% of the GDP, 85–90% of the foreign exchange earnings, employs more than 85% of the workforce, provides 60–70% of the inputs into the manufacturing sector and dominates the commercial and distribution industry (World Bank, 1992; EAD, 1998; Phiri et al., 2003). The major food crops in Malawi include: maize, groundnuts, cassava, sorghum, rice, beans and various other pulses. The major cash crops are tobacco, tea, sugarcane and coffee. Maize is the major staple food crop and is grown on about 65% of the total cultivated land area. Of the total land area of 9.4 million ha, 2.9 million ha (31%) is suitable for rain-fed agriculture, 3.0 million ha (32%) is marginal land; whereas 3.5 million ha (37%) is unsuitable for arable farming (EAD, 1998). Amid all the diversity, the areas most vulnerable to climate change and its associated hazards are the low-lying, hot, dry areas along the lakeshore of Lake Malawi and those along the Shire Valley in southern Malawi.

The Shire Valley is located in southwestern Malawi and extends into Mozambique as part of the Great Rift Valley systems of Africa. It covers an area of some 250,000 ha in the two administrative districts of Chikwawa and Nsanje and has a total population of 450,000 (Government of Malawi, 1998). The valley is flanked in the east by an escarpment that rises 1,500–1,600 m above sea level and in the west by a low range of hills rising to 500 m. The valley is an elongated plain with a width of between 8 and 40 km and lies at altitudes of between 30 and 150 m above sea level (Fig. 1). Within the valley is the Shire River, Malawi's largest and longest river (390 km long), which flows out of Lake Malawi and joins the Zambezi. The river divides the valley into two parts known as the east bank and the west bank.

The climate of the Shire Valley can be classified into three seasons: a cool dry season (*masika*) from May to August; a hot dry season (*malimwe*) from September to October; and a hot wet season (*dzinja*) from November to April. Annual mean rainfall varies from 400 to 700 mm (Fig. 2). Variability of rainfall from year to year is considerable and the effectiveness is low. The greater part of the rainfall is of high intensity with heavy surface runoff at the beginning of the season. The wet season is characterized by variability of onset of the rains which influences planting operations and, occasionally, causes them to be postponed until January. The low and variable rainfall brings about a large variation in crop yields, irrespective of husbandry techniques. Mean maximum temperatures are between 37°C in October and 27°C in June. Maximum temperatures of 43°C are common in October, while minimum temperatures are between 14°C in July and 23°C in February. Open pan evaporation reaches about 2,000 mm annually. During the average year, rainfall exceeds potential evapo-transpiration from December to March, and soil moisture storage can be built up this time.

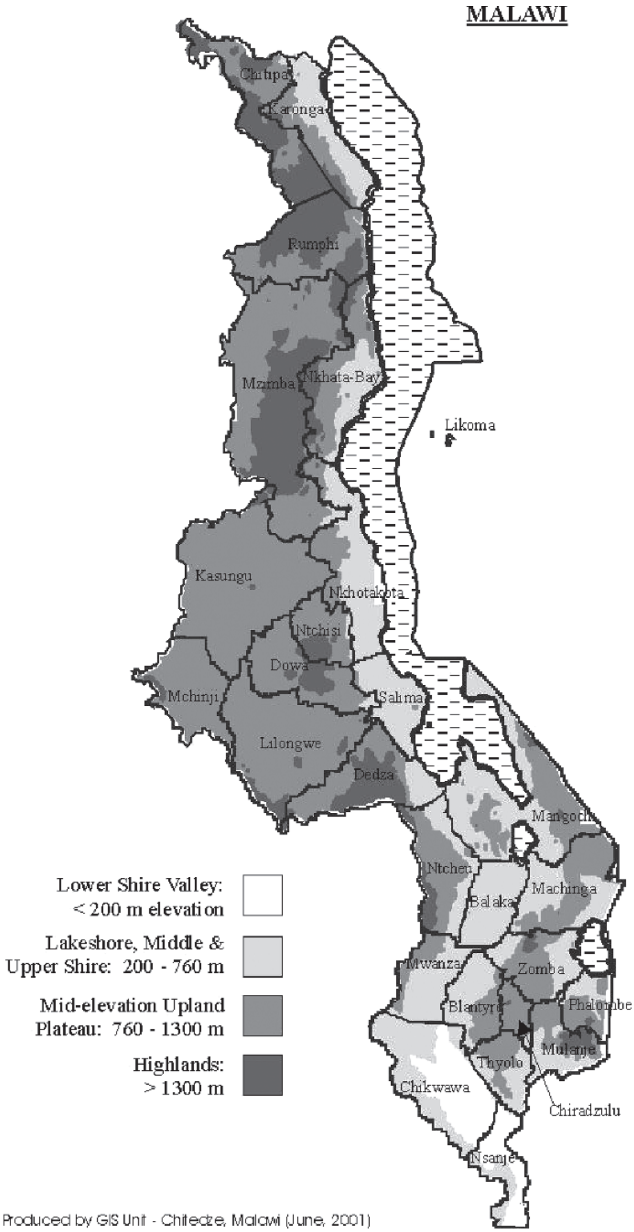

Fig. 1 Major relief units of Malawi

During the last two decades, the Shire Valley has experienced significant weather fluctuations, ranging from the severest drought conditions in 1991–92 to extreme flooding events with flash floods in 2000–01. The rainfall pattern is generally erratic. For instance, while good rainfalls were experienced between 1987 and 1990

Fig. 2 Mean annual rainfall distribution

and between 1995 and 1998, drought conditions were experienced during the 1978–79, 1981–82, 1991–92, 1993–94 and 1994–95 seasons. These droughts have had irreversible and damaging effects on crop and livestock production, and resulted in severe food shortages, malnutrition and hunger, especially among the children of smallholder farmers, female-headed households, the elderly and the urban poor (Sibale et al., 2002). The Shire Valley has been the worst hit of all the ecological regions of Malawi in terms of drought and its associated effects.

This vulnerability and assessment study was undertaken in an attempt to assess the climate change pattern in the Shire Valley and understand how rural communities cope and adapt to climate change. Its main objective was to develop a representative picture of the impact of climate change, defining the risks that households face in producing or accessing food (causes), the household's ability to withstand the risks (responses), the ultimate results of the process (outcomes), and the long-term adaptation measures that have been developed to overcome the risks.

2 Methodology

The study was conducted in two phases. The first phase involved the prediction of climate change using the climate change scenario simulation General Circulation Models (GCM), which have been adopted by the United Nations Framework Convention for Climate Change (UNFCCC) as described in their reference manual (IPCC, 1995). These models provide broad-scale sets of possible future climatic conditions using historical data and greenhouse gas emissions. The model CGCM1-TR, the first version of the Canadian Global Coupled Model (CGCM1) (Flato et al., 1999), was used to generate scenarios for the years 2020, 2075 and 2100 with baseline data from the period 1961–1991 and a mean monthly precipitation pattern correlation coefficient of 0.61.

The second phase of the study involved a household sample survey in Chikwawa district, Shire Valley, through a Participatory Rural Appraisal (PRA). The survey contacted a representative sample of 150 farmers in identified highly vulnerable villages through a structured questionnaire and use of key informants. Most of those contacted were subsistence farmers and local leaders. The survey was aimed at determining the key coping strategies that vulnerable communities use to overcome short-term effects of drought, as well as the long-term adaptation mechanisms that have been institutionalized in the vulnerable communities.

3 Results and Discussion

3.1 Climate Change

The Inter-Governmental Panel on Climate Change (IPCC, 1995) has shown that the most common climate change impacts on agriculture include: (i) direct effects of atmospheric carbon dioxide enrichment on plants, (ii) an increase in global and local temperatures, (iii) changes in water balance, and (iv) changes in the frequency distribution of temperature and rainfall. Results from the current study show evidence of variations in temperature (Fig. 3) and rainfall (Fig. 4) in the Shire Valley from 1970 to 2002. Mean minimum temperatures increased by 3.2%, while mean maximum temperatures increased by 2% between 1970 and 2002. Changes in total rainfall were not as obvious, but the incidence of drought years increased during the late 1980s and early 1990s when compared with earlier decades.

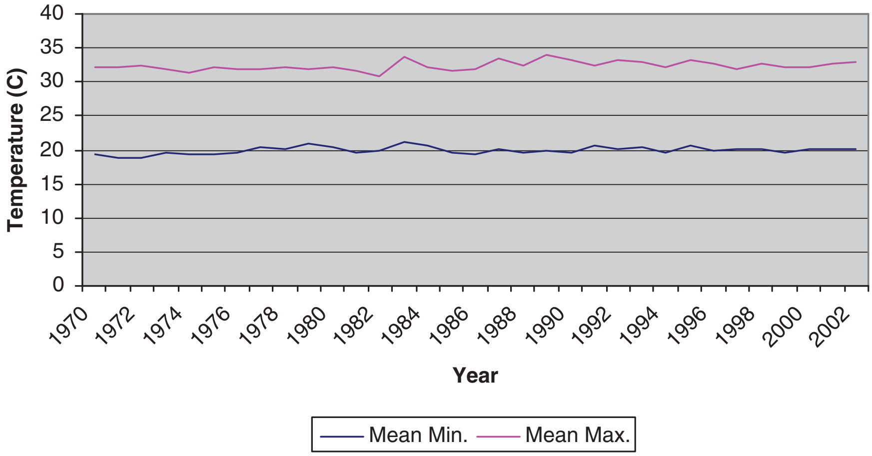

Fig. 3 Mean maximum and mean minimum temperatures from 1970 to 2002, Makhanga Research Station, Shire Valley, Malawi

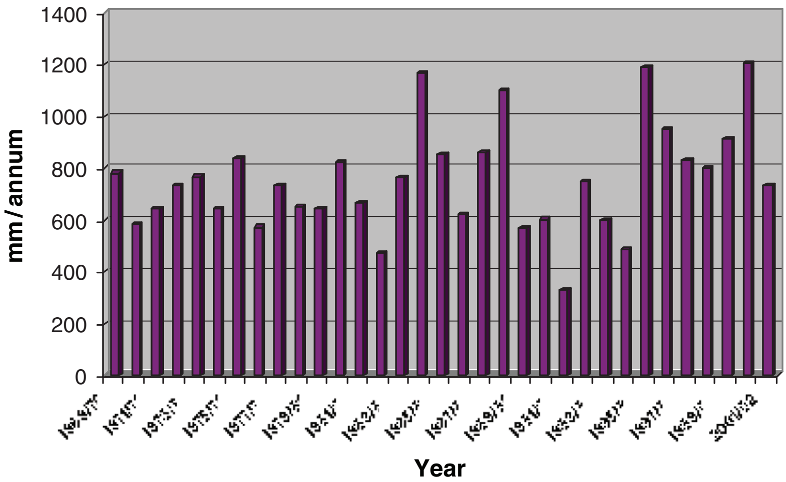

Fig. 4 Annual rainfall pattern from 1970 to 2002, Makhanga Research Station, Shire Valley, Malawi

Predictions from the CGCM1-TR scenario generator show trends similar to the measured data. However, the predicted trends show increases in mean temperature by up to 10°C by the year 2020, 2°C by the year 2075 and 4°C by the year 2100 (Fig. 5). Regarding rainfall, the model predicts reductions of between 2% and 8% in annual precipitation by the year 2100 (Fig. 6). In general, the predictions for Malawi reflect what has been defined by the IPCC (1998) as an 'Aridification Scenario', or the 'dry' and 'core' scenarios; increased temperatures and decreased

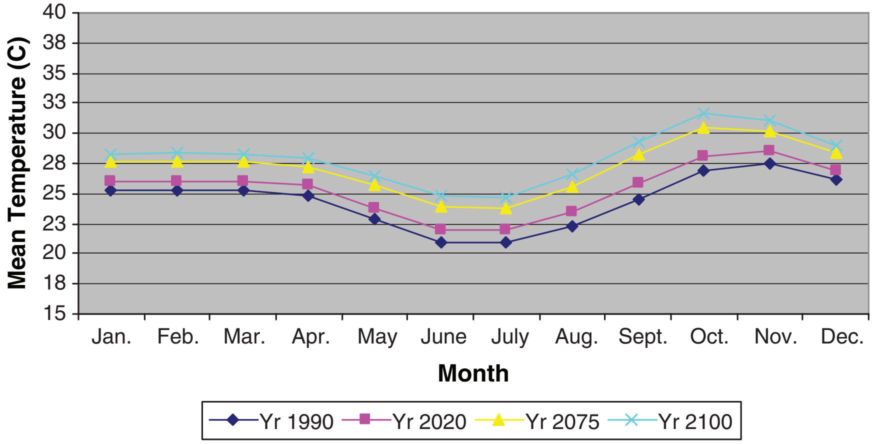

Fig. 5 Predicted temperature patterns for the years 2020, 2050 and 2100, Makhanga Research Station, Shire Valley, Malawi

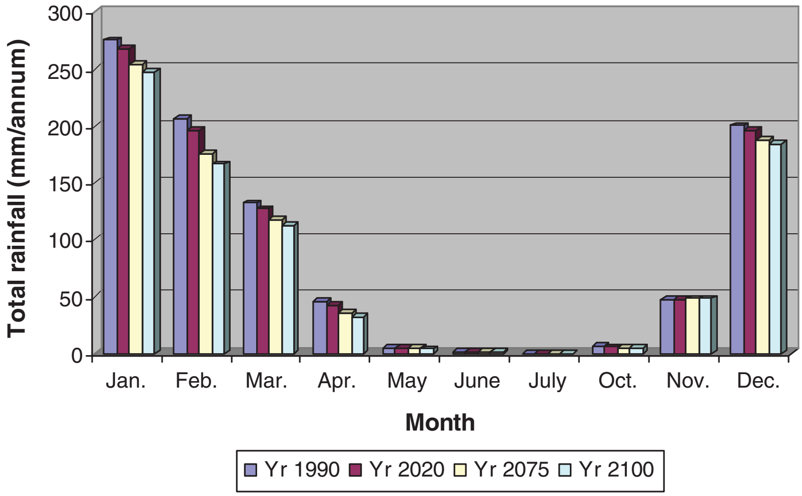

Fig. 6 Predicted rainfall patterns for the years 2020, 2050 and 2100, Makhanga Research Station, Shire Valley, Malawi

rainfall. The results show that the threat posed by climate change is real. Temperature regimes have been on the increase, while rainfall patterns have also changed. This shows the need for communities to develop coping mechanisms in order to overcome such changes in the short term while at the same time developing adaptation mechanisms if they have to maintain their livelihoods in their areas.

4 Coping Mechanisms

Results from the sample survey show that most of the vulnerable households in the Shire Valley are farmers who depend on the sale of crops or other related businesses (Fig. 7). They are mostly female-headed, or elderly-headed and often have orphans from deceased relatives (Fig. 8). In trying to cope with the threats posed by extremes in weather, rural communities use several measures that help them to overcome the threats in the short term. Most of these measures are aimed at ensuring that food is available during the food-scarce months of November to March, or at least attempting to ensure that available reserves last longer than normal. The most common coping responses were found to be the reduction in food consumption as a result of total lack of food or as a means of trying to conserve the available food (Fig. 9). Other changes involved the consumption of foods that would otherwise not be on

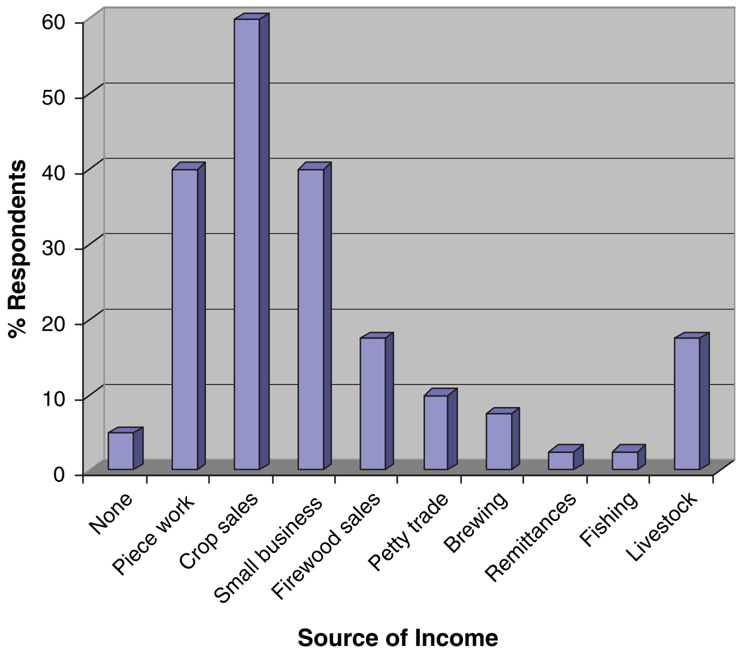

Fig. 7 Status of vulnerable groups – income sources

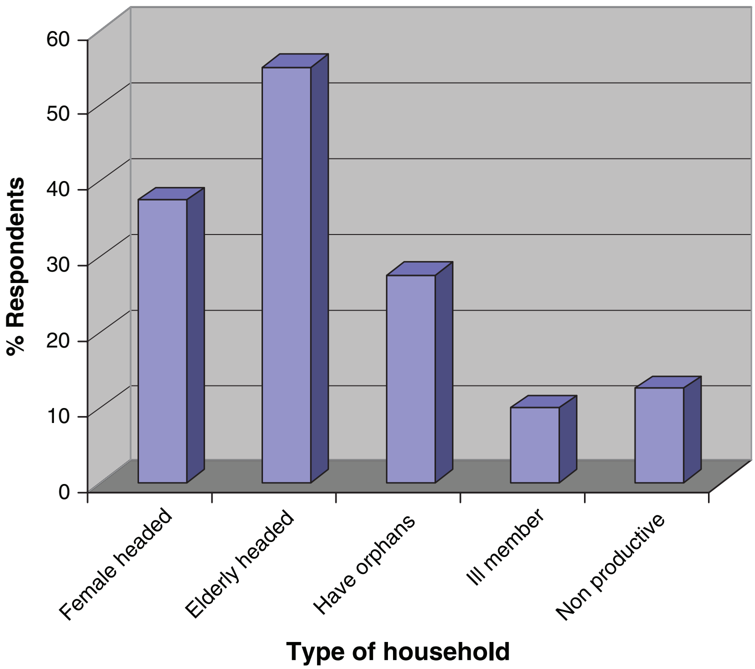

Fig. 8 Status of vulnerable groups – household characteristics

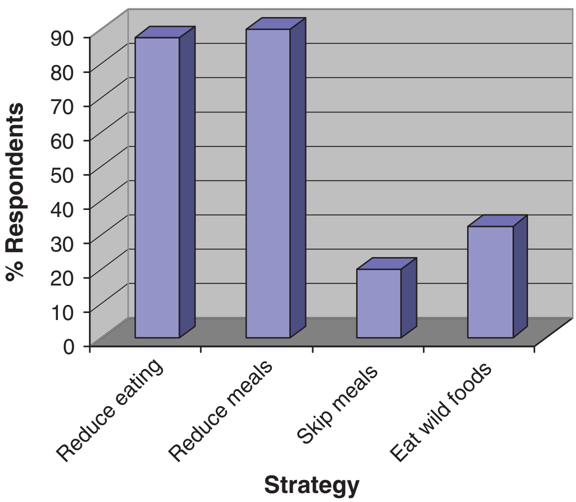

Fig. 9 Changes in meal habits during food-scarce months

the traditional menu, including foods such as wild or indigenous fruits and vegetables, which are not considered staples in some communities. Some families resorted to skipping entire meals so that food reserves could be stretched for longer periods.

Changes in food consumption habits can be illustrated by the reductions in the number of meals consumed during the food-scarce months of November–February as compared with the harvest months of March–October (Fig. 10). Another common feature is the increased diversity of foods consumed during the food-scarce months (Fig. 11) as family members seek nutrition from all available sources, not entirely by choice.

Once families realize that they have run out of food, family heads have to ensure that food is procured. This presents a problem in rural communities, where families do not earn steady incomes. Hence, during drought and flood emergencies, families will first reduce their purchases of non-food items to ensure that available income is used for food. Where the income is not available, families are forced to exchange their assets for cash (Fig. 12). Hence, livestock, household goods and other assets will often be sold off to ensure their ability to purchase food. Families without any assets may have no choice but to borrow money at high interest rates, seek work or even migrate. The latter option has led to the thriving of the tobacco tenancy system as families migrate to farms where food is often provided as part of the work contract.

Clearly, the farmers' own coping mechanisms have become very important for the survival of many families. However, the drought situation of the Shire Valley has often attracted the attention of government agencies as well as non-governmental organizations. Hence, a large number of disaster or risk management programmes are often

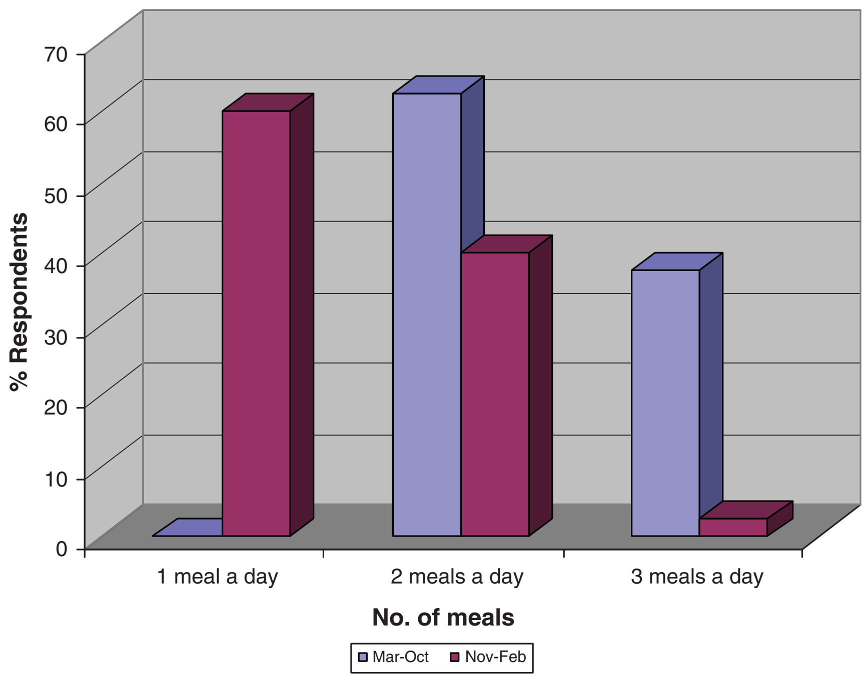

Fig. 10 Changing meal habits – meal frequency

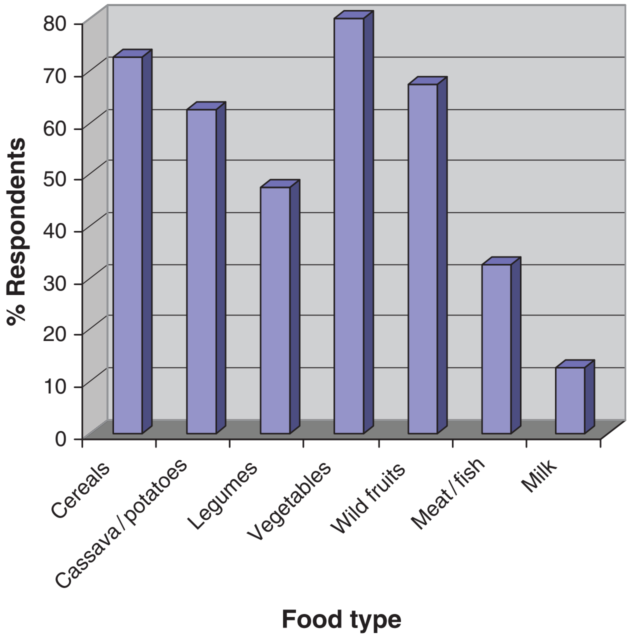

Fig. 11 Changing food habits – diversity of foods consumed from November to March

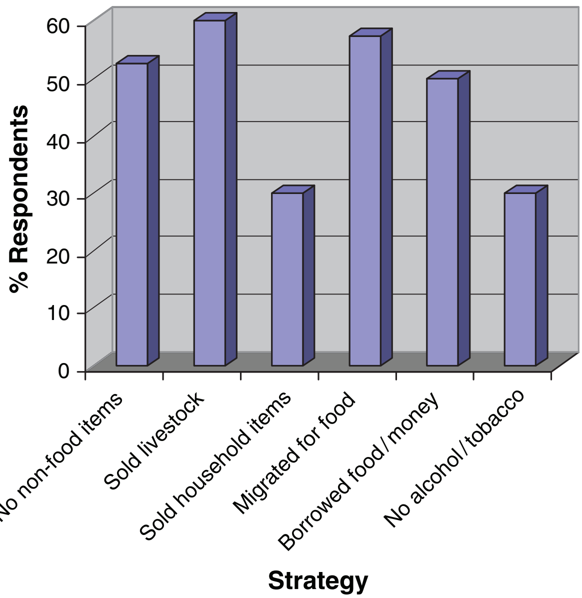

Fig. 12 Coping strategies during food scarce months – buying food

introduced to assist communities cope with the situation. For instance, during the 2002–03 drought in the Shire Valley, the European Union introduced a “cash for work” programme where communities or individuals were encouraged to undertake certain public works projects in exchange for food or cash under a National Safety Nets Programme. At least 250,000 people benefited from this type of assistance (FEWSNET, 2004a). During the 2001 drought season, the Ministry of Health and Population implemented a Supplementary and Therapeutic Feeding Programme for families with malnourished mothers and children. The mothers received food amounting to 1 × 50 kg bag of maize each, while the children received 9 kg of a high concentrate supplement known as ‘Likuni Phala’ every month. This programme, sponsored by the World Food Programme (WFP), served some 3,000 families (FEWSNET, 2004b).

5 Adaptation Measures

The survey found that, at farm level, two broad adaptation options were being implemented for both the crop and livestock sectors: (i) changes in land use, and (ii) changes in crop management strategies. These are illustrated in Fig. 13.

As a means of adapting to the long term effects of drought, communities have institutionalized certain practices. Such mechanisms include changes in land use along the Shire River banks, adoption of drought-tolerant crops or crop varieties

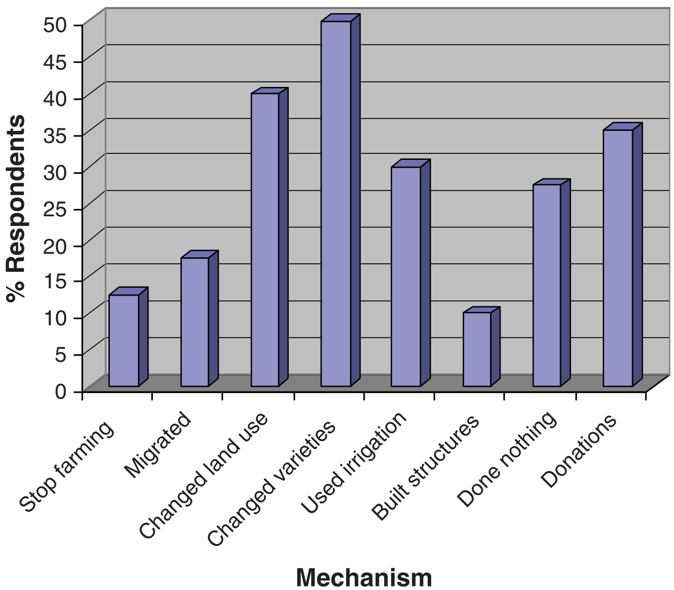

Fig. 13 Mechanisms for adapting to a changing environment, Shire Valley, Malawi

and use of irrigation. In doing so, the alluvial soils deposited by receding waters are used to produce maize and other crops. Over time, this production system has ended up producing more maize than that produced during the normal rainy season. Furthermore, there has been a steady shift over the years to crop types or varieties that have higher thermal requirements or short season crops that are also tolerant to droughts or are specifically adapted to harsh climatic conditions and therefore responsive to changed environmental and climatic conditions.

In another attempt to adapt to the dry conditions in the valley, a number of irrigation systems have been introduced to take advantage of the Shire River. The government has developed several irrigation schemes for the production of vegetables and sugarcane. Most of the schemes pump water into reservoirs from which it is fed into the fields by gravity. The schemes encourage the cultivation of proven high-performance varieties that are more high-yielding, drought-tolerant and disease-tolerant than are currently available on the market. Nonetheless, there are members of the communities in the Shire Valley who have resorted to a high level of dependency on donations that are delivered through emergency programmes. Most of these include the elderly or those who are too ill to work.

6 Summary and Conclusions

Under normal circumstances, the Sire Valley experiences soil-water deficits, increased heat stress and excessive evaporation losses, which greatly reduce crop and pasture yields. At national level, to attain food self sufficiency, Malawi requires policies that support agricultural research and development, increase diversity of agricultural production, strengthen on-going natural resource management programmes, strengthen market liberalization policies, and improve the advisory extension services. There is also need for increased economic and technical support from the international donor community, and for adapting feasible capital investment, technology development and resource management strategies that ensure food security at both household and national levels. In turn, national initiatives should prepare agricultural systems in vulnerable areas such as the Shire Valley for climate change. Climate should be considered a resource for agriculture, stakeholders' capabilities should be enhanced in the agricultural sector so that they are better able respond to climatic variations and climate change. This would entail improving preparedness for climatic hazards, thus reducing vulnerability. Another important aspect is the enforcement of adaptive strategies that mitigate the effects of adverse climate change, as well as taking advantage of likely improvements in climate in some regions. It is not enough to anticipate the coming of drought; it is also necessary to assess the extent to which the country is prepared for such difficult situations, and to be ready with a package of measures to mitigate their adverse effects.

Drought management needs to be based on ecological grounds in order to be sustainable, and it needs to incorporate a mechanism for management of hazards, taking into consideration the following basic principles:

- The inseparable link between drought and desertification
- The fragility and limits of ecological resilience and its permeating influence on people's livelihood and stability
- Drought and desertification management should have specifications compatible with the natural and human modifications of these fragile ecosystems

For the management of drought to effectively capture these principle elements, there must be an early warning (forecasts) mechanism, adequate societal preparedness plan (society organized to face the event), an enabling mechanism that would provide support and relief to the menaced communities, and implementation of projects that mitigate drought and floods, thus enabling vulnerable households to adapt to those conditions while achieving sustainable livelihoods.

Agriculture's adaptation to climate change requires the transfer of new technologies and information to farmers and other stakeholders. These technologies include new genetic stocks, improved irrigation efficiency, improved nutrient use efficiency, and improved risk management and production management techniques. A host of agricultural technologies are suitable for the Shire Valley. Most of these are crop varieties that have proven performance under drought conditions. Examples include the maize hybrids MH18 and NSCM 41, which are suitable for low altitude zones, the groundnut varieties Chalimbana, Manipintar, Mawanga and CG7, pigeon pea variety ICP 9145, cowpea variety Sudan 1, and the bean varieties Nasaka, Napilira, Sapatsika, Maluwa. Among the roots and tubers, known for their tolerance to arid conditions, several varieties have been developed, including those for sweet potatoes (Kenya, Lunyangwa, Tainon 57, and Kakoma), and cassava (Gomani, Nyasungwi, Chitembwere, and Mbundumali).

Adaptation to the uncertainty involved in climate change requires assembling a diverse portfolio of technologies, and keeping the flexibility to transfer and adopt needed technology. Lack of information, financial and human capital and transportation, as well as temporary (land) tenure and unreliable equipment and supplies, discourage the transfer of technology. These hindrances can rarely be surmounted unless the transferred technology has high chances of quickly solving an evident problem. The effectiveness of technology transfer in the agricultural sector in the context of climate change response strategies would depend to a great extent on the suitability of transferred technologies to the socio-economic and cultural context of the recipients, considering development, equity and sustainability issues.

References

Flato, G. M., Boer, G. J., Lee, W. G., McFarlane, N. A., Ramsden, D., Reader, M. C. and Weaver, A. J. 1999. *The Canadian Centre for Climate Modeling and Analysis Global Coupled Model and its Climate Dynamics*, Vol. 16, pp. 451–467.

FEWSNET. 2004a. *Malawi Food Security Update – July 2004*. Famine Early Warning System Network, Malawi.

FEWSNE. 2004b. *Monthly Food Security Report, Mid-January 2004 to Mid-February 2004*. Famine Early Warning System Network, Malawi.

Government of Malawi. 1998. *Malawi's Inventory of Greenhouse Gas Emissions and Sinks for 1990*. Environmental Affairs Department (EAD), Lilongwe, Malawi.

———. 2002. 1998 *Population and Housing Census: A Report of Preliminary Results*. National Statistical Office (NSO), Government Printer, Zomba, Malawi.

IPCC. 1995. *Guidelines for National Greenhouse Gas Inventories: Reference Manual*. Intergovernmental Panel on Climate Change, UNFCC, Bracknell.

———. 1996. The science of Climate Change: Summary for Policymakers. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge/New York, pp. 1–56.

———. 1998. *Summary Report to IPCC. San Jose, Costa Rica*.

Klein, R. J. T. and Tol, R. S. J. 1997. Adaptation to Climate Change: Options and Technologies. Workshop on Adaptation to Climate Variability and Change, Institute for Environmental Studies, Vrije Universiteit, Amsterdam, pp. 13–14.

Phiri, I. M. G., Saka, A. R. and Phoya, R. K. D. 2003. *National Adaptation Programme of Action (NAPA) Malawi – Agriculture Sector*. Environmental Affairs Department, Lilongwe, Malawi.

Sibale, P. K., Chirembo, A. M., Saka, A. R. and Lungu, V. O. 2001. *Food production and security. Module 1 of the 2000–2001 targeted inputs programme*. Reading: Calibre Consultants and Reading: Statistical Services Centre, University of Reading.

World Food Programme. 2002. *Food Assistance to People Affected by Severe Food Shortages in Malawi*. World Food Programme, February.

World Bank. 1992. *Economic Reports on Environmental Policy*. 2 vols. Lilongwe, Malawi, World Bank.

Session VI
Policy, Governance and Socio-economic Dynamics in Changing Drylands

Session Chair: Prof. Boshra Salem
Rapporteur: Dr. Mekhlis Suleimenov

Synthesis of Presentations

A. Dr. Mélanie Requier-Desjardins, University of Versailles, France, presented results of long-term studies on the links between migration and development. Many empirical and theoretical studies deriving from various disciplines, such as demography, sociology, economics and anthropology, show how migration affects the development processes and how it occurs with the departure of families and in some cases entire villages. She emphasized the scant attention focused on the links between desertification and migration. The presentation defined the links between desertification, public policies and migration by investigating the relevant literature on migration and development.

The presenter concluded that one cannot say that informal migrations are driven by desertification at that stage but more evidently and globally by the lack of economic prospects people suffer in these regions.

The review of many works reveals that land degradation is not specifically due to the rise in the rural population nor to the increasing conversion of lands into fields but to the development of new rural industries integrated into the market economy within a legislative context that often fails to define clear rights of access to natural resources (e.g., in the case of deforestation during the 20th century). Furthermore, the lack of nationally integrated agricultural policies (taking into account the heterogeneity of the rural world) leads to greater desertification than the increase of population in itself.

The presenter also talked about the migrants' remittances, their level and use:

- Sub-Saharan Africa is the least doted region in terms of volume of migrants' remittances, which cannot be relied upon to finance the development of such countries.
- The poorest countries receive the highest proportion of the GDP from their migrants.

- These sums are used mostly for current expenditures and rarely for economic investment and/or land rehabilitation.
- Public and international support is therefore required to combat desertification.

She also presented a qualitative inventory of the costs of migration as potential social costs of desertification with emphasis on the benefits of such migrations by distinguishing three cases:

- Migrations to rural African regions
- Migrations to southern towns
- Migrations to northern countries

Currently, we do not know enough about migration and desertification nor about the social costs of desertification, which are crucial issues to focus over the coming years.

B. Mr. Pierre Gerber, Livestock, Environment and Development initiative (LEAD), FAO, Italy, emphasized that grazing systems tend to occupy the driest, least fertile and climatologically least stable areas of the dryland biomes. In Africa, as in many other of the world's drylands, the land frontier for pasture expansion into marginal areas has been exhausted. On the other hand, crop land is encroaching on the most productive land, while protected areas are also increasingly expanding into rangelands. Furthermore, the economic, institutional, social and legal contexts in which traditional Sahelian pastoral systems operate are rapidly changing, following the worst scenario: population growth increases pressure on resources; economic development in urban and coastal areas fuels demand for new livestock products; decentralization empowers local authorities mostly representing sedentary populations, and traditional forms of resource management are increasingly compromised.

In the absence of adequate policy frameworks, pastoralism fails to respond to these changes. This is resulting in increasing conflicts, widespread and often serious environmental degradation, economic losses and social marginalization of pastoralists. There is an urgent need for informed policies and novel practices to facilitate the transition of pastoral systems in an economic, social, and environmentally acceptable manner. This transition requires a better connection to output markets on the one hand, and to additional and improved feed resources based on crop and feed production systems on the other hand. There is also a need for new mechanisms and institutional frameworks to manage and allocate natural resources and compensation schemes for the generation of environmental services.

C. Dr. Olivier Barrière, Institut de Recherche pour le Développement (IRD), France, notes that the governance of the environment in the zones around the Sahara Desert is comprised of methods to regulate access to natural resources, which are particularly vulnerable in the drylands. Social systems depend on ecological systems, within which they exist, for their reproduction and survival. Co-existence is defined as the equilibrium between the needs of the society to reproduce itself and the maintenance of ecological, biotic and a-biotic processes, and of their components. Extreme constraints, to which these areas are subjected, lead to the method of management, which by its legal regulation, serves as a cornerstone for a sustainable development. The 'land-environment' approach was developed to incorporate concepts and methodologies of legal analysis which help to understand the successful co-existence of social and ecological systems. The law is situated at the heart of all these interactions. It identifies itself through a legal diversity of locally practiced laws and the law imposed by the State. The combination of legitimacy (local practices) and legality (official law) contributes more to the successful social and ecologic co-existence then the sole prevalence of the State law. In the dry zones, one can often find the mixture of different legal systems, where community rights overlap with individual rights. The present analysis goes beyond the concept of 'societies/nature', and takes also into account the rights of future generations and those of social resilience.

In some way, co-existence defines the unity of cultural world (social systems), and the natural world (the ecosystem), in other words, it is a reconciliation between the man and the nature. How the law intervenes and contributes to this reconciliation? To answer this question, the approach of legal anthropology must be used, and not that of the formal law, because the laws which are really practiced by the people must be considered.

Legal regulation of environment (ways to access resources) is the cornerstone of sustainable development. The laws regulating the land should be integrated within the framework of environmental governance. The land ownership regime should contribute to the environmental protection and particularly to the fight against desertification. These land resources should be well defined and qualified and ways identified as how they can be integrated in the objective of conservation of biodiversity.

D. Dr. Ian Watson, Department of Agriculture, Western Australia, and Centre for Management of Arid Environments, Australia, presented a happy story from Western Australia, where land degradation has been addressed by joint efforts of producers, scientists, extension and soil conservation agents, as well as of policy-makers. The Gascoyne catchment of arid Western Australia was presented as a desertification case study at the United Nations Conference on Desertification in Nairobi in 1977. The Gascoyne is similar to many other areas in Western Australia that were seriously degraded following the introduction of domestic livestock in the late 19th century. Dr. Watson emphasized that in Australia individual livestock producers play the primary role in land management under leasehold terms and conditions. It is their day-to-day decisions that determine whether the land they manage will continue to degrade or improve. They require good technical information and a sound regulatory and policy framework in which to operate. Improvements in land management in the Western Australian rangelands since the 1970s have been helped by the provision of comprehensive resource inventories, range assessment and ongoing monitoring information, a mixture of regulation and individual responsibility, capacity-building using a variety of approaches, and regional scale strategies that take a co-ordinated approach to land management issues. A strong emphasis on science was used to address technical issues and to improve the understanding of ecosystem dynamics. In general, Western Australian land managers are now better educated than in the past, are more aware of the consequences of their decisions, have a better sense of community expectations, and typically practice a more benign style of land management than their predecessors. There is good evidence that much of the Western Australia rangelands are now in better condition than they were 50 years ago.

Conclusions

a. This session clearly demonstrated that drylands in many parts of the world are in danger, with general trends towards severe land degradation: the land frontier for pasture expansion into marginal areas has been exhausted and crop land is encroaching on the most productive land, while protected areas are also increasingly expanding into rangelands. Furthermore, the economic, institutional, social and legal contexts in which traditional pastoral systems operate are rapidly changing following the worst scenario of increased pressure on resources because of population growth.
b. The session made the following recommendations:

   - To encourage more empirical studies on the links between desertification and migration
   - To consider not only the costs of migration but also its benefits
   - To enlarge the theme of desertification social costs to other types of social costs, such as gender issues
   - Not to use the theme of migration to raise new funding for fighting desertification, but more to refer to the economic costs of desertification to do so

c. Social systems depend on the ecological systems, within which they exist, for their reproduction and survival. Co-existence is defined as the equilibrium between the needs of the society to reproduce itself and the maintenance of ecological, biotic and a-biotic processes, and of their components. The extreme constraints to which these areas are subjected lead to a method of management, that, by its legal regulation, serves as a cornerstone for sustainable development. The laws regulating the land should be integrated in the framework of environmental governance. The land ownership regime should contribute to environmental protection and particularly to the fight against desertification.
d. The successful case of the integrated management of degraded rangeland in Western Australia during 50 years is the result of well-coordinated joint efforts by many stakeholders. Individual livestock producers play the primary role in land management under leasehold terms and conditions. They require good technical information and a sound regulatory and policy framework in which to operate. Comprehensive resource inventories, range assessment and ongoing monitoring information have been provided; regional scale strategies include a mixture of regulation and individual responsibility, as well as capacity-building

using a variety of approaches. A strong emphasis on science was used to address technical issues and to improve the understanding of ecosystem dynamics. In general, Western Australian land managers are now better educated than in the past, are more aware of the consequences of their decisions, have a better sense of community expectations, and typically practice a more benign style of land management than their predecessors.

Session VI
Policy, Governance and Socio-Economic Dynamics in Changing Drylands

Chapter 1
Social Costs of Desertification in Africa: The Case of Migration

Mélanie Requier-Desjardins

Abstract The paper discusses the links between migration and desertification in Africa. As this issue is not the subject of any specific recorded study, it is based on available localized work on migration, as well as reports on the rural exodus. "Migrations and development" is a theme that questions the use of the transfer of migrants to combat desertification. It proposes a qualitative inventory of the costs of migration and demonstrates how it reflects the absence of locally adapted agricultural policies and the development of internal markets, as well as the global treatment of inequalities between industrialized and developing countries.

Keywords Desertification, migration, rural exodus, remittances, development policies, costs

1 Introduction

'Migration is defined as a movement of persons crossing a certain limit so as to establish a new residence elsewhere' (Population Reference Bureau, cited in Domenach and Picouët, 1995).[1] It is recognized as a response to issues of insecurity, notably associated with the economic context and more generally to poverty. For example, in Africa, income stability, which in the past was based on temporal and sectoral agricultural diversification, is today based on spatial diversification of

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This paper is based on a report commissioned by AFD (Agence française de developpement) in 2005 on the economic and social costs of desertification in Africa. The report was co-written by M. Requier-Desjardins (CSFD) and M. Bied-Charreton (CSFD).

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[1] Population reference bureau, quoted by Domenach and Picouët, 1995. No study has to this day been carried out on the eventual statistical relationship of these two types of risks between the regions subjected to desertification and other African regions.

income sources between members of the family unit (Guilmoto, 1997). Rural migration appears closely linked with climatic risk and variability in terms of availability of natural resources, but it is also due to economic risk and notably the variation in agricultural prices.[1]

At the international level, we note that the relationship between the phenomenon of migration and the Millennium Development Goals (MDGs) has not been explored. Moreover, a document produced in 2005 by the International Organization for Migration (IOM) briefly but specifically examined the links of interdependence between migration and the MDGs (Usher, 2005). We are concerned here with Objective 1 (Eradicate extreme hunger and poverty) and Objective 7 (Ensure environmental stability). The following elements can be considered:

- Sixty per cent of the world's population of migrants, estimated at 175 million people in 2000, actually live in the more developed countries.
- The migratory flux occurs to a large extent within and between developing countries. The developing world thus welcomes the majority of internal migrants (a number greater than international migrants).
- As long as internal and international migrations continue to increase and a change of migratory flux is taking place from permanent and unidirectional migration, it appears increasingly temporary, seasonal and cyclical.
- The link between internal and international migration is controversial; some assert that it involves different stages of the same process.
- Generally, migratory movements have been observed between cities and the countryside (in both directions).
- Problems related to the systems of reliable recording and data constitute a true obstacle to fully understanding the migratory phenomenon.

2 Migrations and Desertification in the African Region

2.1 Dynamics of African Migration

Generally, since the period of independence of African nations, the frequency of migrations in Africa has continued to rise. Short- and long-distance population movements are both increasing. The number of refugees is also rising. At the same time, African immigration policies have become increasingly constraining (Bonnassieux, 2005).

There is little quantitative data available on international migrations within Africa. However, the few studies that have been carried out in West Africa reveal that migration is particularly developed in this region.

- At the end of the 1990s, 13% of the total population of the West African region (excluding Nigeria) lived in a country that was not their country of birth and 40% of them no longer lived in the district or region of their birth (Cour, 2001).

- A survey carried out in seven countries (Burkina Faso, Guinea, Ivory Coast, Mali, Mauritania, Niger and Senegal) during 1988–1992 revealed that migrations are 2.6 times more developed in West Africa than in Europe. It has been noted that the immigration of people from the seven countries above to Europe represents only 9% of intra-African migrations observed during this period (Traoré and Bocquier, 1996).

Migration is particularly developed in Africa and functions as a sort a mechanism of organized social protection against the diverse risks, notably climatic and economic risks. However, it also appears that these recent changes testify to rather specific socio-economic difficulties, like the rise in poverty and the multiplication of conflicts (Pliez, 2002).

2.2 Migratory Movements: Environmental and Economic Factors

The principal migratory movements that have developed in Africa between the period of independence and 1990–2000 are linked both to the availability of natural resources and to economic opportunities in the adopted country (plantation agriculture, mining and transformation industries, amenities, etc.). For instance, we can cite:

- Migrations towards the coastal zones of Abidjan and Dakar from landlocked countries of the Sahel; today "reverse" migrations back from Ivory Coast to northern countries for political reasons are observed
- Migrations from southern countries to gold or diamond mines in South Africa despite the fact that it is known that the country closed its borders to immigration since the 1990s (Guilmoto and Sandron, 2003)
- Migrations to Nigeria up until the 1980s following the industrial development of the country and the eviction of many migrants thereafter
- Migrations to Libya until the tightening of the migration policy at the beginning of 2000 (Bredeloup and Zongo, 2005)
- Migrations of sub-Saharan countries towards North African countries, notably Morocco (Bredeloup and Pliez, 2005)[2]

Migratory trends change and the countries of immigration become countries of emigration (Ivory Coast, Democratic Republic of Congo and Senegal); the reasons for this can be multiple: conflicts, unfavourable legislation on migration, economic and social difficulties. New destinations or centres of employment emerge, such as Ghana for migrants from Burkina Faso.

[2] As we are only covering internal migrations in Africa, the migrations from North Africa to the Emirates and the migrations from Africa to Europe, have not been taken into account.

'However, the change in the pattern of population settlement in West Africa indicates that overall there is a continuation of migrations from zones exposed to desertification' (Court, 2001).[3] These shifts in population towards the south undoubtedly reflect on regional inequalities in available natural resources, but they are also increasingly determined by the size and the location of the urban markets, as well as the available infrastructure:

- The density of the rural population decreases with distance to markets
- Agricultural output and productivity are linked to the presence of markets
- Immigration zones contribute four-fifths to regional output

2.3 Geographic Typology of Migrations: The Rural Exodus

Geographic typology distinguishes between country–city migrations or rural exodus, city–city migrations, city–rural migrations called "disurbanization", and rural–rural migrations (Domenach et Picouët, 1995).[4]

Desertification can be linked to migrations either from rural regions towards zones with improved lands or towards pioneer fronts, as well as the rural exodus.

- In Burkina Faso a statistical study carried out on inter-provincial migration from rural to rural regions revealed that the principal reason for permanent migration from the northern parts of the country, i.e. the drylands, was desertification (Henry et al., 2003).
- In Morocco a study carried out on the rural exodus emphasizes the high proportion of rural migrants in the country's city slums, thus suggesting a strong link between migration in cities and desertification and poverty (Lahlou and Zouiten, 2001). In fact, the informal sector absorbs the majority of migrants from the rural exodus: in 2000, it employed two-thirds of the urban population as compared to one-third in 1960; on average, the consumption needs as well as their income needs of these migrants in the city multiply threefold (Cour, 2001).

Urbanization in Africa is very high in the Sahelian region, with an eight-fold multiplication of the urban population between 1960 and 2001 as compared to a total population that has multiplied by 2.8 (Bossard, 2004) during the same period.

[3] As a reminder, the entire Sahelian region (Mali, Mauritania, Chad, Niger, Burkina Faso) is characterized by high population growth rate of about 2–3%.

[4] Several typologies of migrations exist; for e.g. Guilmoto and Sandron (2003) proposed a typology based on the migratory profile.

Following independence, priority was generally assigned to growth in the capital cities. However, this growth had negative impacts: rise in unemployment as well as under-employment in cities, pressure on urban services (education, housing and sewage), destruction of the social fabric, rise in criminality, and environmental degradation. This trend has fallen at the end of the 1990s with the emergence of secondary cities, whose growth rate is actually greater than that of the capitals.

Presently, the phenomenon of urban exodus is growing because of the increasingly difficult living conditions in the cities (United Nations demographic data).[5] Forecasts appear to predict future urbanization as more flexible and temporary with round-trips from city to countryside depending on socio-economic and political events.

In Africa the rural exodus and urban growth are accompanied by:

- A degradation of urban life linked to a lack of infrastructure and characterized by a rise of slums where the population becomes vulnerable, and by the development of the informal sector.
- A ruralization of cities, i.e. the development of agricultural activities in peri-urban areas with such commercial activities as garden allotments and rearing. These activities in fact create desertification because of their strong anthropic pressure.
- A scramble to find space on the periphery of cities, another vector of desertification.[6]

Desertification and land degradation are therefore factors that encourage the growth of slums; conversely, the rural exodus, due to a lack of prospects of city employment, aggravates desertification in peri-urban areas.

2.4 Migrations and Rural Development Policies in Drylands

Since independence, rural development policies and later, urban dispersion, has been established to develop agriculture, reduce or even reverse the phenomenon of rural exodus and give priority to the emergence of secondary cities. The land planning policy carried out in the region of St Louis in Senegal has thus created favourable conditions for the urbanization of this region. The population of the villages, including those from the city of St Louis, has moved to secondary cities, called 'intermediate urban or semi-urban zones' (Regnard, 2001).

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[5] Site: http://esa.un.org/unup/

[6] For example, 140,000 ha have been lost around greater Algiers, and the growth of the city of Sfax in Tunisia has resulted in the loss of 9,000 ha of agricultural gardens (Benoît and Gomeau, 2005).

A number of studies on the impact of rural development policies and urban dispersion demonstrate that they influence migratory behaviour:[7]

- One of the studies concerns the role of different socio-economic variables in migration from data collected in 12 villages in Senegal (Guilmoto, 1997). For instance, the level of education (measured by illiteracy), though positively linked to migration, has a lesser importance than expected, probably due to the slim prospects offered by cities. In addition, short-stay migrations often involve lesser educated individuals. The presence of infrastructures (educational establishments, trade outlets and health) is negatively linked to migration, favouring the stability of settlements (an obstacle to mobility).[8] The proximity of the road network does not have an incidence on migration, and the more enclosed regions are in fact the most affected by emigration. Finally, at the family scale, irrigation (modern agriculture) acts as an obstacle to mobility.
- Another study carried out in Burkina Faso (Beauchemain and Shoumaker, 2005) concerns the effects of local development policies implemented both in rural zones and in secondary cities in order to reduce migration to principal cities. Local development is defined as the availability of public services and public infrastructure, income-generation activities and commercial services. The components of local development in the economic context (village markets, large companies and agricultural opportunities) in secondary cities prevent migration. On the other hand, road and health infrastructure encourage migration, which is contrary to the results of the study mentioned earlier.

These studies, however, demonstrate the dynamism of the local economic context, particularly when it is extended to non-agricultural activities, while the transformation of local products (agro-alimentary, craft industries, etc.) contributes to the stabilization of populations.

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[7] The strategies of rural development emphasize the development of agricultural and non-agricultural labour as well as infrastructure (electricity, water, roads, etc.), access to credit for small producers, the development of health services, and the improvement of education and agrarian reform in order to improve the quality of life and increase the income of the rural population and thereby reduce the propensity for the rural exodus.

The strategy of urban dispersion aims to increase economic opportunities and living conditions in the secondary urban centres so that the rural migrants diversify their choice of destination. This implies the development of labour in the selected places via public investment in infrastructures and state industries, assistance to local governments, and the promotion of private investments within the framework of a strategy of decentralization of labour. One of the objectives of these strategies is also to reduce inter-regional inequalities (Beauchemin et al., 2005).

[8] According to Guilmoto (1997), infrastructures are also indicators of the state of development of non-agricultural activities, diversity of resources and size of the village.

3 Remittances by Migrants and Combating Desertification

3.1 Remittances in Africa

Remittances relate to private funds. In 2005, registered international remittances by migrants to their country of origin reached US$ 232 billion, of which US$167 billion is remitted to developing countries. In reality these amounts are doubled if we take into consideration the informal transfers that characterize a large portion of transfers to African countries (Cotula and Toulmin, 2004); transfers increase at a greater rate than the number of migrants (World Bank, 2006). Globally, these remittances are twice as important (in terms of amounts) as Public Development Aid (PDA). However, in Central, Southern and sub-Saharan Africa, PDA (in terms of volume) remains greater than remittances, contributing 50% of external financial flows compared to only 14% for remittances (Sander, 2003).

Africa, particularly sub-Saharan Africa, represents the lowest number of remittances by volume; however, they receive a greater amount of remittances proportional to their wealth (percentage of GDP of the country), which confirms its importance for the economy (see Figs. 1 and 2).

3.2 The Use of Remittances

For the most part, migrants use remittances to improve daily living conditions, addressing everyday consumption needs or primary needs, such as health, food, education and housing (notably construction) (Cotula and Toulmin, 2004).

The purchase of durable goods to improve well-being (hi-fi, games, etc.) is also part of everyday uses of remittances (Kapur, 2003). Remittances also contribute to the improvement of social status: investment in socio-cultural life (weddings, births, etc.) enables a migrant family to improve its status. In addition, it serves as an investment in land (sale), cattle, debt reimbursement due to migration, savings as well as investment in economic activities (entrepreneurialship). The rise of local demand due to remittances contributes to stimulating economic activity, except when the demand is due to imported products.

3.3 Small Investments and Remittances in Actions to Combat Desertification

The investment to combat desertification is only marginally concerned with the remittances. Local studies provide conflicting results:

- Remittances can discourage agricultural investment and even economic activities; households expect to receive funds that allow them to live on a daily basis (observations made in Morocco, for example).
- Remittances would offer greater technical efficiency in agricultural plots of the families concerned (Mochebelele, 2000, Lesotho case study).
- We could also underline the contribution in terms of the human capital migration can potentially provide.

The collective use of transfers account for the smallest proportion of amounts transferred. They can be directed towards socio-economic investments (Fig. 3). Migrant associations also finance schools or even universities (investment in human capital), hygiene infrastructure (water points, pharmacies, sewage), as well as economic activities, such as the development of eco-tourism, branches known as "fairtrade" and a few operations of land rehabilitation.

4 Costs of Migration

4.1 What Do We Understand by 'Migration Costs'?

If we wish to differentiate the direct costs with respect to the place of departure and arrival, they include:

- ***The direct costs assumed by the migrants***: At the time of departure of a person or an entire family, direct and immediate costs are incurred: displacement, setting up, the runner – the cost can range from a few hundred to several thousand euros.
- ***The direct costs assumed by the local community and the adopted communities***: Additional infrastructure for water, sewage, connection to networks, urbanism, dwellings; if the level of integration in the adopted society is high, then there are additional costs for schooling and health.
- ***The indirect costs assumed by the environment fled***: Loss of maintenance of the natural environment, worsening of erosion; disintegration of the society, loss of often qualified human resources.
- ***The indirect costs assumed by the adopted environment***: Environmental impact due to a greater number of people (notably in the case of refugee camps), impact on crop and husbandry systems of the adopted areas and risks of degradation; depending on the policies of the host countries, there may be a specific social cost to the integration of migrants.

If the migrations generate partially quantifiable costs, it goes without saying that they also bring many benefits to the host country. The first economic benefits come from migrants who move to find work; the input of cheap labour in the more dynamic host regions stimulates economic development. This is the dominant theoretical (and liberal) model, which presents migration as a factor of economic development because it allows for a reduction of production costs and stimulated competition (Domenech and Picouët, 2004).[9] Other authors insist instead on consumer aspects and human capital: migration stimulates consumption in the host country and therefore production and investment, thereby encouraging the native population to improve their skills (Oudinet, 2005).

4.2 A Qualitative Inventory of the Costs and Benefits of Migration from the Drylands

We propose a qualitative inventory of costs and benefits in the form of the following three tables, and according to three types migration:

- Internal migration in Africa from agricultural region to agricultural region
- Internal migration to African cities
- External migration from Africa to OECD (member states of the Organisation for Economic Co-operation and Development) countries in particular

From the Tables 1, 2 and 3 we can see that complete cost-benefit analyses with respect to migration appear complex. We observe similarities between the three situations: the economic benefits linked to labour costs in the host regions and the social costs of integration are common elements in all three migration types. As for environmental aspects, in this case desertification, they are more difficult to evaluate because of the socio-economic, environmental and institutional contexts to which they are subjected in both the fled and adopted regions. Migration can be the vector of increasing desertification in both the places of departure and arrival; or conversely, it may exert less pressure on resources or even lead to the development of appropriate techniques to combat desertification. We can clearly see that the series of causality that link on the ground migrations and desertification are complex, and that they can also be contradictory depending on the context.

5 Conclusions and Recommendations

A study conducted by FAO's environmental service (2000) reveals that rural societies, subject to severe crises, react according to the degree of rising severity. It distinguishes the following adjustments in response to economic crises due to poor rainfall (or floods, social problems, predators, etc.):

- Adjustments to the level of crops and husbandry
- Changes to the food diet
- "Famine" food, such as wild fonio (*Digitaria exilis* Stapf)

[9] The delocalization of companies is another possible response.

- Food loans from parents/neighbours/friends
- Search for non-agricultural work
- Temporary emigration to seek work
- Off-season farming with emigration
- Sale of small animals
- Sale of cattle
- Food loan and/or money other than from family/neighbours/friends
- Temporary emigration
- Sale of assets (i.e. land)
- Permanent emigration

As we can see, migration is not the first reaction to a worsening of the consequences of desertification. Local solutions are sought in the first instance as far as food and social solidarity are concerned. The development of solidarity has been studied in depth and in all its diverse forms: reciprocity, self-financing savings groups and remittances. In Africa, this is generally applied to a group that adheres to the phenomenon of the "redistribution chain", a sort of mechanism of protection or security net, but it also has a strong social constraint. Recent studies on household budgets in the Ivory Coast show that about 15% of the budget is devoted to the exercise of diverse forms of solidarity.

In the cities, these solidarity phenomena are less evident among the middle classes (depending on the distance from the original village) but also in some poverty-stricken areas: the link between the city and the country remains but benefits from contribution in nature (like cereals) from the countryside. The relationship among city dwellers in slums, (in terms of solidarity) tends to disappear, no doubt due to a lack of means (Frayne, 2004, case of Namibia).

The elements mentioned above enable us to establish two forms of relationship between desertification and migration, which recalls the lack of locally adapted rural policies.

- Certain authors defend the idea that the lack of development policies of internal agricultural markets has encouraged the rise in migratory movements in Africa, which has led to the abandonment of agriculture and constitutes a major risk of desertification (Domenach and Picouët, 2000).
- Conversely, other interpretations see migration as a response to land saturation of agricultural zones combined with the fall in outputs (in particular, in the case of Niger); they also regard the lack of land security policies and the development of internal agricultural markets as factors that discourage any agricultural investment, and especially the investment in land fertility and preservation.

These results confirm that desertification is a problem of drylands development (Cornet, 2002). The recent development in African migration as a mechanism of regulated social protection in time and space against a series of urgent and short-term displacements is an indicator of both worsening living conditions and desertification.

The question of possible links between desertification and clandestine migrations to OECD countries has not been expanded upon because there is no single study to this day that links this type of migration to desertification, even if experts recognize that it is due to the deepening divide in living conditions (inequalities generated by globalization) (Mouhoud, 2005), and the very marked inequalities between African regions affected by desertification and Europe. Such widely discussed migration still concerns only small numbers of the population, even if they continue to grow, in comparison to internal movements in Africa (Bocquier, 1998).

The most noticeable fact is the increasing departure of migrants from extremely threatened zones. It should be noted that it is practically impossible to determine thresholds, and for at least two reasons:

- Conditions are not the same and depend on the zones in question (diversified activities between agriculture and husbandry, different techniques, etc.); certain zones have the capacity to carry greater densities than others with the same soil and climatic conditions. The notion of carrying capacity is to be treated with extreme caution.
- Although all ecologists mention thresholds beyond which the environment will be irreversibly degraded, no threshold value has been proposed. Indeed, economic conditions come into play: restoration can be expensive but can prove profitable if it can be valorized through production.

We can nonetheless provide at least three early warning signals. Conditions of maximum degradation are reached when:

1. The entire surface of an agricultural plot is cultivated but there is no alternative cropping system: we can be sure that, due to the absence of a system of fallow, conditions will rapidly deteriorate.
2. A regular fall in output is observed.
3. We observe bare soil throughout the year: this indicates that the potential of grain germination is reduced and that there is little chance of root establishment, or water is no longer available for the plants, which leads to hardening of the soil, and renders the restoration effort increasingly difficult.

We have seen that remittances by migrants are enormous, more than double the world's public development aid. However, these funds are not used for agricultural investments and environment restoration.

Should we wish to invest in agriculture and animal husbandry, then we recommend that funds from public development aid be used for this purpose, and at the same time we should ensure that funds reach their beneficiaries. We also recommend the establishment of public-private partnerships:

- For instance, in the case of migrants, their funds could be used to guarantee micro-credits and loans
- By supporting the creation of local businesses in land rehabilitation with institutional components (norms, technical assistance, legislative support, etc.) and strictly private components (capital, management, etc.), which suggests training sessions
- By involving private service companies (maintenance, commerce, etc.)
- By improving road infrastructure
- By creating conditions for dialogue among civil society/administration

As a conclusion to this synthesis, we observe that migration is not the first social consequence of desertification, but that the first effects are observed in the way daily work is organized, in particular between men and women. Other social costs of desertification deserve to be studied and taken into account so as to improve the understanding of the impact of desertification on rural societies. Furthermore, definite migration as the final solution to desertification requires more in-depth study so as to better foresee and organize migration in these cases. Finally, migration as a social cost of desertification brings home the crucial question of economic development of rural drylands as well as the global treatment of inequalities between developed and developing regions.

References

AFD. 2003. *Migrations et phénomènes migratoires*. Agence Française de Développement, Paris.

Beauchemain, C., and Shoumaker, B. 2005. Migration to cities in Burkina Faso: Does the level of development in sending areas matter? *World Development*, Vol. 33, No.7, pp. 1129–1152.

Benoît, G., and Gomeau, A. (eds.). 2005. *Méditerranée, les perspectives du Plan Bleu sur l'environnement et le développement*. Editions de l'Aube, collection Monde en cours.

Bonnassieux, A. 2005. Evolution des migrations et diversité des frontières et de leurs représentations en Afrique de l'Ouest. *Interactions entre frontières et identités. Etudes et travaux de l'école doctorale TESC Université de Toulouse*, Vol. 2, No. 6, pp. 85–98.

Bocquier, P. 1998. L'immigration ouest-africaine en Europe: Une dimension politique sans rapport avec son importance démographique. *Chroniques CEPED*, No. 30, juillet-septembre, pp. 1–3.

Bossard, L. 2004. Questions d'avenir(s) pour les pays sahéliens de l'Afrique de l'Ouest. *Sécheresse*, Vol. 15, No. 3, pp. 225–32.

Bredeloup, S., and Pliez, O. 2005. Migrations entre les deux rives du Sahara. *Autrepart, Revue de sciences* sociales au sud, No. 36, pp. 3–20.

Bredeloup, S. and Zongo, M. 2005. Quand les frères burkinabè de la petite Jamahiriyya s'arrêtent à Tripoli. *Autrepart. Revue de sciences sociales au sud*, No. 36, pp. 123–147.

Cornet, A. 2002. La désertification à la croisée de l'environnement et du développement : un problème qui nous concerne. pp. 91–130. In : R. Barbault, Cornet A., Jouzel J., Megie G., Sachs I., & J. Weber Edit. Johannesburg Sommet Mondial du Développement Durable 2002, Quels enjeux? La contribution des scientifiques au Débat. Paris, ADPF p. 201.

Cotula, L., and Toulmin, C. 2004. Migrations internationales et droits fonciers locaux en Afrique de l'Ouest. *Dossier IIED*, No. 132, Programme zones arides, FAO, Asdi, 90 p.

Cour, J.-P. 2001. The Sahel in West Africa: Countries in transition to a full market economy. *Global Environmental Change*, Vol. 11, pp. 31–47.

Domenach, H. and Picouet, M. (eds.). 2000. *Environnement et populations: La durabilité en question*. L'Harmattan, Paris.

Domenach, H. and Picouet, M. 1995. *Les migrations: Que sais-je*. PUF, France.

FAO. 2000. *Manuel de détermination et de mise en place d'un Système d'information pour la sécurité alimentaire et l'alerte rapide (SISAAR)*. Food and Agriculture Organization of the United Nations, Rome. On-line: http://www.fao.org/docrep/003/X8622F/x8622f00.HTM

Frayne, B. 2004. Migration and survival strategies in Windhoek, Namibia. *Geoforum Elsevier*, pp. 489–505.

Guilmoto, C., and Sandron, F. 2003. *Migration et développement, les études de la Documentation Française*.

Guilmoto, C. 1997. Migrations en Afrique de l'Ouest. La ruralité dans les pays du Sud à la fin du XXème siècle. Gastellu et Marshal J-Y ed sc., éditions ORSTOM, colloques et séminaires, pp. 495–530.

Henry, S., Boyle, P., and Lambin, E. F. 2003. Modeling inter-provincial migration in Burkina Faso, West Africa: the role of socio-demographic and environmental factors. *Applied Geography*, Vol. 23, pp. 115–136.

Kapur, D. 2003. *Remittances: The New Development Mantra*. Harvard University and the Center for Global Development, Washington, DC.

Lahlou, M., and Zouiten, M. 2001. Population et exode rural: Impact sur l'environnement et le tissu urbain au Maroc, Régulations démographiques et environnement, CEPED No. 18, L. Auclair, P. Gubry, M. Picouët and F. Sandron (eds.), pp. 150–176.

Mochebelele, M. T. 2000. Migrant labor and farm technical efficiency in Lesotho. *World Development*, Vol. 28, No. 1, pp. 143–153.

El Mouhoud, M. 2005. *Les nouvelles migrations, un enjeu nord-sud de la mondialisation*. Le tour du sujet, Universalis.

Oudinet, J. 2005. Immigration et marché du travail dans les pays du nord: des effets positifs avérés. *Les nouvelles Migrations, un enjeu nord-sud de la mondialisation*, El Mouhoud, M. (ed.). Le tour du sujet Universalis, Encyclopedia Universalis.

Pliez, O. 2002. Les migrations sud-sud, révélatrices de la pauvreté et de l'instabilité? *Cahier Français*, No. 307, mars-avril, pp. 16–23.

Regnard, C. 2001. Influence de l'aménagement du territoire sur la population: la fécondité dans la région de St Louis du Sénégal. *Régulations démographiques et environnement*. CEPED No. 18, L. Auclair, P. Gubry, M. Picouët and F. Sandron (eds.), pp. 113–120.

Sander, C. 2003. *Migrant Remittances to Developing Countries*. Bannock Consulting, London.

Traoré S., and Bocquier P. 1996. Migrations en Afrique de l'Ouest: de nouvelles tendances. *La Chronique du CEPED*, janvier-mars, No. 20, pp. 1–4.

Usher, E. 2005. *Les objectifs du Millénaire pour le développement et la migration*. Organisation Internationale pour les Migrations, (OMI),

Wimaladharma, J., Pearce, D., and Santon, D. 2004. Remittances: The new development finance. *Small Enterprise Development Journal.*

World Bank. 2006. *La migration peut améliorer le bien-être et réduire la pauvreté*. www.worldbank.org/

Chapter 2
Legal Aspects of the Co-viability of Social and Ecological Systems in African Arid Zones: A Legal Anthropology Approach to Environmental Law

Olivier Barrière

Abstract To the reader unfamiliar with African realities, the approach applied here is very different from the Western context. The African continent cannot be approached without first integrating data derived from cultural, psychological, political and economic dimensions that pervade and condition law, with emphasis on *the* rights. Moreover, the disconcerting aspect for the non-initiated is to be confronted with a diversity of social groups at the heart of which rights are embedded. This emphasizes an essential aspect to understanding the juridical component: the texts enacted by states do not always correspond (and often in a very small way) to the legal referent of actors. We are challenged by a diversity of particularly disconcerting juridical systems, and juridical anthropology is the only field that enables us not to fall irremediably into the trap of ethnocentrism, which tends to "generalize" and even "universalize" our representation of law. The specific case of land tenure is symptomatic of this: the property right, or rights, essentially defines its status or land tenure system.

The diligent lawyer is required to research the issue in order to clarify the object of research: namely, what is the legal qualification of a parcel of land, pasture, forest, etc.? What if the parcel in question is not perceived by its users as *property* but as an object on which their survival depends – should the lawyer unconditionally qualify the parcel as being part of the system covering property? If institutional economists (see references) are given the possibility to attribute *property* status systematically to every object, we nonetheless consider that a lawyer does not possess this privilege without providing an attestation of such. The anthropological approach to law introduces a certain complexity to the case, which is often impossible to appreciate from an objective perspective.

Keywords Land tenure, anthropological approach, rights, ownership, heritage management

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1 Introduction

Social systems depend on ecological systems for their reproduction and survival. Co-viability is defined as the balance between society's need to grow and the maintenance of ecological, biotic and abiotic processes and its components (biotopes and biocenosis). In a way, co-viability defines the union of cultural (social systems) and natural (ecosystems) worlds, as a (re)conciliation between people and the biosphere.

In what way does law intervene? How does one participate in this reconciliation? By applying a juridical anthropological approach to the environment and not only through analysis limited to "positive" law. Furthermore, because we have to apply the practice of law as it is enacted and experienced by the population, juridical anthropology cannot be limited by acts of legislation (state law) but must take into account the sum of all juridical regulations which exists (written and oral).

The anthropological approach to law specifies two essential criteria for the law of co-viability to be effective in Africa: internal legitimacy, within the social groups, is essential; it can exist only by applying the law to nature in a way that is more dialectic than Cartesian.[1] First, the law enacted by the state should not only be based on existing socio-juridical realities but must succeed in integrating the social dimension in order to fully involve the actors concerned. The notion of legality cannot easily be reconciled and justified by a process that is imposed in a top-down manner – from the capital city to the rural world – without appearing presumptuous. Connecting and establishing a relationship with the referents and legitimate local stakeholders will determine the effectiveness of a particular national regulation. Secondly, or rather simultaneously, the effectiveness of the law will depend on its connection to the collective conscience, which does not necessarily consider the environment in which the individual and the group lives. The connection between people and their living space involves constant and profound reciprocal interactions. To be effective, environmental law should be applied not to highlight a difference in position but to heighten shared viability. To this end, the juridical status attributed to the environment, and therefore to ecosystems and their physical support, will be determinant.

The land status to which natural resources are attached is affected by the regulation of its access. If it involves a common resource *in situ*, the right to seize it can itself sometimes become subject to alienation.[2] The usefulness of land status is such

[1] According to François Ost (1993:33 and 34), Cartesian thought generates 'links between linear and hierachal causality', as opposed to 'dialectic thought such that it establishs links between the object, the environment and the observer'. According to the author, it is determined 'to demonstrate that one embodies the other, considering that in a certain way, one exists through the other'. Thus, 'the distinction of dielectic thought is therefore to distinguish without separation, to bring together without confusion'.

[2] We consider lignage pastures *peuls* of the central delta of Niger where the grass can be sold to outsiders for use by their herds. However, in the order of precedence of access to the *bourgoutières*, outsiders are always considered last.

that it can or should be able to be subject to contracts of specific sales. The contractual relationships – more or less formalized – of exchange, loan, donation, and even pledge have for a long time been the usual practice. This describes a context where land status is inalienable, beyond any land market.

In the case of communitarian territories, with land status not being considered property as such, the resources situated in the space in question constitutes objects of law. The "right to pasture", the "right to cultivate", the "right to fish", etc., suggest more a power relationship over an object than a relationship of possession. The status of the "right to do" corresponds to a function capacity that the 1804 civil code qualifies as the "right of use". Here natural resources (grass, wood, water, land, fauna, etc.) are garnered (to pasture, pick, gather, drink, hunt, cultivate, fish, etc.). The object of the law is even carried onto the resources and not in the act to seize, the appropriation of the resource. The right to act in order to "render to oneself" an environmental element is at the heart of an authorized legitimate act, organized and facilitated by the social group or the national society. This faculty is not merged with the resource object as it identifies itself as a prerogative conditioned by the technique (to hunt in a certain way, and only with such a species, to fish with a particular object, etc.) and by the status. Furthermore, the latter recalls the essential notion of "having a right", meaning the one that has the ability to exercise a right. This depends on the category to which the actor belongs (resident, age group, taxpayer, member of a ligneage, etc.), social standing and function, etc. We can suppose that the transfer of the quality of the beneficiary in certain cases occurs with the payment of a fixed sum, set by either the supply and demand ratio or an institution.

With the prospect of co-viability of social and ecological systems, the option to generalize the method in terms of inheritance regulation seems to be more appropriate in the case of commons management. It involves making a distinction from economic thought of "all private property" and to provide an alternative such that true heritage management for sustainable development functions through the use of law. This supposes that the complexity of situations, and therefore the diversity of management systems, is taken into consideration, which needs to be tackled on a case-by-case basis. This approach does not exclude private propriety, but should be referred to only in situations where the costs/advantages ratio justifies it from the point of view of sustainable development.

This comes from the observation that the relationships of land tenure condition the rights of environmental resources: access to space is determinant for access to environmental resources, which leads to our aim of integrating land law in the framework of environmental governance. Consequently, the question remains what land tenure system to adopt for environmental protection. This question is particularly appropriate in countries of the South and leads us to question the definition and identification of these land resources, and their integration within the goal of environmental protection (biodiversity conservation, combating desertification, etc.).

Field studies in the Sahel and the Maghreb have led to substantial doubts on the normative categories used with respect to rights exercised on resources. Two regimes are identified: the ownership type and the inheritance type. While the

Box 1 Example of access to common pastures: The case of the agdals of the Aït Zekri tribe on the south slope of the Moroccan High Atlas

Access to these high-altitude pastures is reserved for the group members of the tribe. Under no circumstances can a stranger to the ligneage clan penetrate with his troop. With this is mind, will each herder benefit from the situation by adding more heads of cattle to these community pastures?

Contrary to the approach by Garett Hardin (1968), the strategy of each member is not to exercise a maximum pressure on the pastures to the detriment of others (maximizing one's personal profit). In fact, the troop itself will guide the herder by its behavioural mobility in space as well as the troop's physical condition. If they are too numerous, the sheep cannot rest for long at the place and will become more mobile: the herder will not allow his animals to lose weight or even die and will divide his herd into two if required to do so, taking into account the state of resources on which the survival and the development of his herd depends. The result is not catastrophic (a starving herd), but a strategy adapted to the state of the resource: rise in the mobility in space and splitting up of the herd into several groups to adapt to the carrying capacity of the summer pastures. The "common" also involves a regulation of access and a regulation of intrinsic management: the rule of mobility that prevents each herder from claiming to *melk* a particular zone as a shelter (*amazir*) around which the herd spends the day. The right of pasture is thus associated with an obligation not to remain too long in the same area.

former is well known (land ownership is a necessary condition for the existence of a market), the latter is lesser known (in terms of readibility, ethnocentrism, the absence of a land tenure market, the need for an interpretation and analytical scale, etc.).

The interest behind the juridical anthropology approach lies in taking advantage of a perspective that differs from the question itself and that, because of its atypical nature and because of the definition of law itself, is not simply limited to the legislative and regulatory act but takes other sources of law into account.

Three points are essential to tackle the question of the relationship between land tenure rights and heritage management of the environnement:

1. The legal nature of the land resource (the type of land tenure relationship)
2. The link between the land and the environmental resources that supports it (environmental approach to land tenure)
3. The beneficiaries: their definition in terms of individual and group status, as well as the question of future generations within a perspective of sustainability where the law enters a long term perspective

2 From the Juridical Nature of Land Resources: Between the Appropriation of Land, the Objective of Numerous Legislators, and the Inheritance Dimension of Territory, the Juridical Order Most Often Exercised in Practice

The legal definition of territory, which is a spatial foundation on which an authority disposes of particular expertise, cannot be applied in the same way in Africa as in Europe. In fact, the stake of land tenure relationships in Africa is principally situated at the level of development of the group as well as social cohesion and does not enter (especially in rural areas), or only rarely enters, a commercial framework (principally in areas of urban, peri-urban or industrial agriculture).

In terms of African juridical multiplicity, the land resources are subject to several regimes: a presumption of dominance benefiting the state (ascendancy of national sovereignty) or to the benefit of the nation (the Senegalese case of national domain),[3] a privatization of the space that is confronted by pre-existing community control (residence communities, clans, lineages or family) and often they are always present in practice.

The regime of common territory of a group is better qualified as common heritage[4] than a form of collective property.[5] This all depends on the analysis carried out: in juridical anthropology, this is oriented towards an endogenous referent that opposes an ethnocentric approach. The land in question does not respond to the definition of appropriation such that the object becomes an asset but corresponds more to a temporal continuity. Moreover, how is inalienable and imprescriptible ownership considered?

In such a case where appropriation (where the land is therefore an asset) can occasionally occur, the principle (induced, organized and structured by the socio-cultural context) links inheritance to space or in the interest of groups (residents, lineage, family) which prevails over individual interests. Although a trend towards land appropriation or land tenure individualization occurs, the absence of a market or an "imperfect commercialization" of the land does not authorize land capitalization.

We have noted that spatial relationships are different according to their systems of exploitation, the socio-ethnic group and their spatial dynamics:

- The farmer tends to demarcate the land by appropriating parcels of agricultural land for cropping. This is carried out without necessarily generating a market of

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[3] The state has a juridicial personality, unlike 'nation'

[4] Common heritage (of a group) is defined as the sum of material and immaterial elements that participates to the socio-cultural reproduction of the group and that is also the object of an inert-generational transmission rendering them unalienable by nature.

[5] Cf. Morocco, the *Dahir* of 27 April 1919 that organizes the administrative supervision of indigenous communities and regulates the management and alienation of collective assets (B.O. 28 April 1919). The tribes possess a right of collective ownership, art. 1 (Modifié, D. n° 1–62–179 6 February 1963 – 12 ramadan 1382, article 1): 'The right of ownership of tribes, fractions, douars or other ethnic groups on agricultural land or course of which they have collective, according to traditional practices of exploitation and uses, can only be exercised under the State's authority and under conditions set by the present *dahir*.'

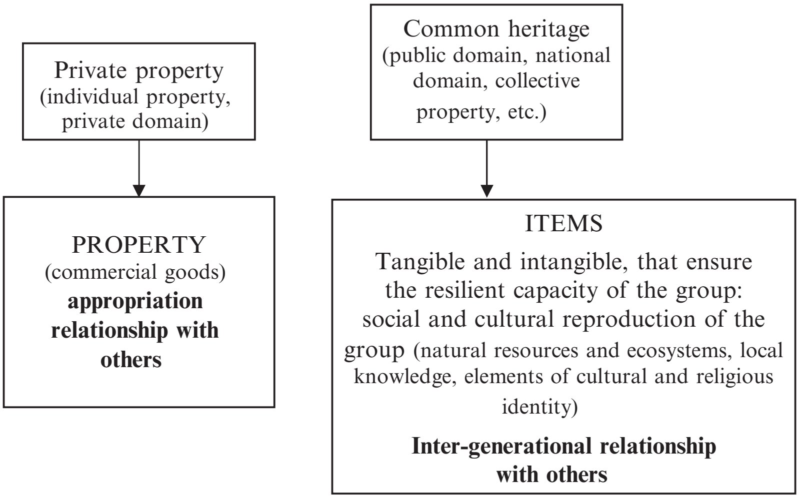

Fig. 1 Comparison of the of two approaches

land tenure due to the juridical nature of the land, which is a resource that is dependent on the survival of the group or family lineage and rarely a commercial asset (cf. in peri-urbain or industrial agricultural development zones).

- The pastoralist, the forest owner, the fisherman and so on, exercise their activities in territorial space governed by the allocation of rights on the uses: of pasture, movement, removal forest products, acces to water, etc.

Figure 1 summarizes the distinction between the two approaches. The regime of appropriation appears only with objects that are assets (all items appropriable is an asset); the inheritance regime is integrated in a socio-cultural growth perspective that entails a more inter-generational logic.

3 Mastering Land Tenure is the Key to Environmental Management: The Access to Environmental Resources Conditioned by Access to the Land (an Environmental Approach to Land Tenure)

Our experiences of the terrain have led to the establishment of a close relationship between the land and the environmental resources it supports. This has been translated by the notion of "resource space" within a rationale of spacial multifunctionality defined by a combination of a perimeter or land route with a renewable natural resource, potentially or effectively becoming the object of removal, exploitation or protection.

By going beyond the framework of Roman law, it has been necessary to develop an original way to interpret endogenous legal regulation of practices. On the basis of the land-environment relationship, a specific interpretation of rights to segments of space and environmental resources has been identified that entails a series of prerogatives: practical rights (of movement, removal, exploitation), exclusion rights (control of access to land: authorization or refusal), alienation rights (land sale), and intentional management rights, which orient actors' behaviour not so much by waving a legal wand as by a negotiated right.

A system of non-ownership in which each individual had the full rights of an owner, would neverthless involve legal limits (even the creation of environmental constraints); such as inheritance system (collective ownership, national domain, etc.) would require a legitimate regulation that is recognized by local actors. This leads to the principle of negotiated rights that interposes with respect to the rights applied by central power (in the form of local charter or convention) leading to the elaboration of an agreed right and therefore locally legitimate.[6] The need to

Box 2 Example of the law of 27 February 2001 entitled 'Pastural Charter in the Republic of Mali

This text is not a periphrase of a Western law, and the authors are African. It is innovative insofar, as it fully recognizes the pastoral activity while outlining the important rights of the herders with respect to the mobility of the animals and access to pastoral resources. In addition, the charter confers on the herders an environmental responsibility in terms of their obligations and their pastoral activities. However, despite its resolute modernity in its environmental approach, the legislators proceed in a very Western way by imposing a norm without due consideration of anthropological sensibilities, for example, by completely eclipsing the existence of indispensable traditional authorities within the interior of the Niger delta, notably the *jowro*, master ligneages of pastures. If the text attempts to integrate the pastoral dynamic, which is extremely strong around the delta, the obvious Cartesian thinking highlights the absence of a necessary dialectic, in this case probably due to a real ignorance of the societies, practices and spaces of the environment concerned. The example is pertinant: a real political will, the emergence of a modern law on pastoralism as concerns the recognition and responsibilities of the herders, but reveals its profound technocracy by its detachment from the local populations. Article 55 gives responsibility to the territorial councils to elaborate local rules and thus is definitely a positive opening, but why did the legislators not go further? Why is there yet a decree of application (to our knowledge) to implement the legalisation of an activity as basic and essential as pastoralism in Mali? If the actual rights do not seem easy to decrypt, it also does not appear easy to manipulate. This example in Mali demonstrates that the junction between the "legal" and the "legitimate" is not a question of simple text.

[6] Cf. the French law of 14 April 2006 on national parks which imposes the adoption of the Charter of Sustainable Development, a veritable instrument of community commitment to societal projects.

establish a negotiated legal order is due to the strong inapplicability of national legislation, which is particularly acute in Africa. The integration of local legal practices in the national framework requires a level of application that is not regulated but derives more from a spirit of solidarity and participation. The relationship established between the local and national contexts proceeds from the nexus of the logic of legality and legitimacy that requires construction through the adoption of regulations emanating from the principal interested parties. This local regulation is expressed through charters (territorial, sustainable development, etc.), conventions and internal regulations of and between groups.

On the basis of socio-cultural endogenous systems of use and representation of the environment, the adopted interpretative framework engages a logic of dissociation that distinguishes the right of its object in order to extract the prerogatives and responsibilities where the utility defines the right.

In fact, due to the principle of spatial multi-functionality (multi-uses), the notion of timeless exclusivity does not apply (or rarely). Effectively, it is the "purpose" that conditions land tenure rights: to access the terrain during a given period in order to grow crops, pasture, hunt, fish (aquatic space), etc.

Figure 2 compares the two types of environmental relationship, where one appropriates the land and the other appropriates only the use of the land due to its multi-functionality.

The interpretation is confirmed by the elaboration of a classification of rights in terms of environmental land control. In fact, it seems necessary to enhance the strong correlation of regulations that combine both land and resources. Our experience of different contexts in Africa has shown the need to establish a framework, in systemic terms, of the legal structures encountered. Table 1 is an outcome of an interpretation of functional legal regulations.

The six prerogative levels encountered (from movement to intentional management) are applied to either the land or uses, or both simultaneously. They give rise to a definition of environmental land control that implies the obligation to conserve the substance in question – the object of the right. The result of our study on local practices concludes that the implementation of environmental regulations relies on a legal framework that is legitimized by both the socio-cultural and economic context (production systems) and its ecological requirements. Although awareness of future concerns is not necessarily instinctive among local actors, they nevertheless

Appropriation of space	Appropriation of uses within the multi-functional space
- **right of use of property** (to cultivate, to construct …) - **right of possession** (sole beneficiary of one's property and to freely dispose with it) - **right of use** (material and juridicial acts / to destroy, to alienate …) Dismemberment: servitudes(real, personal, conventional), usufruct, various rights of use, sole-ownership, right of acreage (lands/tréfonds)	- **functional rights**: of passage, of removal, of exploitation - **rights of exclusion** (of the space or the resource, fix the conditions of access + transfer) - **rights of intentional management**: conventions, incentives, negociations, reglulations, etc.

Fig. 2 Distinction between two types of land relationship: Land ownership or appropriation of uses within the multi-functional space

Table 1 System of environmental land control

Rights (prerogatives)	Objects	An environmental approach to land control (Rights associated with the obligation to conserve)
Passage (access and settlement)	Land	Minimal
Removal (to utilize)	Usage	Intermittent
Exploitation (exploit)	Usage	Specialized
Exclusion (control)	Land/usage	Exclusive
Distribution (alienation)	Land/usage	Absolute (propriety)
Intentional management (consensus, conventions, grants, regulations…)	Land/usage	Intentional

possess an understanding of the non-renewable nature of resources. The legal order, in which we operate as much with national authorities as at the regional or local scale, demonstrates a hybrid nature (ownership/inheritance) with respect to the nature of the land and resources concerned and to the realities of the actors and their production systems.

An example is the convention on the local environment of the rural community of Salémata (a decentralized local community has been in eastern Senegal in the region of Tambacounda). The convention was adopted in 2005 and has been used by several other rural communities from Kedougou province.

Excerpts:

Article 2: The rights and obligations of all persons

(a) The territory of the rural community regroups 44 village terrains. It constitutes the common inheritance of its inhabitants, which itself includes the common inheritance of the nation (according to Art. 16 of the law 96-07 of 22 March 1996).
(b) For this reason, the space is defined as inappropriable (in terms of national domain) and comes under heritage management where each person benefits from rights associated with obligations vis-à-vis society.
(c) Natural resources rights (land, water, vegetation, animals) are associated with obligations.

- **The right of passage** consists of remaining within certain limits, and when crossing the allotted space, there should be no impact on the environment.
- **The right to remove**, to pick and to gather, consists of taking what is needed for personal or family use without affecting the regeneration of the resource and the interest of others.
- **The right to exploit** concerns the right to cultivate, the right to pasture, the right to fish, the right to hunt, the right to cut and clear, and goes beyond simple removal and is likely to result in the commercialization of the obtained products. The extent of the impact on nature through agriculture, breeding, fishing, professional hunting, and any other commercial forestry activity, requires that all conservation measures are taken for the protection of the soil, fauna and flora, and the sustainable management of the environment and natural resources in the short and mid-term.

- **The right of exclusion** consists of authorizing the exploitation of natural resources (land, fauna, flora, water) or to refuse it to others. This obligation is applied in two ways: (1) ensuring conservation measures for soil protection and the sustainable management of the environment (combating erosion, reafforestation, tree-planting, soil enrichment, clearing limited to needs and on ecologically adapted zones, ban on killing or cutting certain species, etc.) in the long term and controlling the mode of exploitation so that it conforms to the sustainable use of the environment; (2) carrying out necessary projects and investments to optimize exploitation and to conserve the capacity of environmental regeneration while maintaining the biological diversity of the land and the rural community.
- **The right of sustainable development management** consists of adjusting individual and group behaviour at the local level in two ways: (1) through economic dynamism leading to food security and economic development; (2) by preserving the capacity of regeneration of the environment and biodiversity conservation.

(d) The right of passage is open providing it does not prejudice the production of others. The right of removal is open as long as it is carried out in non-exclusive areas (non-protected areas or private holdings). The right of exploitation is conditioned through control or authorization by the rural community or the services of the state; it is associated with the right of exclusion. The rural council disposes of the right of sustainable management. Therefore, it manages, at this level, land distribution, clearings (under the advice of the regional council), and behaviour vis-à-vis the environment, and is given the task of implementing local environmental planning.

- Figure 3 provides a succinct overview of the approach of heritage management on African soil. In particular, the relationships between actors and institutions are outlined through the links that emerge between each of the parts of the diagrammatic representation of legality/legitimacy.

4 The Beneficiaries of Environmental Land Resources: Considering Future Generations in Terms of Law from the Perspective of Sustainable Development

The juridical system, which ensures the management of environmental inheritance, must be able to situate itself on a timeline that lies beyond the present and to project itself into the near or distant future.

The notion of the future places the lawyer in an awkward position as rights can exist only through subjects of law. What are we referring to when we talk of the future? And which generations are we referring to? In fact, the future covers two types: the first is anchored in the present (an immediate future) and the second refers to future perspectives (a distant future).

In concrete terms, the notion of future generations covers the two types of future. If we take a generation (covering 25 years), which has the power to make decisions (from 25 to 75 years) (n), the first category of generation concerns the youth up to

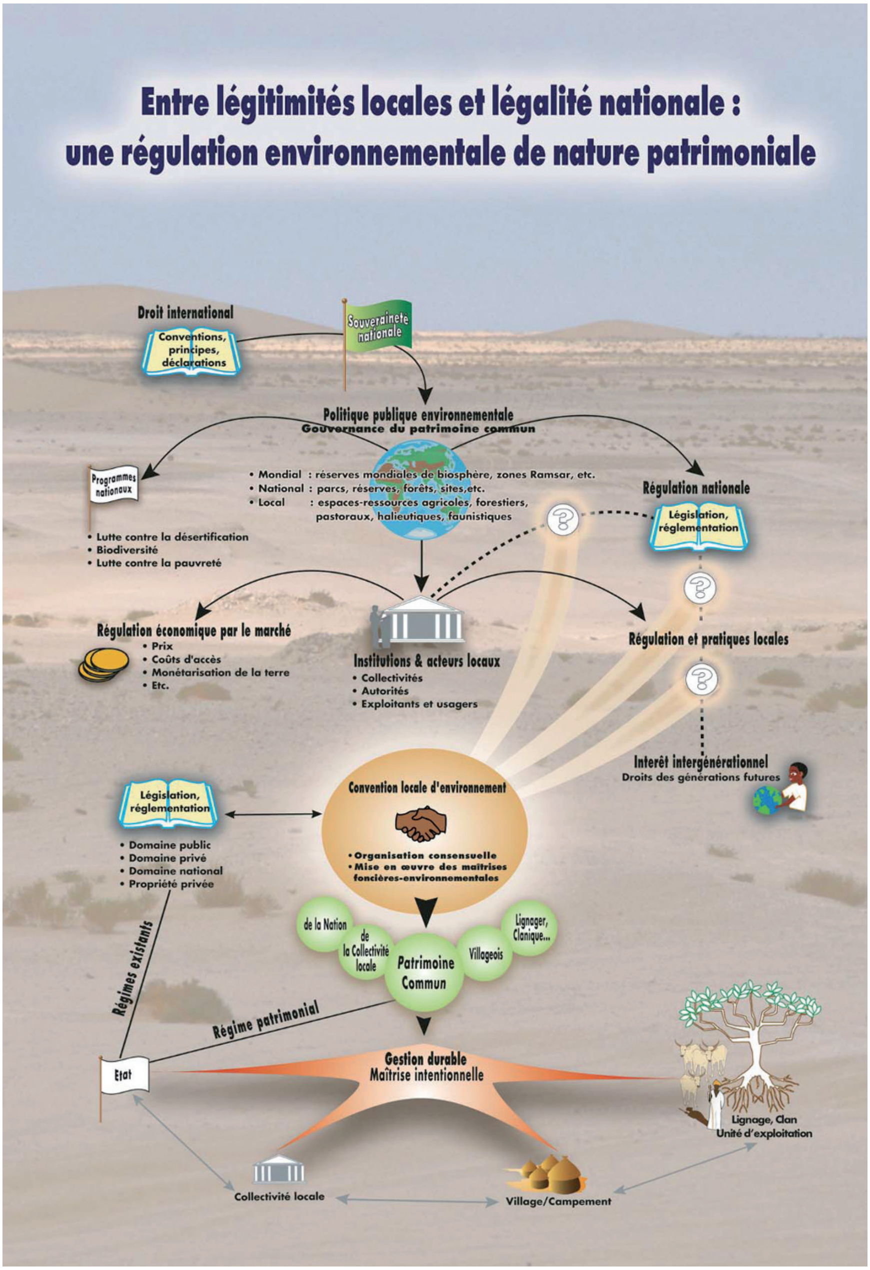

Fig. 3 The environmental regulation of natural heritage: Between local legitimacy and national legality

Beneficiaries of the regime of the right of ownership

- Physical person
- Moral person
  (group of beneficaries)
- Plurality of subjects
  (joint propriety, spatio-temporal property, etc.)

Beneficairies of the regime of common inheritance

Present moral group:
- community of residents
  (territorial communities from the local to national scale)
- ligneage community
  (extended family, clan, tribes, fractions, etc.)
- others

Future moral group:
Future and projected subjects
(not yet conceived but expected)
reproduction, perpetuation of existing communities

Fig. 4 Beneficiaries of property and inheritance regimes

25 years (n + 1) and birth expectancies (n + 2). The second category concerns generations that include 'predicted individuals' (n + 2 + x) that the academic law does not recognize because of their physical inexistence. Moreover, can we not recognize their moral existence due to the fact that reproduction exists and is the driver of survival in every society?

A human being or a generation existing only potentially cannot *a priori* be attributed rights, at least not according to contemporary thinking. However, even if the subject of rights does not yet exist concretely in the Cartesian sense, we can still project his terrestrial existence because of the future of the group. In fact, the reproduction of a social group or a society is incorporated within the genes of each one of its members and gives rise to behaviour that responds to stimuli of biological survival (obligation to procreate). As regards rights, they correspond to a social translation of this biological permanence of the group due to the juridical process that embraces all its vital aspects (e.g. matrimony and fundamental human rights). Consequently, we can attempt to take into account during the present the existence of future subjects to which rights are conferred (n + 2 + x) as the future is an integral part of the perspective of social reproduction.

Conversely, if the subjects of future rights are in part alive and in part projected, the subjects (with obligations and duties) already physically exist as they are considered to be a continuation of present active generations (n).

Figure 4 summarizes the beneficiaries at the centre of the two principles, civil and common inheritance, likely to interrelate in the African context, and especially in the context of sustainable development.

5 Conclusion

To manage land tenure within the framework of environmental governance for co-viable social and ecological systems, it is necessary to reinvent ownership or consider alternative juridical paradigms.

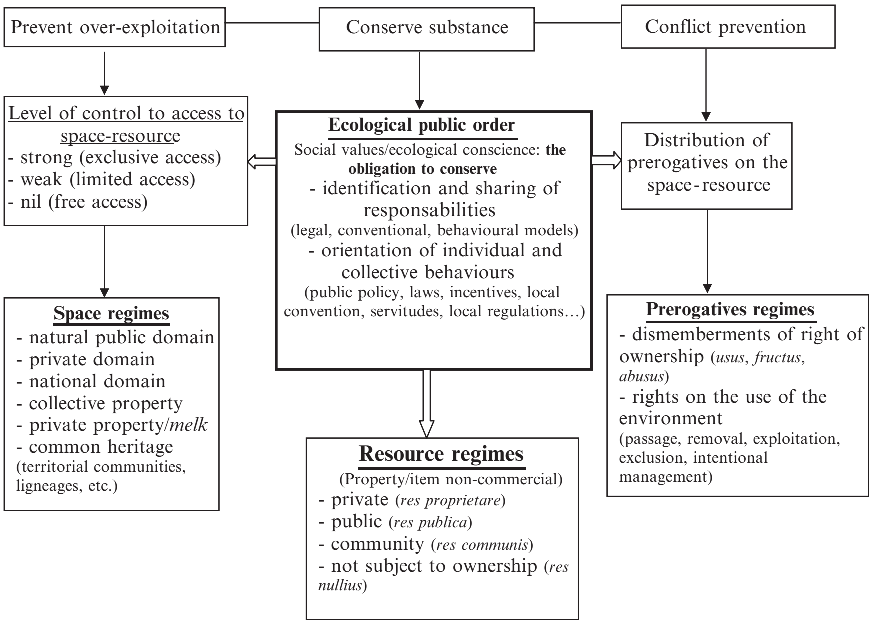

Fig. 5 Objects and modes of legal regulations centred around ecological stakes involving natural resources with a view to inheritance management

Figure 5 summarizes the land and environmental resource systems. Faced with the aim of heritage management, and centred on the definition and expression of ecological public order, it identifies three principal goals: to prevent over-exploitation, conserve substance and avoid conflict. Juridical systems are called upon to contribute to shared responsibility and behavioural orientation.

In Africa, land tenure ownership in practice is low (less than 5% of land is registered). As a result, the use of another paradigm is at issue. This is the reason behind the neutral analysis of land tenure contexts for Africa, and the development of the paradigm of common inheritance. Our concern is to analyze the way in which rights can contribute to heritage management without waving a particular flag. We leave behind rationales, representations and local practices to obtain a form of interpretation that is free from ethnocentrism. With a view to contributing to the development of an appropriate environmental approach to land tenure in Africa, we need to move away from mimetism and systems that are inapplicable to African realities!

Environmental rights in Africa cannot be easily reproduced from those in the North. Attempts to mimic environmental codes (Senegal, Burkina Faso, Mauritania, etc.) promulgated at around the Earth Summit in 1992 or in its wake have rarely been implemented and are more often centred on pollution or hazards, as in the case of Senegal. Moreover, we should question the capacities to carry out environmental impact assessments faced with development stakes in the socio-economic and financial context specific to countries of the South.[7] Africa needs legitimate laws that are recognized by the actors concerned at the heart of cultural diversity more than it needs enforced environmental regulations. Furthermore, African societies are anchored to their rural context, particularly as concerns the removal of resources on which they are dependant and from where they live (land, pastures, aquatic environments, forests), which is so strong, prevalent, consistent and persistent that environmental rights in Africa cannot exist without at the same time being based on rural, forestry and land tenure rights. A regulation that divides up these realities in an attempt to be overly specific has a high risk of ending up for appearance only and superficial.

In the final analysis, the aim is to focus on environmental rights in Africa that reflect cultural and ecological realities. Its intercultural nature, driven by confirmed juridical plurality and transversal in its implementation, questions the isolation of a branch of rights that is particularly dependant on rural activities in Africa. To consider environmental rights in Africa is to base it on an ethic of an all-encompassing nature that embraces societies rather than separating them, to be objective and to examine protection measures. This leads us to prefer co-viability where the social systems rely on the ecological systems in which they live and to which they remain dependant for their reproduction and survival. Our capacity to support the emergence of an ecological public order at the heart of the juridical order will condition the future of dryland communities.

Bibliography

Arnaud, A.-J. 1998. *Le droit trahi par la sociologie*. LGDJ (Librairie Générale de Droit et de Jurisprudence), Paris.

Barriere, O. 2006a. De l'émergence d'un droit africain de l'environnement face au pluralisme juridique. *La quête anthropologique du droit. Autour de la démarche anthropologique d'Étienne Le Roy*. Paris, Karthala, pp. 147–172.

———. 2006b. Juriste de l'environnement en Afrique : l'anthropologie du droit au service d'un nouveau droit. *Juridicités. Cahiers d'Anthropologie du Droit*, Hors série, Paris, Karthala, pp. 105–116.

———. 2005a. Une gouvernance environnementale dans une perspective patrimoniale : Approche d'une écologie foncière. *Droit, gouvernance et développement durable*, Cahiers d'Anthropologies du Droit, LAJP, Paris, Karthala, pp. 73–98.

———. 2005b. Une gouvernance environnementale dans une perspective patrimoniale : Approche d'une écologie foncière. *Droit, gouvernance et développement durable. Cahiers d'Anthropologies du droit*. Paris, Karthala, pp. 73–98.

———. 2004. Une anthropologie juridique de l'environnement. *Anthropologie et Droit, Intersections et confrontations. Cahiers d'Anthropologie du Droit/Revue Droit et Culture*, hors série 2004/4, pp. 51–58.

[7]In fact, we should recall that impact studies are only a procedure, 'it is a scientific process that allows for an often conflictual technical study of projects, but which eventually leads to a political decision. Its success or failure much depends on the commitment of scientists in environmental policy' (Prieur, 1994: 107).

———. 2003. Gestion de l'environnement en pays Bassari (Sénégal oriental); réflexion sur un droit de l'environnement au Sénégal. *Revue canadienne Droit et Société/Canadian Journal of Law and Society*, Vol. 18, No. 1, pp. 73–101. (In French.)

Barriere, O. and Barriere, C. 2001. *Un droit à inventer. Foncier et environnement dans le delta intérieur du Niger*, IRD (Institut de recherche pour le développement), Paris.

———. 1997. *Le foncier-environnement, fondements juridico-institutionnels pour une gestion viable des ressources naturelles renouvelables au Sahel*. Rome, Food and Agriculture Organization of the United Nations.

Berkes, F. (ed.). 1989. *Common Property Resources: Ecology and Community-based Sustainable Development*, Belhaven/Pinter, London.

Berkes, F. and Folke, C. (ed.). 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience.* Cambridge University Press, Cambridge.

Bourjol, M. 1989. *Les biens communaux. Voyage au centre de la propriété collective*. Paris, LGDJ (Librairie Générale de Droit et de Jurisprudence), Paris.

Falk Moore, S. (ed.). 2005. *Law and Anthropology*. Blackwell, Oxford.

Guille-Escuret, G. 1989. *Les sociétés et leurs natures*, Armand Colin, Paris.

Hanna, S. S., Folke, C. and Maler, K.-G. (eds.). 1996. *Rights to Nature: Ecological, Economic, Cultural, and Political Principles of Institutions for the Environment, Beijer International Institute of Ecological Economics*, Island, Washington, DC.

Hardin, G. 1968. The tragedy of the commons: The population problem has no technical solution; it requires a fundamental extension in morality. *Science*, Vol. 162, 13 December, pp. 1243–1248.

Hesseling, G., Djire, M. and Oomen, B. (eds.). *Le droit en Afrique. Expériences locales et droit étatique au Mali*. Karthala-Afrika Studiecentrum, Paris.

Kamto, M. 1995. *Droit de l'environnement en Afrique*, Edicef/Aupelf, Vanves.

Larrere, C. and Larrere, R. 1997. *Du bon usage de la nature, pour une philosophie de l'environnement*, Aubier, Paris.

Le Roy, E. 1999. *Le jeu des lois, une anthropologie « dynamique » du Droit*. LGDJ (Librairie Générale de Droit et de Jurisprudence), Paris.

Ost F. 1993. Le juste milieu. Pour une approche dialectique du rapport homme-nature. *Images et usages de la nature en droit*, Publications des facultés universitaires Saint Louis, Bruxelles, pp. 13–73.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge.

Prieur, M. 1994. *Evaluation des impacts sur l'environnement pour un développement durable: étude juridique*. Food and Agriculture Organization of the United Nations, Rome.

Schlager, E. and Ostrom, E. 1992. Property-rights regimes and natural resources: A conceptual analysis. *Land Economics*, Vol. 68, No. 3, August, pp. 249–262.

Vivien, F.-D. (ed.). 2002. *Biodiversité et appropriation: les droits de propriété en question*, Editions NSS/Elsevier, France.

Chapter 3
Integration of Regulation, Extension, Science, Policy and Monitoring Improves Land Management in the Rangelands of Western Australia

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Abstract The Gascoyne River catchment in arid Western Australia was presented as a desertification case study at the United Nations Conference on Desertification in Nairobi in 1977. The Gascoyne is similar to many other areas in Western Australia that were seriously degraded following the introduction of domestic livestock in the late 19th century. However, there have been many improvements in land management since the 1970s, with good evidence that much of the rangelands are now in better condition. These improvements have been the result of a combination of factors, including: a comprehensive resource inventory; range assessment and ongoing monitoring information; a mixture of regulation and empowerment; capacity-building using a variety of approaches; and regional scale strategies aimed at taking a co-ordinated approach to land management issues. A strong emphasis on science was used to address technical issues and to improve the understanding of ecosystem dynamics. Of course, individual land managers play the primary role in land management. It is their day-to-day decisions that determine whether the land will continue to degrade or improve. In Western Australia, land managers are better educated than in the past, have a better sense of community expectations for land management and generally practice a more benign style of land management than their forebears.

Keywords Land management, rangelands, pastoralism, grazing pressure, monitoring, WARMS

1 Introduction

Pastoral managers make the day-to-day decisions that balance production with environmental conservation (Wilcox, 1988). Governments should not and cannot do this task. The role of government is to provide a framework within which pastoralists can operate,

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[2] Centre for the Management of Arid Environments

[3] Curtin University of Technology

[4] Co-operative Research Centre for Tropical Savannas Management

helping them to manage and to become self-reliant and innovative to meet environmental standards that match broader community standards. The government also has a role through regulatory approaches that enforce strict legislation when appropriate.

Desertification has been well documented in Western Australia's rangelands, including the Gascoyne River catchment, which was reported at the United Nations Conference on Desertification in Nairobi in 1977 (Williams et al., 1980). Other reports, at around the same period, showed widespread and severe degradation of rangelands in other parts of Western Australia (e.g. Payne et al., 1979). Since then, resource condition surveys covering about two-thirds of the rangelands used for livestock grazing show that about 1.0% was severely degraded and eroded, while about 27% was in poor condition, 34% in fair condition and only 39% in good condition (Payne et al., 1998). Although much of the widespread damage occurred in the first few decades of commercial livestock grazing (Watson, 2002), desertification processes continue in many areas. Rehabilitation of degraded areas has also occurred, largely due to better control of livestock and lower grazing pressures.

The extent to which rehabilitation has occurred is subject to debate. Hopkins et al. (2006) suggested that degradation has continued in the Gascoyne since the original assessment of Wilcox and McKinnon (1972). Pringle and Tinley (2003) also report ongoing degradation in terms of catchment dysfunction. But there is also good anecdotal and other evidence that at least some of the rangelands in the Gascoyne have improved (e.g. Watson et al., 2007). Perhaps the most accurate way to summarize the situation is to say that degradation rates have slowed or may even have stopped in some parts of the landscape but acute degradation is still occurring in other parts of the landscape, especially drainage lines (Pringle et al., 2006).

This paper focuses on the Gascoyne-Murchison region, which includes the Gascoyne River catchment. The region was chosen because it was the subject of a case study at the UN's 1977 conference and because it was also the subject of a large-scale regional initiative, the Gascoyne-Murchison Strategy (GMS), which began in 1998 to address a range of economic development and natural resource management issues in the region (Lewis, 2001). However, the general approach outlined here, that of an integrated framework that includes regulation, extension, science, policy and monitoring, applies equally to other parts of the rangelands used for commercial livestock production in Western Australia.

2 The Integrated Framework

Research, development and knowledge, by themselves, are incapable of improving rangeland resources. Prevention of further desertification and promotion of rehabilitation depend on individual land managers having a sound understanding of their environment, their business and themselves (Watson, 2003). Managers make better natural resource management decisions when: (1) they understand a problem; (2) they have the motivation to adopt a management change; and (3) they have the capacity to implement it (Gordon et al., 2001). Research institutions and government agencies can promote this self-reliance but cannot make the day-to-day decisions that have a direct impact on land management.

The general framework for the management of rangelands in Western Australia is the integration of regulation, extension, science, policy and monitoring. By providing pastoralists with good natural resource information and appropriate environmental standards, pastoralists come to understand the context and scale of their management challenges. The motivation to adopt changed practices must come from within oneself, but it can be supported by government in many different ways in a co-operative relationship. Helping to improve the skills and capacity to change is a major role of government, by translating scientific results into extension messages and providing training in self-development, planning and business skills.

Note that this framework has not come about as the result of formal and deliberate design. Rather, it has emerged from a combination of factors in Western Australian society. Pastoralists have a strong agro-political influence. Government departments have become increasingly efficient as budget restrictions have forced them to find better ways of fulfilling their role. Government departments, universities, other research organizations and science-funding institutions have developed many co-operative partnerships. Environmental standards are set through policy and legislation and largely reflect the standards of the urban population as articulated by a strong environmental movement among non-governmental organizations.

3 The Western Australian Context

In Western Australia all pastoral rangelands are leased from the Crown, represented by the State Government. Leases are held by individuals or companies and are not the subject of communal management. The lease arrangement is a deliberate structure to assign responsibility for land management to the individual land manager. However, a number of management conditions are included in the lease under the terms of the Land Administration Act of 1997. Leases are granted for the purpose of commercial livestock grazing, termed “pastoralism”. One or several leases are included in a single pastoral “station” and those who own or manage the station are termed “pastoralists”.

There are about 450 stations within about 900,000 km^2 (90 million ha) of Western Australia, giving an average size of 2,000 km^2 (200,000 ha), although viable stations range from about 75,000 ha to over 500,000 ha depending on location. While there are substantial differences across the state in terms of climate and vegetation, the socio-economic and political context is very similar across the range.

4 The Gascoyne Murchison Strategy Region

About 39.2 million ha of rangelands in the GMS region are available for pastoral use and this supports about 240 pastoral leases (Keogh et al., 2005). Traditionally, and at the time of Wilcox and McKinnon’s original survey (Williams et al., 1980), most stations ran Merino sheep for wool production. In recent years, wool enterprises have been largely replaced by those that produce meat, principally from cattle but also from meat sheep and goats.

Livestock carrying capacities range from about 5–20 ha per Dry Sheep Equivalent (DSE), corresponding to about 35–140 ha per Large Stock Unit (LSU), i.e. cattle equivalents. The average number of DSE per station is about 10,700, or 1,528 LSU (Watson, 2003). A substantial proportion of the total grazing pressure comes from the high number of feral goats and native kangaroos. While no accurate figures are available, estimates suggest that domestic livestock may comprise less than 50% of total large herbivore grazing pressure on many stations. Kangaroo numbers have undoubtedly increased since the provision of artificial water supplies for livestock. There is limited control of kangaroo numbers through commercial shooting, but their addition to total grazing pressure remains substantial. This has been the case for much of the period since pastoralism began. For example, Fyfe (1940) reported that in 1935 one station had '40 people engaged in kangarooing on the run; 35,000 skins were taken off the run' ("run" is an archaic word for station).

The vegetation is almost entirely native, with few exotic species, although the introduction of buffel grass (*Cenchrus ciliaris*) and Birdwood grass (*Cenchrus setiger*) especially to the northern part of the region has provided an improved supply of perennial grass. The native vegetation is diverse, with hundreds of annual, ephemeral and perennial species. Major vegetation types include chenopod shrublands (consisting of mostly *Atriplex* and *Maireana* species), mulga (*Acacia aneura*) shrublands with an understorey of *Eremophila*, *Senna* and *Ptilotus* species, and sandplains often dominated by a range of *Acacia* species (Burnside et al., 1995). Hummock grasslands of both hard (i.e. unpalatable) and soft (i.e. palatable) spinifex (*Triodia* species) occur scattered throughout, particularly in northern and eastern areas.

In the GMS region, the majority of stations are owned and operated by individual families. The livestock are kept within fenced areas without herding. Managerial input is low, with livestock only handled once or twice a year on many stations and in some cases the enterprise is based on harvesting only. On larger stations, one to several permanent staff may be employed. However, on many stations permanent labour consists only of family members, supplemented by temporary staff in periods of peak seasonal demand, such as mustering (i.e. the gathering of livestock) or sheep shearing. Most managers are well educated, many having completed secondary school, while some have tertiary qualifications. Communication systems are good, and all stations have telephones. Most have broadband internet access, and email is a common means of communication (Watson, 2003).

For most of the region, average annual rainfall is within the range of 200–250 mm. Rainfall variability is classed as high to extreme (Bureau of Meteorology, 1998). Towards the western and southern margins of the region, about 70–80% of the rainfall falls in "winter" (here defined as May–October), while towards the northern and eastern margins, winter rainfall is about 30% of the total. Natural surface water is scarce and artificial watering points are provided for the livestock.

The late 19th century saw much of the land first used for commercial livestock grazing, particularly the ten-year period from the mid-1880s to the mid-1890s. Signs of degradation began soon after domestic livestock were introduced. For example, there were reports of severe dust storms by 1889 (Brockman, 1987). Severe drought in the 1930s led to a Royal Commission, which reported widespread and severe degradation (Fyfe, 1940). The range condition survey in the Gascoyne catchment described the rangelands in terms of Rangeland Types and quantified and mapped the degradation (Wilcox and McKinnon, 1972; Williams et al., 1980). Serious erosion was found on 29% of the sites visited.

Overgrazing, even in the early years, was the principal cause of the degradation. Estimates suggest that within the Gascoyne catchment, the number of sheep carried by 1900 was already 60% of the historical peak attained in 1934 (Williams et al., 1980). These large numbers of animals were concentrated within relatively small areas, often along river systems. For example, Brockman (1987) reported that in 1885 Minilya Station (immediately to the west of the Gascoyne catchment) carried 24,000 sheep but with ‘absolutely no improvements’ (i.e. no infrastructure such as fences or artificial watering points). Williams et al. (1980) also reported that ‘prior to 1934 one station carried in excess of 100 000 sheep with no more than three wells and shallow soaks opened up in the river bed’. This pattern of degradation, especially during droughts, has also occurred in other parts of the Australian rangelands (McKeon et al., 2004).

5 Understand the Environment, the Business and Oneself

Pastoralists are best able to make appropriate management decisions when they have a good understanding of the following three key factors and how they interact. First, they need to understand the environment in which they live. Second, they need to understand their business and know how to make a profit. Third, they need to know themselves and understand their own motivation for pastoralism as a commercial enterprise and a way of life. These three factors have previously been discussed by Watson (2003) in relation to the GMS.

Pastoralists must balance the demands of making a profit with the demands of managing the resource. This gives them an unusual responsibility within society because they must make a profit (or absorb losses with income from other sources), yet they must do so through good natural resource management. Most natural resource managers in Western Australia work for governments or institutions and receive stable incomes, not reliant on making short-term profits from business decisions. Pastoralists must make frequent decisions that need to balance the requirements of maintaining income, resource stability and maintaining strong family relationships. This needs to be done within the context of community expectations, which have altered considerably over time. Originally, settlement of the rangelands in the late 19th century was seen as a means of national development and resource condition was a minor consideration. Subsequently, expectations came to include the prevention of land degradation. Currently, expectations increasingly include the broader and more demanding task of biodiversity conservation.

The task is made more difficult because of the effect of discounting. Put simply, this is the concept that money earned in the present has more value than the same amount of money in the future. That is, it is better to make a management decision that ensures income now, rather than make a decision that provides income at some stage in the future. In some cases, foregoing income in the present may lead to increased income in the future. For example, making the decision to destock a paddock now, with the expectation that it will regenerate and allow more livestock to be carried in the future. However, while future income may be higher than current income, it may not be high enough and it may be uncertain. Pastoralists, as indeed most people, generally discount future returns (Stafford Smith et al., 2000). The most common manifestation of this can be seen by over-stocking in an attempt to meet short-term economic pressures. Hacker et al. (2000) suggest that this is particularly the case when the resource is degraded so that a management decision that places emphasis on short-term returns is likely to contribute to further degradation and prevent rehabilitation.

5.1 Understand the Environment

A good understanding of the environment and how it functions is critical to managing it well. In the case of Western Australian rangelands, this is made even more critical because exotic herbivores have been introduced to an environment that has evolved with very low concentrations of grazers. The introduction of livestock and the addition of artificial watering points has therefore exposed the landscape to accelerated degradation prior to its reaching a new equilibrium with current grazing pressures.

The most fundamental management issue for pastoralists, therefore, is "getting the stocking rate right", i.e. matching animal numbers (livestock, feral and native) to land capability (in the medium to long term) and to feed availability (in the short to medium term). This task is made more difficult by the impossibility of determining a single carrying capacity estimate due to rainfall variability being so high. Grazing management prior, during and immediately following a drought is especially important for reducing the chance of degradation.

Within the GMS region, paddock size is typically between about 30 to 100 km^2, and there is substantial resource heterogeneity within each paddock. Livestock therefore concentrate on some areas of the paddock and scarcely graze other areas, a situation made even worse by the irregular spacing of watering points. The variation in grazing pressure can be substantial as Low et al. (1980) showed for seven vegetation communities in a single paddock in central Australia. Relative grazing pressure ranged from 0.1 to 2.2 (mean = 1.0), inevitably resulting in some areas of the paddock being over-grazed and some areas under-grazed. In the GMS region, it is often the more fragile, often alluvial, areas that will be over-grazed and consequently damaged.

Three simple management options are available to pastoralists to help minimize the impact of grazing heterogeneity and the excessive grazing of fragile areas. First, allocate livestock numbers to paddocks based on acceptable grazing pressures on the fragile areas rather than on the total area of the paddock. Second, provide permanent water in areas that are not easily damaged, or not close to areas highly favoured by stock. Where permanent water is only available in fragile areas, this will require preventing livestock access to the water source and piping water to tanks and troughs away from the fragile areas. Third, paddocks can be fenced to minimize vegetation heterogeneity, i.e. by following land system boundaries rather than simply fencing into square paddocks.

Traditionally, pastoralists have been better at managing the health of their livestock than the health of their land. However, it is important that pastoralists understand their landscapes and how the movement of water and associated nutrients are naturally regulated. While some pastoralists can improve their understanding through their own observations, a more formalized learning process can be valuable (e.g. Pringle and Tinley, 2001). This leads to a better appreciation of what the landscape looked like before livestock grazing, including the extent to which erosion is natural or accelerated, and whether or not palatable species should or should not be found in areas in which they are absent. An improved understanding of the natural landscape also helps pastoralists develop their own indicators for when environmental thresholds are likely to be crossed, thereby limiting the amount of irreversible damage that their livestock can cause. Many of these indicators can be developed by pastoralists themselves, through close observation of the interaction between their stock and the environment, as Purvis (1986) demonstrated.

The identification of thresholds by managers is important because of the often slow feedback between implementing a management decision and its impact (Stafford Smith et al., 2000). Environmental damage is often gradual and is either not noticed until it is severe or not until an irreversible threshold is crossed, sometimes triggered by an external impact such as flood or drought. Managers who understand this, and who develop a set of indicators or environmental cues that provide early warning of damage, are best able to avoid crossing these thresholds.

A good understanding of the rainfall environment is necessary to determine the correct stocking rate. Too often pastoralists develop an optimistic bias of what is a "normal" season and an over-estimate of the number of animals that can be carried in "normal" years (Watson, 2004) as well as inadequate preparation for drought. The Australian rangelands have experienced a series of severe degradation episodes during and immediately following drought since pastoral settlement (McKeon et al., 2004). A general pattern has emerged whereby livestock numbers have been allowed to build up in the years preceding a drought and destocking has not occurred quickly enough as the drought progressed. Following good rainfall, further damage can occur if restocking occurs too quickly, a tactic with short-term financial rewards but longer term financial and environmental penalties (Buxton and Stafford Smith, 1996). Even though economic modeling suggests that there are long-term financial benefits to substantial destocking during drought, many pastoralists practice a tactic of 'hopeful inaction' whereby stock are retained in the hope of rain forthcoming (Stafford Smith and Foran, 1992).

In the eastern states of Australia, there has been a large research and development programme focused on preparing for and managing drought (McKeon et al., 2004). This has included research on sea surface temperatures and the El Niño – Southern Oscillation phenomenon. Good access to digital climate data and other climate-related information is available through the Silo web site (http://www.nrm.qld.gov.au/silo/) (Jeffrey et al., 2001) and the 'Long Paddock' (http://www.longpaddock.qld.gov.au/) site. A range of decision support tools, such as Australian RAINMAN (Clewett et al., 1999), have also been developed. Seasonal forecasts have proved less reliable in the GMS region. Rather, training has been provided to pastoral managers to help them understand and manage for climatic variability by analysis of their own historical rainfall records.

5.2 Understand the Business

As Purvis (1986) noted from practical experience 'good financial management must be an integral part of successful land and stock management'.

With the exception of some leases held by indigenous people, pastoralists in Western Australia run livestock as a commercial enterprise. That is, they must make a profit to remain in business and remain as pastoralists. Businesses that do not make a profit must either offset the losses from the pastoral lease using external income or the lease must be sold.

In recent years there has been much emphasis on increasing per head production at the same time as lowering production costs (Watson, 2003). The aim of this is to make more money from less livestock, as both models (Buxton and Stafford Smith, 1996) and practical experience suggest (Purvis, 1986; Morrissey and O'Connor, 1988). This can be done in several ways, such as increasing wool production per head, increasing reproductive performance or by improving the quality and value of livestock sold, such as by selling younger cattle.

In the Gascoyne-Murchison, financial benchmarking has been used to review and improve business performance (Resource Consulting Services, 2004). Benchmarking is used to monitor the business and assess the impact of management changes and marketing decisions. It is also used as part of goal-setting exercises and for measuring progress towards achieving goals. Often, financial benchmarking is used in a group setting with neighbouring pastoralists in order to make comparisons with the wider industry or regional performance. Working in groups also highlights the need to conduct research to address a specific issue, or to seek expert advice. Benchmarking should not be seen as an end in itself. Pastoralists should see it mostly as setting direction for them to improve performance (Resource Consulting Services, 2004).

Off-station income is becoming increasingly important for pastoralists in the GMS area. A survey at the conclusion of the GMS showed that 12.5% of respondents (sample size = 90) received more than two-thirds of their income from non-pastoral activities, while another 12.5% received between one-third and two-thirds

(URS, 2004). This has the effect of making pastoral businesses less dependent on pastoral production and may mean that managers are less inclined to stock heavily in order to ensure short-term profit.

5.3 Know Oneself

Profit is not the primary motivation for most pastoralists. Many pastoralists place great emphasis on maintaining their lifestyle. Indeed, surveys suggested that during the time of the GMS many pastoralists were looking for an opportunity to sell their business (principally for inclusion in the conservation estate) but remain as managers on the property in order to maintain their lifestyle (Dames and Moore – NRM, 1999). Put simply, pastoralists enjoy living on the land.

As Watson (2003) suggested, pastoralists who understand their own motivation for remaining as pastoralists tend to have clear objectives for their business and their life. A number of characteristics were identified as important. They have good powers of observation that enable them to look, listen and continue to learn. Some of this learning is internally driven, as part of an active adaptive management style. However, they are also open to external ideas, seek and accept advice and adapt it to fit their own circumstance. They have minds that can incorporate a wide range of information, which they then process systematically to imagine the impact of their decisions both on the environment and on their commercial enterprise. They do not try to tame the land or conquer it, but attempt to live within its constraints, modifying it where appropriate. They respect the land and often willingly forego profit in order to rehabilitate the land, which also helps to provide inter-generational equity. They have a strong sense of ethics, which they apply to their interactions with the land, their livestock and their family and broader community. They are self-reliant yet have a strong sense of community and inter-dependence with a range of informal and formal groups. These groups relate to health, education (especially for their children), agro-politics and land management, and supply a strong social infrastructure that allows them to build knowledge networks and social supports.

Surveys of pastoralists in the GMS region (Dames and Moore – NRM, 1999; URS, 2004) supported this feeling of self-reliance. Pastoralists were more confident of their own future and their own ability to manage than they were of the future of the pastoral industry in the region. Virtually no respondents suggested that they could not see a future for themselves, and there was a very strong commitment to their pastoral businesses and their pastoral lifestyle. Most pastoralists were keen to pass a viable business on to the next generation. Pastoralists were increasingly valuing the importance of business planning, formal training and personal development. This was seen as demonstrating a significant change within the pastoral culture, which has not traditionally sought these skills.

The 1999 survey also attempted to provide some insight into the qualities and attributes of pastoralists that lead to good land management. For example, a question asked pastoralists to consider the legacy that they would leave for the future. Almost all those surveyed were keen to stay working as pastoralists, with an absolute majority of responses eager to leave a viable station for the next generation and 'in a better (range) condition than what it was found'. Only one or two responses suggested exploitative motives.

Of some concern was the suggestion that pastoralists were generally over-optimistic about the prospects for environmental sustainability. Many pastoralists took the view that this was already accomplished, and it was not identified as an issue that needed to be addressed. Insufficient numbers of pastoralists acknowledged the correlation between environmental sustainability, economic viability and business management.

6 The Role and Impact of Science

The pastoral industry has been well supported by improved scientific understanding. The science has been very broad and includes reductionist-based approaches to ecosystem dynamics, as well as studies focused on social ecology and the way pastoralists make decisions. Much of this work has been conducted with the participation of pastoralists.

The scientific work includes:

- The impact of grazing on vegetation species and community dynamics (e.g. Hacker, 1984; Holm et al., 2003)
- Grazing management (e.g. Hacker and Tunbridge, 1991)
- The rehabilitation of degraded rangelands (e.g. Pringle and Tinley, 2003)
- Livestock production (e.g. Holm et al., 2005), reproduction and grazing trials
- Ecosystem and landscape dynamics (e.g. Holm et al., 2002)
- Monitoring and assessment techniques (e.g. Morrissey, 1976; Watson and Novelly, 2004; Watson et al., in press)
- Feral animal ecology and control methods (e.g. Norbury, 1992; Norbury and Norbury, 1993; Southwell and Pickles, 1993)
- The impact of fire and prescribed burning (e.g. Smith et al., 1998)
- Understanding the way pastoralists make decisions (e.g. Burnside and Chamala, 1994; Watson et al., 1996) and their need for good information (e.g. Keogh et al., 2005)
- Understanding business and financial health (e.g. Resource Consulting Services, 2004)

7 Resource Inventory, Assessment and Monitoring Systems

In Western Australia the Resource Inventory and Condition Survey began in the Gascoyne River catchment, and over 80% of the pastoral rangelands have subsequently been assessed (Payne et al., 1998).

The surveys include:

- Descriptions and mapping of landforms
- Classification of soils and vegetation into land systems
- Describing the land in terms of range condition
- Assessment of the amount and proportion of land in various condition classes (good, fair, poor, severely degraded and eroded)
- Recommendations for remediation

The Western Australian Rangeland Monitoring System (WARMS) was implemented throughout the pastoral rangelands of Western Australia in order to provide government and land administrators with information about changes in the resource (Watson et al., in press 2007). This regional scale monitoring system is focused on measuring changes in perennial vegetation, such as density and frequency, as well as changes in soil surface condition.

A comprehensive network of rainfall recording stations and a smaller network of more detailed climatic stations has meant that we now have a much better understanding of rainfall amounts, timing and variability (Bureau of Meteorology, 1998). These data are quickly updated to national databases and made freely available, often through the use of decision support tools (e.g. Clewett et al., 1999).

8 Regulation and Legislation

Laws governing land management form a base for community behaviour and community standards. Land management expectations are becoming more environmentally focused. Aspects relating to the prevention of desertification are poorly enforced, but the accepted standard is elevated year by year as general community standards relating to wise-use increase.

Relevant acts include (but are not limited to):

- Land Administration Act (1997)
- Soil and Land Conservation Act (1945)
- Agriculture Protection Act (1976)
- Environmental Protection Act (1986)
- Wildlife Conservation Act (1950)
- Various other acts relating to such matters as animal welfare, quarantine and biosecurity, industrial relations, occupational safety and health, etc.

While not all of these acts are directly related to the prevention of desertification, they all have impacts on the sustainability of the business enterprise, particularly in terms of compliance costs, which feed back to the pastoralists' ability to properly manage the land.

The functions of the Land Administration Act (Section 7) include ensuring that: pastoral leases are managed in an ecologically sustainable manner; policies are developed to prevent the degradation of rangelands; and monitoring systems are in place to track changes in the natural resource. This focus on environmental aspects in the 1997 amendments to the Act formally signalled a reduced emphasis on economic development and is one example of how changed community standards make their way through legislation to management. All leases are now inspected using a ground traverse technique on a 1–6 year cycle, depending on the severity of the land degradation. Where degradation issues are raised, the relevant statutory body (the Pastoral Lands Board of Western Australia) may impose conditions on the management of that lease. More commonly, the Board will request that the individual pastoralist develop a management plan to address the degradation issue. This explicitly recognizes that the pastoralist has responsibility for land management and that it is the pastoralist, not the government, that makes the day-to-day decisions affecting land management.

9 Regional Scale Strategies

Individual regional strategies such as the GMS have been introduced to the Australian rangelands in an attempt to provide a whole of government response to economic development, industry adjustment and natural resource management issues within particular regions. They are typically partnerships between the Commonwealth, state and local governments, as well as the local community. An important outcome of these strategies is their ability to implement policy. For example, the Australian Government has a policy of increasing the representation of the rangelands in the conservation estate. The GMS was able, through direct funding, to purchase about 3.9 million ha of pastoral leasehold land over a six-year period. This land was bought on the open, commercial market and nearly quadrupled the proportion of land held in the conservation estate within the region.

Regional Natural Resource Management Strategies are now being developed and implemented across Australia. Western Australia's rangelands were included within a single strategy (Rangelands Natural Resource Management Co-ordinating Group, 2005). The plan identified key natural resource assets, listed the assets of greatest value (ecological, heritage, monetary and aesthetic) and identified threats to these assets. Management strategies to address the threats and a set of management actions and resource condition targets were proposed to implement the strategies. Finally, an investment plan was developed to enable wise decisions to be made about the allocation of funds. The investment plan included targets and milestones that will need to be met. The plan is a mixture of local control of funds but with Commonwealth/state oversight and direction. The importance of the plan is not the hard-copy plan *per se,* but rather the fact that the various stakeholders have a (more or less) common vision, agreed targets and milestones.

10 Does Desertification Continue and Has Rehabilitation Begun?

There is much evidence of improved land management in the Western Australian pastoral rangelands, including the GMS region. Has this improvement translated into reduced degradation? This is a difficult question to address in a quantitative sense because of the lack of systematic recording of change. However, WARMS (Watson et al., 2007), specific case studies (e.g. Payne et al., 2004) and anecdotal evidence (Wilcox and Cunningham, 1993) suggest that this is the case in some areas at least.

Wilcox and Cunningham (1993) concluded, after interviewing range managers, that much of the rangeland degradation had ceased across Australia, except in eroded areas. The first complete set of results from WARMS (which included the GMS region) showed that there have been improvements in shrub density and cover in the region (Watson et al., 2007). A case study within the Ord River catchment in northern Western Australia showed spectacular recovery (Payne et al., 2004). This case study was interesting because the improvement came about through government legislation and regulation. Pastoral managers in the Ord catchment were not adequately addressing overstocking and severe erosion. In response, the Western Australian state government passed legislation in the early 1960s to resume the leases and assume management responsibility for the area. Since that time, much recovery has occurred and, while evidence of degradation still remains, the area has recovered sufficiently to be recently added to the state's conservation estate.

The introduction of domestic livestock to the Western Australian rangelands led to rapid and accelerated erosion, permanently altering landscape processes, such as surface hydrological patterns. Pringle and Tinley (2003) describe ongoing catchment dysfunction, while regular pastoral lease inspections show that many management issues remain and areas of accelerated erosion still exist. By contrast, there are also good signs of recovery. These contradictions are inevitable given the scale and heterogeneity found in rangelands (Pringle et al., 2006).

A major thesis of this paper is that individual pastoralists make the day-to-day decisions that affect land management. In the absence of direct government intervention, such as occurred in the Ord River catchment, it is the expectations and environmental attitudes of these managers that will have the greatest bearing on whether the rangelands continue to degrade. These expectations are heavily influenced by community standards. Community expectations have increased considerably in the 130 years since pastoral land use became widespread in Western Australia. Practices that were acceptable in the past are no longer acceptable. Pastoralists are part of this community and many report that the practices and environmental expectations of their fathers and grandfathers are no longer acceptable in the 21st century.

This will be the single biggest factor in managing the rangelands of the Gascoyne-Murchison region into the future. The severe degradation that occurred in the early years is unlikely to continue and significant gains will be made in regenerating degraded areas and improving range condition.

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References

Brockman, J. 1987. *'He Rode Alone', Being the Adventures of Pioneer Julius Brockman from His Diaries*. Artlook, Perth.

Bureau of Meteorology. 1998. *Gascoyne-Murchison Western Australia, Climatic Survey*. Bureau of Meteorology, Department of the Environment and Heritage, Commonwealth of Australia.

Burnside, D. G. and Chamala, S. 1994. Ground-based monitoring: A process of learning by doing. *The Rangeland Journal*, Vol. 16, pp. 221–237.

Burnside, D., Holm, A., Payne, A. and Wilson, G. 1995. *Reading the Rangeland*. Department of Agriculture, Perth.

Buxton, R. and Stafford Smith, M. 1996. Managing drought in Australia's rangelands: Four weddings and a funeral. *The Rangeland Journal*, Vol. 18, pp. 292–308.

Clewett, J. F., Smith, P. G., Partridge, I. J., George, D. A. and Peacock, A. 1999. *Australian Rainman Version 3: An Integrated Software Package of Rainfall Information for Better Management*. Q198071. Queensland Department of Primary Industries, Brisbane.

Dames and Moore – NRM. 1999. *Baseline Evaluation of the Values, Attitudes and Behaviour in the Gascoyne-Murchison*. Unpublished Report prepared for the Gascoyne-Murchison Strategy Management Team and Agriculture Western Australia, November 1999.

Fyfe, W. V. 1940. *Report of the Royal Commission Appointed to Inquire into and Report upon the Financial and Economic Position of the Pastoral Industry in the Leasehold Areas in Western Australia*. Government Printer, Perth.

Gordon, J., Stafford S., M. and Haberkorn, G. 2001. Indicators within a decision framework. Social, economic and institutional indicators for sustainable management of the rangelands. National Land and Water Resources Audit Rangelands Project Report. Canberra, Australia.

Hacker, R. B. 1984. Vegetation dynamics in a grazed mulga shrubland community. I the mid-storey shrubs. *Australian Journal of Botany*, Vol. 32, pp. 239–249.

Hacker, R. B. and Tunbridge, S. B. 1991. Grazing management strategies for reseeded rangelands in the East Kimberley region of Western Australia. *The Rangeland Journal*, Vol. 13, pp. 14–35.

Hacker, R., Milham, N. and Patton, D. 2000. Policy implications of alternative models of pastoral decision making. S. Nicolson and J. Noble (eds.), *Symposium Papers of the Australian Rangeland Society Centenary Symposium*. Broken Hill, NSW, Australia, pp. 127–132.

Holm, A. M., Loneragan, W. L. and Adams, M. A. 2002. Do variations on a model of landscape function assist in interpreting the growth response of vegetation to rainfall in arid environments? *Journal of Arid Environments*, Vol. 50, pp. 23–52.

Holm, A. M., Watson, I. W., Loneragan, W. A. and Adams, M. A. 2003. Loss of patch scale heterogeneity on primary productivity and rainfall-use efficiency. *Basic and Applied Ecology*, Vol. 4, pp. 569–578.

Holm, A. M., Watson, I. W., Speijers, E. J., Allen, R. J., Eliot, G. J., Shackleton, K. R. and Stretch, J. K. 2005. Loss of patch-scale heterogeneity on secondary productivity. *Journal of Arid Environments*, Vol. 61, pp. 631–649.

Hopkins, A., Pringle, H. and Tinley, K. 2006. Impacts of grazing ungulates on Gondwanan landscapes and responses to those impacts – an example from the Gascoyne River catchment of Western Australia. P. Erkelenz (ed.), *'The Cutting Edge': Conference Papers of the 14th Australian Rangeland Society Biennial Conference*. Renmark, SA, September 2006, pp. 221–224.

Jeffrey, S. J., Carter, J. O., Moodie, K. M. and Beswick, A. R. 2001. Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modeling and Software*, Vol. 16, pp. 309–330.

Keogh, D. U., Watson, I. W., Bell, K. L., Cobon, D. H. and Dutta, S. C. 2005. Climate information needs of Gascoyne-Murchison pastoralists: A representative study of the Western Australian grazing industry. *Australian Journal of Experimental Agriculture*, Vol. 45, pp. 1613–1625.

Lewis, M. 2001. The Gascoyne–Murchison strategy: A pilot for the new way forward for rangelands? *Range Management Newsletter*, 2001/3, pp. 10.

Low, W. A., Muller, W. J. and Dudzinski, M. L. 1980. Grazing intensity of cattle on a complex of rangeland communities in central Australia. *Australian Rangeland Journal*, Vol. 2, pp. 76–82.

McKeon, G. M., Hall, W. Henry, B. H., Stone, G. and Watson, I. W. (eds.). 2004. *Pasture Degradation and Recovery in Australia's Rangelands: Learning from History*. Queensland Department of Natural Resources, Mines and Energy, Brisbane.

Morrissey, J. G. 1976. Photography and range site monitoring. Department of Agriculture Western Australia Rangeland Bulletin, No. 24.

Morrissey, J. G. and O'Connor, R. E. Y. 1988. Twenty-eight years of station management: "Fair use and a fair go". Paper presented to 5th Biennial Conference of the Australian Rangeland Society, Longreach, Queensland, Australia, pp. 13–15.

Norbury, G. L. 1992. An electrified watering trough that selectively excludes kangaroos. *The Rangeland Journal*, Vol. 14, pp. 3–8.

Norbury, G. L. and Norbury, D. C. 1993. The distribution of red kangaroos in relation to range regeneration. *The Rangeland Journal*, Vol. 15, pp. 3–11.

Payne, A. L., Kubicki, A., Wilcox, D. G. and Short, L. C. 1979. *A Report on Erosion and Range Condition in the West Kimberley Area of Western Australia*. Technical Bulletin No. 42. Western Australia Department of Agriculture, Perth.

Payne, A. L., Van Vreeswyk, A. M. E., Pringle, H. J. R., Leighton, K. A. and Hennig, P. 1998. An inventory and condition survey of the Sandstone-Yalgoo-Paynes Find area, Western Australia. Agriculture Western Australia Technical Bulletin No. 90.

Payne, A. L., Watson, I. and Novelly, P. 2004. *Spectacular Recovery in the Ord River Catchment*. Department of Agriculture Western Australia, Miscellaneous Publication 17/2004.

Pringle, H. and Tinley, K. 2001. Landholders designing with nature: An approach to off-reserve conservation in the Gascoyne – Murchison Strategy area. *Range Management Newsletter*, 2001/3, pp. 11–14.

Pringle, H. and Tinley, K. 2003. Are we overlooking critical geomorphic determinants of landscape change in Australian rangelands? *Ecological Management and Restoration*, Vol. 4, pp. 180–186.

Pringle, H. J. R., Watson, I. W. and Tinley, K. L. 2006. Rangeland improvement, or ongoing degradation – reconciling apparent contradictions from the arid rangelands of Western Australia. *Landscape Ecology*, Vol. 21, pp. 1267–1279.

Purvis, J. R. 1986. Nurture the land: My philosophies of pastoral management in central Australia. *Australian Rangeland Journal*, Vol. 8, pp. 110–117.

Rangelands Natural Resource Management Co-ordinating Group. 2005. A strategy for managing the natural resources of Western Australia's rangelands. Draft for public comment and review. http://strategy.rangelandswa.info/ (accessed 22 June 2007).

Resource Consulting Services. 2004. Report on the outcomes and highlights of the Gascoyne Murchison Strategy benchmarking, financial advice and business review project conducted by Resource Consulting Services 1999/2000, 2000/2001 and 2001/2002. Resource Consulting Services, Australia.

Smith, R., McMillan, C., Craig, R., Adams, J. and Steber, M. 1998. Satellite monitoring of bush fires in Western Australia. *Journal of Arid Studies*, Vol. 75, pp. 27–30.

Southwell C. J. and Pickles, G. S. 1993. Abundance, distribution, and rate of increase of feral goats in Western Australia. *The Rangeland Journal*, Vol. 15, pp. 334–338.

Stafford Smith, D. M. and Foran, B. 1992. An approach to assessing the economic risk of different drought management tactics on a South Australian pastoral sheep station. *Agricultural Systems*, Vol. 39, pp. 83–105.

Stafford Smith, D. M., Morton, S. R. and Ash, A. J. 2000. Towards sustainable pastoralism in Australia's rangelands. *Australian Journal of Environmental Management*, Vol. 7, pp. 25–38.

URS. 2004. *Final Evaluation of the Gascoyne–Murchison Strategy*. Prepared for Department of Agriculture and The Board, Gascoyne–Murchison Strategy. URS Sustainable Development. http://www.gms.wa.gov.au/documents/GMS%20Final%20Evaluation%20Final%20Report%20v2.pdf (accessed June 20 2007).

Watson, I. W. 2002. A selected chronology of historical, biological, social, economic and institutional factors that relate to land management, particularly degradation episodes in Western Australia – west Gascoyne and Upper Gascoyne, Appendix 1. G. M. McKeon and W. B. Hall (eds.), *Learning from History: Can Seasonal Forecasting Prevent Land and Pasture Degradation of Australia's Grazing Lands?* Technical Report for the Climate Variability in Agriculture Program (QNR14), May.

________. 2003. Preventing desertification and promoting rehabilitation in Western Australian semi-arid rangelands at the individual property scale. *Global Perspective in Range Rehabilitation and Prevention of Desertification*. The 2003 Obihiro Asia and the Pacific Seminar on Education for Rural Development. (Editor-in-Chief, J. Takahashi). Obihiro University of Agriculture and Veterinary Medicine, Hokkaido, Japan, Aug 26–Sept 2, pp. 33–44.

________. 2004. I had the right number of sheep, but the wrong amount of rain. G. Bastin, D. Walsh and S. Nicolson (eds.), *Conference Papers, Australian Rangeland Society 13th Biennial Conference*. Alice Springs 5–8 July, pp. 291–292.

Watson, I. W. and Novelly, P. 2004. Making the biodiversity monitoring system sustainable: Design issues for large scale monitoring systems. *Austral Ecology*, Vol. 29, pp. 16–30.

Watson, I. W., Burnside, D. G. and Holm, A. M. 1996. Event-driven or continuous – which is the better model for managers? *The Rangeland Journal*, Vol. 18, pp. 351–369.

Watson, I. W., Thomas, P. W. E. and Fletcher, W. J. 2007. The first assessment, using a rangeland monitoring system, of change in shrub and tree populations across the arid shrublands of Western Australia. *The Rangeland Journal*, Vol. 29, pp. 25–37.

Watson, I. W., Novelly, P., Thomas, P. W. E. 2007. Monitoring changes in pastoral rangelands at a regional scale – the Western Australian Rangeland Monitoring System (WARMS). *The Rangeland Journal*, Vol. 29, No. 2 pp. 191–205.

Wilcox, D. G. 1988. Fair use and a fair go. *Australian Rangeland Journal*, Vol. 10, pp. 76–81.

Wilcox, D. G. and McKinnon, E. A. 1972. *A Report on the Condition of the Gascoyne Catchment*. Department of Agriculture and Department of Lands and Surveys, Western Australia.

Wilcox, D. G. and Cunningham, G. M. 1993. Economic and ecological sustainability of current land use in Australia's rangelands. S. R. Morton and P. Price (eds.), *R&D for Sustainable Use and Management of Australia's Rangelands*. Proceeding, National Workshop and associated papers. LWRRDC Occasional Paper Series No. 06/93, pp. 87–171.

Williams, O. B., Suijdendorp, H. and Wilcox, D. G. 1980. The Gascoyne Basin. M. R. Biswas and A. K. Biswas (eds.), *Desertification. Associated Case Studies Prepared for the United Nations Conference on Desertification (Nairobi, 1977)*. Pergamon, Oxford, pp. 3–106.

Session VII
Viable Dryland Livelihood and Policy Options

Session Chair: Prof. Dali Najeh
Rapporteur: Prof. Marc Bied-Charreton

Synthesis of Presentations

The presentations treated three different aspects of the issue and led to some very interesting discussions:

A. The two synthesis and methodology presentations, by **Dr. Gemma Shepherd, UNEP,** and **Dr. Richard Thomas, ICARDA**, focused on the following points:

1. The need for a multi-level approach, from the local to international level
2. The need to take into consideration the entire range of ecosystem services by attempting to: evaluate the value of non-productive services, measure the costs and losses associated with desertification, determine who pays for the provision of environmental services
3. The need for an integrated approach
4. The need to define how researchers and decision-makers should work together and how best to make the research findings available
5. The need to establish good analyses of the actual situation and to identify weaknesses and vulnerabilities before project implementation
6. Analysis of the priorities and definition of project beneficiaries: for whom we are working, i.e. farmers, herders, civil society, researchers, the state. A study has shown contradictory priorities among the different categories of actors
7. Recognition of the multifunctionality of drylands and the valorization of their comparative advantages

B. A presentation on a new farming system, by **Dr. Moncef Ben-Hammouda, Ecole Supérieure d'Agriculture du Kef (ESAK), Tunisia**, drew attention to a new system of agriculture, sowing under vegetation cover, with its associated economic and environmental benefits, such as the restoration of soils, the increase in organic matter and water availability for plants and underground reservoirs, the rise in biodiversity and the capacity for carbon sequestration.

C. Two presentations by **Mr. Mohamed Elfald, University of Helsinki, Sudan,** and **Dr. Ahmed El Obeidy, King Saud University, Saudi Arabia**, demonstrated the benefits of two characteristic dryland plants, *Acacia senegal*, which produces gum arabic (a potential income source and a way for agroforestry) and cacti, which are particularly adapted to extreme conditions. There are other useful plants that should be valorized, particularly by inciting production through price as well as ensuring a well-structured commercial system.

Session VII

Viable Dryland Livelihood and Policy Options

Chapter 1
An Ecosystems Approach to Natural Resource Management in the Sahel

Gemma Shepherd

Abstract Improving the well-being of dryland peoples in vulnerable countries will require that future decisions take into account the true value of nature—the value of ecological resources and ecosystem services on which dryland peoples depend for their livelihoods. A pilot project is described that aims to build capacity of five West African Sahelian countries in diagnosis of ecosystem degradation, environmental valuation and analysis of policy alternatives for sustainable ecosystem management. The project is developing and promoting tools for assessing land degradation and valuing "free" environmental services as a basis for evaluating policies for improved dryland management. Land degradation trends are being assessed from regional to local levels using remote sensing on multiple scales combined with ground sampling. Land degradation and natural resource depletion, as well as policy options including income-generating agroforestry, are being assessed within the context of the whole environment-economy system on national to local scales using environmental accounting. It is hoped that better valuation of dryland ecosystem services will enhance the ability of governments and the international community to (i) identify key emerging environmental issues related to human use of dryland ecosystems, (ii) proactively target technical and capacity-building support to areas most in need of assistance, and (iii) catalyze coordinated responses at national and international levels. At the same time, the work seeks to increase public awareness of the degree of dependence of dryland country economies on their environmental resource base and the impact of current national and international policies on depletion trends in environmental resource stocks and human well-being.

Keywords Land degradation, ecosystem approach, policy analysis, agroforestry, energy

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1 Introduction

About one-third of the world's population lives in drylands,[1] about 90% of whom are in developing countries. However, dryland people tend to be marginalized – the socio-economic condition of dryland peoples lags significantly behind that of people in other areas (MA, 2005a). Whether urban or rural dwellers, the ultimate well-being of dryland peoples is intimately associated with the ability of dryland ecosystems to provide provisioning, supporting, regulating and cultural services. Examples of these services are: provision of food and woodfuel; support of primary production and nutrient cycling; water and climate regulation; and cultural tourism and heritage values. Maintenance of dryland ecosystem services is thus vital for the welfare of almost one-third of the world's population.

However, about 10–20% of the world's drylands are already believed to suffer from one or more forms of land degradation (MA, 2005a). Land degradation over large areas of dryland, or desertification, is greatly increasing the vulnerability of the one billion rural poor who depend heavily on crop and livestock production as a livelihood and for food security (MA, 2005a). Conversion of rangelands and other silvo-pastoral systems to cultivated croplands is leading to significant, persistent decrease in overall dryland plant productivity, due to soil erosion, nutrient depletion and salinization. Desertification is projected to increase under any likely development scenario, especially in semi-arid areas, due to intensifying use of rangeland and cropland (MA, 2005b).

There is ample evidence that desertification has resulted in widespread loss of biodiversity, unsustainable use of groundwater and degradation of water quality on regional scales in drylands (MA, 2005b). Freshwater availability in drylands is projected to be further reduced from the current average of 1,300 m^3 per person per year in 2000, which is already below the threshold of 2,000 m^3 required for minimum human well-being and sustainable development.

Desertification is adversely affecting regional climate because changes in land surface characteristics affect the flux of energy, moisture and particulates that moderate meteorological processes. There is strong evidence for feedback effects of desertification on regional climate leading to increased droughts in East Asia and the Sahel (Xue and Fennessy, 2002). Dust clouds from West African drylands are thought to have an impact thousands of kilometers away and have been linked to problems including blooms of toxic algae in the region, impact on coral reefs in the Caribbean, and respiratory problems in North America (MA, 2005a).

Improving the well-being of dryland peoples in vulnerable countries will require that future decisions take into account the true value of nature – the value of natural

[1] The Millennium Ecosystem Assessment (MA) definition of drylands is used in this paper, which includes climatic zones with an aridity index of less than 0.65, i.e. dry subhumid, semi-arid arid, and hyper-arid zones.

resources and ecosystem services on which dryland peoples depend for their livelihoods. However, the high quality, well-documented and comparable information needed to be able to establish trends, assess trade-offs among ecosystem services and predict thresholds for irreversible changes in ecosystems is currently lacking.

In an effort to start addressing these critical limitations, a pilot project is described that aims to develop tools for diagnosis of land degradation, environmental valuation and analysis of policy alternatives for sustainable land management, and to build capacity in these tools in five West African Sahelian countries.

2 Project Background

The project, entitled ‘An Ecosystem Approach to Restoring West African Drylands and Improving Rural Livelihoods through Agroforestry-based Land Management Interventions’, is being implemented by UNEP in partnership with the World Agroforestry Centre, the University of Florida Center for Environmental Policy and the governments of Burkina Faso, Mali, Mauritania, Niger and Senegal. The overall goal of the project is to promote an ecosystems approach for sustainable management of the parkland systems (Fig. 1) of the semi-arid lands of West Africa to

Fig. 1 An ecoststem approach in Sahelian Parklands, integrating tree-crop-livestock systems

Fig. 2 Examples of Parkland devastation

improve human well-being and the environment. The project focuses on the Sahelian parklands, which are integrated tree-crop-livestock systems. The sustainable use of these parkland environments is vital for the future welfare of over 40 million people in a belt stretching from Senegal to the Sudan. These rural populations are among the poorest in the world. They will become increasingly marginalized unless the ecosystem services that the parklands provide are maintained (Figs. 2a, b).

The overall objective of the project is to restore degraded West African ecosystems and improve rural livelihoods. The specific objectives are to build regional, national and local capacity in new tools for (i) diagnosis of land degradation problems and targeting of interventions, (ii) valuation of ecosystem services and integrated evaluation of policies for sustainable land management, and (iii) conservation agroforestry practices and adaptive ecosystem management. The expected results are: (i) improved scientific and technical capacity among national and regional institutions for targeting and testing policies for sustainable management of dryland ecosystems, and (ii) increased capacity among pilot village communities and natural resource advisors in adaptive land use management and agroforestry-based land conservation practices.

3 Overview of Approaches and Methods

The project's ecosystem approach consists of three integrated components implemented on nested scales from regional to local levels:

- Land degradation surveillance is a methodology developed by the World Agroforestry Centre to diagnose land degradation problems, target intervention efforts where they are most needed, measure impact on the land resource base and extrapolate findings to other areas of the region.
- Policy analysis and evaluation uses environmental accounting, developed by the University of Florida, to select policy alternatives on different scales designed to maximize public benefit and sustainability. The policy analysis is focused by land degradation surveillance.

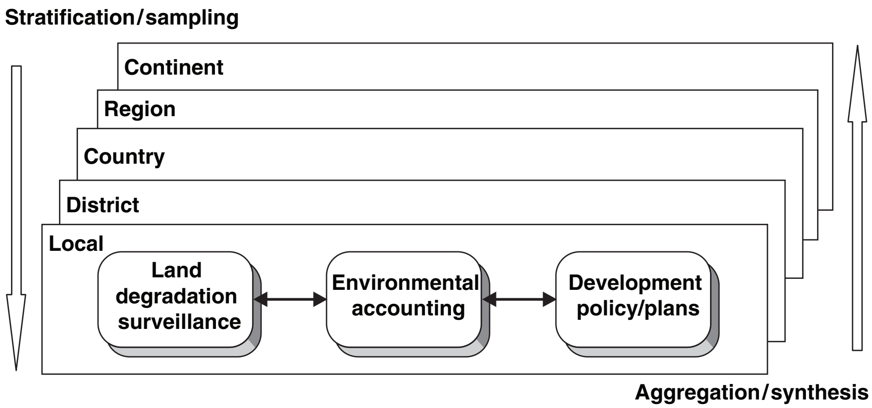


Fig. 3 The ecosystems approach within a multi-scale hierarchical framework

- Conservation agroforestry and sustainable land management practices are extended to village communities, and national/regional policy and extension strategies are developed. The extended practices are guided and targeted by the land degradation surveillance and policy analysis components.

The ecosystems approach is implemented within a multi-scale hierarchical framework (Fig. 3). The framework provides for systematic identification and sampling of areas undergoing environmental degradation and recovery, and provides a method for hierarchical aggregation of policy concerns and knowledge of local conditions to guide policy decisions at district, national, regional and continental levels. This science-based approach has potential to greatly increase the coherence, efficiency and impact of environmental policy initiatives in development planning and to influence international policy. The project is conducting regional training courses and hands-on training in all three areas: land degradation surveillance, environmental accounting and conservation agroforestry practices.

4 Land Degradation Surveillance

Land degradation surveillance is a set of new tools for diagnosing land degradation problems and soil constraints over large areas, developed by the World Agroforestry Centre. The method is designed to provide accurate information on where and how much land degradation is taking place, as well as the main types of land degradation and soil constraints, and to guide intervention strategies to prevent or reverse degradation. Land degradation surveillance combines remote sensing from regional to local levels with ground sampling, and infrared spectroscopy for rapid soil analysis in the laboratory (Fig. 4).

At a regional level, time trends in vegetation cover from 1982 to present are used in combination with long-term rainfall records to identify areas where major land

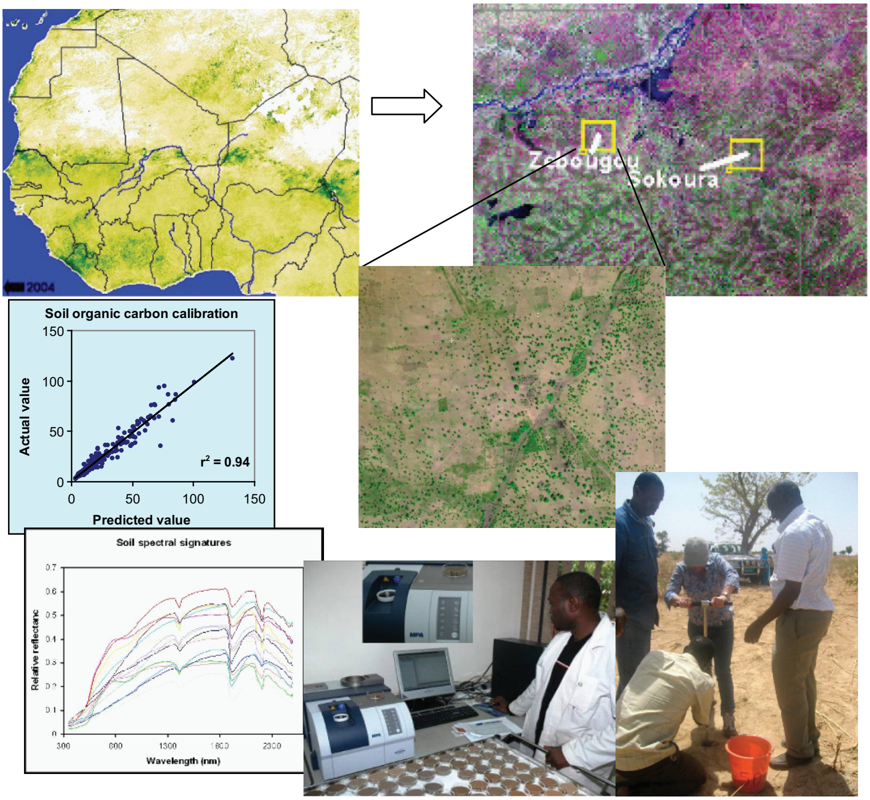


Fig. 4 Soil analyses: from remote sensing and infrared spectroscopy to in situ testing

degradation or recovery may have taken place. This is based on estimates of net primary productivity from NOAH-AVHRR images, available every ten days and aggregated to a spatial resolution of 8 km. The land degradation risk domains identified by this analysis are sampled using moderate resolution satellite imagery (e.g. Landsat), which provides more information (spatial resolution of 30 m) on the processes operating. For example, conversion to agricultural fields or rice schemes or reduction in woody vegetation cover can be detected. Contrasting areas within these images are sampled at still higher resolution using QuickBird imagery (spatial resolution of 0.6 m) acquired for 10 × 10 km blocks, which allows farm boundaries, erosion features and individual trees to be detected. These blocks are sampled on the ground using randomly located plots of 1,000 m^2 (about 35 m diameter).

Within the georeferenced plots, observations are made on landform, topography, visible signs of soil erosion, land use, and vegetation type and cover, vegetation density and distribution; and soil samples are taken. Vegetation type is classified using the FAO Land Cover Classification System (LCCS). Single-ring infiltration measurements are made on a selection of plots. Soil samples are characterized in the laboratory using infrared spectroscopy – a rapid, reliable, low cost method from which soil quality indicators can be derived. A sub-set of the samples are analyzed using conventional soil analytical methods, which are used to calibrate the rapid infrared methods. The georeferenced soil condition indicators are then calibrated back to the satellite imagery and constraints mapped. Socio-economic surveys are also tied into the same sampling frame.

The blocks are also used as a framework for testing interventions across a range of biophysical and socioeconomic conditions. Land management intervention strategies are designed in participation with local communities in relation to the specific degradation problems and their localities. Before-After-Control-Intervention-Pairing designs are used to measure the impact of interventions; these designs control for spatial and temporal confounding influences caused by spatial variability and baseline drift.

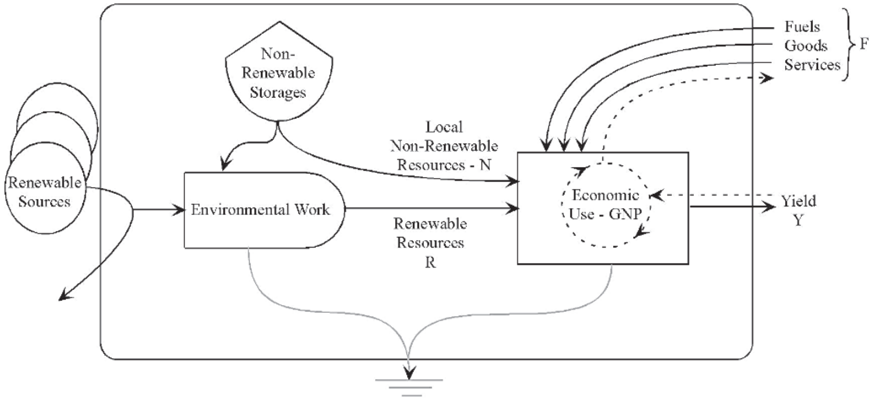
5 Environmental Accounting for Policy Analysis

5.1 Environmental Accounting Method

Ecosystem services are provided by the environment through naturally occurring processes. They are not coupled with the market – they are free, and yet it is usually extremely expensive to pay for replacements (e.g. pollination, soil fertility). To develop sustainable policies there is a need for an accounting framework that can quantify the value of ecosystem services and evaluate trade-offs among services, especially between provisioning and non-provisioning services. With conventional economic accounting methods, the full costs of goods are not embodied in price; markets are lacking for many of the goods and services provided by the environment. The result is that social and environmental costs are borne by society, but the benefits accrue to individuals and corporations.

Economic valuation methods rely on "perceived value", which is what one would pay for a given service. In this project, we use environmental accounting based on "energy" analysis (Odum, 1996). It is a very different but complementary approach to economic valuation. Energy analysis is a method of calculating the value of a resource or product in terms of how much energy went into creating that service, by summing the investment made in each step of its production process. It is a "donor" value-based accounting system. Energy accounting permits evaluation of environmental and economic systems on a common basis, in common units, so that environmental concerns can be quantitatively integrated into development processes.

The first step in the approach is to diagram the environmental resource base of the economy at the national scale (Fig. 5) using energy systems diagrams (Odum, 1996). On the left-side of Fig. 5, renewable flows of energy (such as sunlight and rain) are shown coming into a country. These renewable energy sources support production systems, such as forests, subsistence agriculture, lakes and wetlands.



Transformity (for product Y)	=	EMergy of Y / Energy of Y
Emergy:Dollar Ratio (Em$)	=	(R + N + F) / GNP
Emergy Yield Ratio (EYR)	=	Y / F
Emergy Investment Ratio (EIR)	=	F / (N + R)
Environmenatl Loading Ratio (ELR)	=	(N + F) / R
Emergy Sustainability Index (ESI)	=	EIR / ELR
Percent renewable	=	R/ (R + N + F)

Fig. 5 An energy system diagram of the environmental resource base of the economy at the national scale

However, these production systems can also use up non-renewable resources, such as soil. On the right-side of Fig. 5, we see economic use, such as processing of forest products and crops. These economic processes use purchased inputs of fuels, goods and services, and export of goods. Money flow, shown as dotted arrows, is used to purchase imports and is received in exchange for exports.

A national level systems diagram for Niger is shown in Fig. 6. The different ecosystems represented include woodlands, crop lands, rangelands, wetlands and desert. Livestock and fisheries are also shown. On the right-side is shown industrial processing of outputs from the ecosystems, principally food and agricultural processing. Mining and manufacturing are also depicted, all exporting goods to the global market and earning foreign revenue. Hydroelectric generation, based on the River Niger, which flows through the country, is also an important process. Note that the rural and urban populations are shown separately, so that rural to urban flows, for example of agricultural products and labour, can be analyzed.

The second step is to collect data to quantify the material and energy flows, tabulate them and convert them into energy values. "Emergy" is the energy used in the work processes that generate a product or service, expressed in units of one type of energy. Because one kind of energy is not equivalent in its ability to do work to energy of another kind, all energy flows are converted into one type of energy, so that all flows can be compared in the same units. Solar energy is usually the unit chosen to express emergy values. This conversion is done using standardized transformity values for each product. A transformity for a product is calculated by summing all the emergy inflows to the process and dividing by the emergy of the product (Brown and Ulgiati, 2004). For example, the emergy value of a bag of

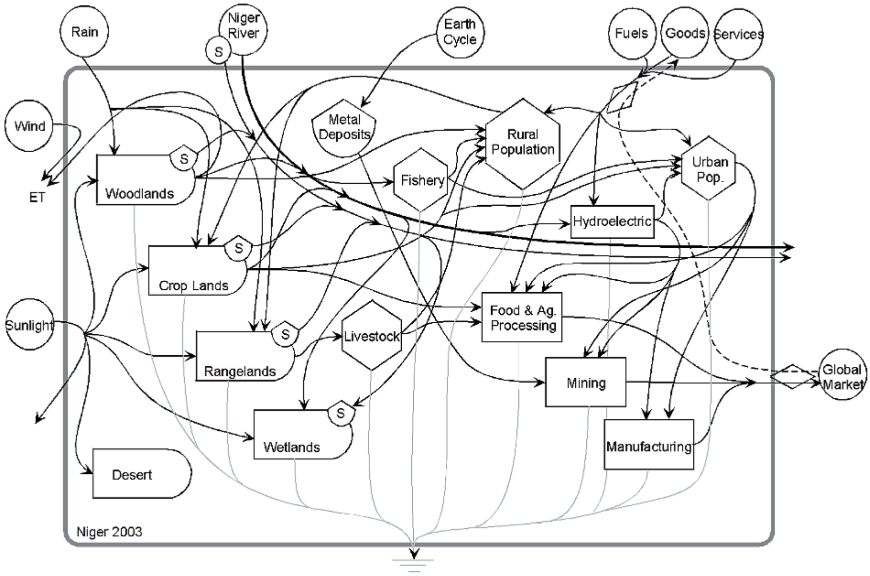


Fig. 6 A national level systems diagram of the different ecosystems in Niger

maize exported from a country includes the cost of non-renewable environmental service (such as soil loss) that has been lost with it.

Once all the flows are in emergy units, various sustainability indices (Fig. 5) are calculated to quantify resource use, fraction of renewable resource use, environmental load, natural capital stocks and depletion, international trade and debt, poverty and total system well-being (Cohen et al., in preparation). These indices help in decision-making by providing information outside of traditional economic analysis.

As an example of the approach, Cohen et al. (2006) used emergy synthesis to estimate the environmental costs of soil erosion on multiple scales in Kenya. The results suggested that erosion losses on the national scale were equal in magnitude to national electricity production or agricultural exports (equivalent to $390 million annually or 3.8% of GDP). On the district scale, the cost of soil erosion in Nyando District was equivalent to the value of total district crop production, or equivalent to 50% of all imports of fuel, goods and services to the district. The results provide a baseline measure of sustainability against which appropriate investment (i.e. scaled to problem magnitude, targeted to hot-spots) in soil conservation may be evaluated.

5.2 Application of Environmental Accounting in the Project

The project is conducting an analysis of the status of national environmental resources, sustainability trends and land degradation impacts on economic/environmental systems for the five participating nations. A regional contrast with national scale emergy evaluation for seven other nations in the region less reliant on dryland resources (Benin, Nigeria, Ghana, Ivory Coast, Guinea, Sierra Leone, and Cameroon) is also being conducted, as well as more detailed historical time series emergy analysis at five-year intervals for Mali, Senegal and Niger. The results are being synthesized into a policy brief to address national dryland management in terms of internal funding allocation and policies for natural resource management. The accounting is being repeated at successively lower levels of scale at selected sites: at district and individual land use systems to guide local policy decision-making. The project is also producing a software tool for training and implementation by national policy-makers throughout Africa on environmental accounting and policy evaluation on national scales, linked to national scale databases for emergy analysis.

6 Conservation Agroforestry

At the local level, the project is developing and helping to implement participatory action plans to intensify agroforestry practices in and around villages, as a strategy for improved rural livelihoods and increased environmental benefits. Examples are woodlots, fodder banks, live fences, tree-vegetable gardens (e.g. dwarf baobab) and fruit orchards. To provide incentive for the re-establishment of parkland tree species, the project is introducing grafting techniques for high-value indigenous trees (Figs. 7a, b), such as Sheanut butter (*Vitellaria paradoxa*), and Baobab (*Adansonia*

Figs. 7a, b Grafting high-value indigenous trees such as *Vitellaria paradoxa* and *Adansonia digitata* enables Parkland species to be re-introduced *digitata*) to reduce time to fruiting from several decades to just a few years. These techniques may provide incentives for the re-introduction and protection of parkland species close to villages, where water and protection are available, and thereby help to conserve biodiversity and increase incomes and food security, while also relieving pressure on more marginal areas. At a regional level, the project is developing a strategy and conducting training courses for extension of agroforestry techniques for national programmes in all five countries.

7 Conclusion

Ecosystem changes are happening too fast for humankind to rely on the very slow and inefficient process of empirical learning by trial and error. A key role for science is to accelerate reliable learning about ecosystem management. Rigorous science includes the use of baselines, controls, replication and reliable monitoring systems, to guard against threats to validity so that sound conclusions can be reached. Rigorous science also involves incorporating knowledge of scientific uncertainty into environmental policy decision-making. These principles have very rarely been rigorously applied in development projects with the result that there has been little reliable learning from massive investments.

Use of science-based approaches for policy evaluation is especially important in dryland countries, where the process of developing empirical knowledge is failing because change is happening faster than experience can accumulate, and because policy impacts take time to have detectable effects across large isolated areas and against the background of climatic variability. Land degradation surveillance and environmental accounting tools, applied in conjunction with participatory land management and monitoring, can contribute towards a science-based learning framework.

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References

Brown, M. T. and Ulgiati, S. 2004. Emergy analysis and environmental accounting. *Encylopedia of Energy*, Vol. 2. Elsevier, New York.

Cohen, M. J., Brown, M. T. and Shepherd, K. D. 2006. Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis. *Agriculture, Ecosystems and Environment*, Vol. 114, pp. 249–269.

Millennium Ecosystem Assessment (MA), 2005a. *Ecosystems and Human Well-Being: Current Status and Trends*. Island, Washington, DC. See http://www.millenniumassessment.org/en/products.aspx (Accessed 17 September 2006).

———. 2005b. *Ecosystems and Human Well-Being: Desertification Synthesis*. Island, Washington, DC. See http://www.millenniumassessment.org/en/products.aspx (Accessed 17 September 2006).

Odum, H. T. 1996. *Environmental Accounting: Energy and Environmental Decision Making*. Wiley, New York.

Xue, Y. and Fennessy, M. J. 2002. Under what conditions does land cover change impact regional climate? *Global Desertification: Do Humans Cause Deserts*? Reynolds, J. F. and Stafford Smith, D. M. (eds.). Dahlem Workshop Report 88. Dahlem University Press, Berlin. pp. 59–74.

Chapter 2
An Integrated Livelihoods-based Approach to Combat Desertification in Marginal Drylands

Richard J. Thomas and Francis Turkelboom

Abstract Previous interventions to combat desertification have often failed because a piecemeal approach was used that was inadequate to deal with the complexities of marginal dryland areas. This paper describes a more relevant, inclusive approach based on the principles of Integrated Natural Resources Management (INRM). It sets out a framework for INRM implementation, with 11 "cornerstones" to guide project design, identify strong and weak areas, and target efforts accordingly. These cornerstones are broadly grouped under three aspects: multi-disciplinary, multi-institution partnerships, local institutional/organizational capacity, and scaling out (including post-project sustainability).

ICARDA and its partners applied this framework to a research project in the Khanasser Valley, a marginal dryland area in Syria. A range of best-bet technological, institutional and policy options was developed with community participation. These options were discussed at multi-stakeholder meetings, and tested jointly by researchers, extension agents and the community. They continue to be implemented and refined through iterative learning cycles.

Crucially, this approach is not limited to technical solutions alone but includes economic, environmental, social, institutional and policy aspects, and links research findings into a long-term development plan that addresses priorities identified by the community. The best-bet options have proved feasible, profitable and low-risk, and adoption is growing. Policy-makers have shown a willingness to replicate the INRM approach in other parts of Syria.

Keywords Marginal drylands, Integrated Natural Resources Management, land degradation, Khanasser Valley, local communities

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1 Introduction

The UNCCD defines desertification as 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities'; but the term remains enigmatic. Desertification is sometimes viewed solely as an environmental problem restricted to dryland areas near desert margins (with misleading images of advancing deserts). In reality it is more of a development problem associated with non-sustainable livelihoods of the people who inhabit drylands. The affected areas may be far removed from desert margins; for example, mosaics of marginal and better endowed areas with irrigation, access to inputs and markets. There are other myths: desertification is caused by irrational land use, is irreversible, and is not important because it occurs mainly in marginal lands or is the result of climatic (rainfall) cycles.

There is now a body of evidence that challenges these assertions and takes a more optimistic view that dryland inhabitants are capable of obtaining livelihoods without necessarily degrading the natural resource base, i.e. soil, water and biodiversity (Reij and Waters-Bayer, 2001; Mortimer, 2004, 2005). This school of thought suggests that there is a need to build on local success stories and practices, adding modern technologies where appropriate, and paying greater attention to institutional and policy factors. The approach is to improve empowerment and income generation in order to prevent or even reverse land degradation. Out-scaling or replication of these success stories remains a formidable challenge that has risen to the top of the global development agenda (Sachs, 2005).

The International Arid Lands Meeting in 1955 set the agenda for most anti-desertification interventions for the next five decades. Many of the recommendations made at the meeting are still relevant (White, 1956; Hutchinson this volume). There have been major advances in understanding the basic processes of desertification and degradation, but not on inter- or cross-disciplinary work and the involvement of local stakeholders. This largely reflects the way our research and development institutions are organized along disciplinary or sectoral lines rather than due to a lack of understanding of the need for a more inclusive, integrated approach.

It is clear today that drylands, rather than being abandoned, deserve increased attention because of the serious environmental and social problems associated with the degradation of their natural resources, the loss of ecological services they provide and the need to enhance and sustain the livelihoods of people who depend on the natural resource base. Recent estimates indicate that over 2 billion people live in drylands, and desertification is thought to be potentially one of the most threatening ecosystem changes likely to impact the rural poor (Adeel et al., 2005), especially when it is compounded by increasing water scarcities and the challenges of a changing climate. Drylands are predicted to become warmer and drier, with increasingly volatile rainfall patterns (IPCC, 2001).

Agriculture has been implicated as a factor in 95% of 132 cases studies on desertification (Geist and Lambin, 2004), but it is often not the mainstay of livelihoods in the affected areas. It is therefore important to diagnose whether agriculture-based interventions are the most appropriate for a given target community, or whether efforts in other sectors, such as tourism or energy, might offer better returns. Interventions to combat desertification will require an integrated, multi-level, multi-sectoral approach. The outputs of such an approach are technological, institutional and policy options that feed into a process of development that is in turn firmly grounded in reality, and relevant to the needs of the rural poor in drylands. In this paper we illustrate such an approach, with case studies from a marginal zone in the Syrian Arab Republic.

2 An Integrated Approach

An integrated approach, rather than piecemeal solutions, is required to solve the problems of land degradation in drylands. This approach will need to handle multiple scales of interaction and response, mainly non-linear processes, and multiple stakeholders with sometimes conflicting objectives. Drawing on past experience, a Task Force of the Consultative Group on International Agricultural Research (CGIAR) identified the key elements in research-for-development projects designed to combat desertification and other natural resource management problems (Campbell et al., 2005a, b). The framework consists of a set of 11 building blocks (cornerstones) representing key functions and processes, grouped into three main themes:

- Working together
- Establishing the institutional and organizational framework
- Improving the approaches to the problem

2.1 Working Together

The effectiveness of teams of scientists, land users, and policy-makers can be enhanced if:

2.1.1 Problems can be identified and clear opportunity foci negotiated and made apparent to all partners through an open, transparent process

Geographic Information Systems (GIS) maps and three-dimensional models of the local farming system and environment – placed at a convenient community location with easy access – can be of great value in diagnosing constraints and opportunities, and can also be used as negotiation platforms.

2.1.2 Partnerships and collaborative arrangements are built on trust, ownership, and joint commitment

Complex problems with multiple causes, such as land degradation, cannot be successfully addressed by the compartmentalized, single-discipline approach that typifies many past efforts. Multi-disciplinary, multi-institution partnerships are required to bridge the divides among different stakeholders, and especially between land users and policy-makers. Collaborators must be motivated by a shared vision and idea of the expected impact. Identifying the relative strengths and weaknesses of existing institutions and partners helps focus on the weak links – which may change over time, as implementation proceeds. Formal agreements on working together (such as memoranda of understanding) will help monitor and evaluate progress.

2.1.3 Cross-disciplinary research and development teams are established

Teams of researchers and development agents need to be set up to focus on problems that require integration of disciplines and complementary skills. These are in addition to the multi-disciplinary research teams, which have separate objectives. Key issues include: mutual learning, synergy, strong leadership, and transparent processes for decision-making and conflict management – all contributing to better accountability and more effective teamwork. Rewards can similarly be focused on team accomplishments.

2.1.4 Effective facilitation, coordination and negotiation is achieved at different levels

Facilitators will need to guide the cross-disciplinary teams, negotiate across institutional boundaries when needed, ensure there is a continuous learning process during project implementation, and assist in monitoring and evaluation. They will work at various levels: with the community, with service providers, and at the larger organizational level.

2.2 Establishing the Institutional and Organizational Framework

Projects are often derailed by seemingly insurmountable institutional barriers among civil society organizations, research, government and policy-makers. To address these problems it is necessary to:

2.2.1 Create enabling governance and policies that provide incentives, capacities and resources to key stakeholders

Decentralization of decision-making – down to the lowest relevant level – is an effective way to improve management of natural resources. It helps remove disincentives that might hamper local people from managing their resources sustainably, and it enables them to voice their concerns and aspirations to policy-makers. Lack of land ownership or land use rights is often a key reason why land users do not invest in interventions to prevent or reverse degradation. Here the focus is on helping groups to coordinate their actions to better manage shared resources. It is important to share and explain policy information among different stakeholders so that different viewpoints can be heard.

2.2.2 Ensure local organizational capacity for collective action and self-governance

As natural resources are often shared by different users, collective action and decision-making is crucial. The priority should be to help establish local organizations and rules of operation. These organizations will need access to information and cheap, effective methods to monitor resource use and degradation. Much research is still required on how to combine indigenous knowledge with modern scientific knowledge in order to develop such methods.

2.3 Improving the Approaches to the Problem

There is a need to ensure that activities continue after a project ends, and that a self-sustaining process of dissemination and adoption is established that can reach many people over a wide geographic area. To establish self-learning cycles, research needs to be more tightly linked with development so that research topics are locally chosen and relevant, yet can be extrapolated to other areas. To achieve this there is a need to:

2.3.1 Provide access to information on technical, institutional, market, and policy options

Land users often do not have access to information on resource management, such as methods successfully used in similar environments elsewhere. Such information needs to be in a form appropriate for each group of land users. Rather than recommendations, it should provide various options and explain their advantages and disadvantages. It is also important to provide examples of how new knowledge can be built on existing knowledge. Harnessing the advances in information and communication technology represents a major challenge in order to bridge the "information divide".

2.3.2 Ensure shared learning through exposure, experimentation, and analysis of successes and failures

There are many examples of innovative farmers who have devised their own solutions based on experience and learning. This learning-by-doing approach can be enhanced by facilitating access to knowledge, for example through field visits and farmer-to-farmer exchanges. There is a need to encourage local experimentation and iteration, perhaps through inducements such as prizes for creative interventions (judged by local people themselves).

2.3.3 Establish and maintain interest created in the short term to get commitment to longer term goals and processes among partners

Resource-poor land users must address their immediate needs and cannot always think about longer term investments. Thus there is a need to generate immediate benefits – often within one agricultural season – in order to create and maintain interest in, and commitment to, longer term objectives. This is often done by focusing on improved crop varieties and animal stock. Here is an opportunity to construct bridges between research organizations and local organizations.

2.3.4 Implement an explicit scaling up/out strategy building on successes and strategic entry points

Given the pace of degradation, it is crucial to reach as many people as possible in the shortest time possible. This requires an understanding of the likely impact pathways and a clear plan for scaling up, i.e. moving across institutional scales from communities to government and international agencies, and scaling out (replication to other sites). This will help not only to disseminate technologies but also to create an enabling environment for development.

2.3.5 Integrate research and development objectives

Research on land degradation will require conventional techniques, as well as informal experimentation in farmers' fields that will not follow the usual replication designs. Many of the results will be derived from both the local and policy levels. The results may not lend themselves to statistical analyses, but it will still be necessary to show that they are relevant beyond the specific location. Lessons learned during participatory learning are important in such extrapolation; in some cases it may be only the process itself (not the results) that can be extrapolated.

This set of 11 building blocks or cornerstones can be used

- As an aid to design and develop projects and programmes
- To monitor and evaluate ongoing projects in a way that allows iteration and change
- As a learning tool
- As a knowledge management tool
- As a tool to create a common understanding
- As a way to remind us of what we need to consider, especially focusing on weak areas

Further details about the concepts and how to implement the integrated natural resources management (INRM) approach are available in Campbell et al. (2005b).

2.4 Tools to Reduce Complexity

The complexity of resource management problems can be addressed by using appropriate methods and tools. Table 1 shows the types of tools used at a research site in Syria where the INRM approach was applied.

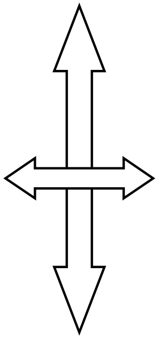
Sets of tools are required for diagnosis, problem-solving and guiding research. Many of these tools are now standard in research-for-development projects. For more details see Turkelboom et al. (2003). A particularly useful tool for diagnosis and evaluation of interventions is the multi-level analytical framework. This helps integrate across spatial and organizational or stakeholder levels and to illustrate the inter-connectivity and off-site effects that are often overlooked. This framework uses inputs from multiple disciplines to identify the 3–5 main driving forces in complex systems (Campbell et al., 2005a, b).

Table 2 shows an application of the framework to address the problems of land degradation (due to unsuitable farming practices) on hillsides that are used predominantly to grow olive trees. The questions posed help identify the main constraints and, eventually, find possible solutions.

Table 1 A toolbox of methods and tools for INRM studies

Diagnostic tools	Tools for problem solving and capitalizing on opportunities	Process tools
1. Integrated research site	7. Multi-level framework for interventions	11. Participatory action research (PAR)
2. Multi-level analytical framework	8. “Plausible option” or “best bets”	12. Envisioning
3. Livelihood, gender and community analysis	9. Decision and negotiation support tools	13. Multi-stakeholder cooperation
4. Analysis of policy, institutional and market environment	10. Scaling-out and scaling-up	14. Cross disciplinary approach
5. Analysis of natural resources status and dynamics		15. Capacity-building of different stakeholders
6. Holisitic system analysis		16. Effective communication coordination and facilitation strategy
		17. Monitoring evaluation impact assessment
		18. Managing knowledge

Table 2 Application of multi-level analytical framework to the management of olive orchards on hill slopes in Khanasser Valley (potential solutions shown in bold font)

Spatial Levels		Stakeholder Levels
Marginal drylands ➢ Climate suitability: – Can olives grow properly in this climate? – **Selection of adapted varieties**		Policy and institutions ➢ Policy on state land? ➢ Olive policy in Syria? ➢ Credit availability? ➢ Institutional analysis + services
Khanasser Valley ➢ Land suitability: Can olives grow on stony hillsides?		Trading links ➢ Are there marketing channels for olives?
(Sub)-catchments ➢ Runoff water use: Is there competition between upslope and downslope?		Communities ➢ Expansion of olive orchards? ➢ Will olives impact on equity? ➢ Competition between grazing and olive orchards and **potential for communal, agreed arrangements**
Field ➢ What are the local management practices, technical knowledge and knowledge gaps? **Awareness, participatory research and training on improved husbandry** ➢ Soil and water management: **Soil and water harvesting, irrigation, tillage, soil erosion, use of ancient terraces** ➢ Tree husbandry: **Pruning, diseases, soil fertility management, diagnosis of unproductive trees**		Household livelihood strategies ➢ Who is interested in growing olives, what are their motives? ➢ Gender divisions related to olive orchards? ➢ What are the sources of technical knowledge? ➢ For subsistence or cash? Enterprise budgets for olives ➢ Alternative tree crops: **Adapted and viable alternatives?**

3 Khanasser Valley and Its Environment

The Khanasser Valley (Fig. 1) is located approximately 80 km southeast of Aleppo in Syria; elevation 300–400 m, average rainfall 220 mm distributed mainly in winter, September to May. With evapotranspiration of approximately 2,000 mm/year, the area is arid. Agricultural land and rangeland are the major habitats. A full description of the site has been published previously (Thomas et al., 2004, 2005; ICARDA, 2005 and references therein). Soils include high pH calcisols, gypsisols, leptosols, cambisols and inceptisols that are generally well drained with high infiltration capacity.

The valley extends over 450 km^2 and has 58 villages with 5–270 households per village, giving a total population of around 37,000. Most of the population is involved in agriculture. Livelihood surveys (La Rovere et al., 2006) classed the households into three groups:

- Agriculturists, who grow crops, fatten lambs and undertake wage labour
- Labourers, who are semi-landless and mostly rely on off-farm earnings and migration
- Pastoralists, who are extensive herders, migrate for wage labour, or occasionally engage in intensive lamb fattening

Depending on the goals of a particular project, one or more groups can be targeted. For example, if the goal is poverty alleviation, interventions should focus on labourers and pastoralists, who are generally poorer than agriculturalists. If the goal is to expand food production, then the focus should be on agriculturalists.

3.1 Major Environmental/Economic Constraints

The local communities identified the following constraints:

- Insufficient rainfall, lack of water for irrigation (erratic rainfall, declining groundwater quality).
- Shortage of barley and other crop varieties that are resistant to diseases and drought.
- Financial constraints affect farmers' ability to meet day-to-day expenses, adopt new technologies, or purchase inputs.
- Widespread lack of information on new technologies and farming practices.
- Unclear land property rights and policies discourage investments and lead to resource use conflicts; lack of compensation for affected groups.

Additional constraints include high population growth rates, shrinking land holdings, decreasing land productivity, increasing poverty, out-migration of men for seasonal work, and lack of markets and market information.

Wells have been installed in the valley to supplement rainfall. The groundwater table is falling because of withdrawals and insufficient recharge; and water quality is deteriorating as a result of increasing salinity (Thomas et al., 2006).

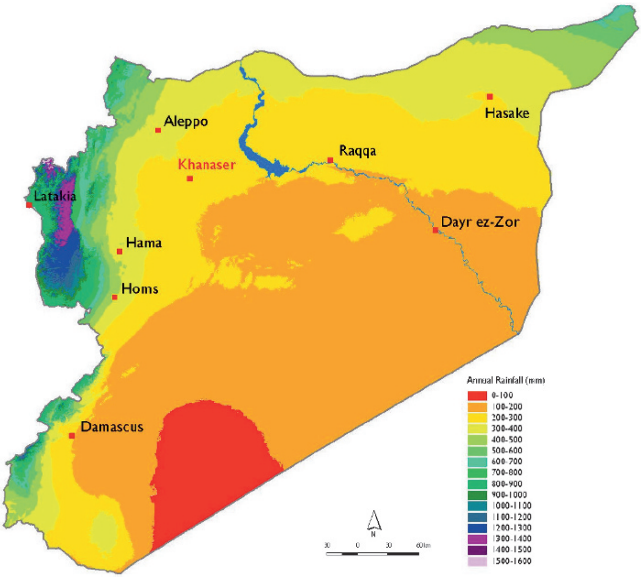


Fig. 1 The integrated research site in Khanasser Valley, Syria

3.2 Perceptions of Land Degradation

Land degradation is occurring, albeit slowly, as a result of soil fertility mining (lack of inputs, export of animal manures to horticultural areas), over-grazing, wind, water and tillage erosion, salinization and pollution of water. However, land users in the valley do not perceive degradation as a major livelihood problem because:

- The rate and impact of degradation is slow
- Irregular rainfall patterns mask the effects of degradation
- They are more concerned about meeting immediate needs than long-term sustainability
- Investments in natural resource management are considered uneconomical
- They have become accustomed to a degraded environment

This lack of awareness or low priority is common in many marginal dry areas.

3.3 Promising Technological, Institutional and Policy Options

3.3.1 Technological Options

ICARDA has been studying a range of potential options for the marginal drylands in Syria for many years. These options have been tested on research stations, in on-farm trails, and finally jointly by researchers and land users, who were encouraged to form farmer interest groups at a number of interactive learning workshops held in the valley. In addition, a UNDP-implemented development project that operates in part of the valley has introduced a micro-credit scheme. From this work, several feasible technological options have emerged:

- Options that strengthen the traditional farming system:
  - Extensive sheep production and technologies to improve animal productivity
  - New barley varieties selected through a farmer-participatory approach
  - Wheat production with supplemental sprinkler and surface irrigation to improve water productivity
  - Dairy production from sheep for household consumption and sale of surplus
- Diversification options:
  - Drought-tolerant vetch varieties to expand cultivation and minimize production risks
  - Improved management of rainfed cumin (a new cash crop) to increase production and price
  - Olive orchards cultivated on foothill slopes, with water harvesting, to increase production and reduce need for groundwater irrigation
  - Barley intercrop with *Atriplex* shrubs to stabilize forage production and enhance protein content in sheep diets
  - Application of phosphogypsum to improve soil fertility, increase and stabilize barley production in dry years
- Intensification options:
  - Lamb fattening with lower-cost feeds

For each of these options, potential production gain, socio-economic feasibility and likely impact on rural livelihoods were assessed (La Rovere et al., 2005; La Rovere and Aw-Hassan, 2006). The analysis suggested that the current best bets were sheep fattening, olive production with water harvesting, drought-resistant barley varieties, and rainfed cumin production. However, other stakeholders had different priorities. In a multi-stakeholder workshop, farmers, researchers, extension agents and policy-makers were presented with a suite of "best bet" options for improving agriculture and livelihoods in the marginal dryland zone of Syria. They were asked to rank these options; each participant was given three labels that could be distributed in any manner among the options (Table 3). Olive and cumin production received low rankings and were therefore omitted from further analyses.

The results show that farmers were more interested in obtaining a quick return and opted for improved drought-tolerant barley varieties. Researchers, perhaps thinking that adequate barley varieties were available, chose lamb fattening (supplementing grazing with purchased concentrates) as the preferred option – this would generate income and also help conserve overgrazed rangelands. Policy-makers prioritized water harvesting and micro-credit, indicating their concern about the common problems of water scarcity and lack of financial support. The views of development and extension agencies were similar to those of farmers, perhaps indicating that they were

Table 3. Results of a multi-stakeholder analysis of best-bet options. Numbers represent the number of votes allocated to each option.

Farmers' views:		**Researchers' views:**	
Barley varieties	9	Lamb fattening	23
Lamb fattening	7	Micro-credit	22
Micro-credit	5	Water harvesting	8
Water harvesting	3	Home garden	8
Development / extension views:		Jabban institution	3
Lamb fattening	14	**Policy makers' views:**	
Barley varieties	9	Water harvesting	8
Water harvesting	6	Micro-credit	7
Micro-credit	6	Modern irrigation techniques	4
Jabban	3	Lamb fattening	3
		Barley varieties	1

more aware of farmers' views than the other participants. This example illustrates the importance of multi-stakeholder dialogue from the very beginning in order to develop a common focus and establish clear partnership arrangements (see 'Working together' and 'Establishing the institutional and organizational framework' above).

3.3.2 Institutional Options

Few formal institutions are present in marginal dry areas, especially if population densities and production potentials are low. The "tragedy of the commons" syndrome is widespread and government institutions are either absent or intermittent. A UNDP-sponsored project has established semi-formal village credit and savings associations (*sanadiq* in Arabic) in the valley to extend credit to the rural poor (Seibel, 2003). Studies showed that households who participated in the credit scheme did improve their physical and financial assets – but also increased their debts, since they borrowed not only from the scheme but also from other informal sources (Buerli and Aw-Hassan, 2005). Also, the credit scheme still did not reach the poorest households. However, it was a valuable intervention overall, and can be applied in other marginal dry areas.

The studies revealed an interesting informal institution: the cheesemaker/trader (*jabban* in Arabic). This consists usually of a single family that lives in the valley for only a few months per year and contracts with farmers for milk, which it processes into cheese and other products. Loans and credits are actually made in advance of milk collection; payment is made as a proportion of the future processed products. The *jabbans* are also an important source of veterinary medicines and vaccines.

Such arrangements need to be carefully studied. Local institutions can be invaluable in neglected areas. Replacing them with a central milk processing unit, for example, may lead to the loss of other essential services for which there are no alternative providers.

3.3.3 Policy Options

The Khanasser Valley is classified as a marginal zone for cropping (Zone 4 according to the rainfall-based Syrian classification system). Yet this zone occupies 11% of the country's land and houses 2 million people, with pockets of high poverty and limited access to education and health services. To raise awareness of potential options and development strategies, a series of workshops was organized with local and national authorities, including cabinet-level policy-makers. Land users and other stakeholders also participated. Rather than emphasize the problems and constraints (which are well known), we discussed the areas' comparative advantages and potential for development (Table 4).

After reviewing the results of the integrated research project, the meeting agreed that solutions should be not just technical but should also focus on economic, environmental, social, institutional and policy options through a long-term development plan. Proposed policy interventions included expanding the micro-finance schemes, more information on market services, greater support to value-added enterprises such as milk and milk products, and environmental subsidies to encourage conservation and improvement of habitats.

It was concluded that any development strategy should consider the multi-functionality of Zone 4 in terms of:

- Agricultural production
- Social dimensions: reducing poverty, creating employment
- Environmental services: biodiversity conservation, wind erosion control, recreation
- Combating desertification

Policy-makers have shown a willingness to replicate the Khanasser approach in other parts of Syria. There is now a growing realization that the INRM approach can help navigate through the complexity of these marginal dry areas.

Table 4 Comparative advantages of the Khanasser Valley

Biophysical	Socio-economic
• Relatively unpolluted environment • Low risk of crop and animal diseases • Low pesticide use • Specific biodiversity • Ecological hotspots (e.g. local salt lake with migratory birds)	• Indigenous knowledge and local innovations • Relatively cheap land and labor • Some investments from off-farm income into productive resources • Improved access to education • Presence of social networks • Cultural heritage
Market	Institutional
• Improved market knowledge via mobile phones and other media • Reasonable mobility, transport • Available • Accessible markets (remote, but not too far from urban markets)	• Improved basic services (electricity, roads, mobile phones) • Increased government focus on poverty and the environment

The multi-stakeholder workshops helped establish a scaling-up strategy with government policy-makers and also initiated learning-by-doing activities through farmer interest groups (see 'Improving the approaches to the problem' in the INRM framework outlined above).

4 Conclusions

The complexity of the issues facing rural areas subject to desertification requires a cross-disciplinary approach that includes technological, institutional and policy factors. The piecemeal approaches of the past are not sufficient. Rather, we need to consider the multi-functionality of drylands to attract investments in order to reverse and prevent degradation. An integrated approach was tested in a marginal dry area of Syria and resulted in a series of technological, institutional and policy options that are being implemented and refined through iterative learning cycles. The approach was sufficiently robust to ensure that all major stakeholders were involved; and that the inter-connectivity of the various sectors was included in the diagnostic and planning stages.

Promising technical options will continue to be tested, validated and adapted by farmers, including participatory barley breeding and alternative crops such as olives and cumin. This will help improve productivity, income generation and efficient use of natural resources; but large-scale environmental problems such as water scarcity will require increased public awareness and the creation of an enabling environment by policy makers. These efforts should eventually lead to greater empowerment of local communities and the creation of a community development plan with the participation and approval of local authorities. Policy-makers exposed to this approach are now more aware of the potential livelihood options in similar marginal areas.

For longer term sustainability it will be essential to supplement agricultural income. One possibility would be for dryland communities to receive development investments as a form of payment for the multiple environmental services that their drylands provide.

This integrated approach can be rapidly scaled out of through networking projects such as the Sustainable Management of Marginal Drylands Project (SUMAMAD) illustrated in this volume (King, 2006; Schaaf, 2006).

References

Adeel, Z., Safriel, U., Niemeijer, D., White, R., de Kalbermatten, G., Glantz, M., Salem, B., Scholes, M., Niamir-Fuller, M., Ehui, S. and Yapi-Gnoare, V. 2005. *Ecosystems and Human Well-being: Desertification Synthesis*. A Report of the Millennium Ecosystem Assessment. World Resources Institute, Washington, DC.

Buerli, M. and Aw-Hassan, A. 2005. Microfinance in marginal dry areas: Impact of a village credit and savings associations on poverty in the Jabal al Hoss region in Syria. Poster presented at the Conference on International Agricultural Research for Development, Deutscher Tropentag, Berlin, October 5–7, 2004. Abstract in Book of Abstracts: *Rural Poverty Reduction* *through Research for Development and Transformation*. (See http://www.tropentag.de/2004, accessed 20 August 2006.)

Campbell, B., Hagmann, J., Sayer, J., Stroud, A., Thomas, R. and Wollenberg, E. 2005a. What kind of research and development is needed for integrated natural resource management? *Water International* (In press).

———. 2005b. *Navigating amidst Complexity: Guide to Manage R&D Interventions for Improving Livelihoods and the Environment*. Centre for International Forest Research (CIFOR), Bogor.

Geist, H. J. and Lambin, E. F. 2004. Dynamic causal patterns of desertification. *Bioscience*, Vol. 54, pp. 17–829.

Hutchinson, C. 2008. The Future of Arid Lands – Revisited: Executive summary. (This volume.)

ICARDA. 2005. *Sustainable Agricultural Development for Marginal Dry Areas – Khansser Valley Integrated Research Site*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo.

IPCC, 2001. Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Watson, R. T. and the Core Writing Team (eds.) Cambridge University Press, Cambridge, UK.

King, C. 2006. Sustainable management of marginal drylands (SUMAMAD): Sharing success stories from indigenous, adaptive and innovative approaches. (This volume.)

La Rovere, R. and Aw-Hassan, A. 2005. *Ex-ante Impact Assessment of Agricultural Technologies in Marginal Dry Areas: The Khanasser Valley Case in Syria*. Integrated Natural Resources Management Series, No. 6. Integrated Research Site. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo.

La Rovere, R., Aw-Hassan, A., Turkelboom, F. and Thomas, R. 2006. Characterizing livelihoods for enhanced targeting of agricultural research in the dry marginal areas of Syria. *Development and Change*, Vol. 37, No. 3.

Mortimer, M. 2004. Why invest in drylands? Synthesis paper prepared for the UNCCD-Global Mechanism, International Fund for Agricultural Development (IFAD), Rome.

———. 2005. Conditions for sustainable farming systems in Sahelian drylands: What can we learn from 'success stories'. Omanya, G.O. and Pasternak, D. (eds.), *Sustainable Agricultural Systems for Drylands. Proceedings of the International Symposium for Sustainable Dryland Agriculture Systems*, 2–5 December 2003, Niamey, Niger. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Reij, C. and Waters-Bayer, A. (eds.), 2001. *Farmer Innovation in Africa: A Source for Inspiration for Agricultural Development*. Earthscan, London.

Sachs, J. D. 2005. *The End of poverty; Economic Possibilities for Our Time*. Penguin, Harmondsworth.

Schaaf, T. 2006. UNESCO's experience of 50 years of drylands research and outreach. (This volume.)

Seibel, H. D. 2003. *Rural Community Development in Jabal al Hoss: An Integrated Rural Development Project with a Focus on Sustainable Microfinance Institutions and Income and Employment Generation*. Interim Assessment of Phase II. United Nations Development Program (UNDP), Mezzah, Damascus.

Thomas, R. J., El Mourid, M., Ngaido, T., Halila, H., Bailey, E., Shideed, K., Malki, M., Nefzaoui, A., Chriyaa, A., Awawdeh, F., Hassan, S. H., Sweidan, Y. and Sbeita, A. 2003. The development of integrated crop-livestock production systems in the low rainfall areas of Mashreq and Maghreb. Harwood, R. R. and Kassam, A. H. (eds.), *Research towards Integrated Natural Resources Management: Examples of Research Problems, Approaches and Partnerships in Action in the CGIAR*, pp. 97–110. Interim Science Council/Center Directors Committee on Integrated Natural Resources Management. Consultative Group on International Agricultural Research (CGIAR).

Thomas, R., Turkelboom, F., La Rovere, R., Oweis, T., Bruggeman, A. and Aw-Hassan, A. 2004. Towards integrated natural resources management (INRM) in dry areas subject to land degradation: The example of the Khanasser Valley in Syria. *Sustainable Management of Marginal*

Drylands (SUMAMAD). Proceedings of the 2nd international workshop. Shiraz, Islamic Republic of Iran, 29 November–2 December, 2003. UNESCO-MAB Dryland Series No. 3, UNESCO, Paris, pp. 80–93.

Thomas, R. J., Bruggeman, A., El Dessougi, H., Luijendijk, E., Turkelboom F. and La Rovere, R. 2005. Sustainable management of marginal drylands – the Khanasser Valley Integrated Research Site in Syria. *Sustainable Management of Drylands*. *Proceedings of the 3rd Project Workshop, Djerba, Tunisia*, 15–20 Dec. 2004. UNESCO, Paris, pp. 137–148.

Thomas, R. J., Bruggeman, A., El Dessougi, H., Luijendijk, E. and Turkelboom, F. 2006. Sustainable management of marginal drylands – Khanasser Valley Integrated Research Site in Syria. *Sustainable Management of Marginal Drylands (SUMAMAD). Proceedings of the 4th Project Workshop, Islamabad, Pakistan*, 27–31 January. UNESCO, Paris, pp. 121–134.

Turkelboom, F. Thomas, R., La Rovere, R. and Aw-Hassan, A. 2003. An integrated natural resources management (INRM) framework for coping with land degradation in dry areas. Ecosystem-based assessment of soil degradation to facilitate land users' and land owners' prompt actions. Zduli, P., Steduto, P., Kapur, S. and Akca, E. (eds.), *MEDCOASTLAND Project, Adana, Turkey*, 2–6 June. CIHEAM, Bari, pp. 91–109.

White, G. F. 1956. *The Future of Arid Lands: Papers and Recommendations from the International Arid Lands Meeting*. Publication No. 43. American Association for the Advancement of Science, Washington, DC.

Chapter 3
Conservation Agriculture Based on Direct Sowing

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Abstract A research development initiative at the farm level was conducted within the framework of a service contract between ESAK and the GCP/TUN/028/ITA-FAO Project in Siliana Governorate at three sites (Hamzet, Kharrouba and Mnara-Rjeybia). The project sought to encourage cereal producers to adopt a conservation-based agriculture using direct sowing (DS) in agricultural lands known to have a high risk of water erosion. An agro-climatic characterization and one growing season (GS) study (2003–2004) of edaphic and production parameters was carried out. An agro-climatic characterization of ten GSs (1993/1994–2002/2003) showed that grass cereals grew in water deficient conditions during their entire growth cycle under rainfed conditions, which requires sowing in late December when the evapotranspiration (ET) curve approaches the rainfall curve. Barley (*Hordeum Vulgare* L.) appeared to be the most efficient cereal species in terms of water use (4.8 kg mm^{-1}). Rainfall in autumn, winter and spring provide an opportunity for agronomy (two crops per year under rainfed conditions), whenever an agronomic scenario is appropriately set up. The rate of water infiltration was greater by 58%, 12% and 56% with DS compared to conventional sowing (CS), in Hamzet, Kharrouba and Mnara-Rjeybia, respectively. The apparent soil density and soil porosity, two indicators of soil quality, were in favour of DS. However, water dynamics associated with the soil was variable among the experimental sites and growing periods with a general trend revealing DS to perform better in terms of water retention, especially during the grain filling period (June). Phyto-toxicity expressed by a prior allelopathic cereal-species/variety could be a major constraint for DS. Therefore, the choice of an appropriate rotation, based on an agronomic sequence of a least depressive cereal-species/variety to a subsequent tolerant cereal-species/variety, remains an efficient agro-physiological approach (technique of bioassays) to reduce the effect of phyto-toxic residues for DS. Adoption of DS remains essentially related to how much more grain is yielded (quintals ha^{-1}) compared with CS. For the 2003–2004 GS, durum wheat (*Triticum durum* L.) grain yields

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were greater by 12%, 33% and 9% in DS compared to CS, for Hamzet, Kharrouba and Mnara-Rjeybia, respectively. Any grain yield increase coupled with an increase in hay yield (bales ha^{-1}), as in the case of Hamzet (263 bales ha^{-1} vs. 169 bales ha^{-1}) and Mnara-Rjeybia (336 bales ha^{-1} vs. 325 bales ha^{-1}), would motivate cereal growers to raise animals while practicing DS.

Keywords Direct drilling, water dynamics, agronomy of opportunity, yields, allelopathic potential

1 Introduction

For the majority of the cultivated surface in Tunisia, cereal production is faced with a semi-arid climate where the annual rainfall average is 400 mm and experiences high irregularity in terms of quantity, of which the estimated variability over 40 years is 52% compared to annual requirements of water estimated at 500 mm (M'Hedhbi and Chouen, 2003). Direct sowing (DS) seems to be an alternative to conventional sowing (CS), particularly in semi-arid or arid zones, in as much as it supports a better valozisation of hydric resources while providing better protection for soils against erosion (Mrabet, 2003), which is the main consequence of the irrational soil practices (Gilbert et al., 1996), due mainly to the abusive and inadequate use of labour, and thus threatens long-term agricultural production (Saber et Mrabet, 2002).

The current work has been conceived in three parts. During the first phase, an agro-climatic characterization was carried out over a period of ten years (1993/94–2002/03) in the Siliana zone at three experimental sites (Hamzet, Kharrouba, Mnara-Rjeybia). During the second phase, a study was conducted that compared the two methods of sowing (CS, DS) for the 2003–2004 growing season (GS), involving: (i) edaphic factors, (ii) water dynamics and (iii) outputs (grains, straw). For the third phase, a study was carried out involving the allelopathic effect of the 2003–2004 GS durum wheat residues that would be used as vegetation cover (mulch) for a DS during the 2004–2005 GS knowing that the phyto-toxic potential of residues can be a major constraint in the practice of DS if the management of residues is not properly carried out (Ben-Hammouda et al., 2003).

2 Material and Methods

2.1 Choice of Sites

The study concerns three sites, Hamzet, Kharrouba and Mnara-Rjeybia, situated in the Governorate of Siliana. They are situated in the heart of the great cereal fields that are under threat both from drought and hydrological erosion.

2.2 Agro-Climatic Characterization

To evaluate the predisposition of the Siliana zone to the introduction of DS, the adoption of an "agronomy of opportunity" approach, an agro-climatic characterization of the zone encompassing the three sites was carried out. The climatic data registered over ten months (September–June) during ten years (1993/94–2002/03), consisting of monthly/seasonal/annual rainfall, average temperatures and average monthly evapotranspiration, was collected at the Ramlia meteorological station situated 10 km from the most distant site. The output in grains of durum wheat (*Triticum durum* L.), common wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) were collected from the Cellule territoriale de vulgarisation (CTV) of Siliana.

2.3 Determination of the Period of Hydric Deficit

Evapotranspiration (ETP) for the period 1993/94–2002/03 was estimated according to the Espinar formula (Mouggou and Ben Sliman, 1978) in order to trace the curve of hydric deficit (Gardner et al., 1985) and better calculate the date at which the grass cereals could be sown under rainfed conditions, as well as to identify the periods when water requirements are gradually felt and needed for active growth of the cereal seedling.

2.4 Crop Control

Experimental work was carried out during the 2003–2004 GS on alkaline soils that were alkaline (pH = 8), silty-clay (Hamzet, Kharrouba) and silt-loam (Mnara-Rjeybia), with a rate of organic matter of 1.7%, 1.5% and 2.1% for Hamzet, Kharrouba and Mnara-Rjeybia, respectively. The crop control was carried out on surfaces of 2–5 ha equal patches for the DS and the CS at each experimental site. The technical procedure used for the cereals was respected except for DS, where an average mulch of 0.5 t ha^{-1} was used requiring in addition 15 kg ha^{-1} of ammonitrate (33% N) to compensate for any possible immobilization of nitrogen by the microbiological tissue. Sowing was carried out between 24 November 2003 and 4 December 2003 for the CS and DS, respectively, without any rain occurring between the two dates.

2.5 Follow-Up of Certain Edaphic Parameters

For the 2003–2004 GS, the soil humidity at different depths was determined by the two sowing methods (DS, CS) using the gravimetric method. The double-ring method (also known as the Porchet method) was used to estimate the rate of water infiltration in the soil. The apparent density of the soil is defined as the ratio of dry weight of the soil to the total volume of the soil. Porosity is the index of volume relative to the pores of the soil (Hillel, 1982).

2.6 Measurement of Grain and Straw Outputs

For the 2003–2004 GS, the "Razzag" variety of durum wheat was cultivated at the three sites. The registered output of grains and straw for the three sites are those obtained by the cereal growers with their standard combines.

2.7 Allelopathic Potential of the Prior Crop

During the 2003–2004 GS, and in order to study the allelopathic potential of the "Razzag" residues on the crop envisaged for the following year (2004–2005 GS), bio-essays of the young seedlings (radicle growth) were carried out for a hypothetical sequence of monoculture (durum wheat/durum wheat), following the procedure described by Ben-Hammouda et al. (2001).

The bio-essays of young seedlings were carried out in Complete Randomized Design (CRD) with four repetitions. Each experimental unit was made up of ten test tubes. The data were subjected to an analysis of variance using the Statistical Analysis System (SAS, 1985). The treatments with significant effects were separated by the Smallest Significant Difference (SSD) test with a probability threshold of 5% (Little and Hills, 1978).

3 Results and Discussion

3.1 Agro-Climatic Characterization

3.1.1 Seasonal Rain

There is as much rain during winter as autumn; this is followed by spring with a relatively large difference in semi-arid zones, enabling a grass cereal with autumnal sowing to benefit from a total rainfall on average of 403.9 mm during the period from September to May.

The distribution of rain (Table 1) provides the possibility to practice an "agronomy of opportunity" in order to take advantage of the late spring rains. This rainfall is not generally taken up by grass cereals, in addition to those during the summer. This is the case particularly for barley, which matures early. Consequently, it is possible to sow

Table 1 Characteristics of seasonal rainfall (mm) in the Siliana zone during the period 1993/94–2002/03

	Season			
Parameter	Autumn	Winter	Spring	Summer
Maximum	238.1	410.0	143.3	89.8
Minimum	77.1	53.4	34.7	5.0
Average	150.1	154.1	99.7	46.4

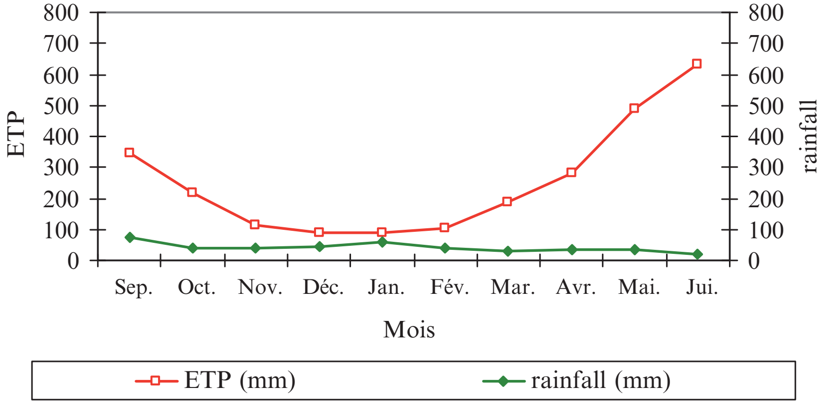

Fig. 1 Hydric deficit curve for the Siliana zone for the period 1993/1994–2002/2003

a summer cereal such as sorghum-forage as plant cover, whose eventual biomass could serve for grazing. The biomass remaining after a controlled passage of the herd could be used as vegetation cover (mulch) for autumnal sowing.

3.1.2 Determination of the Period of Hydric Deficit

The period of hydric deficit for the Siliana zone covers the totality of the biological cycle of the cereals, whose hydric stress intensifies from February. From the hydric deficit curve, it is advisable to delay the sowing date of the rainfed cereal until late December in order to guarantee the minimum amount of soil humidity to ensure rigorous growth of the plant seedlings. For the irrigated cereals, and if water is available, it is advised to irrigate further from mid-February (Fig. 1).

3.2 Efficient Use of Water

On average the efficient use of water over a period of ten years (1993/94–2002/03) for durum wheat, common wheat and barley in the Siliana zone is estimated at 2.3 kg mm^{-1}, 4.3 kg mm^{-1} and 4.8 kg mm^{-1}, respectively. Therefore, barley is the species most adapted to the climatic and edaphic conditions of the Siliana zone, followed by common wheat and durum wheat.

3.3 Soil Humidity

The change of humidity in the Mnara-Rjeybia site during the first couple of weeks in June favoured DS, regardless of the soil horizon. This trend is also true for the other two sites, with slight differences from one period to another during the biological cycle of the durum wheat (Fig. 2).

The excess residue could be used directly on the fields by cattle. Moreover, care should be taken to ensure that the herd does not exhaust the entire amount of residue so as to ensure that the soil receives the minimum quantity required (Crovetto, 1999). The choice of species, with a capacity to produce an important amount of biomass, can be an alternative to favour the integration of the breeding with DS (Husson et al., 2003).

3.4 Rate of Water Infiltration in the Soil

The results clearly a show greater rate of infiltration with DS as compared to CS, with a difference of 1.4 cm h^{-1}, 0.5 cm h^{-1} and 1.5 cm h^{-1} for Hamzet, Kharrouba and Mnara-Rjeybia, respectively (Fig. 3).

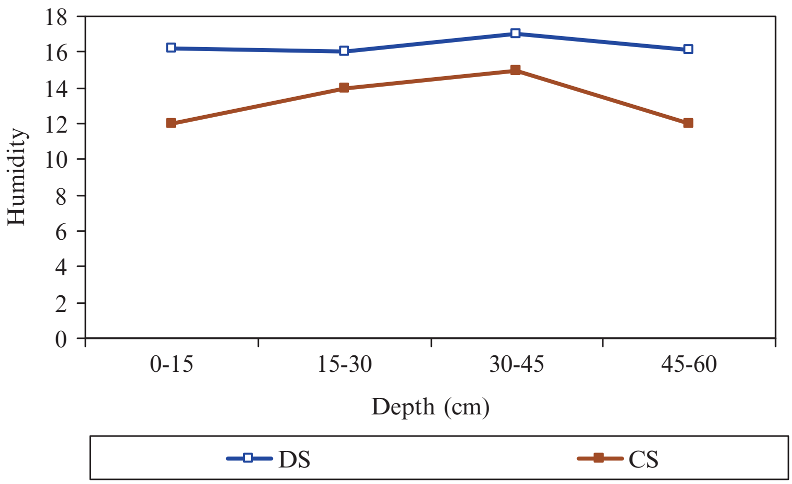

Fig. 2 Development of humidity (%) at different soil depths with two modes of drilling in the first two weeks of June (Mnara-Rjeybia)

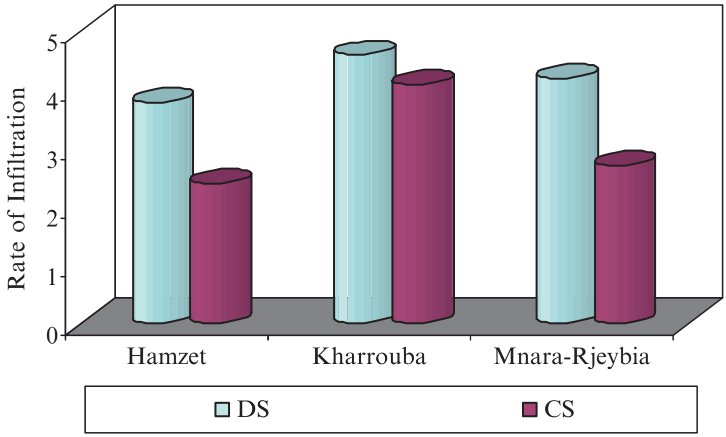

Fig. 3 Variation in the rate of infiltration (cm h^{-1}) of water in the soil with two modes of drilling (Hamzet, Kharrouba, Mnara-Rjeybia)

3.5 Apparent Soil Density

The apparent density was much greater with CS than with DS for the site of Mnara-Rjeybia regardless of the depth of soil tested. As with the other two sites with similar volume, the soil is lighter with DS than with CS, which allows for greater water storage (Fig. 4).

Similar results associated with concentration of organic matter and biological activities were obtained (Crovetto, 1999).

3.6 Soil Porosity

Porosity at Mnara-Rjeybia was greater with DS than with CS at all tested depths, except at a depth of 15–20 cm. This trend is similar for the other two sites (Fig. 5).

This result can be attributed essentially to compaction due to the excessive use of soil preparation tools in CS.

3.7 Outputs of Grain and Straw

For the 2003–2004 GS and with a total rain of 500 mm for the period September–May, the output in grain was greater by 12%, 33% and 9% for Hamzet, Kharrouba and Mnara-Rjeybia, respectively. This superiority was the same for outputs in hay, except for Kharrouba (Table 2).

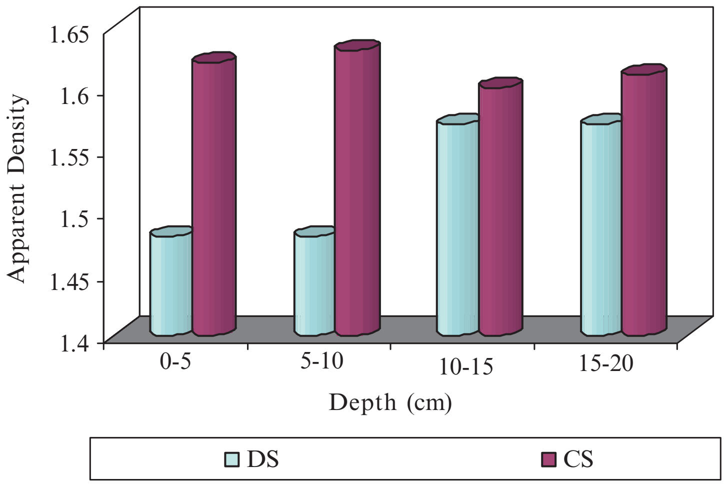

Fig. 4 Variation of apparent density (g cm^{-3}) at different soil depths with two modes of drilling (Mnara-Rjeybia)

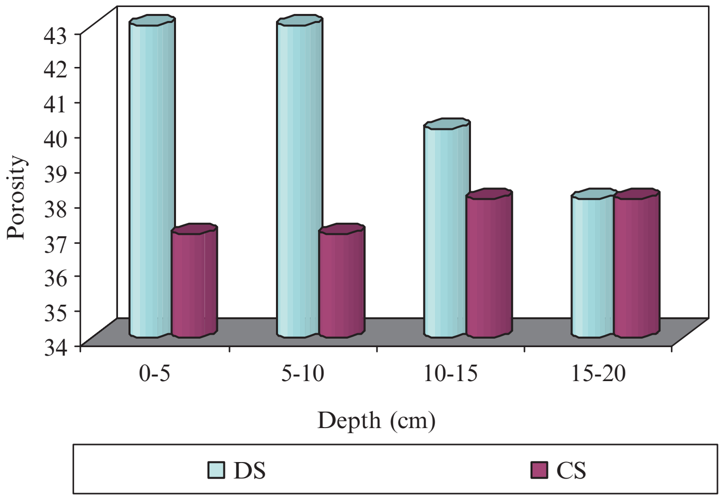

Fig. 5 Variation of soil porosity (%) at different depths with two modes of drilling (Mnara-Rjeybia)

Table 2 Grain outputs (q/s ha^{-1}) and hay (bales ha^{-1}) at the three sites, with the two sowing types: direct sowing (DS) and conventional sowing (CS)

	Grain outputs		Hay outputs	
Site	DS	CS	DS	CS
Hamzet	11.5	10.3	263	169
Kharrouba	16.0	12.0	179	189
Mnara-Rjeybia	12.8	11.8	336	325

3.8 Allelopathic Effects of the Prior Crop at the Kharrouba Site

All three extracts-water (leaves, stems, roots) inhibited the growth of the 'Razzag' radicle. The most pronounced inhibition (46%) was shown with extract-water-leaves. For 'Karim', only the extract-water-leaves inhibited the growth of the ridicule by 15%. This reveals that the auto-toxicity of "Razzag"/ "Razzag" was more severe than the hetero-toxicity of "Razzag"/"Karim" at the varietal level (Table 3).

The phyto-toxic effect of the residues represents the principal constraint that needs to be managed in order to better practice DS (Ben-Hammouda et al., 2003). This effect is defined by the presence of allelochemical substances secreted or liberated by the seedling during the decomposition of its residues (Tollenaar et al., 1993). Moreover, the persistence of allelochemical substances is less than for herbicides (Reigosa et al., 2001). This is essentially due to microbial action (Roth et al., 2000).

4 Conclusion

DS is the basis of sustainable conservation agriculture especially in the semi-arid and arid regions. This mode of sowing is capable of improving soil characteristics and increasing cereal outputs, a major concern for cereal growers. The effect of DS on edaphic parameters and outputs (grains, hay) was a function of the site. In terms of soil humidity, the results were highly variable between the sites and between the different growth periods of the cereal seedlings. The rate of water infiltration in the soil, the apparent density and porosity of the soil – soil quality indicators – were in favour of DS. Thus, the reduction of labour and the conservation of harvest residues helps improve soil structure by increasing its porosity and, as a consequence, its capacity to retain water by infiltration, thus reducing runoff and erosion. Outputs of grains and hay were generally greater with DS than with CS, which facilitates the integration of breeding with DS.

Table 3 Length of radicle (cm) of the two varieties of durum wheat ('Razzag', 'Karim') treated with two water extracts of residues from 'Razzag'

	Variety	
Treatment	'Razzag'	'Karim'
Control	5.4a	4.8a
Extract-water-leaves	2.9c	4.1b
Extract-water-stems	4.2b	4.7a
Extract-water-roots	4.7b	4.8a
SSD (0.05)	0.5	0.3

The study of the allelopathic effect of the prior crop has shown that, in the case of monoculture (durum wheat/durum wheat), a varietal choice is necessary for succession by the adoption of an agro-physiological approach based on the technique of bioassays.

In general, the results show that cereal grasses (durum wheat, common wheat, barley) in the Siliana region is subject to hydric stress throughout its biological cycle. This suggests DS as an alternative so as to better stock/conserve water (soil humidity) and mitigate the effects of stress. The success of DS remains dependant on several factors, particularly the management of harvest residues (biomass, homogeneity of distribution on the soil, pressure of cattle fields, the choice of crop for the appropriate rotations, and more importantly, weed control). These results will be further confirmed once the work is carried out over a series of years while applying appropriate agronomic scenarios for each zone/production site.

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References

Ben-Hammouda, M., Ghorbal, H., Kremer, R. J. and Oueslati, O. 2001. Allelopathic effects of barley extracts on germination and seedlings growth of bread and durum wheats. *Agronomie*, Vol. 21, pp. 65–71.

Ben-Hammouda, M., Oueslati, O. and Ben-Ali, I. 2003. Persistence of the allelopathic potential of durum wheat residues. *II World Congress on Conservation Agriculture, Parana, Brazil, 11–15 August 2003*, pp. 245–248.

Crovetto, L. C. 1999. *Les Fondements d'une Agriculture Durable*. Chapitre: La conduite du non-labour. PANAM, Chequen, Chili, pp. 45–130.

Gardner, F. P., Pearce, R. B. and Mitchell, R. L. 1985. *Physiology of Crop Plants*. The Iowa State University Press, Ames, IA.

Gilbert, V., Mathurin, M. and Francis, F. 1996. Semis direct dans l'aménagement de Sanguéré-Djaling. *Cahiers Agricultures*, Vol. 5, No. 3, pp. 161–169.

Hillel, D. 1982. *Introduction to Soil Physics*. Academic, New York.

Husson, O., Chabane, A., Tuan, H. D., Lecomte, P., Martin, C., Castella, J. C., Tivet, F. and Séguy, L. 2003. Integrating crops and livestock through direct seeding on vegetal cover in Vietnam. *International Journal of Agricultural Sustainability*, pp. 1–4.

Little, T. M. and Hills, F. G. 1978. *Agricultural Experimentation*. Wiley, New York.

M'Hedhbi, K. and Chouen, S. 2003. Conditions and constraints of testing direct sowing in semi-arid areas, Tunisia. *II World Congress on Conservation Agriculture*, *Parana, Brazil*, *11–15 August 2003*, pp. 239–245.

Mouggou, R. and Ben Salem, G. 1978. *Estimation de l'Evapotranspiration: Cas de la Tunisie*. Institut National de Météorologie, Tunis. Tunisie.

Mrabet, R. 2003. No-tillage as a technology to prevent desertification. *II World Congress on Conservation Agriculture, Parana, Brazil*, *11–15 August 2003*, pp. 182–193.

Reigosa, M. J., Gonzalez, L., Sanches-Moreiras, A., Duran, B., Puime, D., Fernadez, D.A. and Bolano, J. C. 2001. Comparison of physiological effects of allelochemicals and commercial herbicides. *Allelopathy Journal*, Vol. 8, pp. 211–220.

Roth, C. M., Srroyer, J. P. and Paulsen, G. M. 2000. Allelopathy of sorghum on wheat under several tillage systems. *Agronomy Journal*, Vol. 92, pp. 855–860.

Saber, N. and Mrabet, R. 2002. Influence du travail du sol et des rotations de cultures sur la qualité d'un sol argileux gonflant en milieu semi-aride Marocain. *Etude et Gestion des Sols*, Vol. 9, No. 1, pp. 43–53.

SAS Institute. 1985. *SAS User's Guide: Statistics*. Version 6.0. SAS, Cary, NC.

Tollenaar, M., Mihaijlovic, M. and Vyn, T. J. 1993. Corn growth following cover crops: Influence of cereal cultivar, cereal removal, and nitrogen rate. *Agronomy Journal*, Vol. 85, pp. 251–255.

Chapter 4
Introducing New Crops with High Water-Use Efficiency in the Middle East and North Africa

Ahmed A. El Obeidy

Abstract Water has been a scarce resource in the Middle East and North Africa (MENA) since early civilizations. MENA is located in an arid region with limited renewable freshwater supplies. A large portion of MENA is desert, the majority of which is uninhabitable because of the lack of biological production. In most countries in the region, the water shortage problem is close to crisis level. Furthermore, agricultural activities encouraged through government-sponsored financial investments and urban landscaping are causing a significant deficit in water resources far beyond its natural renewal capacity. In addition, most plants growing in the area have a high water requirement. It is vital that the type of agriculture practiced there should use as little water as possible. In addition, agricultural activities should use crops with an economic potential. Introducing new crops with high water-use efficiency in MENA will help to curb the rising demand for water. Over millions of years, through natural selection, only the most adapted species could survive the desert environment. Xerophyte species have evolved, becoming well-adapted to extremely xeric conditions. They have developed physiological and morphological methods of exploiting harsh environments that would desiccate other species. Characteristics of xerophyte species fit most of the requirements of a drought-tolerant crop with high water-use efficiency. Several xerophyte species were introduced into the area and their potential as horticultural crops lies in the production of fruits that can offer commercial opportunities. The introduced species may provide the inhabitants of MENA's arid and marginal lands means of earning a living. However, the spread and use of these species is still very limited.

Keywords Arid region, drought resistance, Middle East and North Africa (MENA), xerophyte species, water-use efficiency

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The water shortage problem is close to crisis levels in most countries of the Middle East and North Africa (MENA). Water has been a scarce resource in MENA since early civilizations (Asano & Mills, 1990). Much of the land in the region is too dry for cultivation or grazing (FAO, 2003a). Rainfall variability between different years is also large and renders the region's population vulnerable to drought (World Bank, 2007). Within MENA, most of the potential water resources have already been developed and exploited. The region is affected by drought, and the water shortage is becoming increasingly difficult to manage because of growing demands for water (Araus, 2004). In addition, agricultural activities, encouraged through government-sponsored financial investments and urban landscaping, are responsible for significant overuse of water resources beyond the natural renewal capacity (Wilhite, 2000). Water extraction as a percentage of internal renewable water resources reached 171% and 317% in North Africa and the Arabian Peninsula, respectively (FAO, 2003a). Water extraction as a percentage of renewable water resources was astonishing in some counties in the area; more than 600% in Saudi Arabia and 700% in Libya (AQUASTAT, 2000), while water-use efficiency in the area is about 40% (FAO, 2003b).

Agricultural practices in the area are one of the major causes of the high water demand, as most crops grown in the area have a high water requirement. Date palm is one of the most cultivated crops in the area and can tolerate long periods of drought; however, it has a high water requirement (Morton, 1987b). For date palm, soil moisture should be maintained in the range of 100–75% availability. Date palm needs regular irrigation during flowering and fruiting in order to produce good yields. It requires 25,000–35,000 m^3/ha or more depending on the region (Liebenbergand Zaid, 2002). On the other hand, it was estimated that 40 and 20 million date palm trees were gown in the United Arab Emirates and Saudi Arabia, respectively, in 2000. This seems considerably more than is needed for consumption.

It is urgent in MENA to use the available water as efficiently as possible. It is also vital that the type of plants grown in the area should use as little water as possible. In addition, plants with economic potential should be grown. Although biotechnological advances and breeding are currently being applied in the development of these plants, expectations have yet to be met. One reason for this is the polygenic nature of adaptation to stress factors such as drought. Moreover, there is no fully interdisciplinary approach that combines these new technologies with an ecophysiological understanding of the interactions between crop plant genotypes and the growing environment (Wickens, 1998; Hawkesford and Buchner, 2001; Araus et al., 2003). However, economic reasons may also be responsible for the lack of development of better adapted crops since multinational companies invest in research aimed at improving pest and disease resistance and quality traits rather than combating abiotic stress. This is even more apparent for crops of regional interest (ElObeidy, 2006c).

Introducing new drought-tolerant crops combined with high water-use efficiency in the area could be an alternative. Over millions of years, through natural selection, only the most adapted species survived the arid environment (John, 2001). Many plants are highly adaptable to arid environments and able to tolerate drought, heat and the saline soil.

Several fruiting cactus species were introduced into Egypt and United Arab Emirates (Fig. 1) (ElObeidy, 2004, 2006b), including *Carnegiea gigantea*, *Cereus hexagonus*, *C. peruvianus*, *Hylocereus undatus, Myrtillocactus geometrizans*, *Pachycereus pecten-aboriginum*, *P. pringlii*, *Stenocereus griseus*, *S. stellatus* and *S. Thurberi*. Cactus species characteristics fit with most of the requirements for drought-resistant plants with very high water-use efficiency. Cactus species of the cactus family *Cactaceae* originated from North, Central, and South America (Anderson, 2001). The potential use for cactus species as horticultural crops lies in the production of unique fruits that can offer commercial opportunities (Casas et al., 1997). However, they are unexplored, underutilized fruit trees (Morton, 1987a).

Several cactus species are ideal as feed crops for arid regions where drought is common (Nobel, 1994). Because consumption of cactus can improve the flavour of milk and the colour of butter produced from it, milk from cactus-fed cows commands higher prices in Mexican markets (Russell and Felker, 1987).

Cactus plants exhibit beauty in their symmetry of form as well as in their brightly coloured flowers (Kaiser and Tollsten, 1995). They are very often used to develop a landscape that is water efficient. The practice of developing a water-wise landscape, known as xeriscape, is very important in arid zones, which conjure up images of cacti and rocks (Hewitt, 2003). Moreover, cactus species can play an important ecological role in combating desertification in the area.

Fig. 1 Several fruiting cactus species were introduced and grown in the deserts of MENA

Cactus species have physiological and morphological methods of exploiting environments that would desiccate other plants. They are well adapted to extremely xeric conditions (Mauseth, 2000), being able to tolerate drought, heat and poor soil. They were also found to recover easily from severe drought or heat damage (Fig. 2)

The larger columnar cacti consisting of fewer cylinders are better at conserving water and have a lower transpiration rate than smaller plants with more segments. The cactus stem is succulent and acts as a reservoir for storing water. The water taken up into the stem is converted into a mucilaginous substance that does not evaporate as readily as water (Saag et al., 1975); it binds to water and prevents it from evaporating. The mucilage cell, like virtually all secretory cells, is a parenchyma cell; and even though it only has a thin primary wall, the wall is compact enough to prevent the mucilage from leaking out into the intercellular spaces. As the mucilage accumulates, the protoplast must shrink and the limited amount of volume is enclosed by the cell wall. Ultimately, the protoplast shrinks to virtually nothing and dies, and then the entire volume fills with mucilage (Mauseth, 1980).

The tough skin of the cactus stem is covered with a waxy cuticle layer that helps it to hold water vapour, thus reducing water loss. Cactus leaves are absent or reduced to spines to minimize transpiration (Sowell, 2001). The spines create a microclimate around the stem (Fig. 3). The shade produced by the spines is important for the plant's survival. Without this shade, the stem would lose moisture too

Fig. 2 Cactus plants can easily recover from severe drought or heat damage

rapidly and eventually scorch or burn in the hot sun. Spines also allow any moisture in the air to condense and slow down blowing wind, which reduces water evaporation on and around the cactus.

Two cactus structures, the ribs and tubercles, help the cactus stem to expand and contract as water availability changes (Fig. 4). Such a mechanism enables the stem to conserve water and survive hot and dry conditions. The ribs also help to channel water from rainfall to the roots and help to shade portions of the stem throughout the day.

Fig. 3 Cactus leaves were reduced to spines that create a microclimate around the stem to minimize transpiration

Fig. 4 Two cactus structures, the ribs and tubercles, help the cactus stem contract (A) and expand (B) as water availability changes

The pathway of photosynthesis in cacti is the crassulacean acid metabolism (CAM) (Malda et al., 1999), which is the process whereby stoma open at night (when evaporation rates are usually lower) and usually remain closed during the day. CO_2 is converted into an acid and stored during the night. During the day, the acid is broken down and the CO_2 is released to an enzyme, Rubisco, for photosynthesis. When conditions are extremely arid, cacti can keep their stoma closed night and day. Oxygen released in photosynthesis is used for respiration, and CO_2 released in respiration is used for photosynthesis (Winter and Smith, 1996). The importance of crassulacean acid metabolism species increases in the face of the expansion of desertification around the world (Cushman and Borland, 2002).

Adaptations to survive hot and dry conditions are not restricted to the plant parts found above ground. The roots are non-succulent and require small amounts of water. Cacti typically have long and extensive root systems so they can absorb even relatively small amounts of water that moisten the soil surface during light rain showers. These roots grow close to the surface, collecting as much water as possible. As the soil dries, fine lateral roots generally die, while larger ones become covered with a corky layer (periderm) (Sowell, 2001). The root water conductivity decreases dramatically during soil drying, which reduces water loss from the plant tissues to the soil (Huang and Nobel, 1994; Nobel and Cui, 1992).

One of the epiphytic mechanisms in cacti to secure required water is the development of aerial roots from the sides of the stem to collect water from the surroundings (Fig. 5). Consequently, the absorbed water can easily be stored in fleshy stems. There are approximately 20 species of fruiting epiphytic cacti, ranging from Mexico through to Central America to northern South America and from southernmost Florida and throughout the West Indies (Zee et al., 2004).

The Pitaya or dragon fruit, *Hylocereus undatus*, is a perennial, epiphytic, climbing cactus native to southern Mexico, Guatemala and Costa Rica (Zee et al., 2004).

Fig. 5 Epiphytic cactus plants grow out aerial roots to absorb water from the humid atmosphere

Fig. 6 *Zyzyphus* plants can produce fruits under hyper-arid conditions (Agricultural Experimental Station, King Saud University)

Pitaya is considered a promising crop to be grown commercially in the dry regions (Vaillant et al., 2005). Pitaya is found to have high water-use efficiency (Nobel and de la Barrera, 2004). In addition to its low moisture requirement, the early ripening of its fruits increased interest in pitaya production (Ebert et al., 1993). A pitaya clone was imported from the *Jardin Exotique* in Monaco and propagated by different methods in Egypt and United Arab Emirates (ElObeidy, 2006a).

Tropical almond, *Terminalia catappa*, is another plant that can produce fruits under dry conditions. However, tropical almond was introduced onto the Arabian Peninsula in the past but received little attention. Recently, King Saud University began to improve propagation and selected superior clones of the tropical almond (AlAbd-AlJabar, 2007).

Zizyphus plants are ancient in the area. *Zizyphus* adapted to the hyper-arid environment and actually needs the intense sun and heat to ripen its fruits (Fig. 6). Superior clones of *Zizyphus* were selected and agricultural practices were developed. However, it has not been implemented intensively in the agricultural system in the area.

Generally, introducing and cultivating crops with high water use efficiency will curb rising demands of water in MENA. The introduced species may provide the inhabitants of MENA's arid and marginal lands with a means to earn a living.

References

AlAbd-AlJabar, S. S. 2007. *Propagation Enhancement of Terminalia catappa L. (Alhasaa Almond)*. M.Sc. thesis, King Saud University, Riyadh, Saudi Arabia. (In preparation.)

Anderson, E. F. 2001. *The Cactus Family*. Timber, Portland, OR.

AQUASTAT. 2000. *Review of Agricultural Water Use per Country*. Report of Land and Water Development Division. Food and Agriculture Organization of the United Nations, NRL, Rome.

Araus, J. L., Bort, J., Steduto, P., Villegas, D. and Royo, C. 2003. Breeding cereals for Mediterranean conditions: Ecophysiological clues for biotechnology application. *Annals of Applied Biology*, Vol. 142, pp. 129–141.

Araus, J. L. 2004. The problems of sustainable water use in the Mediterranean and research requirements for agriculture. *Annals of Applied Biology*, Vol. 144, pp. 259–272.

Asano, T. and Mills, R. A. 1990. Planning and analysis for water reuse projects. *Journal American Water Works Association*, Vol. 82, pp. 38–47.

Casas, A., Pickersgill, B., Cabal lero, J. and Valient Banuet, A. 1997. Ethnobotany and domestication in xoconochtli, *Stenocereus stellatus* (Cactaceae), in the Tehuacan Valley and La Mixteca Baja, Mexico. *Economic Botany*, Vol.51. pp. 279–292.

Casas, A., Caballero, J., Valient-Banuet, A., Soriano, J. A. and Davilla, P. 1999. Morphological variation and the process of domestication of *Stenocereus stellatus* (Cactaceae). *American Journal of Botany*, Vol. 86, pp. 522–533.

Cushman, J. C. and Borland, A. M. 2002. Induction of Crassulacean acid metabolism by water limitation. *Plant, Cell & Environment*, Vol. 25, pp. 295–310.

Ebert, G., Fischer, G. and Ludders, P. 1993. Pitaya – A new fruit species from Colombia. *Erwerbsobstbau*, Vol. 35, pp. 49–52.

ElObeidy, A. A. 2004. Introducing and growing some fruiting columnar cacti in a new arid environment. *Journal of Fruit and Ornamental Plant Research*, Vol. 12, pp. 127–136.

———. 2006a. Mass propagation of pitaya (dragon fruit). *Fruits*, Vol. 61, No. 5 pp. 313–319.

———. 2006b. Growth behavior of apple cactus in a hyper arid region. *Journal of Applied Horticulture,* Vol. 8, No. 1, pp. 47–51.

———. 2006c. Status and obstacles of agricultural biotechnology in the Arab Region. *The 11th IAPTC&B Congress, Beijing, China*, 13–18 August.

FAO. 2003a. Sustainable water resources management for food security in the Near East region. High-Level Technical Workshop, Jeddah, Saudi Arabia, 8–9 October.

———. 2003b. *World Agriculture: Towards 2015/2030 – An FAO Perspective*. Earthscan, London.

Hawkesford, M. J. and Buchner, P. 2001. Molecular analysis of plant adaptation to the environment. *Handbook Series of Plant Ecophysiology*, Vol. 1. Kluwer, Dordrecht, The Netherlands, 276p.

Hewitt, T. 2003. *Garden Succulents*. RHS Wisley Handbooks, Woking, UK.

Huang, B. and Nobel, P. S. 1994. Root hydraulic conductance and its components, with emphasis on desert succulents. *Agronomy Journal*, Vol. 86, pp. 767–774.

John, S. 2001. *Desert Ecology: An Introduction to Life in the Arid Southwest*. University of Utah Press, Salt Lake City, UT.

Kaiser, R. and Tollsten, L. 1995. An introduction to the scent of cacti. *Flavour and Fragrance Journal*, Vol. 10, pp. 153–164.

Liebenberg, P. J. and Zaid, A. 2002. Date palm irrigation. *Date Palm Cultivation*. FAO Plant Production Protection Paper, 156 Rev. 1.

Malda, G., Backhaus, R. A. and Martin, C. 1999. Alterations in growth and carassulacean acid metabolism (CAM) activity of in vitro cultured cactus. *Plant Cell, Tissue and Organ Culture*, Vol. 58, pp. 1–9.

Mauseth, J. D. 1980. A stereological morphometric study of the ultrastructure of mucilage cells in *Opuntia polyacantha* (Cactaceae). *Botanical Gazette*, Vol. 141, pp. 374–378.

———. 2000. Theoretical aspects of surface-to-volume ratios and water-storage capacities of succulent shoots. *American Journal of Botany*, Vol. 88, pp. 1107–1115.

Morton, J. F. 1987a. Cactaceae, strawberry pear. *Fruits of Warm Climates*, J. F. Morton (ed.). Miami, FL. pp. 347–348.

———. 1987b. Dates. *Fruits of Warm Climates*, J. F. Morton (ed.). Miami, FL. pp.

Nobel, P. and de la Barrera, E. 2004. CO_2 uptake by the cultivated hemiepiphytic cactus. *Hylocereus undatus. Annals of Applied Biology*, Vol. 144, pp. 1–8.

Nobel, P. S. 1994. *Remarkable Agaves and Cacti*. Oxford University Press, New York.

Nobel, R. S. and Cui, M. 1992. Hydraulic conductances of the soil. The root-soil air gap, and the root: Changes for desert succulents in drying soil. *Journal of Experimental Botany*, Vol. 43, pp. 319–326.

Russell, C. E. and Felker, P. 1987. The Prickly pears (*Opuntia* spp., Cactaceae): A source of human and animal food in semiarid region. *Economical Botany*, Vol. 41, pp. 433–445.

Saag, L. M. K., Sanderson, G. R., Moyna, P. and Ramos, G. 1975. Cactaceae mucilage composition. *Journal of the Science of Food and Agriculture*, Vol. 26, pp. 993–1000.

Sowell, J. 2001. *Desert Ecology: An Introduction to Life in the Arid Southwest*. University of Utah Press, Salt Lake City, UT.

Vaillant, F., Perez, A., Davila, I., Dornier, M. and Reynes, M. 2005. Colorant and antioxidant properties of red-purple pitahaya (*Hylocereus* sp.). *Fruits*, Vol. 60, pp. 3–12.

Wickens, G. E. 1998. *Ecophysiology of Economic Plants in Arid and Semi-Arid Lands: Adaptations of Desert Organisms*. Springer, Berlin/New York.

Wilhite, D. A. 2000. Drought as a natural hazards. Concepts and definitions. *Drought, A Global Assessment*. D. Wilhite (ed.), Vol. I. Routledge, London/New York, pp. 3–18.

Winter, K. and Smith, J. A. C. 1996. *Crassulacean Acid Metabolism: Biochemistry, Ecophysiology and Evolution*. Springer, New York.

World Bank. 2007. *Making the Most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa*. MENA Development Report. World Bank Group Middle East and North Africa. World Bank, Washington, DC.

WWDR. 2003. *Water for People, Water for Life*. World Water Development Report. UNESCO and Berghahn, Paris.

Zee, F., Yen C. and Nishina M. 2004. Pitaya (Dragon Fruit, Strawberry Pear). College of Tropical Agriculture and Human Resources, Cooperative Extension Service, University of Hawaii, *Fruits and Nuts*, Vol. 9, 3pp.

Session VIII
Education and Knowledge-Sharing in Drylands

Session Chair: Dr. Mary Seely
Rapporteur: Prof. Boshra Salem

Synthesis of Presentations

A. Dr. Zafar Adeel, United Nations University International Network on Water, Environment and Health (UNU-INWEH), Canada, discussed a recent global assessment of desertification undertaken by the Millennium Ecosystem Assessment (MA), which shows that desertification in drylands threatens the homes and livelihoods of millions of poor. Environmental impacts of desertification are further exacerbated by political marginalization of the dryland poor and slow growth of health and education infrastructure. The MA report also highlights the global nature of environmental and social challenges posed by desertification. Impacts on the global environment – increasing dust storms, floods and global warming – are well known and documented. Less well-known are the strong impacts of desertification on societies and economies, notably those related to human migration and economic refugees. The MA report points to a variety of integrated policy options to reverse the decline of drylands while optimizing economic output, and emphasizes the inclusion of these in the mainstream national strategies for poverty reduction.

The MA report suggests that full understanding of the significance of desertification is constrained by many uncertainties regarding the relationships among desertification, climate change, biodiversity, ecosystem services and human well-being. The KM:Land initiative by a group of UN agencies aspires to develop a knowledge management network for issues relevant to land degradation, including desertification and deforestation.

B. Dr. Mary Seely, Desert Research Foundation of Namibia, Namibia, discussed the challenge of connecting scientific research with community action. During the latter part of the past century, the scientific community conducted extensive research related to or directly addressing desertification control and rehabilitation. Despite these efforts, little has improved among an increasing rural population faced with decreasing productivity. One causes of this is that researchers usually do not translate and indicate ways of applying their results and communities and their support organizations do not have platforms for easily accessing, interpreting and facilitating application of useful research results. Policy-makers must be included in the dialogue. Examples from Namibia explore the challenges of making these essential connections.

C. Dr. Krishna Prasad, UNESCO-IHE, the Netherlands, discussed the role of education and knowledge-sharing in the development and management of drylands. Growing population and unsustainable human activities leading to degradation and climate change pose increasing threats to integrity and productivity levels of drylands. Nevertheless, drylands are a substantial part of the world's land surface housing about a billion mostly poor people. Exemplary societies and dryland management practices have evolved and local people often show remarkable resilience and innovative management strategies to cope with natural calamities and sustain ecosystem services.

A combination of understanding historical approaches and application of present-day technology can enable sustainable approaches for development and management of drylands. The importance of cultural and social context for learning and knowledge management, and attempts to expand these through participatory processes to achieve societal goals is acknowledged. Options for education and knowledge transfer were illustrated with pertinent examples.

D. Dr. Mark Reed, University of Leeds, UK, developed and applied a learning process for land degradation assessment that integrates local and scientific knowledge bases. He reported results from three degradation hotspots in the Kalahari, Botswana; ongoing research in UK uplands was discussed in relation to an international EU-funded project facilitating two-way learning and knowledge-sharing between local communities, researchers and policy-makers to monitor land degradation and respond appropriately. Application of the process in Botswana identified innovative management options to prevent, reduce, reverse or help rangeland stakeholders adapt to land degradation. Communities identified a wide range of sustainability indicators, the majority of which were validated through field-based scientific research that could be applied without specialist training. Indicators and management options were integrated in a manual-style Decision Support System. Projects in southern Europe, China and USA extend the process by using an iterative combination of integrated modeling and focus group discussions to evaluate potential remediation strategies.

E. Ms. Hélène Gille, UNESCO, Division of Ecological and Earth Sciences, France, presented a creative approach to environmental education.

The UN Convention to Combat Desertification (UNCCD) recognizes the importance of capacity-building, education and public awareness in efforts to combat desertification. In drylands especially, educational programmes that define a pedagogical method to raise environmental awareness among pupils and help them learn about sustainable development is a major instrument to empower pupils and the population.

UNESCO's Man and the Biosphere (MAB) Programme is currently developing two teaching resource kits, one designed for use in dryland countries. The kits, for primary and secondary school teachers worldwide, use a creative approach to awaken environmental knowledge through creative and thought-stimulating activities that encourage rediscovery and appreciation of the natural environment and biodiversity. Sustainable development is introduced through the application of creative activities in real-life situations and through specific exercises, such as creating illustrative inventories, role playing, scenario building, achieving frescoes and gardening. Pupils learn to think of people as playing an integral part in the ecosystem and develop their capacity to think critically about the impact of human activities on the environment. The kits are consistent with activities developed as part of the Decade of Education for Sustainable Development (2005–2014), of which UNESCO is lead agency, and with the vision of education developed by the Education Sector Paper, which specifies that 'pursuing sustainable development through education requires educators and learners to reflect critically on their own communities; identify non-viable elements in their lives; and explore tensions among conflicting values and goals. ESD brings a new motivation to learning as pupils become empowered to develop and evaluate alternative visions of a sustainable future and to work to collectively fulfill these visions.' An important point brought up during the question period was the concept of how to integrate urban and rural understanding, since peri-urban areas are amongst the most endangered.

F. Prof. Farida Khammar, Laboratoire de Recherche Zones Arides, Algeria, discussed environmental education and its role in development. He noted that, more than 30 years after the Belgrade Charter (1985) and the Tblissi Conference (1987), many countries are still in urgent need of environmental education to enable sustainable development and even survival. It is difficult to say what impact educational programmes have had up until now, due to lack of evaluation. However, today there is widespread recognition that for environmental education to succeed, all spheres of society have to be more engaged.

Since the Johannesburg Summit in 2002, environmental education has become a priority for Algeria. The Ministries of Land Management and Environment, Education, and Vocational Training have agreed to integrate education into sustainable development programmes on the one hand, and to modify academic programmes to better accommodate this issue on the other.

G. Ms. Caroline King, United Nations University – International Network on Water, Environment and Health (UNU-INWEH), Canada, discussed the interagency project on Sustainable Management of Marginal Drylands (SUMAMAD), is a coordinated international initiative involving farmers, pastoralists and scientists in participatory research. With support from the Flemish Government, this project includes a network of research teams at eight study sites in marginal dryland areas in North Africa and Western Asia. The project approach, developed in a collaborative effort between UNESCO, UNU-INWEH and ICARDA, focuses on supporting local populations in their efforts to use their natural resources in a sustainable manner.

Over the past two years, a compilation of sustainable management approaches and technologies – indigenous, adaptive and innovative – has been made at each of the participating locations. These have included practices for water management, rangeland rehabilitation and sustainable cultivation of crops, trees and livestock. Sustainable management approaches are supported by complementary alternative income-generating activities in order to reduce the pressures caused by overdependence on natural resources. Exploration and scientific testing of these management approaches is being undertaken by the study teams and local communities with a view to combating environmental degradation, increasing dryland agricultural productivity and enhancing resource conservation. Success stories reported so far show considerable improvements to local livelihoods.

H. Dr. Thomas Schaaf, UNESCO, Division of Ecological and Earth Sciences, France, gave an overview of UNESCO's experience of 50 years of drylands research and outreach.

UNESCO's work related to drylands is based on: (1) environmental conservation using international normative instruments such as the World Heritage Convention and the World Network of Biosphere Reserves; and (2) on scientific studies on ecosystem structure, functioning and dynamics to better understand human-environment interaction in drylands. As the first UN agency, UNESCO initiated international drylands studies in the 1950s. With the launch of the UNESCO Man and the Biosphere (MAB) Programme in 1971 and the International Hydrological Programme (IHP) in 1975, UNESCO dryland studies have continued to be carried out in the framework of these two intergovernmental programmes until today.

Several MAB international pilot projects implemented since the late 1970s illustrate a "learning" process in the field of drylands research and communication. While earlier projects focused primarily on natural ecosystem dynamics and natural resource use, later projects have taken more fully on board socio-economic and socio-cultural parameters and dimensions to promote sustainable development in drylands. Today, information-sharing among scientists and outreach of scientific results for the benefit of local communities and to decision-makers even across international boundaries is seen as key in putting dryland sciences at the service of sustainable dryland development.

Conclusions

a. A scientifically robust baseline is needed to assess land degradation and to make scientifically informed decisions about drylands development. This requires a major global effort in monitoring and assessment, including close participation of communities living with aridity and land degradation.
b. Land degradation is contextual: different methods lead to different understandings of degradation severity and extent. Only by integrating between methods and scales (including participatory approaches) and focusing on persistent reduction in provision of benefits from ecosystems can we hope to provide realistic assessments of land degradation in the future.
c. Information exchange requires robust platforms for people to interact so that information and needs for information from all levels can be exchanged among communities, service providers, researchers and decision-makers. Decision-making at various needs to be linked directly to scientific information, such that

science directly feeds the development approaches. Many good examples of best practices exist, but they are not available, mutually understandable or shared.

d. Site-specific variations are important and need to be integrated into general principles. Synthesis of indigenous and scientific knowledge is essential. Land, water and income generation are all key considerations.
e. Learning to learn from lessons of the past is still an issue after 50 years, while integration of urban and rural concerns for sustainable development is a recently recognized issue requiring attention.
f. All people living in and managing drylands need to develop capacity to understand environmental issues, and causes and solutions to problems. Critical thinking is the aim of all education and capacity-building. The role of the researcher should be to raise challenges, rather than simply to provide solutions.
g. Evolution of research, education and knowledge-sharing has shifted from a focus on the biophysical to the social and cultural, and now incorporates information exchange. In the future, even more emphasis must be placed on breaking down communication barriers between different land user groups, and between land users and researchers from different disciplines, to better facilitate training, education and outreach.
h. Research must not just document but must contribute to the Future of Drylands.

Session VIII
Education and Knowledge Sharing in Drylands

Chapter 1
Findings of the Global Desertification Assessment by the Millennium Ecosystem Assessment – A Perspective for Better Managing Scientific Knowledge

Zafar Adeel

Abstract A global assessment of desertification undertaken by the Millennium Ecosystem Assessment (MA) shows that desertification in drylands threatens the homes and livelihoods of millions of poor. Environmental impacts of desertification are further exacerbated by political marginalization of the dryland poor and the slow growth of health and education infrastructures. The MA report also highlights the global nature of the environmental and social challenges posed by desertification. The impacts on the global environment – increasing dust storms, floods and global warming – are well known and documented. Less well-known are the strong impacts of desertification on societies and economies, notably those related to human migration and economic refugees. The MA report points to a variety of integrated policy options to reverse the decline of drylands while optimizing economic output, and emphasizes the inclusion of these in the mainstream national strategies for poverty reduction.

The MA report suggests that full understanding of the significance of desertification is constrained by many uncertainties regarding the relationships among desertification, climate change, biodiversity, ecosystem services and human well-being. To counter these uncertainties, we need to significantly improve and document our knowledge of the interactions between socio-economic factors and ecosystem conditions. A framework developed by a group of UN agencies provides the underpinnings for improved management of scientific knowledge and monitoring – leading to improved understanding of the human-ecosystem interactions. The framework is part of a new initiative to evaluate the global environmental benefits of combating land degradation. While building on the conceptual approach espoused by the MA, this initiative aspires to develop a knowledge management network for issues relevant to land degradation, including desertification and deforestation.

Keywords Millennium Ecosystem Assessment, desertification, ecosystem services, knowledge management

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1 Background

1.1 The Millennium Ecosystem Assessment (MA)

The MA was a global effort undertaken during the period between 2002 and 2005; it engaged some 1,360 experts worldwide from 95 countries. The primary purpose was to carry out a systematic and scientific assessment of the global ecosystems, understand the challenges faced, and provide some perspectives on the future response options.

Conceptually, it refined some key terms in the environmental science and policy arena. These innovations included the notion of "assessment", which was taken to imply the assessment of existing science to bring the findings of science to bear on the needs and concerns of decision-makers. Further, this assessment explicitly avoided any policy prescription; rather, the policy-relevant scientific findings were presented as a series of different scenarios. The MA also attempted to better define "ecosystem" as a dynamic complex of human, plant, animal and microorganism communities and their non-living environment interacting as a functional unit. This definition explicitly included people as integral parts of ecosystems and pointed to the dynamic, two-way interactions that exist between people and other parts of ecosystems. While similar definitions have existed before, such as that in UNESCO's Man and Biosphere Programme (UNESCO, 1995), wider scientific acceptance had so far been a bit elusive.

The most significant contribution of the MA was its introduction of a framework that linked human well-being to the provision of ecosystem services in a dynamic way. This framework is schematically presented in Fig. 1.

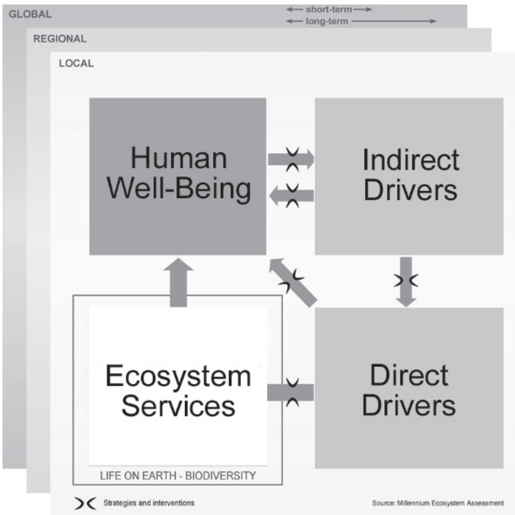

Fig. 1 A simplified schematic layout of the Millennium Ecosystem Assessment framework. It shows that ecosystem services, impacted by direct and indirect drivers, play a key role in determining human well-being. Intervention points are shown as cross marks on connecting arrows (From: MA, 2003).

1.2 The Global Desertification Synthesis Report

Within the MA, a team of experts focused on desertification issues and reviewed four sets of detailed publications: conditions and trends of ecosystems; future scenarios for ecosystems; response options; and analysis of problems at the sub-global level (MA, 2005a, b, c, d). Based on the findings from these four sets of reports, the team developed a "Synthesis Report" that described desertification as a process, the challenges faced in overcoming desertification, and the gaps in our knowledge and understanding (Adeel et al., 2005; this report is simply referred to as the "MA report" in this paper). More specifically, it posed the following six questions and then set out to answer them:

1. How has desertification affected ecosystems and human well-being?
2. What are the main causes of desertification?
3. Who is affected by desertification?
4. How might desertification affect human well-being in the future?
5. What options exist to avoid or reverse the negative impacts of desertification?
6. How can we improve our understanding of desertification and its impacts?

To answer these questions, the writing team relied exclusively on the information and data available in all the MA publications. It also analyzed spatial, socio-economic and biophysical data at the sub-national level, and then aggregated it on the global scale. This allowed, for the first time, many social and economic indicators (e.g., GNP[1] per capita, mortality rates, infant mortality, percentage hungry) to be aggregated in a way that they overlapped with GLASOD[2]-based delineation of dryland categories. This aggregation enabled an improved understanding of how the level of aridity plays a role in determining well-being of people.

The writing team met three times; the meetings took place in Tashkent, Uzbekistan (August 2003), Hamilton, Canada (August 2004), and Scheveningen, the Netherlands (January 2005). The report underwent an extensive peer review process, and received nearly 400 comments from experts, national governments and international agencies. This review process was further bolstered by an internal review undertaken by an independent review panel, followed by a final commentary and approval by the MA Scientific Advisory Board. Such detailed review ensured the scientific validity of arguments presented in the report and their broader acceptance in the science and policy communities.

[1] Gross National Product

[2] Global Assessment of Human-induced Soil Degradation (GLASOD). The GLASOD project (1987–1990) produced a world map of human-induced soil degradation. Data were complied in cooperation with a large number of soil scientists throughout the world. The status of soil degradation was mapped within loosely defined physiographic units (polygons), based on expert judgment. The type, extent, degree, rate and main causes of degradation have been printed on a global map, at a scale of 1:10 million, and documented in a downloadable database.

2 Some Key Findings of the Global Desertification Synthesis Report

The MA report identified desertification as the most threatening ecosystem change impacting on livelihoods of the poor and land productivity (Adeel et al., 2005). It reinforced the definition of desertification in common usage (and endorsed by the United Nations Convention to Combat Desertification) by stating that desertification is a result of a long-term failure to balance demand for and supply of ecosystem services. More importantly, however, it suggested that measurement of a persistent reduction in the capacity of ecosystems to supply services is a robust way to quantify desertification. This is a more profound finding of the MA report, given that there are many estimates of desertification available that rely on a variety of methodologies and have varying degree of reliability. By measuring the provision of ecosystem services and their persistent degradation over time, one may determine the extent and rate of desertification. As the provisioning of many ecosystem services (e.g., crop production, water resources, land cover, biodiversity) is monitored routinely, such an approach provides a robust monitoring mechanism.

It is understood that population growth, inappropriate policies and some aspects of globalization contribute to stresses on drylands that cause desertification. The MA report determined that growing desertification in drylands – which occupy over 41% of the world's land area and are home to over two billion people – threatens the homes and livelihoods of millions of poor. Best available estimates of desertification put the number of people living in presently desertified areas between 100 and 200 million (Adeel et al., 2005); however, a much larger population is at risk. Evaluation of future development scenarios by the MA shows that the global extent of desertified areas is likely to increase. There is medium certainty that population growth and increase in food demand will drive an expansion of cultivated land, often at the expense of woodlands and rangelands.

Some of the starkest findings from the MA report relate to well-being, or rather lack thereof, for the dryland populations. It was clearly demonstrated that the dryland populations on average lag far behind the rest of the world in human well-being and development indicators. One example of such disparity is the infant mortality rate in drylands. Figure 2 shows that the infant mortality rates in developing countries of Asia are highest in drylands when compared to any other ecosystem. This disparity is even more dramatic when comparing the infant mortality rates in drylands globally (average value of ca. 45 deaths per 1,000) with those for developed or OECD countries (ca. 4 deaths per 1,000). Similar disparities are also observed in GNP and other economic indicators. While one can legitimately argue that there are many non-environmental, policy, economic and social factors that determine the value of these indicators, the fact remains that conditions are worst for dryland dwellers regardless of how one views the information.

Human-induced factors, termed direct and indirect drivers in MA jargon, were found to be at the heart of desertification processes. Many human interventions are thought to be the main drivers behind desertification. For example, when improperly managed, conversion of rangelands to cultivated land leads to long-term loss in

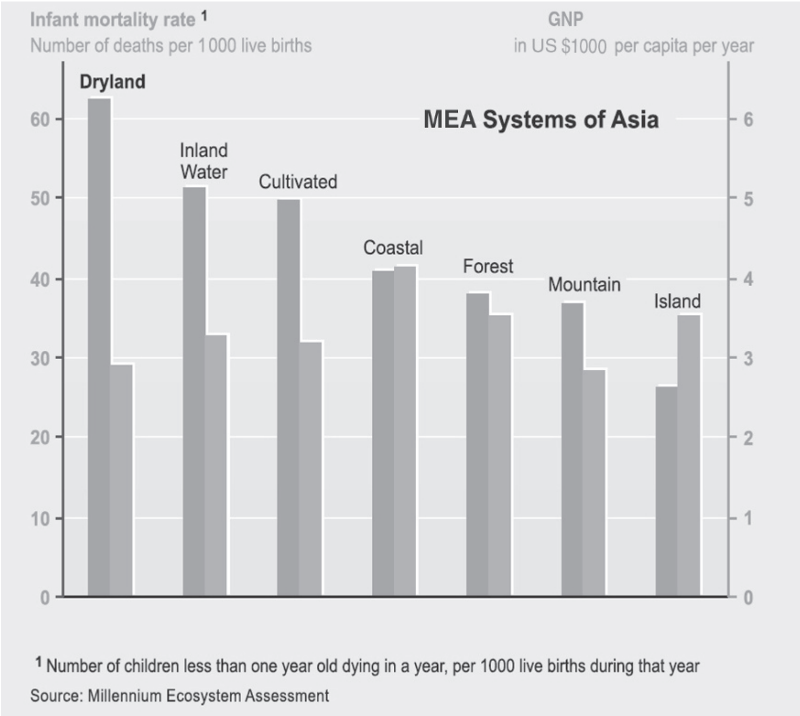

Fig. 2 A comparison for Asia by ecosystem type. The dark gray bars show infant mortality rates while, the light gray bars show GNP (from Adeel et al., 2005)

productivity. The silver lining in this situation is that the desertification process can be reversed by altering the human-induced drivers and the underlying societal behaviours. There are two significant ways to reduce the stress on dryland ecosystems:

- Introduce alternative livelihoods that do not put unsustainable stress on the natural resources of drylands, e.g., utilizing available solar energy and developing sustainable ecotourism using the attractive dryland landscapes.
- Create economic opportunities in urban centres and non-drylands areas.

Another significant contribution by the MA report was the finding that desertification processes in drylands have an adverse impact on non-drylands areas, which in some cases can be quite severe. The scientific community is generally well-aware of the possible global biophysical impact of desertification. These include transcontinental dust storms, downstream flooding, impairment of the global carbon sequestration capacity and regional/global climate change. A broad range of scientific evidence has been compiled on these global processes (see, e.g., the recent assessment reports developed by the Intergovernmental Panel on Climate Change; IPCC, 2001).

However, we know much less about the social impact of desertification at the global level. There is generally an understanding that desertification causes mass movement of people – either within national boundaries or across borders. Significant variability exists in the published literature on the number of these "environmental refugees" and the projections about the number of people who will likely be displaced in the coming decades. Similarly, significant uncertainty also exists in the attribution of a single factor like desertification to the movement of populations. Usually, any number of social and economic factors as well as political marginalization might exacerbate adverse situations created by desertification. Such scientific uncertainties notwithstanding and based on analysis provided by MA "future scenarios", it is clear that this threat of transboundary migration will only grow bigger with time.

3 Knowledge and Information Gaps Identified

The MA report also focused on the knowledge gaps in our understanding of the desertification process. It pointed to the lack of a scientifically robust and consistent baseline of desertification; available estimates on the global extent vary between 10% and 20% of the global land surface area. Each of the available desertification estimates are constrained by conceptual and methodological challenges, which puts their reliability in question. No reliable estimates exist about the rate at which desertification is increasing globally. One may consider that such lack of baseline and rate information would be a serious constraint on priority setting and impact assessment of actions. Indeed, dwindling resources being allocated globally for overcoming desertification signifies the policy relevance of this "ignorance".

The report also suggested ways through which the uncertainty in desertification can be readily reduced. These *inter alia* include the following:

- Developing means to identify and detect thresholds of human intervention and/or ecosystem state beyond which dryland ecosystems would change irreversibly
- Quantifying the effects of poverty-reduction options and actions on service-provision by dryland ecosystems
- Better understanding the linkages between social and economic factors and provision of ecosystem service (which can be taken as a key indicator of desertification rate and extent)
- Qualifying and quantifying the feedback loops between desertification, climate change and biodiversity loss on global and local scales
- Quantifying the impacts of desertification as well as global benefits of combating desertification, through a better synthesis of existing knowledge

These points, particularly the last two, have drawn the attention of the international community. For example, United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations University (UNU) and the International

Center for Agricultural Research in the Dry Areas (ICARDA) have teamed up to better understand sustainable management approaches in marginal drylands (Adeel and King, 2005). In another initiative, the Global Environment Facility (GEF) – which was incidentally a major funding agency for the MA process – has initiated a broad exercise to follow up on these recommendations.

4 Better Knowledge Management Related to Land Degradation

This section provides a brief overview of a global initiative, developed with support from GEF and in partnership with key United Nations agencies; these include the United Nations Development Programme (UNDP), United Nations University (UNU), United Nations Food and Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD), World Bank, African Development Bank, and Asian Development Bank. UNU is executing this initiative on behalf of this working group of agencies, and with funding from the GEF. The project is entitled 'Ensuring Impacts from SLM - Development of a Global Indicator System'.

It is a phased initiative that will:

- Develop a conceptual framework with programme and project-level indicators – to demonstrate global environmental benefits and related local livelihood benefits
- Manage and disseminate knowledge and practices generated through sustainable land management (SLM) projects and programmes through a Learning Network
- Measure results and performance of SLM projects and programmes through a coordinated and/or harmonized inter-agency monitoring and evaluation approach

In the long term, it is anticipated that this initiative will contribute to the enhancement of ecosystem integrity, functions and services by encouraging the diffusion of best practices. Such enhancement is essential to improving the well-being of people affected by desertification and deforestation. To make this work, building of capacity in developing countries will be a major element. Overall, the cross-fertilization of ideas will lead to increased opportunities for innovation in land degradation mitigation activities. (A more detailed description of this initiative is available on-line at: http://www.gefonline.org/projectDetails.cfm?projID = 2863.)

This initiative will actively seek broad linkages at regional, international and thematic levels to help create a 'Learning Network'. Such a network is meant to be inclusive and diverse; possible partners include, but are not limited to:

- Third World Network of Scientific Organizations (TWNSO)
- TerrAfrica
- CGIAR system-wide networks

- World Initiative for Sustainable Pastoralism (WISP)
- Collaborative Forest Partnership of the United Nations Forum on Forests (UNFF)
- EcoAGriculture
- Interagency and Expert Group on Millennium Development Goal (MDG) Indicators
- CBD's work on forests and agrobiodiversity
- UN FCCC's work on the Clean Development Mechanism (CDM)
- GEF project: Land Degradation Assessment in Drylands (LADA)
- Global Land Cover Facility (GLCF)
- DeSurvey (A Surveillance System for Assessing and Monitoring of Desertification)

5 The Future Outlook for Knowledge Management

On the whole, the insights from the MA effort have become instrumental in guiding some new, and perhaps unconventional, ways of viewing the relationship between human society and the ecosystems we depend upon. The argument is that conservation, protection and restoration are in our enlightened self-interest because we depend on these ecosystems for the services they provide us. This notion, while being a considerably different argument than the one typically used by the so-called "tree-hugging" environmentalists (i.e., save the nature for its beauty), provides a rational basis for environmental conservation. It is also an argument that lends itself to easy assimilation into national economic and development policies.

The MA has thus provided the underpinnings for collecting, managing and disseminating knowledge related to ecosystems: that is, ecosystem services could serve as a robust monitoring and measurement tool. The GEF inter-agency initiative is a clear manifestation of this thinking. To make this initiative successful, a broad effort for creating partnerships will be essential. While this initiative provides GEF the tools to better manage its projects in an adaptive and dynamic manner, one can easily argue that the benefits of the MA-based conceptual framework and the international partnership for knowledge management will create benefits far more broadly.

References

Adeel, Z. and King, C. 2005. Development of an assessment methodology for sustainable development of marginal drylands. *Proceedings of the Third Project Workshop for Sustainable Management of Marginal Drylands (SUMAMAD), Djerba, Tunisia, 11–15 December 2004*.

Adeel, Z., Safriel, U., Niemeijer, D., White, R., de Kalbermatten, G., Glantz, M., Salem, B., Scholes, B., Niamir-Fuller, M., Ehui, S. and Yapi-Gnaore, V. 2005. *Ecosystems and Human Well-being: Desertification Synthesis, a Report of the Millennium Ecosystem Assessment*, World Resources Institute, Washington, DC.

IPCC. 2001. *Climate Change 2001: Synthesis Report*. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Watson, R.T. and the Core Writing Team (eds.). Cambridge University Press, Cambridge, UK.

Millennium Ecosystem Assessment (MA). 2003. *Ecosystems and Human Well-Being – A Framework for Assessment*. Island Press, Washington DC.

———. 2005a. *Global Assessment Reports, Volume 1: Current State & Trends Assessment*. Island Press, Washington DC.

———. 2005b. *Global Assessment Reports, Volume 2: Scenarios Assessment*. Island Press, Washington, DC.

———. 2005c. *Global Assessment Reports, Volume 3: Responses Assessment*. Island Press, Washington DC.

———. 2005d. *Ecosystems and Human Well-Being: Multiscale Assessments – Findings of the Sub-global Assessments Working Group*. Island Press, Washington DC.

UNESCO. 1995. *The Seville Strategy for Biosphere Reserves – The First Twenty Year*s. United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris.

Chapter 2
The Unmet Challenge of Connecting Scientific Research with Community Action

Mary Seely[1], Patrik Klintenberg[1,2] and Albertus S. Kruger[1]

Abstract During the past century, desertification was identified as negatively influencing productivity of drylands, although the process had been underway for millennia. The challenge presented was recognized at the UN Conference on Environment and Development and resulted in the UN Convention to Combat Desertification. Meanwhile, spurred, *inter alia*, by the UN Conference on Desertification in the 1970s, the scientific community has conducted research related to or directly addressing desertification control and rehabilitation for decades. Despite these efforts, little has improved among an increasing population faced with decreasing productivity of degraded lands. The results of scientific research are generally not accessible to or being used by those addressing desertification, e.g. communities, extension officers, policy-makers and others not usually informed by results of scientific research. A multi-pronged approach is required. Researchers must translate and indicate ways of applying their results. Communities and their support organizations need to establish platforms for accessing, interpreting and facilitating application of useful research results. Moreover, both groups have a responsibility to establish mechanisms to engage with policy-makers concerning their results, needs and actions to address desertification control. The challenges of making these essential connections, with examples from Namibia, are explored in this presentation.

Keywords Community action, Forum for Integrated Resource Management (FIRM), Local level monitoring (LLM), scientific research, Namibia

1 Introduction

The issues of desertification in drylands have been widely discussed by scientists since at least 1977, when the UN Conference on Desertification was convened to review the status of knowledge about desertification (UNCED, 1977). This conference attempted

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to, *inter alia*, define, describe and identify causes and effects of desertification. Since that time, scientists have increased their focus on desertification, including rehabilitation of degraded lands (Hellden, 1991; Koning and Smaling, 2005; Leach and Mearns, 1996; Mainguet, 1994; Rapp, 1974; Rapp et al., 1976; UNCED, 1977). While scientists have continued their endeavours, the UN Convention to Combat Desertification (UNCCD) was negotiated and ratified with scientists making only a modest contribution to the process. Scientific input into the Convention was limited, partly due to the approaches scientists used to communicate information (Corell, 1999). Application of the scientific method requires a long process of information verification, and scientists tend to write for their peers rather than for application of results. Such approaches are, understandably, guided by the reward system inherent in academic and scientific spheres (Seely and Wöhl, 2004).

Under the UNCCD umbrella, several conferences have pointed out that making a change on the ground where desertification is taking place requires that results of scientific research be made accessible and understandable to those dependent on or working with natural resources and to those who make policies affecting their use (Mouat and Lancaster, 2002; Mouat and McGinty, 1997). This requires time and skills not usually used by scientists and not rewarded by the existing system (Seely and Moser, 2004). Huppert (1999) points out that communication is limited even among international agricultural research and technical (development) cooperation experts nominally working toward the same objectives on a similar level.

This paper will illustrate the Namibian experience of information exchange among scientists, service providers, policy-makers and people faced with desertification in their daily lives to support practical application of jointly established results.

2 Attempts to Connect Scientific Research with Community Action in Namibia

Namibia is the driest country south of the Sahel with spatially and temporally variable rainfall. For ten years, Namibia's National Action Programme, known as the Programme to Combat Desertification (NAPCOD), tested and implemented a variety of approaches to address desertification (Kambatuku, 2003a, b; NAPCOD, 1997, 1999). The resulting experience was integrated into several complementary projects and programmes of the Namibian Government including the Farming Systems Research and Extension programme, formation of basin management committees (Botes et al., 2003; Manning and Seely, 2005; Seely et al., 2003) and the Desert Margins Programme (Koala and Tabo, 2004). Research results were integrated into capacity-building, organizational development and local level monitoring, which contributed to decision-making on all levels. The key was connecting research results with community action to address the effects of variable rainfall and sub-optimal management in communal farming areas.

One strong experience from NAPCOD is known as the Forum for Integrated Resource Management (FIRM), an approach designed to put rural communities in the driver's seat in terms of their own development (Kambatuku, 2003a; Kruger et al., 2003). FIRM is centred on a community-based organization (CBO) of rural farmers, which takes the lead in organizing, planning and monitoring development while coordinating the interventions of their specific array of service providers. These service providers may be traditional authorities, government extension services, non-governmental organizations (NGOs) or short- or long-term projects (Kambatuku, 2003a). In Namibia, the FIRM approach has been adopted by agricultural extension services in their Farming Systems Research and Extension programme and continues to be expanded and applied more broadly. Moreover, FIRMs give pastoralists the required representation in defining the research agenda with their needs, priorities and knowledge (e.g. Vetter, 2003 and 2005). The flexibility and applicability of the FIRM approach, with the FIRM itself serving as a platform and facilitating communication and information flow among individual farmers, service providers, researchers and high-level decision-makers, is spreading in southern Africa with support from several diverse regional programmes (e.g. IVP, 2005; Koala and Tabo, 2004).

Local level monitoring (LLM) is a tool, supporting FIRMs, that is designed with farmers to provide them with information for decision-making. The methods, with a research base, are specifically designed for communal farmers and their unique requirements. The tools help farmers to assess rainfall, livestock condition, grass biomass (including recommended stocking rates) and veld condition (especially woody bush encroachment). The system provides detailed, relatively immediate and useful information needed for sustainable management of rangelands (Kambatuku, 2003b).

Recording of observations by farmers is a key part of the system. Most farmers, as part of their normal procedures, make decisions based on one or several social or environmental indicators. However, observations are usually kept in the head of the individual farmer. Such information is soon lost as memories fade and are mixed up between years. By making a permanent record of his/her observations, the farmer obtains a better understanding of how variable environmental conditions, e.g. amount, location and seasonality of rainfall, influence agricultural production. Secondly, by recording each observation in an established format, a historical record is created, allowing comparisons over years and with fellow farmers (Kambatuku, 2003b; Klintenberg et al., 2006).

Discussion of results among farmers in a community is a key feature of the LLM system, providing an information base for joint planning and decision-making by FIRM groups (Kruger et al., 2006). Having a permanent record also helps farmers to communicate with service providers, other natural resource managers and policy-makers.

One example of the application of the FIRM and LLM approach took place under the Oshikoto Livestock Development Project (EU funding). Communal farmers in central northern Namibia are prohibited from exporting livestock because of the area's endemic disease status (Mendelsohn et al., 2000). Although farmers in the area have a business orientation, livestock on the hoof represents wealth to an individual.

Farmers would prefer not to sell livestock in their prime for meat production but only when they are old, or under drought conditions, thus restricting themselves to the informal market. Off-take figures in the northern communal areas are 1.7% on average over the last five years compared to 18.8% for the country as a whole (Meatco, The Meat Corporation of Namibia 2005, personal communication). The buyers in the formal market who slaughter and process the meat offer their best prices for prime animals. Quarantine is also essential for buyers to offer good prices. Based on a long history of interactions between buyers and sellers, farmers' perceptions are fixed. These include: 'it is decreasing rainfall rather than increasing livestock pressure that degrades traditional grazing areas', 'animals lose weight during quarantine', 'distances to quarantine facilities make transport too expensive', 'poor prices are offered for good livestock' and 'payment is often deferred and less than promised'. Working through the Onyuulaye FIRM, known as the Onyuulaye Cooperative, and using LLM tools to monitor livestock condition, the first fully successful action in central northern Namibia took place in March 2005 (Botelle, 2005; OLDeP, 2005). All 246 head of livestock that could be accommodated in the Onyuulaye quarantine facilities at the auction site were sold at prices considered satisfactory by owners and buyers. Of the livestock in quarantine, 65% gained weight, contrary to all expectation of their owners, while 25% lost weight and 10% remained the same.

The research base for the Onyuulaye auction came from economists, veterinary and rangeland scientists, although little was new specifically for the auction. The key to successful application of the existing information was facilitating connections between researchers, local farmers and other stakeholders. The FIRM members renovated the quarantine feed lot and auction facilities and supervised livestock during the quarantine period. They also facilitated use of LLM by the livestock owners and helped them weigh their animals as they entered quarantine and when they were auctioned. The project communicated with the 28 buyers, the several veterinarians and the livestock owners and made sure the Minister of Agriculture and other political figures were present. It also facilitated training on livestock quality assessment, marketing and income optimization by mentor-farmers for 150 livestock owners prior to the auction using the animals on auction for demonstration (OLDeP, 2005) (Fig. 1). Without the platform provided by the Onyuulaye FIRM or the tools provided by LLM, this small step towards better management of the grazing, the livestock sales could not have taken place.

Extensive communication between researchers and other stakeholders was the basis for success of this application of taking quarantine and auctions to the people. Another innovation included commissions paid by the owners. These included: 1% to the Onyuulaye Community Trust, 0.5% to the Traditional Authority, 2% to the Onyuulaye Cooperative and 3.5% to the Auctioneer (Agra) accepted by the farmers as an appropriate deduction from their sale price. One of several research challenges remaining is to investigate the advantages and disadvantages, from an economic, social and environmental point of view, of the smaller-framed Sanga cattle, better adapted to droughts, heavier stocking rates and sub-optimal management in the area, and of larger-framed livestock preferred by marketers and buyers (OLDeP, 2005).

Fig. 1 FIRM members organizing and looking after livestock at the Onyuulaye auction, central northern Namibia

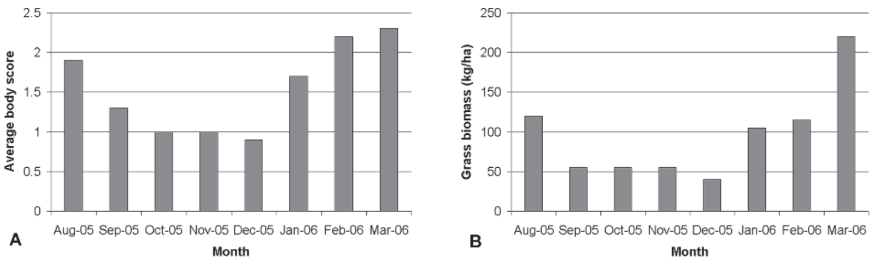

Fig. 2 Diagram A: average body condition of 25 head of cattle per month measured on a scale of 1 (poor) to 5 (good). The LLM guide, developed with farmers based on research experience of rangeland scientists, and record books were used. Diagram B: Grass biomass (kg/ha) at Okondjatu estimated using the LLM guide. The available fodder at the end of March 2006, 214 kg/ha, indicated a stocking rate of 18 ha/LSU

A second example of connecting scientific research with community action comes from Okondjatu in eastern Namibia. There the Desert Margins Programme (GEF funding) also works with the FIRM and LLM approaches. Farmers measured rainfall this season (2005–06) as 623 mm, while long-term average in the area is 400–450 mm (Mendelsohn et al., 2002). Despite above average rains, "drought" was identified by local farmers. At a FIRM meeting using their own recorded rainfall data and grass biomass data extending back to August 2005 collected using LLM tools (Fig. 2), farmers recognized that their grazing areas were overstocked by 100%. In discussion they also concluded that the numerous small-fenced grazing areas were not allowing them to take best advantage of available grazing (DMP, 2006).

Recommendations for removal of restrictive fences and reduction of livestock numbers on these grazing areas were the result of communication based on the FIRM platform supported by the research-backed data generated by farmers using LLM tools (Fig. 3).

A third example of connecting science with community action is the use of basin management committees. Basin management is a key element of Namibia's Water Resources Management Act, No. 24, 2004. It supports the principles of integrated water resource management including sustainable use of Namibia's limited water resources. The process is iterative, transparent to all, open to voluntary participation, information rich, enhances capacity of stakeholders and focuses on sustainable development while passing through three stages: start-up phase (emphazising information exchange among interested parties); stakeholders' forum phase (where representatives and interested individuals from all levels are encouraged to participate); basin management committee phase (leading to establishment of a formal basin management committee) (DRFN, 2005; Seely et al., 2006).

Fig. 3 Small stock grazing close by Olukonda settlement, central northern Namibia

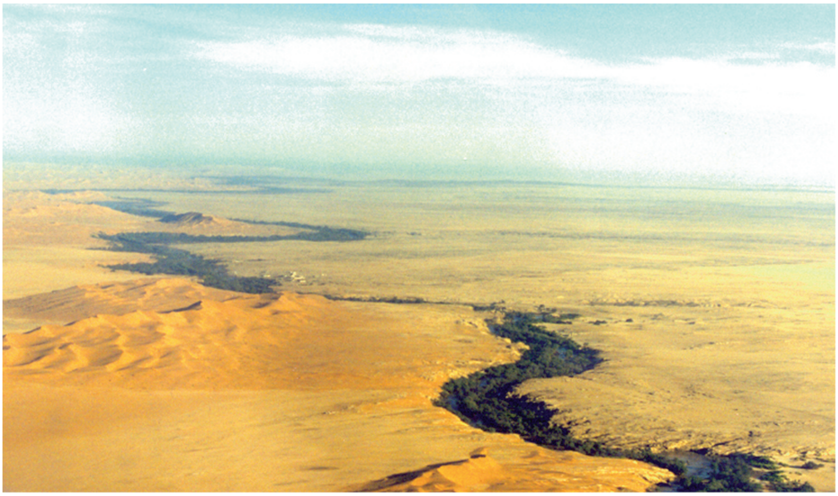

Fig. 4 Kuiseb River in the Namib Desert, where the basin management approach was first established in Namibia, with the Gobabeb Training and Research Centre on the right bank towards the middle of the picture.

The process of basin committee formation took place over three years in the Kuiseb River Basin (Fig. 4) with the number of participants in the forum increasing with every meeting. Also increasing were the questions and requests for information based on the presence of a "platform" for information exchange among scientists, service providers and resource uses coupled with experts from various disciplines who were willing and able to provide the information (Manning and Seely, 2005). This opportunity also opened up communication among water managers who had not cooperated previously in such a forum. Although formal project funding has ended, the Kuiseb Basin management committee continues quarterly meetings and enjoys its acknowledged role as a communication platform for scientists, service providers and farmers using and managing natural resources in the basin.

As illustrated in the three examples above, combating desertification and good management of natural resources depends on action from farmer to national level. For actions at the farmers' level to be successful, local communities require support from service providers ranging from government extension to NGOs and the private sector. To be effective, service providers require information from many sources, including relevant research results. Researchers, service providers and communities need to convey their messages to policy- and decision-makers if change is to be expected. Often there is no mutual ground for any of these groups to interact. To communicate between levels, at least two factors must be considered. First is "translating" or "interpreting" information and requests for information in straight-forward language understood by other levels or sectors. Second is a requirement for "communication platforms", be they a local level committee or a research institution (Fig. 5).

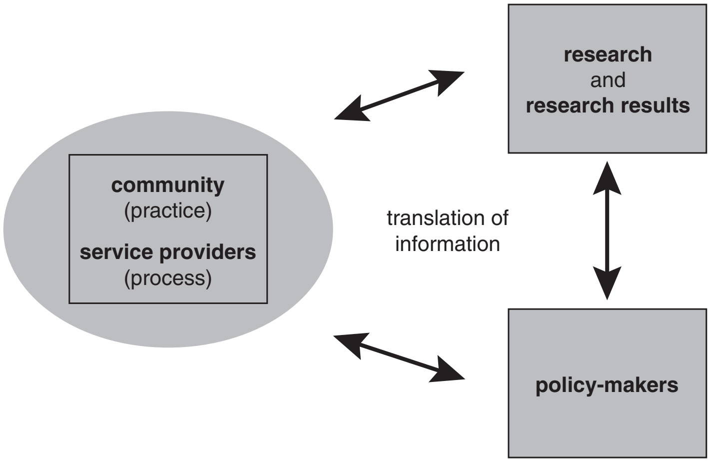

Fig. 5 A conceptual model showing the three levels – scientific community, local communities and policy-makers – and required interactions between these for successful communication. Platforms of differing configurations are required to support intra- and inter-level communications.

3 Discussion

Experiences gathered while addressing the threat of desertification and supporting good natural resource management have revealed many challenges. These include the time and money necessary to ensure good communication among all the stakeholders involved (Seely and Moser, 2004). They also include the academic reward system, which focuses on peer-reviewed publications for scientists and does not encourage interpretation or translation for uses of research insights and results (Huppert, 1999; Seely and Wöhl, 2004). Fixed perceptions of "other" stakeholders, e.g. 'they are not educated, they wouldn't understand', 'they only talk to each other and ignore our experience' and 'we need to get on with our real work, not listen to unproved theories' are major hindrances to communication and information exchange.

At the same time, experiences gathered while addressing the threat of desertification and supporting good natural resource management suggest several approaches to connecting scientific research to community action. Primary is the establishment of platforms for communication and fostering of information exchange among different levels (e.g. Enne, 2006). In some traditional societies, functioning organizational structures facilitate information circulation. Drylands, where the challenge of desertification is most prevalent, are often areas affected by drought, causing, *inter alia*, civil unrest. Even where this is not a threat, appropriate communication networks addressing key challenges are not necessarily functional, as in rural, newly independent Namibia. Organizational development is required to support information sharing under these diverse conditions.

A platform to support information exchange and connect scientific research to community action must facilitate dissemination, receipt, synthesis or interpretation of information, and then further communicate the relevant information. In Namibia, two main structures are operational at the local level. One, known as a Forum for Integrated Resource Management (FIRM), consists of a grassroots-level farmers', cooperatives or water point associations usually connected to a higher level within the same sector (Kambatuku, 2003a). A second approach, a Conservancy Committee, focuses on wildlife and tourism in a particular area in a similar way (NACSO, 2004). These forums or committees serve as platforms at the grassroots level as well as between the grass roots and service providers. They help to reach policy- and decision-makers as required and to connect scientific research and integrate it into community action.

References

Botelle, A. 2005. *Cattle Meat Market*. Ministry of Agriculture, Water and Forestry, Namibia. Video, 38 min.

Botes, A., Henderson, J., Nakale, T., Nantanga, K., Schachtschneider, K. and Seely, M. K. 2003. Ephemeral rivers and their development: Testing an approach to basin management committees on the Kuiseb River, Namibia. *Physics and Chemistry of the Earth*, Vol. 28, pp. 853–858.

Corell, E. 1999. *The Negotiable Desert: Expert Knowledge in the Negotiations of the Convention to Combat Desertification*. Linköping University, Linköping.

DMP. 2006. *Report on a Participatory Rangeland Management Meeting Held on 23 March 2006 in Okondjatu Area*. Desert Margins Programme (DMP), Windhoek.

DRFN. 2005. *Basin Management Approach: A Guidebook*. Desert Research Foundation Namibia, Windhoek.

Enne, G. 2006. *AID CCD Seminar: Role of Information Circulation Systems (ICS) in Scientific and Practical Approaches to Combat Desertification*. AID CCD (Active exchange of experience on indicators and development of perspectives in the context of the UNCCD), Ondangwa.

Hellden, U. 1991. Desertification: Time for an assessment? *Ambio*, Vol. 20, pp. 372–383.

Huppert, W. 1999. Toward service chain integration: A discussion paper on synergies from integrating international agricultural research and technical cooperation activities. Unpublished.

IVP. 2005. Report on educational trip by IVP stakeholders to rangeland management initiatives in Namibia. Indigenous Vegetation Project, Botswana, 36 pp. Unpublished.

Kambatuku, J. R. (ed.). 2003a. *FIRM, the Forum for Integrated Resource Management: Putting Communities at the Centre of Their Own Development Process*. National Programme to Combat Desertification (NAPCOD), Windhoek.

———. 2003b. *Local Level Monitoring for Enhanced Decision Making*. National Programme to Combat Desertification (NAPCOD), Windhoek.

Klintenberg, P., Kruger, A. S. and Seely, M. K. 2006. Local level monitoring for improving farming management. SADC (South African Development Community) Symposium on Land and Water Management for Sustainable Agriculture, Lilongwe, Malawi, 14–16 February 2006.

Koala, S. and Tabo, R. 2004. *Turning Adversity into Opportunity: The Desert Margins Program – Towards Sustainable Management of the Desert Margins of Sub-Saharan Africa*. Project Document 2002–2008. International Crops Research Institute for the Semi-Arid Tropics. Global Environment Facility (In English and French.)

Koning, N. and Smaling, E. 2005. Environmental crisis or 'lie of the land'? The debate on soil degradation in Africa. *Land Use Policy*, Vol. 22, No. 1, pp. 3–11.

Kruger, A. S., Gaseb, N., Klintenberg, P., Seely, M. K. and Werner, W. 2003. Towards community-driven natural resource management in Namibia: The FIRM example. *VIIth International Rangelands Congress, Durban, South Africa*. N. Allsopp, A. R. Palmer, S. J. Milton, K. P. Kirkman, G. I. H. Kerley, C. R. Hurt and C. J. Brown (eds.), pp. 1757–1759.

Kruger, A. S., Klintenberg, P., Stenkamp, J. G. S. and Seely, M. K. 2006. Forum for Integrated Resource Management in Namibia. *SADC (South African Development Community) Symposium on Land and Water Management for Sustainable Agriculture, Lilongwe, Malawi, 14–16 February 2006*.

Leach, M. and Mearns, R. 1996. *The Lie of the Land: Challenging Received Wisdom on the African Environment*. The International African Institute, London.

Mainguet, M. 1994. *Desertification: Natural Background and Human Mismanagement*. Springer, New York.

Manning, N. and Seely, M. K. 2005. Forum for Integrated Resource Management (FIRM) in Ephemeral Basins: Putting communities at the centre of the basin management process. *Physics and Chemistry of the Earth*, Vol. 30, pp. 886–893.

Mendelsohn, J., El Obeid, S. and Roberts, C. 2000. *A Profile of North-central Namibia*. Environmental Profiles Project. Macmillan, Windhoek.

Mendelsohn, J., Jarvis, A., Roberts, C. and Robertson, T. 2002. *Atlas of Namibia: A Portrait of the Land and Its People*. David Philip Publishers, Cape Town.

Mouat, D. and Lancaster, J. 2002. *Desertification 2002: Alternative Ways to Combat Desertification: Connecting Community Action with Science and Common Sense*, Environmental Monitoring and Assessment, Kluwer, Cape Town.

Mouat, D. and McGinty, H. K. 1998. Combating desertification: Connecting science with community action. *Journal of Arid Environments*, Vol. 39, pp. 97–340.

NACSO. 2004. *Namibia's Communal Conservancies: A Review of Progress and Challenges*. Namibian CBO Support Organisation, Windhoek.

NAPCOD. 1997. *Namibia's National Programme to Combat Desertification: Fighting Desertification Together*. Desert Research Foundation of Namibia, National Programme to Combat Desertification, Windhoek. Unpublished.

———. 1999. First national report on the implementation of the United Nations convention to combat desertification, National Programme to Combat Desertification, Ministry of Environment and Tourism, Windhoek, Namibia, 23 pp.

OLDeP. 2005. *Onyuulaye Action Report*. Oshikoto Livestock Development Project, Windhoek.

Rapp, A. 1974. *A Review of Desertification in Africa: Water, Vegetation and Man*. (Secretariat for International Ecology, Sweden) SIES Report No. 1, Stockholm.

Rapp, A., Le Houerou, H. N. and Lundholm, B. (eds.). 1976. *Can Desert Encroachment Be Stopped? A Study with Emphasis on Africa*. Swedish Natural Science Research Council, Stockholm.

Seely, M. K., Henderson, J., Heyns, P., Jacobson, P., Nakale, T., Nantanga, K. and Schachtschneider, K. 2003. Ephemeral and endoreic river systems: Relevance and management challenges. *Transboundary Rivers, Sovereignty and Development: Hydropolitical Drivers in the Okavango River Basin*, A. Turton, P. Ashton and E. Cloete (eds.). African Water Issues Research Unit (AWIRU) and Green Cross International (GCI), pp. 187–212.

Seely, M. K., Matros, A., Mazambani, C. and Klintenberg, P. 2006. Basin management committees as a platform for enhanced natural resource management. *SADC (South African Development Community) Symposium on Land and Water Management for Sustainable Agriculture, Lilongwe, Malawi, 14–16 February 2006*.

Seely, M. K. and Moser, P. 2004. Connecting community action and science to combat desertification: Evaluation of a process. *Environmental Monitoring and Assessment*, Vol. 99, pp. 33–55.

Seely, M. K. and Wöhl, H. 2004. Connecting research to combat desertification. *Environmental Monitoring and Assessment*, Vol. 99, pp. 23–32.

UNCED (ed.) 1977. *Desertification: Its causes and consequences*. Pergamon, Oxford, 448 pp.
Vetter, S. 2003. Equilibrium and non-equilibrium in rangelands: A review of the debate. *Proceedings of the VIIth International Rangelands Congress 26th July - 1st August, Durban, South Africa*. Professional Workshop 01: Rangelands in Equilibrium and Disequilibrium, pp. 2–15.
Vetter, S. 2005. Rangelands at equilibrium and non-equilibrium: recent developments in the debate, *Journal of Arid Environments,* Vol. 62, No. 2. pp. 321–341.

Chapter 3
Development and Management of Drylands: The Need for Adapted Education and Knowledge-Sharing

Bart Schultz[1] **and Krishna Prasad**[2]

Abstract Growing population, unsustainable human activities leading to degradation and climate change pose increasing threats to maintaining the integrity and productivity levels of drylands, which make up a substantial part of the world's land surface and house about a billion, mostly poor, people. Besides representing vulnerable ecosystems, drylands are natural resource systems that require a comprehensive understanding of the systems' interdependent biophysical and socio-economic characteristics. Exemplary societies and dryland management practices have evolved in dryland regions, and locals often have shown remarkable resilience and innovative management strategies to successfully cope with natural calamities and sustain ecosystem services.

A combination of understanding both the historical approaches and the proper application of present-day technology can enable expression of sustainable approaches for the development and management of drylands. By combining the knowledge and expertise of local people with the new generation of information and communication technology (ICT) tools, knowledge can be made more accessible. Such efforts of coupling idiographic expertise and nomothetic knowledge and tools essentially reflect the approach of adaptive and collaborative management, which can be instrumental in responding to the ever-increasing stress on drylands and the fight against poverty.

Education allows learners to acquire the skills, capacities, values and knowledge required to ensure sustainable development. Education at different levels and in different social contexts is crucial for safeguarding the fragile environments. The importance of the cultural and social context for learning and knowledge management, and attempts to expand these through participatory processes to achieve the societal goals, is acknowledged. Options for improved education and knowledge transfer are explored.

Keywords Drylands, education, capacity building, water management, natural resource systems

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1 Drylands

Drylands are generally characterized by low rainfall and high rates of evaporation.[1] A recently published report by the United Nations Environmental Programme (UNEP) released on the World Environment Day, 5 June 2006, reports that drylands occupy 41% of earth's land area, 43% of world's cultivated lands.[2] One estimate says that more than a billion people, half of them below poverty line, live in drylands and depend on environmental services for their basic needs and livelihoods. The majority of people living in drylands are from developing countries, which already lag behind on human development indices.

2 Vulnerability and Threats

Drylands represent sensitive natural resource systems or ecosystems that are highly vulnerable to degradation of land, water and other environmental resources due to their relatively fragile bio-physical characteristics and lower productivity levels. In rainfed areas of drylands, low rainfall combined with climate variability is a major constraint to increasing agricultural productions. For instance, in rainfed farming systems in semi-arid sub-Saharan Africa, dry spells exceeding 15 days invariably reduce crop growth almost annually (SIWI et al., 2005). Even the cultivated portion of drylands largely depends on water from sources typically located outside the drylands.

Semi-arid climates pose particular challenges to meet water requirements for unimpeded grain production. The current agricultural yields in semi-arid and less developed regions are quite low, as is the income. Greatest vulnerability is recognized in sub-Saharan and Central Asian drylands. The droughts in these areas repeatedly expose a vast number of people to severe water scarcity, leading to major food and health crises.

The situation is worsened by lower productivity levels of the limited resources, and hence lower returns, offering fewer incentives for conservation measures, in fact, they often compel the resource poor to overexploit the available resources to meet their needs (McCornick et al., 2003).

Besides, drylands face additional pressures resulting from population growth, increasing economic activities and climate change. Climate variability and climate

[1] The United Nations Convention to Combat Desertification (UNCCD) uses aridity zones to define drylands. It includes three aridity zones – arid, semi-arid, and dry sub-humid – in its definition of drylands. The ratio of mean annual precipitation to mean annual potential evapotranspiration, called aridity index, on such lands ranges in between 0.05 and 0.65 (excluding polar and sub-polar regions). Ratios of less than 0.05 indicate hyper-arid zones, or true deserts, which have very low biological productivity. Ratios of 0.65 or greater identify humid zones.

[2] http://www.unep.org/wed/2006/english/Information_Material/index.asp

change are expected to exacerbate the frequency and severity of droughts and floods (SIWI et al., 2005). Recent trends indicate that there has been a continued degradation of drylands (MEA, 2005; SIWI et al., 2005). In addition, natural recovery rates are typically much slower in drylands compared to those in humid areas. The phenomenon of land degradation, often characterized as "desertification" – resulting from climatic factors and unsustainable human activities – have multiple socioeconomic and environmental consequences:

- Increased competition for available water
- Diminished food production
- Reduced water quality
- Decrease in land's natural resilience
- Decreased plant and animal biodiversity
- Reduced and unreliable productivity levels of dryland resources
- Sedimentation in rivers and lakes
- Siltation of reservoirs and navigation channels
- Loss of livelihoods forcing affected people to migrate
- Deepening poverty, conflicts and social instability
- Added pressure on yet-to-degrade fringes
- Aggravated health problems due to wind-blown dust, including eye infections, respiratory illnesses, allergies and mental stress
- Downstream flooding, etc.

3 Link to Education and Knowledge-Sharing

3.1 Complexity, Diversity and Dynamism

The pressing need to address the challenges to maintain the integrity and productivity levels of drylands, and possibly also to reverse the process of desertification of drylands, begins with the adequate comprehension of interdependent biophysical and socio-economic characteristics of the dryland natural resource systems. Moreover, these characteristics are rarely steady over time and scale. Synergies among them are inherently dynamic and tend to be only temporal and context specific (Put and van Dijk, 2000; McDougall and Braun, 2003). Natural resources management in drylands faces multiple challenges if it is to contribute to environmental sustainability, improved livelihoods and equitable social development. Achieving these objectives largely depends upon three main factors that determine the resilience of human and natural systems: complexity, diversity and dynamism as depicted in Fig. 1 (McDougall and Braun, 2003).

Population, climate, soil fertility, extent of the resource base, etc., as well as the nature and quantity of services and benefits that dryland peoples expect from the use of available natural resources, are all subject to change. In addition, the methods and practices of resource use are also subject to evolution. Moreover, the macro-level

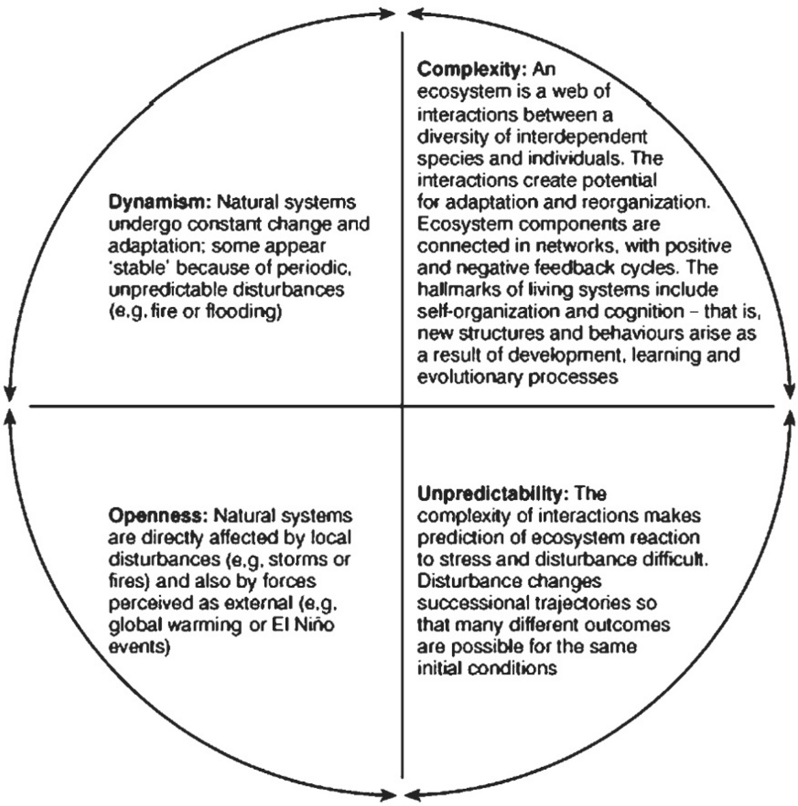

Fig. 1 Characteristics of natural resource systems (from McDougall and Braun, 2003)

policies, globalizing forces and enabling environment, which significantly influences the prevalent natural resource use and management practices (MEA, 2005), are hardly static. Being relatively more sensitive and fragile resource systems, drylands require a particularly encompassing understanding of such a dynamic interconnectedness between biophysical and socio-economic attributes of the drylands, which also varies from case to case and from one dryland to another. In other words, such understanding encompasses a diverse set of interrelated constituents of natural resource management and the need to recognize site-specific variations.

3.2 Idiographic and Nomothetic Knowledge

Drylands generally have a diverse range of local stakeholders, including local communities, who possess a wealth of local site-specific knowledge and time-tested understanding about the complexity, diversity and dynamism of dryland resource systems. In many instances, indigenous initiatives and knowledge have proved to be highly effective in checking or even reversing the unsustainable use of natural resources in drylands (Put and van Dijk, 2000). Exemplary societies and land management practices have evolved in dryland regions, and locals have often shown remarkable resilience and innovative management strategies to successfully cope with natural calamities and sustain ecosystem services. Similarly, many farmers in sub-Saharan Africa have increased yields and reduced animal traction needs by adopting different types of conservation tillage practices, such as ripping and sub-soiling. These examples indicate the need to build on experiences from local initiatives, which make up a bulk of idiographic knowledge, in order to make the traditional education and knowledge-sharing methods more effective.

Such idiographic knowledge, which people in a given dryland have acquired over time and continue to develop, is invariably experience-based (often tested over centuries of use and adapted to local culture and environment) and dynamic. Such knowledge and skills, also interpreted as traditional or local knowledge, refer to the large body of knowledge and skills that has developed outside the formal education system. Efforts at synergizing the idiographic knowledge with scientific and general nomothetic knowledge acquired through formal education systems have proved to be highly beneficial in numerous successful examples of collaborative and adaptive management of complex natural resource systems around the world (Freeman, 1989; Brunner et al., 2002).

3.3 Capacity-building

Capacity-building covers a diverse set of activities: awareness raising, information and knowledge-sharing, skill enhancement through education and training, facilitation, support, etc. By means of these activities, various stakeholders – individuals, groups and organizations – improve their capacities to achieve sustainable natural resource management suitable to local, site-specific conditions and cultural contexts. (http://www.nrm.gov.au/publications/capacity-building/). Capacity-building includes: awareness, skills, knowledge, motivation, commitment and confidence. Participants in various capacity-building activities include:

- Landholders, their representatives and other resource users
- Indigenous communities
- Regional and local community-based groups and organizations
- Scientific and research personnel and organizations
- Local government and representative bodies
- Resource developers, managers, service providers, including facilitators and coordinators
- Technical and financial advisors and consultants

With the view to realizing sustainable development of dryland resources management, capacity-building of various stakeholders – to assist them in better managing the fragile and vulnerable dryland resources – has been integral part of most uni- or multi-lateral initiatives planned or underway worldwide (DAC, 2006). It has also been demonstrated that creation of such human and social capital through various capacity-building activities is a prerequisite for obtaining desirable and long-lasting results on the ground. Undoubtedly, formal education and knowledge-sharing by other means play a significant role in creating much needed human (individuals) and social (networks) capital in drylands for their sustainable development and management.

However, education and knowledge sharing, as part of capacity-building, in natural resource management goes beyond the traditional, top-down approach of enhancing skills and knowledge through training and provision of technical advice. There is wider recognition that it also involves enhancing genuine community engagement and participation of various stakeholders in all aspects of collaborative and adaptive management of common pool resource systems, including in the capacity-building process itself (participatory learning) (Brunner et al., 2002). Similarly, until recently, capacity-building of stakeholders through education and knowledge-sharing activities was viewed mainly as a technical process, involving the simple transfer of knowledge or organizational models from North to South. Evidence suggests that not enough thought was given to the broader political and social context within which capacity development efforts took place, nor to the interconnectivity of related constituent subjects, with little or no appreciation of the idiographic knowledge (DAC, 2006). With respect to improved dryland management needs, various efforts of capacity-building have ineptly appreciated the local and site-specific knowledge and expertise of the local stakeholders. The process of education and knowledge-sharing has remained generally overshadowed by nomothetic knowledge and expertise.

This pre-structured and exogenously led educational and knowledge-sharing approach has led to an overemphasis on what were seen as externally determined “right answers”, as opposed to approaches that best fit the site-specific biophysical and socio-economic conditions and interconnectedness between them. This gap is also reflected in insufficient ownership and institutionalization of various capacity development initiatives that were led exogenously (ibid.). Realizing this, a new consensus, articulated strongly in the 2005 *Paris Declaration on Aid Effectiveness* (http://www.oecd.org/document/18/0,2340,en_2649_3236398_35401554_1_1_1_1,00.html), saw capacity development as a necessarily endogenous process, strongly led from within the concerned locale, with donors and service providers playing a supporting role.

The job of capacity-building through education and knowledge-sharing is increasingly being recognized to be so all-encompassing and challenging that several related agencies, including UNESCO-IHE, have begun revisiting the traditional approaches and exploring innovative options to improve programme effectiveness.

4 UNESCO-IHE (Institute for Water Education and Experience)

Along the same line, but mostly focused on water resources, UNESCO-IHE (Institute for Water Education) has sought to contribute to the process of capacity development in the water sector by providing the best academic education and training on water-related topics to a diverse group of participants, mostly from developing/transition countries. In addition, it has undertaken various relevant research works for addressing pressing challenges, scientific advancement and methodological innovations in this sector and is a complementing part of the institute's activities. In the past decades, several capacity development initiatives were undertaken with the financial and collaborative support of various donors and partners (Annex 1). Specifically, the Institute has the following core activities (Annex 2):

1. **Postgraduate programmes:** Masters- and PhD-level courses on water, the environment and physical infrastructure. All courses are aimed at educating participants to develop a problem-solving attitude, taking into account the multi-disciplinary setting of problems and aiming at achieving sustainable solutions.
2. **Tailor-made training courses:** Development and implementation of training courses on demand. Short courses are used for upgrading of knowledge and skills of more senior experts, refreshment of the knowledge basis or exposure to applications of conventional, modern and new technologies. Knowledge is transferred through lectures, workshops, role-playing, video, study tours to European projects, lecture notes and other printed materials.
3. **Institutional capacity-building:** It offers a wide range of expertise to facilitate institutional or organizational reform programmes. Experts contribute to, for example, training needs assessments, human resources development, strategy development, training courses, decentralization strategies and other relevant activities. The Institute can also provide support to strengthen in-house training centres of sectoral ministries or authorities.
4. **Research relevant to development:** The Institute conducts applied, strategic and fundamental scientific research in its field of interest and in collaboration with its network of research institutions in Europe, Asia, Africa and Latin America. The main aim of R&D programmes is to contribute to knowledge-base development and to research capacity-building ultimately leading to sustainable development, and fully within the framework of international agreements for water, environment and infrastructure.
5. **Policy development:** The Institute's experts have been contributing to several international and national policy discussions on strategies for water and environmental management, sharing international water resources and urban infrastructure management.

6. **Advisory services:** The Institute's staff frequently participates in identification, formulation, appraisal, monitoring and evaluation teams for development projects.
7. **Standard-setting for education and training**: The Institute serves as a standard-setting body for postgraduate water education programmes and continuing professional training.
8. **Establishment and management of water education and water sector networks**: The Institute creates and reinforces networks of water sector educational institutions, and acts as an international forum for experts and professionals to exchange scientific, educational and technical information and knowledge on all aspects of integrated water management.
9. **"Policy forum" function**: The Institute carries out a "policy forum" function for UNESCO Member States and other stakeholders to initiate and facilitate international policy dialogues on scientific and technical grounds concerning issues of water management.

Since the 1990s, a gradual shift in attention has been observed from delivering technical assistance, in which capacity development was perceived merely as training (skills to operate), towards creating enabling institutional environments, which enable or constrain the intended developments. This shift has also been influenced by the emergence of the systems approach and the involvement of gamma sciences. Besides the technical or academic training of individual participants, institutional strengthening by building and supporting networks of professionals (such as NBCBN, WaterNet [Southern Africa], CKNet-INA [Indonesia]), involving both public and private sectors, and are gaining in importance.

In recent years, however, the Millennium Development Goals (MDGs) have increasingly made the new capacity-building undertakings more focused on outputs and targets than on inputs. This shift, which places greater emphasis on the desired impacts at the ground, mainly aims to ensure that most efforts are geared precisely towards achieving the MDGs. Meeting MDGs has generally been perceived as a reliable proxy for assessing the ultimate effects and impacts of development interventions, including the capacity development activities in the water sector as a whole.

5 Dryland–Water Nexus

In reference to drylands, the Institute has been engaged in very crucial components of natural resource systems – water, the environment and infrastructure, which would be wrong to consider in isolation and, in many ways, are highly pertinent to drylands as well. For instance, efficient water use and management methods play vital roles in arid and semi-arid areas (McCornick et al., 2003; Araso et al., 2006). Site-suitable water harvesting techniques and conservation measures, such as the use of contour bunds in arid areas, have great potential to mitigate the risk of chronic drought. In many countries of the semi-arid regions of sub-Saharan Africa, rainfed agriculture is widely practiced. But rainfed agriculture is highly dependent on the quantity and reliability of rainfall, which determine critical decisions, such as crop choice and planting dates, to realize satisfactory agricultural returns. If properly designed and managed, irrigation can help overcome many of the disadvantages inherent in rainfed agriculture which is a more pressing need particularly in drylands. In addition, efficient dryland irrigation can help overcome the need for shifting cultivation to reduce the pressure on fragile environments. The risk of crop failure can be minimized and farmers can hope for higher and more reliable agricultural production, better levels of income, and food security.

Irrigation facilities are less than adequate in Africa for several reasons. The International Commission on Irrigation and Drainage (ICID) 2006 statistics show that currently only 8% (2% with drainage and 6% with irrigation) of the total arable land in Africa is equipped with water management systems. If we consider only the sub-Saharan region, the figure is even lower, dropping to less than 5% of the agricultural land that is provided with an irrigation or drainage system. The last six-year surveys done by the FAO (2004) show that Africa has a substantial trade deficit of about 38% of its own food production.

On the other hand, population growth in sub-Saharan Africa from 730 million people in 2005 to an estimated 1,650 million in 2050 is about the highest in the world (Araso et al., 2006). In addition, improvements in the standard of living may be expected. These two developments are the basis for increased demand for agricultural water. The increase in population and standard of living often results in:

- Decline in arable land per capita
- Decline in annual renewable water resources per capita
- Increase in need for food production
- Increase in competition for fresh water among different sectors

In general, with the fast increase in population, especially in the least developed countries, and rapid rise of the standard of living in emerging countries of the region, agriculture is faced with an increasing demand for food. Based on these developments, the FAO also indicated that in the coming decades the food supply will have to grow by at least 45% in the emerging countries and with 100% in the least developed countries, to which category most of the sub-Saharan Africa countries belong.

So the challenge for the water management sector is to increase the productivity of land and water resources in a sustainable way without degrading the environment. This challenge becomes more pressing in the case of drylands. Therefore, improved water management systems for the sustainable development of scarce resources are a prerequisite for improving water-use efficiency. Such systems would use different techniques of water harvesting, construction of water storage facilities, water recycling (naturally or artificially), and the conjunctive use of surface and groundwater with low-cost pumps like treadle pumps. Improved water management systems are also necessary so as to minimize the environmental damage (Araso et al., 2006).

Furthermore, the unpredictable, infrequent and low rainfall patterns in most of the semi-arid areas limit agro-pastoral farming systems. Although desertification is land degradation in arid, semi-arid and dry sub-humid areas, the main element of desertification is the unavailability of water resources. This renders the ecosystems in the affected areas fragile. Desertification refers not only to the expansion of already existing desert but also to over-exploitation and inappropriate use of resources in dry ecosystems. Deforestation, overgrazing, ill-designed and mismanaged irrigation practices, poverty, political instability and inappropriate macro-policy directions can all adversely affect natural resources and land productivity, leading to "desertified" environment. The results are often seen in a loss of biological productivity, disturbed and deteriorated water cycling, and a loss in economic productivity, famine, starvation and general poverty ranging from the household to national level. Thus, poverty over-utilization of resources including water, and to environmental deterioration thus creating a vicious circle to the process (McCornick et al., 2003 MEA, 2005; DAC, 2006).

The emergence of institutions like the Arbaminch Water Technology Institute and Mekelle University College of the Drylands in Ethiopia that train professionals in irrigation, hydrogeology and soil and water conservation skills are good news and continued support to the networks of such education and knowledge transferring institutions in dryland arid and semi-arid regions is a necessity to check the desertification process and its effects.

6 Conclusions

Traditional approaches to and methods of education and knowledge-sharing are increasingly being revised because they have failed to address the burning issue of maintaining the integrity and productivity levels of dryland resources. While much progress can be observed in terms of focus, approach, techniques, and even in the availability of the tools such as modern information and communication technology, there are several issues that are still inadequately addressed with regard to capacity-building through education and knowledge-sharing. These issues encompass both the contents and the methods of education and knowledge-sharing. They include the following:

- How can we foster a more comprehensive understanding of the interconnectedness of biophysical and socio-economic attributes of drylands?
- What can be done to better address the complexity, diversity (site specificity and variety of stakeholders) and dynamism of dryland resource systems?
- Which measures can be taken to ensure blending of idiographic expertise with nomothetic knowledge?
- How can the critical role of water management in drylands be manifested?
- How can more emphasis be placed on participatory learning methods?
- What needs to be done to strengthen the collaborative and adaptive management approach in drylands?
- What options exist to help make education and knowledge-sharing more of an endogenous process?

Nevertheless, along with the evolution in the approach, methods and contents, the pursuit of improved educational methods and techniques of knowledge-sharing continues. Reflecting on the decades of learning and experiences, UNESCO-IHE is currently engaged in analyzing several options for improving educational and knowledge-sharing methods, including the following:

- (Educational) Innovations (e.g. blended learning: face-to-face and computer-based)
- Distance learning (e-learning module, interactive)
- Internationalization of the programmes (sandwich, joint degrees, credit transfer, etc.)
- Linking teaching and research

References

Araso, G. S., Schultz, B. and Hollanders, P. 2006. Contribution of water management measures to food in the sub-Sharan Africa Region. Paper to be presented in ICID Conference, September 2006, Kuala Lumpur, Malaysia.

Brunner, R. D., Colburn, H. C., Cromley, M. C., Klein, R. A. and Olson, E. A. 2002. *Finding Common Ground: Governance and Natural Resources in the American West*. Yale University Press, New Haven, CT.

OECD/DAC. 2006. *The Challenge of Capacity Development: Working towards Good Practice*. DAC Network on Governance. Development Co-operation Directorate and Development Assistance Committee. OECD/Organization for Economic Cooperation and Development, Paris. (http://www.cbnrm.net/resources/training/index.html; http://www.cbnrmasia.org/).

Freeman, D. 1989. *Local Organizations for Social Development: Concepts and Cases of Irrigation Organization*. Westview, Boulder, CO.

McCornick, P. G., Kamara, A. B. and Tadesse, G. (eds.). 2003. Integrated water and land management research and capacity building priorities for Ethiopia. *Proceedings of a MoWR/EARO/IWMI/ILRI international workshop held at ILRI, Addis Ababa, Ethiopia, 2–4 December 2002*. IWMI (International Water Management Institute), Colombo, Sri Lanka, and ILRI (International Livestock Research Institute), Nairobi, 249p + CD.

McDougall, C. and Braun, A. 2003. Navigating complexity, diversity and dynamism: Reflections on research for natural resource management. *Managing Natural Resources for Sustainable Livelihoods: Uniting Science and Participation*. Pound, B., Snapp, S., McDougall, C. and Braun, A. (eds.). Earthscan/IDRC, (International Development Research Center), Ottawa, pp. 20–47.

Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and Human Well-being: Desertification Synthesis*. World Resources Institute, Washington, DC. (http://www.undp.org/drylands/gov-ltenure-more.htm#ldegradation).

Put, M. and van Dijk, M. P. (eds.). 2000. *Government and NGO Interventions in Dryland Agriculture: A Study of Two Projects in Andhra Pradesh*. IDPAD/Manohar, New Delhi. (http://www.unesco.org/most/bpindi.htm).

Motschnig-Pitrik, R. and Mallich, K. 2004. Effects of person-centred attitudes on professional and social competence in a blended learning paradigm. *Educational Technology and Society*, Vol. 7, No. 4, pp. 176–192.

SIWI, IFPRI, IUCN, IWMI. 2005. *Let it Reign: The New Water Paradigm for Global Food Security*. Final Report to CSD-13. Stockholm International Water Institute, Stockholm, Sweden.

Annex 1: Examples of UNESCO-IHE Capacity Building in Water Sector of Sub-Saharan Africa (Source: UNESCO-IHE project database, June 2006)

Completed

SN	Country	Topic	Content details
1	GHANA	Water and Environmental Sanitation Sector Capacity Building	Development of an indigenous education, training and research capacity in urban and rural water supply and sanitation at the UST-Kumasi.
2	ZIMBABWE	Programme for Capacity Building in the Water Sector of Zimbabwe	The project aims at strengthening the capacity of the Dept. of Civil Engineering of UZ and of the IWSD. The project comprises staff development, the implementation of a MSC-programme in WRM at UZ, short courses for professionals at IWSD and the establishment of research capacity. Main target countries are Zimbabwe, Botswana, Namibia, Malawi, Uganda, Kenya, Tanzania and Mozambique.
3	ZIMBABWE	WaterNet, Forging the Network	The project aims are to establish a Network for education, training and research on IWRM in Southern Africa. Core activities are the establishment of a WaterNet Secretariat, the development of a regional MSc programme on IWRM, setting-up a research fund and improving the mobility of lecturers and researchers in the Southern Africa region. Most probably Harare will be the hub in the programme while nodes will be created in neighboring countries.
4	ZIMBABWE	Capacity Building at the MSc Programme in Water Resources Engineering and Management at UZ	To develop expertise at the University of Zimbabwe and develop an educational module in the field of Environmental Water Demand and River Flow Requirements for the water allocation and management practices in river basins in Zimbabwe and the Southern Africa region. The module will be part of the regional MSc programme of WaterNet.
5	KENYA	Support for Post-Graduate Education in Applied Hydrology and Water Management for the Anglophone African Region	Training of Trainers of the Postgraduate Hydrology course in Kenya.

6	SOUTH AFRICA	Special Masters-level Fellowship Programme South Africa and Zimbabwe, 1997-1999	Group training 1997-98 at M.Eng. level for 23 persons and 5 MSc-extensions. 20 professionals from South Africa and 5 from Zimbabwe have participated in this special training. They attend the following courses: 2 EST, 16 WERM, 4 SE, 1 HY, 1 HI, 1 HE.
7	SOUTH AFRICA	Special Masters-level Fellowship Programme South Africa, 1998-1999	Group Training for 12 participants from South Africa in Integrated Water Resources Management at MEng level. This is a follow-up of the group training 1997-1999.
8	SOUTH AFRICA	Group Training on Community Water Supply and Sanitation	Funding for 11 Diploma and 4 MSc participants at IHE
9	*VARIOUS COUNTRIES*	Water for African Cities Programme: Training and Capacity Building Component	The ‘Managing Water for African Cities Programme’ is a regional initiative to support African cities to manage the growing water demand and protect their fresh water resources. The training and capacity building component focuses on institutionalizing a training programme through training of trainers and technical support to regional institutions. Main subjects are demand management and pollution control. Training is foreseen at three levels: policy and decision makers, senior managers and mid-level managers. Overview of activities: Activity1.1: Participation of the Int’l CB Institute in workshop with WAC Cities; Activity 1.2: Survey by International capacity building institute; Activity 1.3: Workshop with local TCs and regional RCs and ICB institutes; Activity 2.1:Develop curriculum and training materials (collection of information); Activity 2.2: Training of Trainers (2 week programme)(); Activity 2.3: Upgrading of facilities; Activity 2.4: 1st Training of middle managers (3 week programme); Activity 2.5 1st Training of senior managers (1 week programme; Activity 2.6: 1st Training of policy and decision (1 week programme); Activity 2.7: 2nd Training of middle managers (3 week programme); Activity 2.8: 2nd Training of senior managers (1 week programme); Activity 2.9: 2nd Training of policy and decision-makers (1 week programme); Activity 3.1: Co-ordinate project by International capacity building institute.

(continued)

Annex 1: (continued)

Completed

SN	Country	Topic	Content details
11	*VARIOUS COUNTRIES*	Preparatory Phase Water for African Cities Programme: Training and Capacity Building Component	Preparatory missions to conduct a survey to identify local training institutes in Nairobi, Addis Ababa and Lusaka. Furthermore debrief the results of the survey to UNCHS and attend the City Managers Meeting in Dakar Senegal
12	GHANA	Refresher Course on Environmental Impact Analysis	Refresher course on Environmental Impacts: Assessment, Monitoring and Control
13	ZIMBABWE	Seminar on the Development of a Role-Play on Water Resources Management	Seminar on Water Resources Demand Management for SADC countries
14	ZIMBABWE	Refresher Course on Water and Environment	Refresher Seminar on Integrated Water Resources Management
15	KENYA	Short Mission for the Consolidation of Kenya Wildlife Services Wetland Management Training Project	Two-weeks mission to Naivasha, Kenya, to assist Kenyan trainers in developing teaching materials for a East African Wetlands Management Course, to be offered in the framework of the DGIS-sponsored project "Consolidation of Kenya Wildlife Services Wetland Management Training Capacity".
16	KENYA	Refresher Course on Integrated Water Resources and Wetlands Management	-
17	TANZANIA	IUCN Wetland Biodiversity Training Workshop in Tanzania	-
18	TANZANIA	Refresher Course on Integrated Water Resources and Wetlands Management	-
19	ETHIOPIA	Water Supply and Sanitation Training Ministry of Water Resources in Ethiopia	Training in Ethiopia to make a number of 25 key players in the water supply and sanitation sector aware of and prepared for the upcoming chances in the water sector in Ethiopia. Water sector is subject to change due to the creation of independent town water supply corporations.
20	UGANDA	Refresher Course on Public-Private Partnership for African Water Utilities	-
21	UGANDA	Refresher Course on Water Resources & Wetland Management for Sustainable Development	-

22	ETHIOPIA	Tailor made Programme on Financial Management for Ethiopian Professionals from ESRDF	Development and delivery at IHE of a 3-week training on Financial Management for 8 staff of the Ethiopian Social Rehabilitation and Development Fund (ESRDF). Content: 1. Financial Management of Grant Assisted Projects 2.Disbursement procedures for donor funded projects 3.Applications of WB and other dev. Agencies' standards for managing grants and procurement 4.Computerized management and admin of projects 5.Financial risk 6.Prepararion of projects and effective implementation.
23	UGANDA	Refresher Course Uganda	-
24	TANZANIA	Development and First Delivery of a Training Course for Municipal Wastewater Managers in Tanzania	The project activities are 1) development of a training course module for municipal wastewater managers in East Africa, using the Train Sea Coast Methodology, 2) delivery of training course in Tanzania, and 3) adapt the training course according to lessons learned.
25	GHANA	Urban Infrastructure Provision and Management: Integrating Engineering, Social and Environmental Considerations	-
26	SOUTH AFRICA	Wetland systems, water resources and climate variability and change: a challenge for southern Africa. Building a Community of Wetland Professionals.	-
27	*VARIOUS COUNTRIES*	Development of a Multidisciplinary Water Demand Management Tertiary Training Module	-
28	SOUTH AFRICA	Development of a Multidisciplinary WDM Tertiary Training Module	-
29	UGANDA	Use of Wetlands for Water Quality and the impact of Re-use of Nutrients	6 day refresher with worldwide focus

(continued)

Annex 1: (continued)

Completed

SN	Country	Topic	Content details
31	RWANDA	Refresher Course Rwanda on Geo-informatics for Hydrological Modeling	-
33	KENYA	Refresher Course in Solid Waste Management and Engineering	-
34	TANZANIA	Refresher Seminar on Environmental Flows for Rivers	-
35	KENYA	Upgrading training TSC methodology	Within the GPA programme for the Protection of the Marine Environment IHE will upgrade the pilot course on management for municipal Waste water for Decision Makers at municipal level, will provide content for two handbooks and will assist in course delivery in East Africa

Ongoing

Country	Topic	Content
SOUTH AFRICA	Supporting the South African Counterparts in Exploring Service Delivery Models "Assistance on International Water Service Models"	Project to assist the DWAF/WS and DPLG 1) by inventorizing and addressing their immediate 'international' advice and information needs relative to their present and future responsibilities in water supply and sanitation; 2) by developing a capacity building programme for management staff in the Water Services Branch of DWAF.
VARIOUS COUNTRIES	Knowledge Networks for the Nile Basin, Using the innovative potential of knowledge networks and CoP's in strengthening human and institutional research capacity in the Nile region	Using the innovative potential of Knowledge networks and CoP's in strengthening human and institutional research capacity in the Nile region. The main challenge is to activate the knowledge and learning cycle and to facilitate the network development process in such a way that it will directly contribute to the socio-economic development of the region and thus to the achievement of the Millennium Development Goals. By involving professionals and institutes in additional and complementary activities laid down in the Shared Vision Programme of the Nile Basin Initiative in the area of water resources management in the Nile Basin, the project creates a solid passage from potential conflict to confidence building between riparian states.

SUDAN	Programme for the Rehabilitation of Waterways in Sudan	UN initiative to start a programme for the rehabilitation of waterways of Sudan. Details not yet known. Opportunity for UNESCO-IHE in the framework of the Nile Basin Capacity Building Network for River Engineering (NBCBN-RE).
VARIOUS COUNTRIES	Water programme for Africa (WPA) - Phase 1	First phase of the Italian funded component of the UNESCO-IHP's partnership, the WSSD Type II Partnership/Initiative: Water programme for Africa (WPA). Activities comprise short courses on water resource management including fieldtrip: 1. 2X3wk short course north africa (Egypt) wastewater/groundwater 2. 2 wk short course Eritrea (also for Ethiopia. Somalia) LWD 3. 1 wk Yemen renewable energy 4. 1 wk Algeria (also Tunisia & Morocco) 5. 1 wk study tour Vietnam - WPA contract 30 nov 2004 has budget for preparatory missions to Egypt, Algeria and Eritrea and also coordination time
RWANDA	Rwanda NUR MSc Programme in Water Resources and Environmental Management	This capacity building project will play a vital role in upgrading academic and professional expertise in the Water sector of Rwanda. It will prepare and implement a post-graduate Master'sof Science programme in Water Resources and Environmental Management (WREM) within the Department of Civil Engineering of the National University of Rwanda. This MSc programme will train Rwandan graduates to address rural and municipal WREM coverage, quality and management problems. Furthermore, the project aims to develop NUR staff at PhD, MSc and Certificate level, to train in curriculum development, to develop and implement the MSc programme, to launch an interdisciplinary research group and to upgrade didactic, laboratory and library facilities and materials.
ZIMBABWE	WaterNet Strategy-Phase II: 2005-2009	Strengthening a collaborative network of some 30 universities and professional organizations. WaterNet provides a joint Masters Programme Integrated Water Resources Management and short professional training. The objective(s) of the project/programme are: 1.Forging a strong, demand driven and sustainable network of universities and research institutions in southern Africa in the field of IWRM. 2. To deliver and strengthen the jointly owned regional Master degree programme in IWRM. 3. To develop and deliver demand-driven training and education for practicing water sector professionals in Southern Africa. 4. To stimulate, regionalize and strengthen the research in the field of IWRM in Southern Africa. 5. To raise awareness and understanding of IWRM and its implementation at local, national and trans-boundary scale.

(continued)

Ongoing (continued)

Country	Topic	Content
VARIOUS COUNTRIES	Activities related to the project Wetlands and Poverty reduction	Subcontract between WI and UNESCO-IHE for activities related to the Wetlands and Poverty Reduction Project. Main responsibilities: 1. co-developing and review of the stakeholder workshop materials for East and West Africa. 2. Review of overall report form East Africa and West Africa stakeholder workshop. 3. Support the development of the overall and combined report and capacity building framework for the region from both the stakeholder consultation workshops and facilitating the framework consultation the workshops. 4. Co-development of the terms of reference for contracting the course module development, etc.
ETHIOPIA	Conservation Tillage Systems Using Improved Implements for Small-Scale Dryland Farmers in Ethiopia	PhD-study
BURKINA FASO	Role of Ecological Sanitation in achieving the MDG targets in West Africa	Refresher Course on Ecological Sanitation for IHE alumni from Sub-Saharan Africa (1 week course).

Annex 2

UNESCO-IHE
Institute for Water Education

A Short Profile

VISION AND MISSION

UNESCO-IHE's vision is a world in which people control their water and environmental resources in a sustainable manner, and in which all sectors of society, particularly the poor, can enjoy the benefits of the basic services.

The mandate given by UNESCO to IHE is to:

strengthen and mobilise the global educational and knowledge base for integrated water resources management; and
contribute to meeting the water-related capacity building needs of the developing countries and countries in transition.

Within this mandate the mission is defined as follows:
UNESCO-IHE's mission is to contribute to the education and training of capable professionals and to build the capacity of knowledge centres and other organisations in the fields of water, environment and infrastructure in developing countries and countries in transition. The Institute associates with partners to do research in the context of integrated water resources management and aims at global dissemination and knowledge sharing.

UNESCO-IHE is dedicated to scientific research, postgraduate education and training in the fields of water, the environment and infrastructure. The Institute is a globally active "partner in action" in the developing countries, through ***solution-oriented*** research, education and capacity building operations. UNESCO-IHE determines education, training and research **demands** through its international network of: 12,000 alumni in more than 120 countries, the Institute's community of partnerships, including public and private organisations active in water sectors worldwide, interactions with international agencies, 'sandwich' research projects, collaborative research projects and consultancy work. Together, representing an extensive network of international water professionals of yesterday, today and tomorrow.

ORGANISATIONAL BACKGROUND

IHE Delft was established in 1957 and is located in Delft, The Netherlands. In November 2001, UNESCO's General Assembly declared the existing IHE Delft to be established as the UNESCO-IHE Institute for Water Education. Within UNESCO's mandate, the new Institute shall strengthen and mobilise the global educational and knowledge base for integrated water management and contribute to meeting the water-related capacity building needs of the development community.

One of the main vehicles geared towards achieving the UNESCO-IHE mission is the international "Partnership for Water Education and Research" (PoWER), an open network of 17 founding partners in Africa, Asia, Latin America and the Middle East. Through the use of Internet, satellite and other advanced ICT in distance learning and joint education delivery, UNESCO-IHE is consolidating collaboration efforts in response to the needs of the water and environment sectors worldwide.

The Institute's total permanent staff amounts to 160, with 80 permanent academic staff members (of which 14 professors and 17 associate professors). A part of the lecturing is provided by 350 guest lecturers from the private sector, . UNESCO-IHE has an experienced team of hydraulic engineers, hydrologists, irrigation engineers & management experts, sanitary engineers, chemists, biologists, environmentalists, ecologists, institutional development experts, educationalists, economists, transport and road engineers and physical planners in the following departments: *Water Engineering, Environmental Resources, Management & Institutions, Municipal Infrastructure, and Hydroinformatics & Knowledge Management.*

Clients include multilateral agencies, national governments, bilateral donor agencies, sectoral associations, sectoral ministries and universities. UNESCO-IHE's target group for its courses are mid-career and senior professionals and decision-makers aiming for higher performance levels in engineering, science and technical-management.

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UNESCO-IHE
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A Short Profile

CORE ACTIVITIES

Postgraduate Programmes: UNESCO-IHE offers various Masters and PhD level courses on water, the environment and physical infrastructure. All courses are aiming at educating participants to develop a problem-solving attitude, taking into account the multi-disciplinary setting of problems and aiming at achieving sustainable solutions. UNESCO-IHE-trained professionals are trained to work on technical and managerial challenges at local, national and international levels.

Tailor-made Training Courses: Development and implementation of training courses on demand is one of UNESCO-IHE's core competencies. Short courses are used for upgrading of knowledge and skills of more senior experts, refreshment of the knowledge basis or exposure to applications of conventional, modern and new technologies. Knowledge is transferred through lectures, workshops, role-plays, video, study tours to European projects, lecture notes, and other printed materials.

Institutional Capacity Building: UNESCO-IHE offers a wide range of expertise to facilitate institutional or organisational reform programmes. UNESCO-IHE experts contribute to, for example, training needs assessments, human resources development strategy development, training courses, decentralisation strategies and other relevant activities. UNESCO-IHE can also provide support to strengthen in-house training centres of sectoral ministries or authorities.

Research Relevant to Development: UNESCO-IHE conducts applied, strategic and fundamental scientific research in its field of interest and in collaboration with its network of research institutions in Europe, Asia, Africa and Latin America. The main aim of UNESCO-IHE's R&D programmes is to contribute to knowledge base development and to research capacity building ultimately leading to sustainable development, and fully within the framework of international agreements for water, environment and infrastructure.

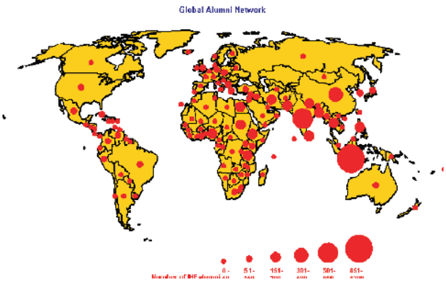
Policy Development: UNESCO-IHE's experts have been contributing to several international and national policy discussions on strategies for water and environmental management, sharing international water resources and urban infrastructure management.

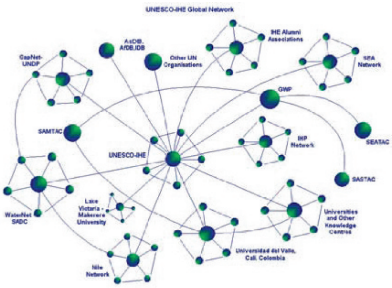
Advisory Services: UNESCO-IHE staff frequently participates in identification, formulation, appraisal, monitoring and evaluation teams for developmental projects.

Standard Setting for Education and Training: UNESCO-IHE will serve as a standard-setting body for postgraduate water education programmes and continuing professional training.

Establishment and Management of Water Education and Water Sector Networks: The Institute will create and reinforce networks of water sector educational institutions, and act as an international forum for experts and professionals to exchange scientific, educational and technical information and knowledge in all aspects of integrated water management.

"Policy Forum" Function: UNESCO-IHE will also carry a "policy forum" function for UNESCO Member States and other stakeholders, to initiate and facilitate international policy dialogues on scientific and technical grounds on issues concerning water management.





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Chapter 4
Participatory Land Degradation Assessment

Mark S. Reed and Andrew J. Dougill

Abstract Land degradation is one of the most pressing environmental issues facing the world's drylands. However, current assessments of its global extent and severity are methodologically flawed and do little to promote sustainable land management. Comparisons between UNEP's (1997) assessment and five alternative methods in Botswana demonstrate that degradation extent and severity are highly dependent on the methods and context of the assessment. A combination of methods, including public participation, are necessary for future global assessments to begin capturing this complexity. We show how the integration of local and scientific knowledge about degradation indicators and remediation options may empower land users, researchers and policy-makers to work hand in hand to assess and respond appropriately to land degradation.

Keywords Land degradation, Botswana, indicators, encroachment, sustainability goals, participation

1 Introduction

There is increasing recognition that approaches currently used to assess the global extent and severity of land degradation are methodologically flawed and do not provide outputs that can help improve the sustainability of land management. Based on expert opinion of the extent and severity of soil physical and chemical degradation, UNEP's *World Atlas of Desertification* (Oldeman et al., 1990; UNEP, 1997) is still the only global assessment of degradation. However, it does not capture ecological or economic components or consider the context in which environmental change occurs, lacks replicability and objectivity due to its reliance on opinion, and does not provide the information necessary for policy-makers or land users to tackle degradation. This contrasts with the emphasis of the United Nations Convention to Combat Desertification (UNCCD) on community involvement in assessment and remediation. However, local participation is largely absent from most national implementation

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of the Convention. This is partly due to incompatibility with national political contexts (Stringer et al., 2007), but it is also due to a lack of awareness among policy-makers about potential benefits, and methodological concerns that meaningful participation can only be achieved at the expense of scientific rigour (Abbot and Guijt, 1997). Although the limitations of participatory approaches are increasingly being recognized (Cooke and Kothari, 2001; Stringer et al., 2006), emerging research suggests that by combining participatory and science-led approaches to land degradation assessment, it may be possible to combine rigour and accuracy with relevance and sensitivity to local perspectives and context (Fraser et al., 2006; Reed et al., 2006, 2007; Stringer and Reed, 2006). This is an important step towards realizing the goals of the UNCCD and enhancing approaches to global degradation assessment.

This article compares UNEP's (1997) assessment with five alternative methods in Botswana, a well-studied country described as 'one of the most desertified countries in sub-Saharan Africa' (Barrow, 1991:191). It then investigates whether local and scientific knowledge can be integrated to develop locally relevant and reliable degradation indicators and remediation options. By integrating information from a range of methods, we aim to enable land users, researchers and policy-makers to work hand in hand to assess and respond appropriately to land degradation.

2 Methods

Expert opinion, remote sensing and economic data were used to provide a rapid and cost-effective coarse-scale assessment of land degradation in Botswana: (i) an international panel of advisors were interviewed and asked to map their opinions of land degradation severity and extent (following a similar approach used by the UNEP); (ii) remote sensing assessments were collected through literature review; and (iii) time-series livestock population data from Botswana's agricultural census were analyzed (for detailed methods see Reed et al., 2007).

We then used this assessment to identify degradation hotspots, where we conducted participatory and ecological research to develop degradation indicators and remediation options for finer-scale assessment and response. We followed a four-step process designed to stimulate social learning among communities, researchers and government officials in each study area (Reed et al., 2006). First, we established the human and environmental context we were working in through interviews and focus groups. Second, in these fora we identified and evaluated environmental sustainability goals and potential strategies for reaching these goals. Third, we identified potential land degradation indicators from interviews with local communities and literature that could be used to monitor progress towards sustainability goals. We evaluated the proposed indicators qualitatively in focus groups using Multicriteria Evaluation (Fig. 1) and quantitatively through field-based sampling, to select those that were accurate and sensitive and yet easy for local communities to use. Finally, we integrated indicators

Fig. 1 Evaluation of proposed indicators using Multicriteria Evaluation in Study Area 1, showing allocation of counters (left) to indicator cards (right)

with remediation strategies in a decision support system to empower communities to monitor and respond to land degradation. Figure 2 incorporates these steps into a methodological framework that describes the order in which different tasks fit into a learning process for land degradation assessment (Reed et al., 2006). Results will now be presented from each of the four steps. Detailed methods for each step can be found in Reed and Dougill (2002), Reed (2005) and Reed et al. (2007).

3 Results and Discussion

The assessment of land degradation developed from the outputs of our expert panel *(12)* (Fig. 3a) was broadly consistent with UNEP's map in the east of the country (Fig. 3b) but differed significantly elsewhere. For example, national parks and the southern border area were not degraded according to UNEP, but were degraded (sometimes severely) in our new expert map. The time lag between assessments may partly account for these differences, but there is evidence that degradation in some parts of our new map pre-dates the UNEP map (e.g. extensive bush encroachment along the southern border was reported by Donaldson in 1969 and Archer in 1996). Degradation hotspots identified in the new expert map are largely consistent with ecological research (e.g. Skarpe, 1991; Perkins and Thomas, 1993; Moleele and Perkins, 1998). Botswana's Ministry of Agriculture has used a remotely sensed

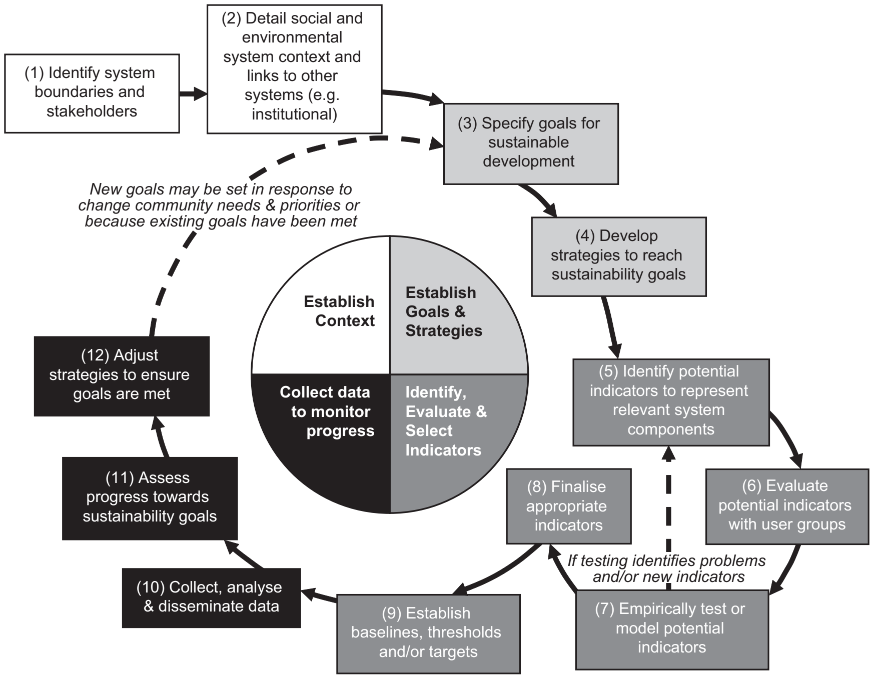

Fig. 2 Methodological framework for participatory land degradation assessment (Reed et al., 2006)

grazing capacity map[1] to infer degradation (Fig. 3c), but this map principally represents a rainfall gradient (Fig. 3d). According to Moleele et al. (2002), 6.4% of Botswana was affected by bush encroachment in 1994 (Fig. 3e). However, they were unable to distinguish between bush encroachment and natural tree cover using remote sensing. Alternatively, Fig. 3f provides an economic assessment of degradation based on district cattle population trends. Although such data must be used with great care, literature and interviews with Ministry of Agriculture officials suggested most trends were due to disease outbreaks or borehole provision, but a lack of alternative explanations for declining productivity in the Eastern Hardveld could be used to suggest land degradation, consistent with both the expert maps and ecological work. Land user assessments tend to contrast with other evidence. For example, Dahlberg's (2000) work in North East District (moderately or severely degraded according to UNEP and new expert maps, respectively) suggested, contrary to literature, that firewood was plentiful, and bush encroachment was considered easily reversible by local people. We found that degradation was highly localized around settlements in mid-Boteti District (severely degraded according to both expert maps and remote sensing literature [Ringrose et al., 1996]) and interviewees emphasized the resilience of the rangeland, recovering rapidly from drought with good rains producing enough forage to maintain herds for at least two years. This illustrates the contextual nature of land

[1] Botswana Rangeland Inventory and Management Project, unpublished data

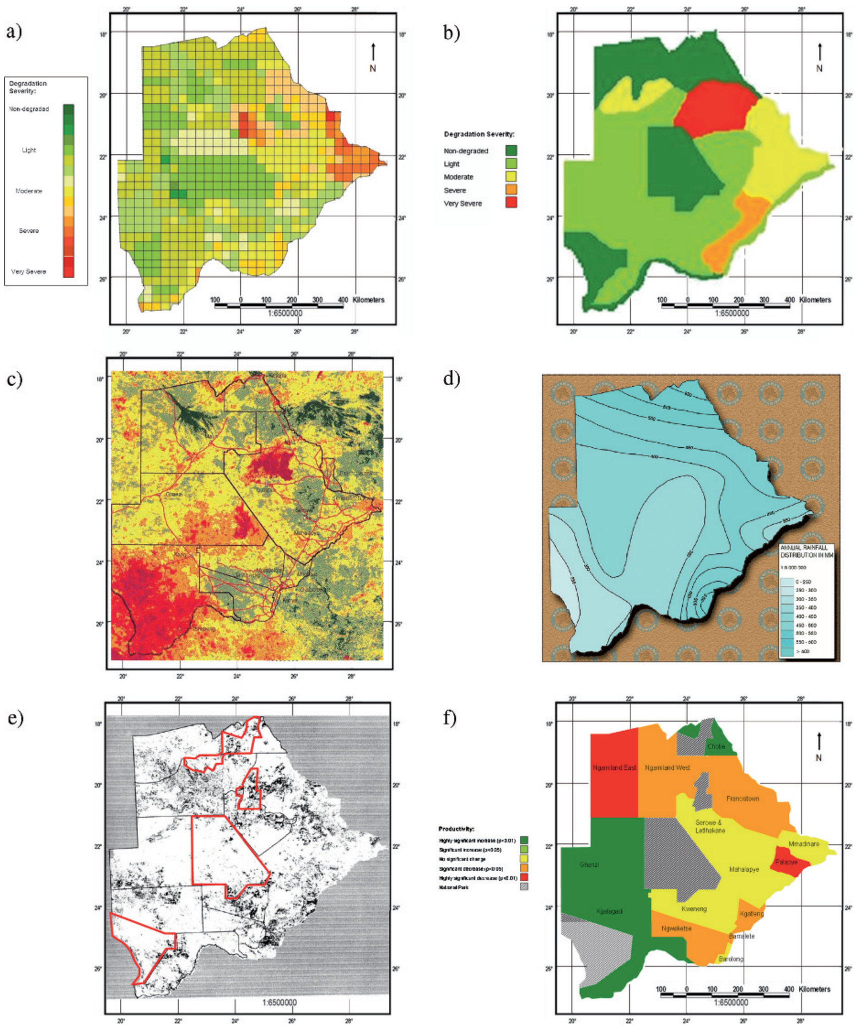

Fig. 3 a) Land degradation map of Botswana based on combined opinions of eight advisors; b) Human induced soil degradation map of Botswana from GLASOD (recoloured from 26); c) Grazing capacity map based on NDVI readings showing biomass in green *(18)*; d) Mean annual rainfall and interannual variability in Botswana *(27)*; e) Remotely sensed map of bush encroachment in Botswana showing bush in black and National Parks outlined in red (adapted from 19); f) Cattle productivity trends in Botswana by veterinary district, 1980

degradation: extent and severity may vary between land users with different management goals in different places at different times and in different socio-economic, environmental and technological contexts. Each approach used in isolation produces different results, presenting policy-makers with a confusing picture. The learning process described in Fig. 2 therefore attempts to integrate information from each of these approaches.

Table 1 Examples of land degradation remediation options developed from local and scientific knowledge

Option	Methods
Soil management	• Avoid felling trees near boreholes (where vegetation cover is usually lowest) to reduce wind erosion. • If no other trees are available, pollard trees near boreholes. • Move kraals regularly so that they do not make soils toxic. • Make piles of manure beyond the borehole vicinity (where soils are already enriched), allowing it to be dried and spread by wind. If browse is limited, smallstock manure may be used to promote browse species, but this should be avoided if managing for cattle. • During bush clearance, leave strips of bush lined against prevailing wind to reduce erosion. • During bush clearance, breaking up thorn bushes and laying them on the ground can: protect against wind erosion; allow recycling of nutrients from bush biomass; and enable grass to re-establish under protection from thorny branches.
Better use of *Rhigozum trichotomum*	• Cutting and grinding: Since young bushes (1–2 years) make most nutritious fodder, old bushes must be cut first and left to re-sprout from their base. The waste can be used to stabilize and revegetate encroaching dunes. The following year, new material can be harvested and fed into a hammer mill to produce fodder. • Harvesting flowers and pods: Many more flowers and pods are produced than can be consumed by livestock each year, but surplus flowers and pods can be harvested by hand. If there is a danger that all surplus flowers will be harvested, it is better to wait and collect the pods as these are more nutritious. The pods and flowers need to be dried and stored in a dry and dark place for use during the dry season or drought. *Note:* Because *R. trichotomum* only flowers and fruits after three years, it is only possible to *either* grind whole bushes *or* harvest flowers and pods in any one area.
Borehole rotation	Create a large syndicate with farmers from at least two other non-neighbouring boreholes. Rest the rangeland that is in worst condition first by moving all livestock to the other boreholes in the syndicate. This will reduce pressure, giving the rangeland a chance to recover. Then pile manure from kraals in rangeland around the resting borehole (see option 1). In the first year, supplementary feeding may be necessary to maintain the herd around fewer boreholes (the more boreholes in the syndicate, the less feed will be needed). If rangeland around all boreholes in the syndicate is very poor, supplementary feeding may be necessary until rangeland around each borehole in the syndicate has been rested. In future years, it should be sustainable to maintain the herd around fewer boreholes. It is not possible to use this approach in rangeland where boreholes are spaced closely, or if water yields are low or salty. If drought persists, it may still be necessary to destock.

The first step was to identify system boundaries and invite relevant stakeholders to take part (Fig. 2). The system of interest was identified as the rangeland system as this supported the majority of livelihoods, and the same four groups of stakeholders were identified in each area.

The second step was to establish environmental sustainability goals, and identify strategies to reach them (Fig. 2). In each study area, goals centred on income generation, and the prevention, reduction or reversal of rangeland degradation. Reed et al. (2007a) reviewed literature on current management practices and options for semi-arid rangelands in southern Africa. However, much of the published literature was geared towards privately owned and fenced rangeland and few strategies were compatible with communal tenure. More options were identified during interviews with stakeholders, and discussed alongside ideas from the literature in focus groups where innovators evaluated, refined and sometimes combined these ideas. Table 1 provides examples of these strategies. Many were species-specific, for example new uses for the encroacher bush, *Rhigozum trichotomum* (Table 1). A key preventative strategy was to move livestock at the onset of drought. Although destocking is widely recommended in the rangeland management literature (Behnke et al., 1993), this focuses on sale rather than movement. In areas of extensive bush encroachment, a number of control and adaptation strategies were suggested. For example, stemming bush stems beneath the soil surface can successfully prevent re-growth (Fig. 4a) and individual bush burning can be successful where there is too little grass to fuel prescribed burning (Fig. 4b). Two strategies were suggested that could aid rangeland rehabilitation after bush clearance. First, respondents suggested that any sort of bush removal should leave wind-breaks arranged against the prevailing wind to reduce erosion. Second, for recovery the rangeland must be rested. For example, breaking up thorn bushes that have been cut or uprooted and laying them

Fig. 4 Ministry of Agriculture bush clearance exclosure between Makopong and Werda done using below-ground stem cutting, showing control plot (left), cleared (centre) and partially cleared (right); and b) individual stem burning of bushes on Hereford Farm, near Bray, Kgalagadi District, Bostswana (Reed *et al.*, in press)

on the ground can: protect the soil from wind erosion; allow recycling of nutrients from bush biomass; and enable grass to re-establish under protection from thorny branches. Adaptation options included game farming, charcoal production and shifting from cattle to smallstock production to utilize bushes for browse. It should be noted, however, that many of the suggested strategies could be effectively applied only under common property regimes. (For further details, see Reed et al., 2007b).

The third step in the learning process was to identify, evaluate and select potential degradation indicators to monitor progress towards sustainability goals (Fig. 2). A significant number of indicators representing a wide range of system components were elicited from communities. A total of 84, 79 and 64 indicators were elicited in Study Areas 1, 2 and 3, respectively, making a total of 140 different indicators. The range of indicators elicited was far broader than many published indicator lists, encompassing vegetation, soil, livestock, wild animal and socio-economic indicators. However, this knowledge was thinly spread: on average, individuals could only describe 6, 8 and 7 indicators each in Study Areas 1, 2 and 3, respectively. For this reason, the focus groups we used to shortlist potential indicators acted as a valuable learning opportunity, quickly sharing collective knowledge that was not known to any single individual. Participatory evaluation against community-derived criteria led to short-lists of 38, 63 and 42 indicators that were perceived to be both accurate and easy to use by pastoralists in Study Areas 1, 2 and 3, respectively. Table 2 shows short-listed indicators that were common to all three sites. Indicators short-listed by at least two out of three focus groups in each site were then tested using ecological and soil-based sampling. It was possible to test 49%, 53% and 62% of short-listed indicators, providing evidence to support 67%, 26% and 60% of indicators in Study Areas 1, 2 and 3, respectively (at significance level $p < 0.01$; excluding indicators for which there was insufficient data to conduct statistical analyses). The lower proportion of indicators validated in Study Area 2 may be due to a less successful short-listing process (significantly lower focus group attendance and far less indicators rejected during short-listing). (For further details, see Reed and Dougill, 2002 and Reed, 2005.)

The considerable overlap between scientific and local knowledge, and the results of empirical testing, suggest that a trade-off between meaningful participation and scientific rigour is by no means inevitable. However, indicators elicited from pastoralists are not always sufficiently accurate or reliable for objective degradation assessment. For example, indicators elicited from pastoralists may be valid only during certain seasons, at certain scales, or may be difficult to distinguish from indicators of drought. On the other hand, although most indicators developed by researchers may be accurate and reliable, they are not accessible to land users and hence have little effect on management. Our approach strikes a balance between developing indicators that can achieve widespread uptake and application while providing accurate and reliable results.

The final step in the learning process (Fig. 2) was to facilitate the collection of data by local communities to monitor and respond to land degradation. We developed manual-style Decision Support Systems for each study area in response to the

Table 2 Indicator testing results (*significant $p \leq 0.01$; NS = not significant; ^ = insufficient data; - = not short-listed in this site)

Indicator	Supported by literature	Site 1	Site 2	Site 3
Decreased grass cover	Yes	*	*	*
Increased abundance of grass unpalatable to cattle	Yes	*	*	*
Decreased abundance of grass palatable to cattle	Yes	*	*	*
Decreased availability of thatching grass	No literature	–	NS	*
Decreased abundance of medicinal plants	No literature	^	^	^
Decreased abundance of trees	No	NS	NS	NS
Stunting of trees and bushes	No	NS	NS	NS
Tree canopy die-off	No literature	*		
Increased abundance of *Boscia albitrunca*	No literature	*	–	–
Decreased abundance of *Grewia flava*	Yes	NS	^	^
Increased abundance of *Acacia mellifera*	Yes	*	–	*
Decreased vegetation cover/increased bare ground	Yes	*	*	*
Decreased soil organic matter content	Yes	–	*	*
Increased soil looseness	No	NS	NS	*
Increased density of cattle tracks	No literature	NS	NS	–

different indicators and management options deemed relevant by local communities. The assessment procedure is flexible, designed to make recording and interpretation of results simple. Short textual descriptions of indicators are illustrated with photographs representing healthy and unhealthy rangeland states. Each indicator is cross-referenced to a range of management options, and there are a range of options to suit different budgets and time-frames.

The learning process in Fig. 2 has been adapted to UK uplands in ongoing research funded by the UK Research Councils Rural Economy and Land Use Programme (Dougill et al., 2006). The process has also been applied with mixed farming communities in Swaziland (Stringer and Reed, 2006), and is now being applied internationally through an EC-funded project based in northern, southern and Sahelian Africa, southern Europe, USA, Austrailia, China and South America.[2]

[2] Desertification Mitigation & Remediation of Land, DESIRE, www.env.leeds.ac.uk/ mreed/ DESIRE.html.

4 Conclusion

This research shows how land degradation extent and severity are highly dependent on the methods and context of the assessment. A combination of methods, including public participation, are necessary for future global land degradation assessments to begin capturing this complexity. This research shows that it is possible to effectively integrate local and scientific knowledge about land degradation, and by doing so, obtain more reliable and relevant information than either approach alone. By involving local communities in land degradation assessment, it is possible to go beyond simply monitoring degradation. It is possible to empower communities to both recognize and respond to degradation, to protect the environment and their livelihoods. This is a key goal of the UNCCD that has yet to be fully realized. Although the methodological challenge is just one barrier to more participatory national implementation of the Convention and more work is necessary, this research suggests that the methods are beginning to catch up with the rhetoric.

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References

Abbot, J. and Guijt, I. 1997. *Changing Views on Change: Participatory Approaches to Monitoring the Environment*. SARL Discussion Paper 2. International Institute for Environment and Development, London.

Archer, S. 1996. Assessing and interpreting grass-woody plant dynamics. J. Hodgson and A. W. Illius (eds.), *The Ecology and Management of Grazing Systems*. CAB International, Wallingford, pp. 101–134.

Barrow, C. J. 1991. *Land Degradation: Development and Breakdown of Terrestrial Environments*. Cambridge University Press, Cambridge/New York.

Behnke, R. H., Scoones, I. and Kerven, C. (eds.), 1993. *Range Ecology at Disequilibrium: New Models of Natural Vulnerability and Pastoral Adaptation in African Savannas*. Overseas Development Institute, London.

Cooke, B. and Kothari, U. 2001. *Participation: The New Tyranny?* Zed Books, London.

Dahlberg, A. C. 2000. Interpretations of environmental change and diversity: A critical approach to indications of degradation – the case of Kalakamate, northeast Botswana. *Land Degradation and Development*, Vol. 11, pp. 549–562.

Department of Tourism. *Annual Rainfall Map*, available at: http://www.botswana-tourism.gov.bw/tourism/maps/img/rainfall_map.gif

Donaldson, C. H. 1969. *Bush Encroachment with Special Reference to the Blackthorn Problem of the Molopo Area*. Government Printer, Pretoria.

Dougill, A. J., Fraser, E. D. G., Holden, J., Hubacek, K., Prell, C., Reed, M. S., Stagl, S. T. and Stringer, L. C. 2006. Learning from doing participatory rural research: Lessons from the Peak District National Park. *Journal of Agricultural Economics*, Vol. 57, pp. 259–275.

FAO/AGL. *GLASOD Country Maps,* available at http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp

Fraser, E. D. G., Dougill, A. J., Mabee, W., Reed, M. S. and McAlpine, P. 2006. Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management, *Journal of Environmental Management*, Vol. 78, pp. 114–127.

Moleele, N. M. and Perkins, J. S. 1998. Encroaching woody plant species and boreholes: Is cattle density the main driving factor in the Olifants Drift communal grazing lands, south-eastern Botswana? *Journal of Arid Environments* Vol. 40, pp. 245–253.

Moleele, N. M., Ringrose, S., Matheson, W. and Vanderpost C. 2002. More woody plants? The status of bush encroachment in Botswana's grazing areas. *Journal of Environmental Management*, Vol. 64, pp. 3–11.

Oldeman, L. R., Hakkeling, R. T. A. and Sombroek, W. G. 1990. *World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note*. ISRIC & UNEP, Wageningen and Nairobi, Kenya.

Perkins, J. S. and Thomas, D. S. G. 1993. Spreading deserts or spatially confined environmental impacts – land degradation and cattle ranching in the Kalahari desert of Botswana. *Land Degradation and Development*, Vol. 4, pp. 179–194.

Reed, M. S. and Dougill, A. J. 2002. Participatory selection process for indicators of rangeland condition in the Kalahari. *Geographical Journal*, Vol. 168, pp. 224–234.

Reed, M. S. 2005. *Participatory Rangeland Monitoring and Management in the Kalahari, Botswana*. PhD Thesis, School of Earth & Environment, University of Leeds, UK.

Reed, M. S., Fraser, E. D. G. and Dougill, A. J. 2006. An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics*, Vol. 59, pp. 406–418.

Reed, M. S., Dougill, A. J. and Taylor, M. J. Responding to land degradation in semi-arid rangelands: Drivers and emerging options in Botswana, *Journal of Arid Environments* (in Press).

Reed, M. S., Dougill, A. J. and Taylor, M. J. 2007. Integrating local and scientific knowledge for adaptation to land degradation: Kalahari rangeland management options. *Land Degradation and Development,* Vol. 18, pp. 249–268.

Ringrose, S., Chanda, R., Nkambwe, M. and Sefe, F. 1996. Environmental change in the Mid-Boteti Area of North-Central Botswana: Biophysical processes and human perceptions. *Journal of Environmental Management*, Vol. 20, pp. 397–410.

Skarpe, C. 1991. Spatial patterns and dynamics of woody vegetation in an arid savanna. *Journal of Vegetation Science*, Vol. 2, pp. 565–572.

Stringer, L. C., Thomas, D. S. G. and Twyman, C. 2007. From global politics to local land users: applying the United Nations Convention to combat desertification in Swaziland. *The Geographical Journal*, 173(2): 129–142.

Stringer, L. C., Prell, C., Reed, M. S., Hubacek, K., Fraser, E. D. G. and Dougill, A. J. 2006. Unpacking 'participation' in the adaptive management of socio-ecological systems: A critical review. *Ecology & Society*, Vol. 11, pp. 39 [online].

Stringer, L. C. and Reed, M. S. 2006. Land degradation assessment in southern Africa: Integrating local and scientific knowledge bases. *Land Degradation and Development*, Vol. 18, pp. 99–116.

UNEP. 1997. *World Atlas of Desertification*. Edward Arnold, London.

Chapter 5
Environmental Education from the Perspective of Sustainable Development: A Teaching Resource Kit for Dryland Countries

Hélène Gille

Abstract The UN Convention to Combat Desertification (UNCCD) recognizes the importance of capacity-building, education and public awareness in efforts to combat desertification.

Environmental education and awareness is important at all levels and needs to start early in order to make an impact on the consciousness of the individual. In drylands especially, educational programmes which define a pedagogical method to raise environmental awareness among pupils and to help them learn about sustainable development is one of the major instruments to empower these pupils and the population to combat desertification and support biodiversity and environmental conservation.

UNESCO's Man and the Biosphere (MAB) Programme is currently developing two teaching resource kits for environmental education, one of which has been designed to be used in dryland countries.

The kits are intended for primary and secondary schoolteachers worldwide and are based on an innovative approach appealing to the creativity and artistic sensibilities of pupils. As educational material, the kits use a creative approach to awaken environmental knowledge through creative and thought-stimulating activities that encourage rediscovery and appreciation of the natural environment and biodiversity. Another important dimension of this approach is to bring in the very notion of sustainable development through the application of creative activities: in real-life situations and through specific exercices like creating illustrative inventories, role playing, scenario building, achieving frescoes, gardening, pupils learn to think of people as playing an integral part of the ecosystem and develop their capacity to think critically about the impact of human activities on the environment. As such, the kits are consistent with the activities developed as part of the Decade of Education for Sustainable Development (2005–2014) of which UNESCO is lead agency and feed in with the vision of education developed by the Education Sector Paper as it specifies that "pursuing sustainable development through education requires educators and learners to reflect critically on their own communities;

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identify non-viable elements in their lives; and explore tensions among conflicting values and goals. ESD brings a new motivation to learning as pupils become empowered to develop and evaluate alternative visions of a sustainable future and to work to collectively fulfil these visions."

Keywords Sustainable development, drylands, creative approach, environmental knowledge

1 Introduction

In December 2002, the UN General Assembly adopted by consensus a resolution establishing the Decade of Education for Sustainable Development (DESD). The resolution designated a ten-year period (2005–2014) and declared UNESCO as the lead agency to promote the Decade. The Organization has a dual role to play: first as the lead agency in the promotion of the Decade, and second as the responsible agent for the substantive content of the DESD.

In concrete terms this implies a revisional approach and re-think of the way education can more fully integrate the concept of sustainability, which associates economic, social and environmental objectives with cultural diversity and poverty reduction objectives.

2 Education for Sustainable Development

"Education for Sustainable Development" involves the following:

- To share the values and principles underpinning sustainable development
- To learn about sustainable development, which is no longer considered as a separate subject but is embedded in the curricula
- To foster participatory decision-making that reinforces the participation of local populations
- To develop critical thinking
- To use a multi-method approach based on words, discussion, experience, scenario-building, individual creativity, and indigenous knowledge and their transmission

Pursuing sustainable development through education requires teachers, trainers, educators, but also "apprentices", to critically reflect on their own communities – and the way rural areas are organized – in order to identify non-viable and non-sustainable practices and thus analyze the pressures that exist between the benefits of sustainable development and the immediate objectives of the communities that can be in conflict with a sustainable development perspective.

Taking into account environmental issues in the elaboration of development policies is at the heart of this analysis and is an essential dimension of the methodology. In rural dryland ecosystems, every level of the population is affected by land degradation and this in turn influences their potential to live in this challenging environment.

Environmental education and public awareness about sustainable development are therefore important at every level and should begin at an early stage so that they have greater impact on the consciousness of the individual. To achieve this, it is essential to develop educational programmes based on a pedagogical method that will awaken environmental knowledge among the pupils. Such programmes can become major tools to develop the community's ability to combat desertification while endeavouring to conserve biodiversity.

3 Environmental Education Publications at UNESCO

A number of UNESCO publications in the field of environmental education fit exactly within the principle of public awareness programmes on sustainable development. Initiated by UNESCO's Man and the Biosphere (MAB) programme, these publications are specifically tailored to the drylands and endeavour to assist teachers and their pupils to better understand environmental issues and to stimulate their exploration of possible solutions in a way that is both concrete and practical.

Launched in 2001, the *Education Kit on Combating Desertification* is a valuable tool that can be fully adapted by primary and secondary school teachers. The information contained in the kit can be integrated into the regular school curricula. The kit comprises four elements in a presentation case: a teacher's guide, a series of case studies, three copies of a comic book and a poster.

The teacher's guide: *Learning to Combat Desertification* comprises 20 units introducing the various aspects of the desertification phenomenon in a didactic manner.

The case studies: *Combating Desertification Bears Fruit* cites concrete projects implemented in 12 countries affected by desertification and land degradation.

The comic book: *The School Where the Magic Tree Grows* was inspired by one of the case studies where pupils created a nursery in their primary school in Chile.

The poster is intended to be displayed in the classroom, where it is constantly visible. It is essentially a world map presenting the various drylands around the globe, illustrated with representative photographs.

The kit was initially distributed among selected primary schools in countries affected by desertification, in three language versions (English, French and Spanish), and distributed principally through the UNESCO Associated Schools network (ASPnet) and the UNCCD Secretariat.

Today the kit has been translated into a further six languages (Arabic, Chinese, German, Hindi, Mongol, Russian). In order to meet the needs of other countries affected by desertification, other language versions are envisaged. In total, 9,000 copies of the kit have so far been distributed to more than 40 countries.

4 A Creative Approach to Environmental Education

In order to continue the work carried out so far, which has been very encouraging, within the framework of activities developed for the Decade of Education for Sustainable Development, UNESCO has undertaken to develop two new environmental education kits, both of which are being developed using the same methodology. One of the kits has been conceived to be specifically used in drylands.

This kit is entitled *A Creative Approach to Environmental Education – Teaching Resource Kit for Dryland Countries* and is intended for primary and secondary school teachers. It is based on an innovative approach that appeals to the creativity and artistic sensibilities of pupils in the 6–15 age group. It is designed for teachers of various disciplines, such as geography, biology and the visual arts. It is broadly aimed at all teachers wanting to carry out an environmental education project, either alone or as part of a team, in a formal or non-formal educational setting.

Initially, the creative approach of the kit fosters the pupil's discovery of their environment using their own senses and sensibilities. Children living in countries affected by desertification, often situated in rural regions, have a concrete, pragmatic experience of their environment.

With the kit's activities, teachers invite the pupils to venture out of the classroom and guide them in nature. They are encouraged to observe, contemplate and notice things that they might not have readily perceived beforehand. They learn how to observe an element, an object of their environment in detail, as they are invited to describe it using their own words.

By placing them side by side, they rediscover the objects as they compare them within assemblages and compositions they obtain collectively. The teacher encourages the pupils to draw on specific occasions and instances when drawing enables them to better observe and understand. The objective is not to develop an ability to draw but rather a capability to observe nature. The pupils are also made to recognize and identify the smell and taste of plants from which their preparations/dishes are made.

They rediscover the *depth* of the environment by placing themselves *within* the landscape, as well as by putting into practice a number of exercises that distinguish the human scale and the landscape scale.

In short, the environment's aesthetic and inspiring qualities are used in order to arouse pupils' curiosity and attract and maintain their attention. Awakening curiosity and attention works as leverage towards a better transmission of scientific information and environmental knowledge. We better understand those elements that are closest to us – the familiarity derived from this personal experience, and which we have learnt to care for – because we consider them to belong to our universe.

Furthermore, scientific information and environmental knowledge are made clear and passed on to the pupils through the kit's activities, which build upon local and common knowledge that is repositioned within a scientific perspective.

Many activities encourage exchanges with guardians of indigenous knowledge within the community, such as shepherds, farmers, foresters, trackers, medicinal plant healers, craftsmen. A tripartite relationship is often forged, brought out in the very methodology of the activities, between the teacher(s), the resource people within the community and the pupils themselves.

During the implementation stages, should the teacher wish, he or she can create an open forum in the classroom where pupils are invited by members of the community (knowledge-guardians) to explore the relationship between the ecosystem and their local culture. This has the effect of facilitating the transmission of knowledge, know-how, and the practice of oral traditions through stories and anecdotes.

The teachers can then reposition this knowledge within a scientific context: How can indigenous knowledge and scientific information on the fragile dryland ecosystems be combined? How can this be associated such that this leads to a better understanding of conservation as well as the sustainable use of environmental resources?

The pupils are thus shown how to develop their critical senses and the teacher guides them by arousing a gradual observation of the impact of human activities on the environment. By identifying practices that are neither viable nor sustainable, they can better appreciate the meaning behind sustainability in the dryland ecosystem.

The activity ‘Drawing Shapes and Forms: The Anatomy of Plants’ aims at mastering identification of plants, especially trees, ‘from a distance’. The teacher draws upon pragmatic knowledge gleaned from the local habitants, the community elders: On which criteria do local people identify a particular plant from a distance? They often use these empirical data and skills in their daily “practice” of the environment in order to better adjust to it, as when they have to walk great distances to collect fruit or fodder from trees or shrubs for their herds. As this empirical knowledge can be useful to the population, it is important to combine it within the activity with a more comprehensive and scientific description of what a tree is.

Pupils develop an awareness and appreciation of the structure, form and architecture of the trees through to ecological functions achieved by the vegetation, from their roots to their tips (the isolated tree epitomizes a real ecosystem), and to the necessity to integrally conserve it in an environment where the ecological balance is fragile.

The aim is to be thought-provoking, to question the impact of exterior elements on the shape and form of the vegetation and whether they are caused by the impact of wind or by people who remove the vegetation without necessarily realizing the destruction it causes, or are they the result of general impacts of human activities such as overexploitation, or by herbivores feeding?

Another activity of the kit, ‘An Inventory of Useful Plants’, serves to position humans in the ecosystem by exploring the extent to which they play a vital role. At which point is the ecosystem important to the well-being of everyone? And how does biodiversity meet each of the diverse needs of humans?

Regarded as a source of crops and bounty, the ecosystem is likened to a garden whose fruits are consumed by the community: a nourishing garden (edible plants), a healing garden (medicinal plants and oils), and a protecting and reassuring garden (the use of plants in house construction and clothes manufacture).

The pupils are then moved to consider, using the same logic, how, conversely, the community takes care of nature.

In the activity 'The Plant as Mascot', the class selects a specific plant. The pupils present an exhibition that highlights the multiple services provided by the plant, which plays a vital role in the daily lives of the community. They present a specimen of the plant together with all the products and finished items derived from it – for example, soap from olive oil obtained from *Olea europaea* or a pestle or knife handle made from the hard *Balanites aegyptiaca* wood. Assisted by the guardians of local knowledge, they introduce the notion of know-how with drawings that explain the process of production.

The ingenuity of humans is evident from the relationship established between the tool, human creativity and dexterity, and the plant collected from nature.

The exercise helps to clearly identify the types of removal, production and distribution of the plant, which may be harmful to the ecosystem.

Finally, a group of teachers develop a concrete teaching project with the garden in mind. They ensure that the concept of sustainable development is actively considered and at the heart of the project, which teaches pupils to become active in the long term not only for their own benefit but also for the benefit of future generations.

The Experimental Garden is developed *en relais* of a land management programme outlined in the above activity, 'The Plant as Mascot'. The garden site is thus linked to sites selected by the local decision-makers where pilot activities concerning environmental protection are tested. The school class will move between the experimental site, i.e. the garden, and the areas cultivated by the professionals, such as farmers, foresters, landowners, environment experts, as it occurs in a realistic context.

The complete pedagogical kit comprises a teacher's book divided into three thematic chapters:

Chapter 1: Discovering the Ecosystem and Its Biodiversity
Chapter 2: Maintaining the Plant Cover
Chapter 3: Preserving Water Resources

Each thematic chapter contains seven activities ranked according to their content and complexity. The kit also contains classroom materials designed as a complement to the teacher's book, namely an exercise book and a map, used by the class.

The choice of a colour code in each kit clearly identifies the elements and highlights the structure. The design and layout of the *Teaching Resource Kit* attempts to be clear and attractive – reflecting the spirit of the project. Graphic symbols placed alongside the description of each activity allow teachers to better identify and adapt the pedagogical material.

In particular, they will be able to assess:

- The level of the activity (its level of difficulty in terms of content and implementation)
- The site of the activity, whether to be conducted inside or outside the classroom
- The number of sessions required to complete the activity (session length can be determined by the teacher, but generally lasts 2–3 h, depending on the time available)

Each activity begins by first outlining the objectives.

The required methodology is shown by breaking up the activity into sequential steps each exemplified by an action verb such as “collect” or “organize”. This achieves a sense of dynamism and at the same time a feeling of progress made.

Scientific and technical terms related to ecology or environment knowledge are clearly identifiable: they are highlighted in pink and direct the reader to a glossary at the end of the book. This has the effect of strengthening the teacher’s knowledge base while clearly specifying the required knowledge.

The *Teaching Resource Kit for Dryland Countries* will be available in four languages, Arabic, English, French and Spanish.

References

To download a copy of the sample introductory booklet:
English version: http://www.unesco.org/mab/ecosyst/drylands/docs/kitArt_E.pdf
French version: http://www.unesco.org/mab/ecosyst/drylands/docs/kitArt_F.pdf

Chapter 6
Environmental Education: An Alternative to Development in Drylands

Farida Khammar

Abstract Thirty years on after the UNESCO recommendations environmental education is far from becoming a reality in the majority of countries despite the urgency of the matter; its implementation is a veritable condition for survival in developing countries.

In Algeria, initiatives do exist but often they are too isolated. Today environmental education can only achieve a significant stage of expansion if all spheres of society become involved, such as teachers, parents, unions, communities, consumers, businesses, media, public and private organisations, and relevant ministries. Thus since the Johannesburg Summit in 2002, environmental education issues that take into account sustainable development has become a national priority especially as regards apportioning responsibility inherent with major risks.

Agreements signed between the Ministry of Land Planning and the Environment and the Ministry of National Education and Professional Training has enabled on the one hand to renew education and training approaches by proceeding with a veritable introduction of this concept in programmes and, on the other hand, modify pedagogic approaches so as to reinforce the relationship between school and society.

The objective of this paper is to present the Algerian experience and to share this issue with scientists.

Keywords Education and training, sustainable development, Algeria, environmental issues

1 Introduction

People have always had a keen interest in nature by overseeing its protection but the notion of the environment has been gradually constructed, particularly in the last century, as the importance of economic and demographic development has grown. Today, humanity is faced with important environmental problems, most

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notably, water availability, land degradation, biodiversity loss, ecosystem degradation, ozone depletion and the greenhouse effect; these ills are due principally to non-sustainable production and consumption systems. To this effect, numerous commitments have been made but remain to be realized. Environmental issues suggest a conscience and choices that citizens must make themselves, issues on which knowledge and science can only shed light.

Today, the teacher is expected to acquire some certainties on the evolution of the environment and on the dangers that threaten the fundamental equilibrium of the planet. We also understand that environmental issues especially beg the fundamental question of growth and development and the form and content they might take: the important social and environmental stakes linked to environmental education are poverty, urbanization, strong demographic growth, and the inability of human beings to adapt to change. Today, industrial countries produce the greatest quantity of greenhouse gases and enclose developing countries in a world of regression and debt, which are themselves causes of desertification and soil loss. It is therefore urgent to contribute to the elaboration of other models of growth and development that instil a sense of justice and peace, and are concerned with the planet's future. It is in this connection that the future of humanity and the sense and mission of education have appeared, linking several relevant concepts to environmental education.

2 Some Historical References

At the first international environmental conference in Stockholm in 1972 (United Nations Conference on the Human Environment), complementing the *Declaration of Human Rights*, the first article of the final document proclaims:

> Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment of a quality that permits a life of dignity and well-being, and he bears a solemn responsibility to protect and improve the environment for present and future generations.

From the beginning of the 1980s, the economic crisis rendered environmental concerns a non-priority. By the end of the 1980s, the public became aware that the concerns raised by the ecologists were real and, as a result, educational activities were established during this period. In 1987 the term "sustainable development" was affirmed by the Brundtland Commission in its report *Our Common Future* and was later defined at the Rio Summit in 1992: 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. This concept became the subject of many criticisms as it suggested an economic vision for the environment–development relationship. Early on we noted that this concept revealed an obvious cultural dimension, as pointed out by Lucie Sauvé (1997):

> it does not appear that the notion of sustainability has a meaning for indigenous cultures, from whom we should be inspired in order to envisage new models with respect to environment and development.

Moreover, a genuine dynamic of sustainable development can be conceived only if it is based on ethics and social equality.

We therefore recognize that in 2006, more than 30 years after UNESCO's pertinent recommendations adopted at the occasion of the Belgrade Charter (1975) and the Tbilissi Conference (1977), many educational measures and actions were implemented but with little impact – this was probably due to a lack of evaluation and feedback.

3 Some Important Questions

- Within the framework of "Education for Sustainable Development", decisive questions arise about the future, yet many scientists do not share the same vision.
- In less-developed countries, and in particular countries situated in the planet's arid zones, it is important to know how to integrate environmental themes and the tenets of sustainable development into training schemes that serve society.
- In fact, do all societies perceive the environment in the same way, with its considerable political and economical stakes, which oblige us to think globally?
- Can the debate on scientific ethics be considered inseparable from science itself?
- Will less developed countries truly benefit from the interest generated by the environment or will they continue to use its resource pool?
- How is the concept of sustainable development to be introduced into the school? And how is the concept of sustainable development to be valorized rather than using it as a means to maintain world imbalance?
- What is required for education to consistently integrate development issues? Knowledge should have a global and cross-cutting scope (environmental education, health, civility, development).

While questions that constitute a challenge to education cannot be easily answered, a few possibilities can nevertheless be explored here:

- Environmental education should not be limited to teaching behavioural values (responsibility, equality, solidarity, sharing, and tolerance) but should also teach one to acquire the capacity to understand the interactions between scientific, social, ethical, and judicial knowledge that structure the world we inhabit.
- Environmental education is about teaching citizens to evaluate risk, to question various issues and to make enlightened choices. Thus the teacher should be able to provide the student with elements of doubt and thereby teach the causes of problems and not just the solutions – the goal is to attain a level of independent judgment and provide tools for critical reasoning.
- Teacher training, as well as scientific research programmes in this field, should be targeted as a priority, without which progress is impossible (Fig. 1).
- Finally, do not spend too much time debating the concepts, the projects or the correct behaviour to adopt as this has the effect of demotivating the actors.

Fig. 1 Training

4 The Algerian Experience in Environmental Education

Following the example of other countries, Algeria is a major player in the United Nations Decade of Education for Sustainable Development (2005–2014), with UNESCO as the lead agency.

The National Action Plan for the Environment and Sustainable Development (NAPE-SD), adopted in 2002, has enabled Algeria to set out resolutely on the road to sustainable development. It aims to institute this concept at all levels in a way that allows each citizen to comprehend the stakes. At the institutional level, its implementation requires the reinforcement of environmental governance at different levels of orientation, decision-making and execution.

Furthermore, since the Johannesburg Summit in 2002, the growing awareness of environmental education issues has become a priority in the public sector. Memoranda of Understanding have been signed between the Ministry of Environment and the Ministries of National Education and the Ministry of Education and Professional Training. These protocols have, on the one hand, enabled the introduction of this concept into the school curricula, and on the other hand, instilled change in pedagogical approaches, thereby reinforcing the links between school and society.

Didactic research programmes are thin on the ground, however. We note, for example, our experience at the research station in the oasis of Béni-Abbès

(30°7′N, 2°10′E, of Béchar). Secondary teachers and researchers initiated the discovery of the oasis environment and the surrounding natural habitats for children across three principal themes: flora, fauna and water. It also involved valorizing the creative outputs of the children, providing them with tools to document the Saharan environment, and promoting the distribution of documents produced. The topics on flora, fauna and water have made it possible to assess the problems of adaptation to the arid environment and to question water efficiency. With the aim of informing, raising awareness and sharing achievements, activities have been formulated: classes in the field, outings, surveys, model building, video filming and the making of an experimental biological pool. The latter has become a pole of awareness and information for the population of the oasis and the schools in the region. The children have played an impressive driving role in carrying out all the activities. They were both actors and active, they were responsible for conducting surveys, they showed determination to learn more, and they were willing to share their achievements with other children of the oasis, with local associations and even local authorities. This responsibility is undoubtedly at the heart of changing attitudes, which is clearly observable among the youth, not only through their acquisition of knowledge but also by the clarity of values that underlies their new practices. The acquisition of new knowledge was facilitated by the personal contact established with the researchers but also by the interviews carried out or even during the visits to the farms or outings in the field (Fig. 2). The work carried out by the club is structured by the teachers in teams but in an

Fig. 2 Pedagogical outing

autonomous way and is organized in an equipped classroom containing documentation. The teachers gave the children the responsibility for the project, and this became a source of motivation and a way of attributing responsibility. This approach, comparable to the researcher who wishes to share results, is typical of the pedagogical approach of the project proposed by the Réseau 'Ecole et Nature' (1997; School and Nature Network). It creates multiple learning opportunities which can clearly be observed through the children's progress as they gradually invest themselves in the activities (Fig. 3).

The message concerning indispensable water efficiency was relayed by the children. Feedback was established between the children and the families involved in the surveys, which valorized the activity of the club. The need to

Fig. 3 Drawing competition

Fig. 4 Crops irrigated with purified water

Fig. 4 (continued)

cooperate with all the social partners was understood. The pool has now become a pole of awareness and information for the population of Béni Abbès and the schools of the neighbouring oases (Fig. 4). A large project is currently being studied for the entire commune.

5 Conclusion

This paper highlights a few elements facilitating the thought processes of what constitutes education on environment and sustainable development. We should conceive an alternative economy with a new rationale and therefore another conception of progress. We want education that serves *everyone*, and particularly marginal populations, who are continually combating the scourge of desertification.

Bibliography

Giordan, A. 2002. *Une autre école pour nos enfants? Le grand débat*. Delagrave Editions, France, 250 pp.

Khammar, F., Gernigon, T., Benrahou, H. and Radjaa, B. 1999. Evaluation des activités du club de biologie de Béni-Abbès. *Proceedings of the Journées internationales en éducation scientifique (JIES)*, Chamonix, France. Giordan, A., Martinand, J. L. and Raichvarg, D. (eds.), pp. 533–537.

Remki, L., Blidia, M., Gernigon, T., Khammar, F., Reynaud, C. and Favre, D. 2004. *Environmental Education in the Algerian Education System.* BIOED, Rio de Janeiro. Brésil, 13–18 septembre 2004.

Réseau 'Ecole et Nature'. 1997. *Alterner pour apprendre entre pédagogie de projet et pédagogie de l'écoformation*. Edition Ecole et Nature.

Sauvé, L. 1997. *Pour une éducation relative à l'environnement*. Edition Guérin, Montréal.

Chapter 7
Sustainable Management of Marginal Drylands (SUMAMAD): Sharing Success Stories from Indigenous, Adaptive and Innovative Approaches

Caroline King

Abstract The interagency project on Sustainable Management of Marginal Drylands (SUMAMAD) is an international, coordinated research initiative involving farmers, pastoralists and scientists undertaking participatory research. With support from the Flemish Government, this project includes a network of research teams at eight study sites in marginal dryland areas in North Africa and Western Asia (UNESCO, 2004). The project approach, developed through a collaborative effort between UNESCO, UNU-INWEH and ICARDA, focuses on supporting local populations in their efforts to use their natural resources in a sustainable manner (Adeel et al., 2002).

Over the past year, a compilation of sustainable management approaches and technologies – indigenous, adaptive and innovative – has been made at each of the participating locations. These have included practices for water management, rangeland rehabilitation, and sustainable cultivation of crops, trees and livestock (King, 2006a). Sustainable management approaches are supported by complementary alternative income-generating activities in order to reduce the pressures caused by overdependence on natural resources. Exploration and testing of these management approaches is being undertaken by the study teams and local communities with a view to combating environmental degradation, increasing dryland agricultural productivity, enhancing resource conservation and contributing to local livelihoods. Success stories reported so far have been shared across the project network, leading to an exchange of knowledge and expertise, cross-fertilization of ideas and further adoption of such innovative approaches in workplans produced by the research team leaders for the coming year.

Keywords Sustainable management of Marginal Drylands (SUMAMAD), participatory research, knowledge management, water resources

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1 Introduction

This paper considers the sharing of experiences in participatory research in an international cooperative research project on the Sustainable Management of Marginal Drylands (SUMAMAD). This project focuses on harnessing participatory and scientific techniques to promote and test indigenous, adaptive and innovative management approaches. The aim of the current paper is to consider the added benefits that are created by sharing the individual experiences of this research through the framework of a coordinated international project, such as SUMAMAD. The paper describes the coordination of activities across the SUMAMAD project, comparison of management practices and activities, exchange of knowledge between participants, and dissemination to a wider international audience. The international exposure and acclaim that is generated through this process may be seen to stimulate continuing achievements in innovative and adaptive management at each of the study sites. These additional achievements complement the existing work programmes of each individual institution, bringing benefits that reach beyond the immediate project activities and outputs of SUMAMAD alone.

2 Indigenous, Adaptive and Innovative Management Approaches in Drylands

Dryland dwellers in various parts of the world have developed many adaptive management strategies to reduce vulnerability to desertification, land degradation and water shortages. According to the findings of the recent Millennium Ecosystem Assessment, experience in drylands has shown that locally appropriate interventions can introduce dynamics of sustainability and improve human well-being (Safriel et al., 2005; UNCCD, 2000) both through traditional or indigenous knowledge, and through the adaptation of new technologies. Indigenous knowledge and management practices are refined through a continual process of user experimentation and observation over time to be well-suited for use in local conditions (González, 1978; Brokensha et al., 1980; Niamir, 1990; Inglis, 1993; Berkes et al., 1998; Laureano and Adeel, 2002). This process ensures against negative effects on underlying ecosystem processes, such as water, nutrient and soil regulation (Stoorvogel and Smaling, 1990; Thomas, 1997; Rockstrom et al., 2004). In some areas such successful indigenous strategies have been found lacking, rendered obsolete by new developments and challenges (Blaikie and Brookfield, 1987; Safriel et al., 2005). In such cases, the introduction of innovative new technologies can be successful where the trial and development of techniques have been undertaken in an adaptive fashion, involving scientific observation by researchers and land users with an understanding of local conditions (Chambers et al., 1989; Scoones and Thompson, 1994; Prain et al., 1999; Safriel et al., 2005).

In recent years, scientific methods have enhanced the exploration and evaluation of many dryland management practices, providing participatory research methods to involve local communities in an accelerated, scientifically-based, adaptation process

(Chambers et al., 1989; Pretty et al., 1995; Pound et al., 2003; Reij and Waters-Bayer, 2001; Gachimbi et al., 2005). Participatory approaches to technology development often employ research networks to change knowledge, rather than top-down technology transfers, and focus on encouraging partnerships within and between participating locations to enhance social adaptive capacity and connectedness (Critchley, 2000; Wu and Pretty, 2004; Critchley and Mutunga, 2003; Gonsalves et al., 2005). Increasing recognition is given to the role of such “communities of practice”, in many areas of research (Barab and Duffy, 1998), including dryland management. The description of the SUMAMAD project that is provided in this paper focuses on the knowledge sharing aspects of this project as an example of such a network model for learning and exchange in dryland management and research.

3 Background to the SUMAMAD Project

The SUMAMAD project was developed through a collaborative effort between the United Nations University (UNU), United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Center for Agricultural Research in the Dry Areas (ICARDA) (Adeel et al., 2002). This collaboration builds on the longstanding record of achievement of all three institutions in various aspects of dryland research. Nine study sites were selected to receive project support for research and training activities during the period 2003–2007. The location of these study sites are shown on the map below.

4 Methods for Coordination of Research Activities Across the SUMAMAD Network

The nine participating SUMAMAD research sites (Fig. 1) differ widely with regard to their topographic, climatic and demographic conditions, as well as in terms of the administrative and institutional mandates affecting their management (UNESCO,

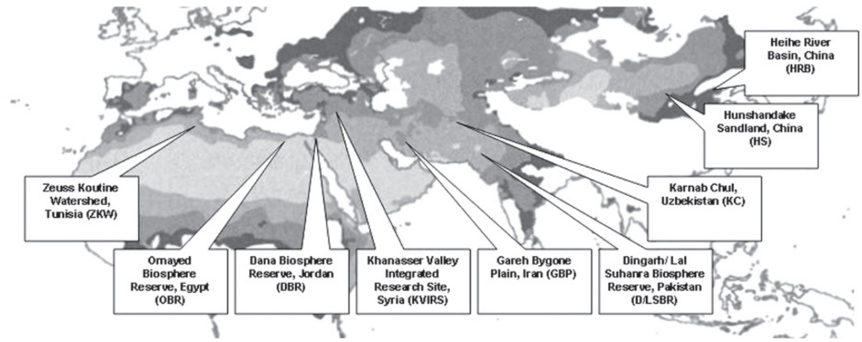

Fig. 1 SUMAMAD Project research sites
(Dryland map from Millennium Ecosystem Assessment: Current State and Trends in Dryland Systems, Safriel et al., 2005)

2003). Comparisons between the study locations have been facilitated by the application of a common, generic assessment methodology for the characterization of the sites during the first year of the project (SUMAMAD, 2004). This methodology focused on describing the state of existing natural resources, characterization of stresses and description of indigenous, adaptive and innovative approaches. Wide variations between conditions at the study sites were revealed; however, many similar and comparable themes regarding the identification of pressures and necessary management approaches were also observed (King, 2004). The principal problems identified at most sites included land degradation, erosion, overgrazing, poor quality and shortage of water, overdependence of the local populations on scarce natural resources, as well as various manifestations of poverty and insecurity of livelihoods.

During 2005 the focus of activities centred on the investigation and promotion of practices for soil and water conservation and the rehabilitation of degraded land through a common approach based on participatory research with local communities. The aim of this research was to identify management practices of relevance to local needs, involving traditional knowledge, modern expertise, or a combination thereof. Participatory research methods used varied from formal participatory techniques (see Chambers, 1993) involving workshops, site visits and surveys to informal discussions over cups of tea that have been taking place for many years between researchers and local people at the study sites (Kahlown, 2006, Field visit discussion. to: King, C., personal communication). In some cases, techniques in Participatory Learning Action Research (PLAR) have been used or adapted by researchers (PCRWR, 2006). The results obtained revealed a series of different practices that had been adapted by dryland dwellers at each site (King, 2006a). Once again, the practices selected for investigation differed widely, according to the context and needs of the study sites and populations (see Tables 1–3 below).

Activities scheduled for 2006 include the testing and promotion of selected management practices through site-specific activities. Although the practices considered vary, the criteria for their evaluation retain a common orientation to the overall project aims to improve the livelihoods of dryland dwellers and reduce vulnerability to land degradation. Two types of indicators have been employed by the study teams in testing activities carried out so far (King, 2006a):

Table 1 Water management approaches

Source	Technique	Study sites[a]
Floodwater harvesting	Check dams	OBR, KVIRS, ZKW, D/LSBR
	Groundwater recharge wells	ZKW, KVIRS
	Floodwater spreading	GBP
Rainwater harvesting	Cisterns	OBR, ZKW, D/LSBR
	Rooftops	OBR
	Jessour	ZKW
Groundwater use	Efficient irrigation systems	D/LSBR, DBR
	Optimal allocation	ZKW
	Saline water use	OBR, LSBR

[a]See key to acronyms in Fig. 1

Table 2 Land management approaches

Type	Technique	Study sites[a]
Soil management	Integrated farming and fertility management	OBR, GBP, D/LSBR, KVIRS
	Soil stabilization	ZKW, KC
	Soil water-holding capacity	OBR, GBP
Planting crops and vegetation	Transplant indigenous species	OBR, KC, GBP
	New water efficient cultivars	GBP, OBR, D/LSBR
	High-value crops	KVIRS
Natural restoration	Soil seed banks	HS
	Carbon sequestration	HS, KC
	Biomass production	HS, OBR

[a]See key to acronyms in Fig. 1

Table 3 Alternative income generating approaches

Source	Activity	Study sites[a]
Alternative products	Chicken-raising	HS
	Fish farming	D/LSBR, GBP
	Agroforestry	GBP, D/LSBR
	Market gardening	KVIRS, DBR, D/LSBR
Natural product processing	Cosmetics/soap	KC, DBR
	Tofu/milk products	HS
	Fruit drying and jam	OBR, ZKW
Ecotourism	Visitor attractions	ZKW, KC, HS
Handicrafts	Sewing, weaving	OBR, KC

[a]See key to acronyms in Fig. 1

- Income generated from alternative activities that are not associated with land degradation
- Increased generation of ecosystem services contributing to human well-being (the reverse of land degradation, which is defined by the Millennium Ecosystem Assessment as a persistent reduction in ecoystem services [Adeel et al., 2005])

Both types of indicators demonstrate improvements to the livelihoods of dryland dwellers and reduced vulnerability to land degradation – the first in the short term, and the second over the longer term. These are variously observed at the different sites.

The development of this coordinated approach has been led by the project management group to ensure coordination with international trends in current drylands research (Adeel and King, 2004; Adeel, 2006; Safriel et al., 2005). Elements from these models have been incorporated into the project workplans by the team leaders through a discursive process of selection, modification, and prioritization with local communities, ensuring that the project approach and frameworks deployed are user-driven. Iterative discussions for comparison, review and coordination of approaches within the project take place each year at an annual international workshop, creating an opportunity for South-South exchange and cooperation.

5 Indigenous, Adaptive and Innovative Approaches to Improve Dryland Livelihoods and Reduce Vulnerability to Land Degradation Identified by the SUMAMAD Project in 2005

This section describes in more detail the broad range of management approaches identified by the SUMAMAD research teams during 2005 to be either currently in use at their research sites, or of relevance to their needs. A summary of these techniques is given in Tables 1–3 (see King, 2006a; PCRWR, 2006). Some of the techniques are longstanding practices, such as the spring-water irrigation of terraced gardens at the Dana Biosphere in Jordan. This practice was formerly used to provide fruit and vegetables to enhance local livelihood security, but had fallen into disrepair as lifestyles and labour patterns in the village changed over recent years. In other cases, the techniques are newer practices that have been developed at the study sites through ongoing experiments, such as soil improvement through the application of olive waste products ("margine") at the Zeuss Koutine Watershed in Tunisia. In some cases, team leaders have used pilot projects to introduce practices hitherto not used by local communities at the study sites, such as the use of solar-powered desalination of saline groundwater at the Omayed Biosphere Reserve, Egypt, or plastic greenhouses for flower and vegetable cultivation in Karnab Chul, Uzbekistan.

The new practices introduced by SUMAMAD are rarely unique or unheard-of – even solar-powered desalination has a long history of use (Delyannis, 2003), but the adaptation and site-specific mix of activities is the key to their success in improving local livelihoods. In each case, participatory scientific methods have been used in order to adapt techniques for use by local communities. In some cases, the adaptations have consisted of new processing methods for traditional products, such as wool, carpets, dried fruits and other farm products, in order to make the products marketable. In other cases, the adaptations have been innovative new design solutions to water management systems, such as design improvements to systems for groundwater recharge in Syria and Tunisia, and to solar desalination units in Egypt. A process of observation and testing with local communities has been undertaken, with early results showing considerable interest and replication of some techniques (PCRWR, 2006). Preliminary reflections on the evaluation of these adaptive management improvements are included in the latest project overview reports (King, 2006a; Adeel, 2006).

6 Adoption and Development of Management Activities Across the SUMAMAD Network

Although Tables 1–3 present a common typology of management approaches identified within the SUMAMAD project, the priorities and experiences of the participating institutions varied. The SUMAMAD project activities at each of the project sites are run alongside a range of other activities taking place within each institution, according to their various mandates. Some of the locations are Biosphere Reserves, with ongoing programmes for nature conservation and outreach to local communities; others, such as the Institut des Regions Arides, Zeuss Koutine Watershed, Tunis, Pakistan Council for Water Resources Research, and ICARDA in Aleppo, are engaged in agricultural research activities; and finally, some are universities. However, the common interdisciplinary approach adopted in the SUMAMAD project is designed to enable the exchange of knowledge and the adaptation of new approaches. Thus the research network should achieve more through its collective activities than the individual institutions would otherwise have done independently. This integrated approach to issues in dryland management therefore complements ongoing work programmes of the institutions, strengthening elements that have not been central to the institutional objectives.

The following brief descriptions of activities at the study sites highlight the progressive development of the focus of activities over the three-year period since the beginning of the project (see UNESCO, 2003, 2004; PCRWR, 2006). Each of the study teams started out with specialist knowledge and expertise addressing dryland management from a particular perspective, determined by the institutional context and background. During the development of the SUMAMAD project, these experiences have developed and broadened to encompass sustainable management approaches that improve local livelihoods and reduce vulnerability to land degradation, often in a wider sense than previously considered. For example, it can be seen that the increasing development of activities on water management shown in Table 1 above builds on existing expertise in some cases, while introducing new aspects to the institutional research programmes in others.

6.1 Hunshandak Sandland (HS), China

Researchers from the Chinese Academy of Sciences had been conducting investigations at the Hunshandak Sandland and Xilin Gol Biosphere Reserve on the effects of natural restoration for several years before the SUMAMAD project began (Peng et al., 2005; Jiang et al., 2003). The SUMAMAD project activities have supported scientific fieldwork studies on restored areas to assess water and carbon storage and net primary production, as well as soil seed banks. In addition, the research team has created a cooperative company for local people to develop sustainable alternative income generating activities, such as raising chickens and processing traditional milk tofu products.

6.2 Omayed Biosphere Reserve (OBR), Egypt

Researchers from the University of Alexandria had been studying environmental processes at the Omayed Biosphere Reserve, and conducting anthropological studies of local Bedouin cultural practices, before the SUMAMAD project began. The project has enabled the continuation of environmental analysis at the study site using satellite data and field studies. It has also included participatory research for the identification of water conservation techniques, and prioritization of solar-powered desalination for further investigation. Activities for alternative income generation have also been identified with local communities, including sewing for women and solar-powered fruit-drying for men.

6.3 Gareh Bygone Plain (GBP), Iran

The technique of artificial recharge of groundwater (ARG) by floodwater spreading in areas under forestry development has been studied over many years by the team leader (Kowsar et al., 1978; Mehdizadeh et al., 1978; Kowsar, 1982; Raeisi and Kowsar, 1998; Naderi et al., 2000; Mirnia and Kowsar, 2000; Mohammadnia and Kowsar, 2003; Kowsar, 2005). With support from the SUMAMAD project, as well as from other sources, a cooperative has been established on the Gareh Bygone Plain through consultation and agreement with the local community. Scientists and local people are now collaborating in the design and construction of an artificial recharge system to support their livelihoods through a sustainable mix of farming, forestry, apiculture and fish-farming activities. Researchers are currently investigating the use of indigenous tree species in the floodwater spreading areas, rather than the exotic *Eucalyptus Camaldulensis* Denh, which has been used hitherto. Biodiversity conservation studies have also been developed to complement the water conservation activities in recognition of the role of biodiversity in improving the sustainability of the system.

6.4 Dana Biosphere Reserve (DBR), Jordan

This study team is made up of staff members of the Biosphere Reserve, which has an ongoing programme of nature conservation and community outreach activities, including income generation through jewellery production workshops and ecotourism activities. Through the SUMAMAD project, detailed surveys of local livelihoods and attitudes towards the conservation project have been carried out to determine the needs and perspectives of the local community. During a community workshop, the study team identified activities on the improvement of water management in traditional gardens around the village. The project has also supported the development of olive oil soap products to be locally manufactured as an additional source of income for local people.

6.5 Dingarh Research Station and Lal Suhanra Biosphere Reserve (D/LSBR), Pakistan

The study team in Pakistan is made up of researchers from the Pakistan Council for Research on Water Resources (PCRWR), conducting research at their own research station at Dingarh, Cholistan, and the nearby Lal Suhanra Biosphere Reserve. PCRWR has well-established expertise in water resources research, and has been developing techniques for the construction of water storage ponds over some years, as well as conjunctive use of saline waters in irrigation. Through the SUMAMAD project, these activities have been continued, with the additional use of saline waters in ponds for experiments in fish-farming and vegetable production to provide alternative sources of income.

6.6 Khanasser Valley Integrated Research Site (KVIRS), Syria

Research activities at this site are led by the International Center for Agricultural Research in the Dry Areas (ICARDA), based on its expertise and experience in dryland farming research. Activities undertaken within the SUMAMAD project have included further studies by ICARDA on Participatory Learning Action Research (PLAR) on fertility management, and also new studies at the research site focusing on groundwater recharge technologies. Contributions to local income generation are under investigation through the testing and development of new options for home gardens that integrate improved soil and water management techniques.

6.7 Zeuss Koutine Watershed (ZKW), Tunisia

The research team is led by researchers from the Institut des Regions Arides (IRA), working in collaboration with a group of six local NGOs. IRA has an extensive and long-standing experience in research on combating land degradation and erosion in the area through various techniques for water harvesting, soil improvement and rangeland management (Ouessar et al., 2004; Fleskens et al., 2005). The SUMAMAD project activities build on these achievements through the pursuit of innovations in soil stabilization, groundwater recharge well design and assessment of rangeland rehabilitation. In addition, through the enhanced collaboration with local NGOs that is supported by this project, schemes for income generation through ecotourism, handicrafts and use of medicinal and herbal plants are being explored.

6.8 Karnab Chul (KC), Uzbekistan

Scientists from Samarkand University are leading a team of researchers conducting studies in the rangelands of this location. In addition to continuing studies on rangeland management, this team has introduced additionnal activities, transplanting fodder plants and studying the distribution of medicinal plants in the rangelands. The SUMAMAD project has enabled the collection of socio-economic data in the study area and has supported exploration of a number of potential income generating activities, ranging from traditional handicrafts, ecotourism and production of flowers and vegetables in plastic hothouses.

Table 4 Shows a summary of the progressive adoption of techniques to improve water storage and efficiency, demonstrating increasing exploration of these techniques within the SUMAMAD project. Such convergences among the study site activities may be attributed, at least in part, to the exchange of ideas and expertise that has been fostered.

Source	Technique	In use at study sites from 2004[a]	Exploration at additional sites in 2006
Water storage	Storage facilities (ponds, cisterns)	OBR, D/LSBR, KVIRS	
	Groundwater recharge wells	OBR, GBP, ZKW	KVIRS
Water efficiency	Moisture conservation and soil improvement	OBR, KVIRS, ZKW, GBP, KVIRS	D/LSBR
	Water efficient species	DBR, ZKW, OBR	GBP, HS, D/LSBR
	Integrated farming and fertility management	OBR, KVIRS	D/LSBR, GBP, HS

[a]See acronyms for study site locations detailed in Fig. 1

Looking back over the successive reports from the project, summarized above, it is possible to identify the introduction of new themes into the research programmes of the participating sites through the SUMAMAD project – for example, participatory research on improvements to water resources management at Dana Biosphere Reserve, or development of ecotourism-related activities by IRA at Zeuss Koutine Watershed. Of course, it would not be possible to claim that these new introductions stem only from the inspiration of the SUMAMAD project (both were identified by local communities as priorities for their development during national coordination meetings held by the project). But the SUMAMAD project offers opportunities for each institution to benefit from the experience of others with leading international expertise in the relevant fields (Table 4).

7 Knowledge Management

Progress reports from all of the eight study sites are collected at the end of each year by the project management group. These reports contain details of the activities undertaken during the year, including results obtained and plans for the following phase of activities. The reports are analyzed and synthesized by the management group to develop an accessible overview of the information collected, and to draw comparisons between the various management approaches investigated by the research teams (King, 2006a). This synthesis of findings is fed back into the discussions between the team leaders and into the management of the project. It is also included in the project publications and presented at international meetings for international dissemination and sharing of success stories (UNESCO, 2003; PCRWR, 2006).

8 Exchange of Knowledge and Experiences Within the Project

The annual international workshop for the SUMAMAD project creates a forum for the exchange of experiences through structured presentations consisting of activity reports from each of the team leaders. This has enabled the team leaders to develop a familiarity with the context and themes of the work programmes at other sites, and has led to lively and critical debates concerning the comparative merits of the varying management strategies adopted (King, 2006b).

In addition to these presentation and discussion sessions, the annual workshops have developed more in-depth reviews of activities through field visits by the project group to individual study sites. The concentrated focus of this expert group has led to the articulation of practical insights of relevance to the individual study site under review, as well as to generic conceptual discussions, applicable across the project. These discussions addressed topics such as conservation of indigenous vegetation species, socioeconomic evaluation of water use efficiency, and adoption of a systems approach to integrated agroindustrial production activities. These particular themes appeared repeatedly in the discussions among the team leaders and experts during the Fourth Annual Project Workshop and are recorded in the workshop report (King, 2006b). They are further reflected in the workplans set out for the coming year. Although it would be difficult to assign the origin and inspiration of innovations proposed to any single source within the project, synergies and cross-fertilization can be identified in the approaches undertaken, and traced back to the workshop discussions (e.g. the opportunity to study a selection of indigenous species of trees, discussed in 2004, appeared in the 2006 workplan for the Gareh Bygone Plain).

Following on from the description of experiences and exchange of advice among participants, cooperation and exchanges of training from one team to another have been proposed, with team leaders identifying areas where they could learn from other participants, on the one hand, and expertise that they could make available to others through training, on the other. So far within the project, the requests for training have focused on innovations to improve local livelihoods, such as training in product processing and saline fish-farming techniques or the use of solar-powered technologies for drying fruit and other applications of use to dryland dwellers. Further exchange visits between research sites have been called for in order to offer training and learning opportunities along these lines to project team-members.

9 International Dissemination

The annual meetings and reports of the SUMAMAD project provide written documentation of the project research findings and experiences that can be of use to other research groups (UNESCO, 2003, 2004; PCRWR, 2006). Through the local efforts of the project team leaders, the project also stimulated media attention to the project activities and successes, including television appearances, reports in local, national and international newspapers and magazine articles (e.g. Al Ahram, 22–28 March 2006). During 2005, one of the project leaders received the Great Man-Made River International Water Prize, focusing additional attention on achievements on floodwater spreading and groundwater recharge activities at the Gareh Bygone Plain in Iran. Furthermore, the creation of the international SUMAMAD network has provided a forum through which researchers can be mobilised for participation in other international initiatives on dryland research, such as the Millennium Ecosystem Assessment (Adeel et al., 2005) and international policy-oriented activities for within the International Year on Deserts and Desertification (Adeel, 2005).

10 Local and National Networking and Capacity-Building

The international networking and exchanges are underpinned by national level partnerships and capacity development. In some cases, project teams are made up of members of a range of institutions. For example, in Pakistan, the project activities take place at both the Pakistan Council for Water Resources Research (PCRWR) and also the Lal Suhanra Biosphere Reserve; in Egypt, researchers from a number of universities are carrying out studies at the Omayed Biosphere Reserve. At each site, a National Coordination Seminar is held once a year in order to prioritize activities, provide training and awareness raising activities, and to promote the achievements of the project at the national level. These seminars are attended by local policy-makers, NGOs, community and research institutions. They have been effective in generating additional financial and political support for improved dryland management programmes at a number of the study locations.

11 Conclusion

The SUMAMAD project has created a network of researchers that actively promotes indigenous, adaptive and innovative approaches in dryland management through the exchange of observations and experience. The exchanges take place between participants, through their own growing partnerships and networks, and through dissemination activities at the international level.

Such sharing of experience in the identification, promotion and adaptation of traditional and innovative techniques in dryland management leads to further uptake of management improvements, reducing vulnerability to land degradation and bringing improvements in dryland livelihoods.

Knowledge-sharing activities between study sites, and through participatory activities at the study sites, have ensured that the project activities are guided by the needs of the users at each site, and that the project will continue to address the issues that are of most concern to them.

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References

Adeel, Z. 2005. *Joint International Conference Desertification and the International Policy Imperative December 2006: Background Paper*, Hamilton, Ontario, UNU-INWEH.

———. 2006. Assessment of sites in marginal drylands: An overview of existing and emerging frameworks. *Fourth Project Workshop on Sustainable Management of Marginal Drylands (SUMAMAD)*, Islamabad, PCRWR, pp. 15–22.

Adeel, Z. and King, C. 2004. Development of an assessment methodology for sustainable management of marginal drylands. UNESCO (ed.), *Sustainable Management of Marginal Drylands (SUMAMAD) Proceedings: Third Project Workshop*, 11–15 December. Djerba, Tunisia, SUMAMAD, pp. 13–22.

Adeel, Z., Safriel, U., Niemeijer, D., White, R., Kalbermatten, G. d., Glantz, M., Salem, B., Scholes, B., Niamir-Fuller, M., Ehui, S. and Yapi-Gnaore, V. 2005. "Ecosystems and Human Well-being: Desertification Synthesis". *Millennium Ecosystem Assessment.* Washington, DC, World Resources Institute.

Adeel, Z., Schaaf, T., Oweis, T., Thomas, R., Salih, A. and Adeel, Z. (eds.). 2002. Sustainable management in marginal drylands – A programmatic overview. *Sustainable Managment of Marginal Drylands: Application of Indigenous Knowledge for Coastal Drylands*, 21–25 September, 2002. Alexandria, Egypt, UNU.

Barab, S. and Duffy, T. 1998. *From Practice Fields to Communities of Practice*. Center for Research on Learning and Technology, Indiana University Bloomington, Indiana. http://cee.indiana.edu/publications/journals/complete.pdf

Berkes, F., Folke, C. and Colding, J. (eds.). 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge, Cambridge University Press.

Blaikie, P. and Brookfield, H. 1987. *Land Degradation and Society*. New York and London: Methuen.

Brokensha, D., Warren, D. M. and Werner, O. (eds.). 1980. *Indigenous Knowledge Systems and Development*. Washington, DC, University Press of America.

Chambers, R. 1993. *Challenging the Professions – Frontiers for Rural Development*. Rugby, Warwickshire, ITDG.

Chambers, R., Pacey, A. and Thrupp, L. A. (eds.). 1989. *Farmer First: Farmer Innovation and Agricultural Research*. London, ITDG.

Critchley, W. R. S. 2000. Inquiry, initiative and inventiveness: Farmer innovators in East Africa. *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere* 25(3): 285–288.

Critchley, W. R. S. and Mutunga, K. 2003. Local innovation in a global context: Documenting farmer initiatives in land husbandry through Wocat. *Land Degradation & Development* 14(1): 143–162.

Delyannis, E. 2003. Historic background of desalination and renewable energies, *Solar Energy* 75(2003): 357–366.

Fleskens, L., Stroosnijder, L., Ouessar, M. and De Graaff, J. 2005. Evaluation of the on-site impact of water harvesting in southern Tunisia. *Journal of Arid Environments* 62(4): 613–630.

Gachimbi, L., van Keulen, H., Thuranira, E., Karuku, A., de Jager, A., Nguluu, S., Ikombo, B., Kinama, J., Itabari, J. and Nandwa, S. 2005. Nutrient balances at farm level in Machakos

(Kenya), using a participatory nutrient monitoring (NUTMON) approach. *Land Use Policy* 22(1): 13–22.

Gonsalves, J., Becker, T., Braun, A., Campilan, D., Chavez, H. d., Fajber, E., Kapiriri, M., Rivaca-Caminade, J. and Vernooy, R. (eds.). 2005. *Participatory Research and Development for Sustainable Agriculture and Natural Resource Management: A Sourcebook*. Ottawa, CIP-UPWARD/IDRC.

González, N. L. (ed.). 1978. *Social and Technological Management in Dry Lands: Past and Present, Indigenous and Imposed*. Boulder, CO, Westview.

Inglis, J. (ed.). 1993. *Tradtional Ecological Knowledge Concepts and Cases*. Ottawa, IDRC.

Jiang, G. M., Liu, M. Z., Han, N. Y., Zhang, Q. and Li, W. J. 2003. Potential for restoration of degraded steppe in the Xilingol Biosphere Reserve through urbanization. *Environmental Conservation* 30(3): 304–310.

King, C. and UNESCO (eds.). 2004. A Coordinated Approach to Dryland Assessment: Review of Reports on Sustainable Management of Marginal Drylands (SUMAMAD), 2003. *Fourth Project Workshop on Sustainable Management of Marginal Drylands (SUMAMAD)*. Djerba, Tunisia, UNESCO.

King, C. 2006a. Indigenous, Adaptive and Innovative Dryland Management Approaches: The UNU-UNESCO-ICARDA joint project on The Sustainable Management of Marginal Drylands (SUMAMAD) 2005. *Fourth Project Workshop on Sustainable Management of Marginal Drylands (SUMAMAD)*. Islamabad, PCRWR.

———. 2006b. Workshop Report. *Fourth Project Workshop on Sustainable Management of Marginal Drylands (SUMAMAD)*. Islamabad, PCRWR.

Kowsar, A. 1982. Water harvesting for afforestation.3. Dependence of tree growth on amount and distribution of precipitation. *Soil Science Society of America Journal* 46(4): 802–807.

Kowsar, A., Mehdizadeh, P., Vaziri, E. and Boersma, L. 1978. Water harvesting for afforestation.2. Survival and growth of trees. *Soil Science Society of America Journal* 42(4): 650–657.

Kowsar, S. A. 2005. Abkhandari (aquifer management): A green path to the sustainable management of marginal drylands. *Journal of Mountain Science* 2(3): 233–243. http://www.imde.ac.cn/journal/Vol_06/233-243Sayyed%20Ahang%20Kowsar.pdf (Accessed 22 May 2006.)

Laureano, P. and Adeel, Z. (eds.). 2002. *A History of Traditional Water Management*. Sustainable Managment of Marginal Drylands: Application of Indigenous Knowledge for Coastal Drylands, 21–25 September, 2002. Alexandria, UNU.

Mehdizadeh, P., Kowsar, A., Vaziri, E. and Boersma, L. 1978. Water harvesting for afforestation.1. Efficiency and life-span of asphalt cover. *Soil Science Society of America Journal* 42(4): 644–649.

Mirnia, S. K. and Kowsar, S. A. 2000. Reclamation of a sandy desert through floodwater spreading, II: Characterization of clay minerals in the watershed and the freshly-laid sediment. *Journal of Agricultual Science and Technology* 2: 198–206.

Mohammadnia, M. and Kowsar, S. A. 2003. Clay translocation in the artificial recharge of a groundwater system in the southern Zagros Mountains, Iran. *Mountain Research and Development* 23(1): 50–55.

Naderi, A. A., Kowsar, S. A. and Sarafraz, A. A. 2000. Reclamation of a sandy desert through floodwater spreading, I: Sediment induced changes in selected soil chemical and physical properties. *Journal of Agricultural Science and Technology* 2: 9–20.

Niamir. 1990. Community forestry: Herders' decision-making in natural resources management in arid and semi-arid Africa. *FAO Community Forestry Note 4*. FAO, Rome, pp.—. http://www.fao.org/documents/show_cdr.asp?url_file = //docrep/t6260e/t6260e00.htm (Accessed 6 June 2006.)

Ouessar, A., Sghaier, M., Mahdhi, N., Abdelli, F., De Graaff, J., Chaieb, H., Yahyaou, H. and Gabriels, D. 2004. An integrated approach for impact assessment of water harvesting techniques in dry areas, The case of oued Oum Zessar watershed (Tunisia). *Environmental Monitoring and Assessment* 99(1–3): 127–140.

PCRWR (ed.). 2006. *Proceedings of the Fourth Project Workshop on Sustainable Management of Marginal Drylands (SUMAMAD)*, Islamabad, PCRWR.

Peng, Y., Jiang, G. M., Liu, M. Z., Niu, S. L., Yu, S. L., Biswas, D. K., Zhang, Q., Shi, X. and Yang, Q. S. 2005. Potentials for combating desertification in Hunshandak Sandland through nature reserve". *Environmental Management* 35(4): 453–460.

Pound, B., Snapp, S., McDougall, C. and Braun, A. (eds.). 2003. *Managing Natural Resources for Sustainable Livelihoods Uniting Science and Participation*. London, Earthscan/IDRC.

Prain, G. D., Fujisaka, S. and Warren, M. D. 1999. *Biological and Cultural Diversity: The Role of Indigenous Agricultural Experimentation in Development*. London, ITDG.

Pretty, J., Gujit, I., Scoones, I. and Thompson, J. 1995. *A Trainer's Guide for Participatory Learning and Action*. London, IIED (International Institute for Environment and Development).

Raeisi, E. and Kowsar, A. 1998. A system performance evaluation of the Gooyom floodwater spreading project. *Iranian Journal of Science and Technology* 22(2): 169–184.

Reij, C. and Waters-Bayer, A. (eds.). 2001. *Farmer Innovation in Africa: A Source of Inspiration for Agricultural Development*. London, Earthscan.

Rockstrom, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., de Vries, F., Rwehumbiza, F., Sally, H., Savenije, H. and Schulze, R. 2004. A watershed approach to upgrade rainfed agriculture in water scarce regions through Water System Innovations: An integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. *Physics and Chemistry of the Earth* 29(15–18): 1109–1118.

Safriel, U., Adeel, Z., Niemeijer, D., Puigdefabregas, J., White, R., Lal, R., Winslow, M., Ziedler, J., Prince, S., Archer, E., King, C., Shapiro, B., Wessels, K., Nielsen, T., Portnov, B., Reshef, I., Thonell, J., Lachman, E. and McNab, D. 2005. Dryland Systems. *Current State and Trends*, Vol. 1. Washington DC, Island Press, Millennium Ecosystem Assessment, pp. 623–662.

Scoones, I. and Thompson, J. (eds.). 1994. *Beyond Farmer First: Rural People's Knowledge, Agricultural Research and Extension Practice*. London, ITDG.

Stoorvogel, J. J. and Smaling, E. M. A. 1990. *Assessment of Soil Nutrient Depletion in Sub-Saharan Africa: 1983–2000*, Vol. 1: *Main Report*. Report No. 28. Wageningen, Winand Staring Centre Wageningen.

Thomas, D. 1997. Science and the desertification debate. *Journal of Arid Environments* 37: 599–608.

UNCCD. 2000. Traditional Knowledge: Report of the ad hoc Panel Note by the Secretariat. ICCD/COP(4)/CST/2, Bonn.

UNESCO. (ed.). 2003. *Combating Desertification*. UNESCO-MAB Drylands Series. Shiraz, UNESCO.

________. 2004. *Final Report of Third Project Workshop. Sustainable Management of Marginal Drylands (SUMAMAD)*. Proceedings of the Third Project Workshop, Sustainable Management of Marginal Drylands (SUMAMAD). Djerba, UNESCO.

Wu, B. and Pretty, J. 2004. Social connectedness in marginal rural China: The case of farmer innovation circles in Zhidan, north Shaanxi. *Agriculture and Human Values* 21(1): 81–92.

Chapter 8
Innovations of an Indian Non-governmental Organization in Building the Capacity of People Inhabiting the Drylands

J. Justin Pious

Abstract The Centre for Charity Health Education and Social Service is a grass root level non-governmental organization with more than a decade of experience in addressing the sustainable livelihood issues of farmers and farm labourers in Dindigul district of Tamilnadu state, south India. The bulk of the rural poor in Dindigul district depend on drylands for their livelihood. The problems of land degradation have reached serious proportions threatening their very existence. The Indian planning commission announced this district as a 'backward' as agricultural productivity plummeted and people began to migrate to cities and other states in search of work. Our organization proposed to address these issues through a community owned integrated watershed development project which incorporates the principles of sustainable development with special reference to the bottom-up approach advocated by the United Nations Convention to Combat Desertification (UNCCD).

Firstly, we identified a degraded micro-watershed for intervention. The entire project was divided into two phases namely a Capacity Building Phase and a Full Implementation Phase. During the capacity building phase, 10% of the total area of the watershed was selected for treatment and the capacity of the watershed community was built through a series of field demonstrations to plan, implement, and monitor the treatment measures themselves. An important aspect of the capacity building was equipping the people to maintain the 25 Management Information Systems. Once capacity is reached, the watershed community is allowed to enter the full implementation phase. Our organization has only a facilitator role. People have taken up ownership of this project.

Keywords Capacity building, watershed development, community, rural development

The Centre for Charity Health Education and Social Service (CCHESS) is a grassroots-level non-governmental organization with more than a decade of experience in addressing the sustainable livelihood issues of farmers and farm labourers in the

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Dindigul District of Tamilnadu state, southern India. It was started in 1992, the year in which the sustainable development concept was adopted by the international community at the United Nations Conference on Environment and Development, the 'Rio Summit'. The mission of our organization is: 'To pilot community based capacity building approaches for promoting sustainable development in accordance with Agenda 21 and to contribute considerably for accomplishing the Millennium Development Goals and national priorities.'

1 Dindigul District: Background

In 2002 the Dindigul District was categorized as a "backward" district by the planning commission of India under a special scheme called the 'Backward Districts Initiative'. The aim of this scheme is to reduce imbalances and speed up development in underdeveloped areas. Under this scheme, 100 "backward districts" and 32 left-wing extremism-affected districts out of 604 in India were selected for intervention. The identification of backward districts was made on the basis of an index of backwardness comprising three parameters with equal weighting: (i) value of output per agricultural worker; (ii) agriculture wage rate; and (iii) percentage of scheduled caste/scheduled tribe population in the districts. In addition, the incidence of poverty was given priority in categorizing the backward districts. The main objectives of the scheme are to address the problems of low agricultural productivity and unemployment and to fill critical gaps in physical and social infrastructure.

2 Reasons for "Backwardness"

The bulk of the rural poor in the Dindigul District depend on drylands for their livelihood. After extensive study we found that the low agricultural productivity, which led to poverty, was the direct result of environmental degradation. As a consequence of the lack of employment opportunities in the drylands, the people inhabiting the drylands began to migrate to industrialized cities, such as Tirupur and Coimbatore within Tamil Nadu state, and to adjacent states, such as Kerala, Karnataka and Andhra Pradesh, in search of work.

3 Efforts to Redress the Situation

The backwardness described above occurred despite the fact that the Indian Government has provided a huge amount of funding for agriculture and rural development through a number of development programmes. Generally, all the development programmes undertaken by both government as well as non-governmental sectors are formulated by keeping the revenue boundaries as a basic unit. However, environmental degradation does not recognize administrative and political boundaries, such as the village, block, taluk and the district levels. A watershed provides the best environmental unit for planning a development programme that involves all stakeholders. The naturally demarcated area allows for effective and more result-oriented planning. Hence, our organization proposed to address these issues through a community-owned Integrated Watershed Development Project that incorporates the principles of sustainable development with a special reference to the bottom-up approach advocated by the United Nations Convention to Combat Desertification (UNCCD). We believe that the dryland community can accomplish all its economic and social objectives within the limitations of environmental resources, i.e. sustainable development can be ensured only by developing and harvesting resources within the carrying capacity of the watershed. We have dovetailed various schemes of government departments and resources of domestic donors, the private sector, industry, volunteer organizations and other like-minded organizations, and community contributions to this project so as to reverse the backwardness of the district. We strongly believe that if our innovative approach is replicated in all 132 districts of India selected under this scheme, then not only will the backward districts become developed but also the districts affected by left-wing extremism can also counter the challenges posed by Naxalism.[1]

We experimented in this project by keeping the above vision in mind.

4 The Background of the Selected Watershed

We identified K. Pudukottai, the most degraded micro-watershed, for intervention. It is situated in Reddiarchatram rural block of Dindigul District in which the groundwater level is extremely low compared to other areas of the district. Furthermore, within this block, the K. Pudukottai micro-watershed was categorized as having very high soil erosion. The funding for watershed-related activities was provided by the National Bank for Agriculture and Rural Development (NABARD), the apex bank of the Government of India that facilitates agriculture and rural development through credit.

5 Two Phases of the Project

The entire project was divided into two phases: the Capacity Building Phase (CBP) and the Full Implementation phase (FIP). During the Capacity Building Phase, 10% of the total area of the watershed was selected for treatment and the capacity of the

[1] Naxalite or Naxalism is an informal name given to radical, often violent, revolutionary communist groups that were borne out of the Sino-Soviet split in the Indian communist movement. Ideologically, they belong to various trends of Maoism. Initially the movement had its epicentre in West Bengal. In recent years, it has spread into less developed areas of rural central and eastern India, such as Chattisgarh and Andhra Pradesh, through the activities of underground groups like the Communist Party of India (Maoist). The CPI (Maoist) and some other Naxal factions are considered terrorists by the Government of India and various state governments in India.

watershed community was built through a series of field demonstrations to plan, implement and monitor the treatment measures themselves during the project period, as well as to maintain the assets created during the post project period. As the watershed community acquired the necessary skills, it then entered the process towards the Full Implementation Phase.

6 Capacity Building Phase

I would like to highlight how we have systematically built the capacity of the people inhabiting this dryland area. During the Capacity Building Phase, we never forced the community to do anything. Instead, we designed our communication strategies in such a way that the desired behavioural change occurred with their whole-hearted co-operation. We motivated the people to grasp the ideas themselves and deliver the expected output as their own. We saw to it that each and every decision was their brainchild. To achieve this, we studied the watershed community in-depth in various respects, such as religion, culture, the caste system, the existing groups (both formal as well as informal), social structure and economic status, political and social awareness, the level of education, behavioural patterns, the influence of mass media, and their sentiments. As we utilized the collected information strategically and were able to harvest fruitful results.

7 Engaging the People in Cause and Effect Analysis

A special public meeting was held to motivate the community to take part in the project in an effective way. During the meeting, the watershed community firmly explained that agriculture had become a failure and that they had no option except to migrate from their villages in order to survive. Elders from their community were then invited to tell about the status of agriculture in their parents and grandparent's days. The elders shared their memories of the then profitable agriculture. At the same time, they regretted that the rate of return from their agricultural land had gradually declined over the years while the cost of production had increased dramatically. From their stories, it was evident that they were aware of their problems but could not identify the reasons for this trend.

8 Engaging the People in Solution Analysis

Then we illustrated to the people that the Integrated Community Owned Watershed Development project, which incorporates the principles of sustainable development and the bottom-up approach advocated by the UNCCD, could make a difference in their lives. We illustrated to the community how the watershed development project addresses the migration issue. We clearly demonstrated that watershed development involves not only environmental regeneration but also the management of the needs of the community in such a way that their demands are sustainable with the available resources, including land, water and vegetation, and that take into account present and future needs. Furthermore, we stated that the equilibrium described above would lead to increased resistance to drought, an increase in the supply of food, water, fuel, fodder and agri-produce. Finally, the community began to understand how an increase in agricultural production could improve the standard of living and reduce migration.

9 Capacity-building: Knowledge-sharing from Farmer to Farmer

After the initial orientation programme, we took 50 members of the watershed community to visit the ongoing watershed development project area (Fig. 1). Representatives of all the villages in the watershed participated in this visit. Nearly 50% of the participants were women. The participants witnessed the impact of the watershed development undertaken by farmers similar to themselves. Farmers benefiting from the project shared their problems and experiences with the visiting farmers. During the visit, our farmers visited the area's treatment measures, such as the field bund, Continuous Contour Trench (CCT), Water Absorption Trench (WAT), agro-forestry, dryland horticulture and agro-horticulture, the farm pond, the stone gully plug and the well recharge pit. They also visited drainage line treatment measures, such as the sunken pond, channel training, channel forming, check weir,

Fig. 1 Knowledge sharing from farmer to farmer during a visit

Table 1 Net planning – A participatory learning and decision making process

S.No.	Criteria	Gross planning	Net planning
1.	Community involvement	Involvement of a few selected representatives of the community	Involvement of each and every member in the community is ensured
2.	Accuracy	Accuracy depends on the involvement of the representatives	High degree of accuracy in planning
3.	Sustainability	Sustainability depends on the degree of accuracy in planning	Better chance of sustainability due to community involvement
4.	Resource requirement	Requires comparatively fewer resources	Requires more resources
5	Fulfillment of needs	Chances of exclusion of some members of the community	High degree of fulfillment of community needs
6.	Variation between planning and implementation	Variation will be very high since the people are not generally involved in planning	Variation will be very low since all the people are involved in planning

check dam and gabion structures. During the visit, the farmers exposed their many doubts about the method of creating each structure and their purpose, and these queries were subsequently clarified. Members of our Self-Help Group (SHG) interacted with the farmers to learn from them about the role of SHGs in watershed development. Thus knowledge-sharing took place from one farmer to another, which resulted in a positive change in behaviour.

We adopted the Net Planning process as it has many advantages over Gross Planning. The comparison of Gross Planning and Net Planning is given in Table 1.

Each and every land survey number[2] was visited by the planning team along with the farmers concerned in order to survey the area and decide on the proposed soil and water conservation treatments and land use. During this participatory learning and planning process, both the husband and wife of the farming family were involved.

The team comprising the technical persons, community organizer and members of the Village Watershed Community (VWC) motivated the farmer. The farming couple whose land was surveyed presented their field on the day of planning. The details regarding rainwater flow, erosion in their fields, crop types and so on were discussed with the farmer concerned. The land was classified based on measurements of land slope, soil depth using an auger, soil texture and erosion status of the field observed. After gathering this information, the team suggested the most suitable land use and treatments to the landowner. We helped the farming couple to visualize how those treatments would help to solve the existing problems on their land. After achieving consensus, all the information was recorded in the Net Planning format. This includes details of the present and proposed treatment, land

[2] The land of each owner was allocated a unique identification number by the government's land survey department. All the landowners in the selected area were consulted before deciding on the treatment in their respective land area.

use, type of horticultural species, number of trees, etc. At the end of the exercise, the farming couple was given a paper with a diagram of their land on which details (present and proposed) were indicated together with an agreement that formalized their consent to undertake and maintain the proposed treatments.

10 Participatory Rural Appraisal: A Two-way Knowledge-sharing Process

While the landowners decided on the area treatment for their individual lands using the Net Planning process, treatments to be carried out on common land and in drainage lines were decided on by the entire watershed community. The participatory methodologies, like social mapping, resource mapping and transect walk and seasonality analysis, were employed to prepare the Integrated Watershed Development plan for the watershed (Fig. 2). During the transect walk, the farmers shared their knowledge of the local resources. They explained in detail their traditional practices of harvesting rainwater. A large number of farmers participated in this process. After the transect walk, the resource mapping was done using coloured powder. The entire watershed boundary along with the gullies, existing ponds and so on was drawn on the resource map. Subsequently, our technical team, consisting of the agriculture engineer, agronomist, sociologist and project manager, suggested suitable treatment measures for common land and drainage lines. After detailed deliberations, and after reaching a consensus, the plan was finalized. In this process, knowledge-sharing was not a one-way process but took place in both directions.

Fig. 2 A female farmer explaining resource mapping and the existing water resources

11 Capacity-building through the Transfer of Sustainable Agriculture Technologies

One of the main challenges faced by the farmers was the increasing cost of production. The cost is high because they depend more on high external inputs. Chemical-intensive farming practices aggravated the problem further. Hence, we decided to promote low-cost sustainable agricultural technologies.

11.1 Creating Awareness among the Farmers and Creating the Demand for Sustainable Agricultural Technologies

As I mentioned earlier, we never force people to adopt anything immediately because the efforts to change behaviour suddenly will only create resistance and the desired behavioral change will not occur. Hence, we strategically motivated some progressive farmers to participate in the workshop on "community-based pesticide monitoring and action", which was run by Dr. Romeo Quijano, the southern co-chair of International Persistant Organic Pollutants Elimination Network and the President of the Philippines Pesticide Action Network. He clearly explained how the excessive application of pesticides and chemical fertilizers affect the environment and human health in the long term (Fig. 3). He cited international as well as local examples to support his argument. He demonstrated simple ways of identifying and documenting the symptoms of pesticide poisoning of the human body. After gaining knowledge of the harmful consequences of applying excessive amounts of pesticides and chemical fertilizers, the progressive farmers participating in the workshop shared their experiences with their fellow farmers during formal training programmes arranged in the watershed, and in which the participants of the workshop were the resource people. Shocked by the facts shared by the workshop participants, the watershed community requested that we initiate some alternative strategies to tackle the situation. Thus we motivated the people to think of alternative methods, which they considered their own idea. By doing so, we indirectly created the demand for sustainable agricultural technologies.

11.2 Training in the Preparation and Application of Panchakavya *and Medicinal Plant-based Pesticides*

Panchakavya preparation and application was demonstrated to the farmers. *Panchakavya* is an alternative to chemical fertilizers and pesticides that minimizes the input cost to the farmers. *Panchakavya* is a Sanskrit word which means 'mixture of five products', and it has been used in traditional Hindu rituals throughout history. It is a concoction prepared by mixing five cow products. The three direct constituents are dung, urine and milk. The two derived products are curd and ghee

Fig. 3 Dr. Romy Quijano, the southern co-chair of the International Persistent Organic Pollutants Elimination Network and the President of the Philippines Pesticide Action Network demonstrating to the farmers the simple method of identifying pesticide poisoning

(clarified butter). These are mixed in the following ratio and then allowed to ferment. It is prepared from cow dung slurry (5 kg), cow's urine (3 l), milk (2 l), curd (2 l), ghee (1 l), sugar cane juice (3 l), bananas (12) and tender coconut water (3 l). It promotes growth, enhances flowering and extends shelf life. One mixes 300 ml of *panchakavya* with 101 ml of water and sprayed, and costs only Rs. 300 per acre if purchased and costs practically nothing for a farmer who owns cows. It is popularly called 'organic tonic'.

Furthermore, the medicinal plant-based pesticide preparation and application was also demonstrated to the farmers. The ingredients for this product are aloe vera, *neem* seed, *nochi* leaves, *peenari* leaves and *erukalai* leaves. These are pressed into powders and then mixed with a small quantity of water. The concentrated pesticide is mixed with water in the ratio of 5:100. The cost of production for one acre is Rs. 300. The ingredients are readily available locally, and it has proved to be effective, efficient, economical and eco-friendly.

11.3 Training and Demonstration on Vermicompost Preparation

This project was funded under the Advancement of Rural Technology Scheme of the Council for Advancement of Peoples Action and Rural Technology (CAPART), an autonomous organization of the Ministry of Rural Development, Government of India. We identified 50 progressive farmers and provided training in vermicompost preparation and the application procedures in their fields. Today, 25 vermicompost pits have already started production. All 50 farmers have been organized under an organic farmers association. We have extensive plans to motivate these farmers to adopt organic farming.

11.4 Promotion of Organic Entrepreneurs

Some progressive farmers have been identified for launching the commercial production of vermicompost. The selected farmers underwent training under the Khadi and Village Industries Commission of the Government of India (Fig. 4). The participants were exposed to large-scale preparation of vermincompost, market analysis, pricing and formulation of project reporting for available subsidies and bank loans.

Fig. 4 Farmers filling up the *vermicompost* pit themselves after earlier demonstration

12 Capacity-building for Sustainability

We formed various people-oriented organizations at the watershed level for specialized purposes and built capacity among the people so as to manage them effectively as autonomous institutions. Furthermore, we linked some of them with various government schemes. We have formed a village watershed committee (VWC) comprising community representatives from all the hamlets. We have provided training to the VWC for maintaining 25 Management Information Systems. The Organic Farmers Association was formed. The Farmers Club, the Self-Help Groups and their federations have been formed and linked with the service area bank to provide credit. We are now in the process of registering all the above institutions under the State Registration Societies Act to provide them with the legal status to function effectively in the post-project period.

13 The Behavioural Change of the Watershed Community as a Result of Sustainable Development Education and the Knowledge-sharing Process

Since the capacity of various stakeholders in the watershed has been built steadily, the watershed community has understood the concept of sustainable development and responded positively. Some examples are given below:

13.1 Social Fencing

The entire watershed community has banned free grazing in treated areas and tree cutting within the watershed area. Furthermore, they agreed to impose fines on persons violating the ban.

13.2 Carrying Capacity of the Watershed

As the concept of carrying capacity has been clearly explained to the watershed community. All agreed to reduce the livestock population to the carrying-capacity of the watershed. In addition, farmers have promised to avoid cultivating water-intensive crops.

13.3 Unity in Diversity

People belonging to different religions, cultures, castes and political affiliations are living within the watershed. As they have understood the common benefits emanating from watershed development activities, they have set aside their differences and now participate and cooperate on all the activities.

13.4 Contribution in Treatment Measures

Each landowner contributes 16% of the labour costs for the treatments undertaken on his land. The watershed community as a whole contributes 16% of the labour costs when treatments are carried out on common land and drainage lines.

Before the start of the project, each landowning family in the watershed participated in four days of community contribution voluntary work to demonstrate the unity and commitment of the watershed community, as it is the community that feel, the need for the watershed development project.

13.5 Ridge to Valley Approach

Every villager expected the work to begin only in their village. We therefore explained to them about the need to adopt a ridge to valley approach. They understood the concept and have fully co-operated in the project activities.

Chapter 9
UNESCO's Experience of Fifty Years of Drylands Research and Outreach

Thomas Schaaf

Abstract The United Nations Educational, Scientific and Cultural Organization (UNESCO) was the first UN agency that addressed dryland ecosystems from a scientific point of view. By using field research projects from Kenya, Ghana, Northern Africa and Asia, the paper provides examples of some fifty years of UNESCO's involvement in dryland studies. More importantly, the paper illustrates how the type of research projects has changed over time. In the earlier days, field research was mostly conducted by specialists trained in the natural sciences; in the 1990s, social and cultural components to promote environmental conservation and gain a better understand of human-nature interactions grew in relative importance vis-à-vis the natural sciences. Today, UNESCO's research projects take primarily an information sharing approach involving scientists from different dryland countries. Outreach to decision-makers on sustainable land management and environmental education targeted at schools are considered key components in combating desertification.

Keywords Dryland research, sacred sites, Sustainable Management of Marginal Drylands project, desertification, outreach, education

Dryland ecosystems are often outstanding areas of beauty, serenity and spirituality, and it is no wonder that the three large monotheistic religions have originated in the drylands. The diversity of plant and animal species is less significant than in most other ecosystems. But they have developed remarkable resilience strategies to cope with the lack of water, occasional excessive floods and extreme diurnal temperature changes, which confers an important conservation value to dryland species.

However, desertification, with its resulting land degradation and decline of biological soil productivity, is on the increase in most drylands. Extended droughts, sandstorms and wind erosion jeopardize the lives of millions of dryland dwellers and their livestock, leading to famines and ever increasing poverty. Poverty, in turn, is often said to contribute to additional land degradation as population pressure and

UNESCO, Division of Ecological and Earth Sciences, Man and the Biosphere (MAB) Programme, Paris, France

lack of alternative incomes force people to cultivate marginal areas, which quickly become completely unproductive, at least on the temporal scale of foreseeable human generations.

To gain knowledge about the structure, functioning and dynamics of dryland ecosystems, and to better understand human–environment interrelationships so as to assess and improve the socio-economic well-being of dryland people, UNESCO launched – as early as 1951 – an international study on arid and semi-arid zones. In fact, arid zones were at the centre of UNESCO's earliest efforts at international scientific cooperation in the study of natural resources. The arid zones study and research programme was continued until 1964, following the rise of its status becoming a Major Project of the Organization in 1957 as a direct outcome of the International Arid Lands Meetings in New Mexico in 1955. This Major Project was a pioneer programme in many respects. One of its merits, and not the least, was that it blazed a trail in its interdisciplinary approach to the study of natural resources and its holistic approach to the problems of arid and semi-arid zones. It was then followed by a series of other intergovernmental programmes having significant components relating to drylands, such as UNESCO's Programme on Man and the Biosphere (MAB) created in 1971 following the 1968 International Biosphere Conference held at UNESCO, and the UNESCO International Hydrological Programme (IHP) launched in 1975 as a follow-up to the 1965–1974 International Hydrological Decade.

The Man and the Biosphere (MAB) Programme, hosted by the Division of Ecological and Earth Sciences, can be traced back to a series of international pilot projects on dryland research implemented by UNESCO in various dryland regions, but particularly in Africa. These projects include:

- Integrated Project on Arid Lands in Kenya (IPAL-Kenya), Marsabit and Turkana districts of Kenya, 1975–1984
- Kenya Arid Lands Research Station (KALRES) project, Marsabit district of Kenya, 1984–1987
- Integrated Project on Arid Lands in southern Tunisia (IPAL-Tunisia), 1980–1984
- Integrated Project on Arid Lands for the Drought-Prone Southern Districts in Lesotho (IPAL-Lesotho), Mohale's Hoek District and Quthing River Valley of Lesotho, 1988–1991
- Turkana Resources and Evaluation Monitoring Unit (TREMU) Project, Turkana District, 1988–1992.
- Training and education on integrated pastoral management in the Sahel (FAPIS project), 14 Sudano-Sahelian countries were involved, 1980–1989
- Strengthening of scientific capacities in the agro-silvo-pastoral domain; CILSS Member States, West Africa, 1989–1994
- Cooperative Integrated Project on Savanna Ecosystems in Ghana (CIPSEG); Northern district of Ghana, 1992–1996
- Strengthening of scientific capacities in West African biosphere reserves: Benin, Burkina Faso, Cote d'Ivoire, Mali, Niger, Senegal, since 2004
- Sustainable Management of Marginal Drylands (SUMAMAD): China, Egypt, Iran, Jordan, Pakistan, Tunisia, Syria, Uzbekistan, since 2004

Collectively, these projects provide a wealth of experience in dryland research. In implementing these projects, UNESCO and the author of this article have gained knowledge in designing and implementing activities that not only help run dryland research projects for scientific purposes but also places them within a research-cum-development context with information sharing and outreach as their core concern. The following three selected project examples will illustrate a shift from a classical research approach to one that also incorporates socio-cultural values, eventually leading to an approach that heralds knowledge-sharing across national boundaries.

1 Integrated Project on Arid Lands (IPAL) in Kenya

The IPAL-Kenya project in northern Kenya's Marsabit and Turkana districts spanned a period from 1975 to 1984 and generated two follow-up projects, KALRES and TREMU, which terminated in 1987 and in 1992, respectively. Fifteen years of applied field research on the structure, functioning and dynamics of dryland ecosystems brought a multitude of scientific findings and publications to the fore, which would fill several meters of book shelves! Therefore, the following findings provide only a glimpse of the many ramifications and results of the project.

The starting point of the project was the increasing sedentarization of the nomadic Rendille and Turkana nomads in northern Kenya. Due to well-meaning development aid schemes initiated by churches and other aid organizations in the early half of the 20th century, schools and medical dispensaries were established in an area that in the past offered no physical and/or social infrastructures to improve the livelihoods of people living in these extremely harsh climatic and desert environments with large diurnal temperature ranges, little and erratic rainfall and a fragile vegetation cover. Because of the introduced amenities (schools and pharmacies), some of the nomadic population created permanent settlements around the new villages, thus putting enormous pressure on the fragile dryland ecosystem. In particular, the grazing pressure of their livestock led to an intensification of vegetation removal and soil erosion, exacerbating human and livestock casualties in periods of drought (Schaaf, 2001).

The UNESCO IPAL-Kenya project therefore focused on questions of the carrying capacity of drylands, using an integrated approach that analyzed both the natural and social environment of the nomadic Turkana and Rendille populations. For example, the project owned its own camel herd of about 20 individuals, which served as a control group *vis-à-vis* camels owned by nomads that received free veterinary treatment from the project. Growth dynamics, annual and seasonal milk production, fodder selection and eating behaviour, tick infestation and health conditions in general were among the many topics studied (Fig. 1).

The dwarf shrub *Indigofera spinosa* received a particular scientific study (Fig. 2). Despite its spines, the shrub can be eaten by livestock and in particular by browsers such as goats and camels. IPAL-Kenya scientists, and in particular Dr. Gufu Oba, discovered that browsing was actually beneficial in terms of growth dynamics. They concluded that

Fig. 1 Measuring lactation yields (T. Schaaf. With permission)

Fig. 2 *Indigofera spinosa* (T. Schaaf. With permission)

the shrub should be browsed – and thus defoliated – by up to 30%, which seems to be the best rate for reducing transpiration rates and for conserving water availability in the soil. Moreover, the plant should be browsed especially during the dry season as the reduced foliage again helps to conserve water in the soil and the plant itself.

These results can be formulated into important management guidelines for nomads to enhance sustainable seasonal range management. The project strived to convey the results to the nomads, through with varying results at times. One of the main issues among the nomads concerned their preference for numbers of individual livestock instead of quality livestock: fewer animals per area unit would be less destructive to fragile dryland environments, while higher quality animals would fetch higher market prices. Yet when one of the nomad field assistants married, it was a question of family pride and honour to provide him with the greatest number of livestock they could afford as a dowry and gift. This anecdote reveals that it is relatively easy to work out scientific solutions to adequate and sustainable pastoral management in the drylands but that socio-cultural parameters often hamper the effective implementation of scientificaly tested and sound land management practices.

2 Cooperative Integrated Project on Savanna Ecosystems in Ghana (CIPSEG)

The Cooperative Integrated Project on Savanna Ecosystems in Ghana (CIPSEG), which was carried out in northern Ghana's savanna region from 1992 to 1996, drew lessons from the earlier IPAL-Kenya project and tried to base environmental conservation on socio-cultural parameters. In fact, the project invoked traditional belief systems and "natural sacred groves" to study sustainable development and dryland conservation in an integrated and interdisciplinary manner (Schaaf, 2001).

In Ghana, as in most African countries, rapid population growth and expansion of economic activities have lead to deforestation and environmental degradation. In many parts of the country, the natural vegetation has been seriously affected by bush fires, agricultural cultivation, overgrazing, firewood cutting and even urbanization and village sprawl. Although environmental degradation is widespread in northern Ghana, which is a dry sub-humid savannah of the Guinea type, small pockets of residual closed canopy forests remain near human settlements. Many of these forest pockets are, in fact, "sacred" groves, which have survived environmental degradation because of traditional religious belief systems. Almost all existing sacred sites in Ghana have been, and continue to be, protected by taboos, traditional beliefs and local customs. Thanks to the general perception of the sacred groves and their associated reverence, these sites have resisted encroachment or unwarranted exploitation of resources.

Against this background, CIPSEG was carried out by UNESCO to assess whether the sacred groves could be used as indicator sites for the potential natural vegetation of the savannah area. Could they provide clues to how the Guinea type savannah looked before the onset of intense human pressure on the savannah? With this is mind, the project's first goal was to develop a scientific knowledge-base on the relict sacred groves ecosystems and to study the plant and animal species composition contained within them. This knowledge-base was then geared towards achieving the second main aim of the project: to restore the adjacent and degraded savannah areas by using native plant species from the sacred groves' gene pool. The project therefore had both a scientific orientation (study of the sacred groves' genetic resources) and a development orientation (rehabilitation of degraded environments), both based on cultural values. In order to address these two main objectives, several scientific teams were set up, carrying out their work in an interdisciplinary approach. For example, the Botany Department of the University of Ghana carried out plant inventories of the three selected sacred groves. The Geography Department of the same university looked into the overall land use systems of the three districts in which the sacred groves are located, with a view to elaborating environmentally sound management plans.

Apart from ecological research, the project also attached great importance to the socio-cultural dimensions of the sacred groves. The Centre for National Culture in Tamale undertook in-depth studies of the traditional beliefs that had led to the protection of the sacred sites; the Centre also analyzed the function of sacred groves for ceremonies performed by the priests (Fig. 3). Moreover, studies focused on traditional resource use by village communities, such as tree planting, ownership of tree and forestry products, and marketing (Fig. 4). These studies were particularly important for the restoration of degraded savannah environments so as to meet the specific needs of village communities without violating cultural values. Environmental education on the importance of conservation while involving local people was considered essential for the success of the project.

The project's main counterpart institution, the Environmental Protection Agency (EPA) of Ghana, carried out multi-layered education programmes: for example, seminars were organized on:

- The control and prevention of bush fires, which could seriously affect the sacred groves
- The establishment of shelter belts around the groves
- Women and tree planting

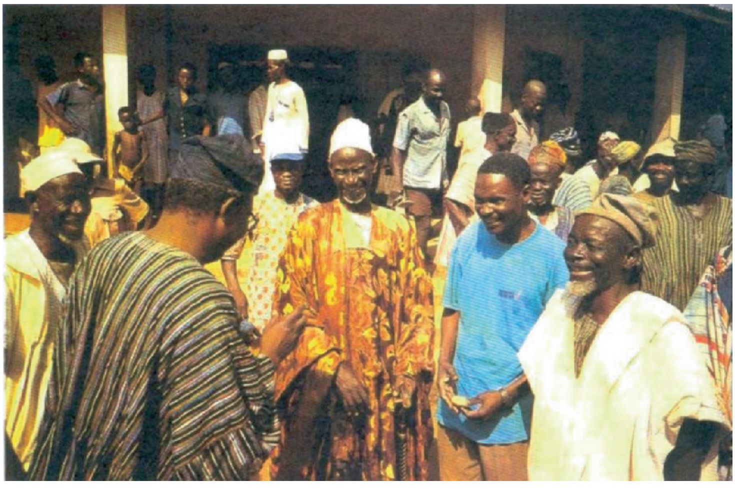

Fig. 3 Paramount chief (centre) as custodian of sacred groves (T. Schaaf. With permission)

Fig. 4 Tree planting for dryland rehabilitation (T. Schaaf. With permission)

The project results go far beyond the scope of this overview, so only a few will be briefly mentioned.

One of the working hypotheses was that biodiversity within the sacred groves could be much higher than in the adjoining "non-sacred" areas. However, this proved to be only half true. In terms of animal species diversity, birds, reptiles and mammals were more abundant within the sacred groves than beyond them. This result is not surprising as sacred sites also function as wildlife sanctuaries, where hunting is prohibited outright, and trespassing, as is customary law, is penalized by the custodian of the sacred grove. For example, an antelope can be hunted outside the grove, but as soon as it enters the sacred grove it can no longer be hunted. On the other hand, plant species diversity was shown to be greater at the periphery of the sacred groves than within the sacred sites. We assume that the fringes of the sacred groves function like ecotones, where two different environmental conditions meet: an ecosystem with a closed canopy cover (sacred grove) and a human-impacted ecosystem, where bush fallow or agriculture occurs. Hence, the differing light conditions at the edges of the sacred groves give rise to greater heterogeneous plant diversity than within the groves. It may also be assumed that the sacred groves in this savannah environment are dry forests in their climax or sub-climax stage, which are less species-rich than groves with secondary undergrowth.

Research on the cultural aspects and significance of the sacred sites also provided fascinating results. Interviews with the village elders and extrapolation of historic events led to the assumption that some of the sacred groves are more than 300 years old. They originated as the abodes of either one or several gods. The three selected groves were the respective abodes of a python god, a leopard god and a monkey god; they can command bumper or lean harvests. Other sacred groves in the study area served and still serve as burial grounds of ancestors and over time have become taboo. The power of a chief is intrinsically linked with his function as supreme custodian of a sacred grove. Regardless of whether the chief is a practicing Muslim or Christian, his power over the community derives from his role as protector of the sacred grove. Should he relinquish this function, he would forfeit his power as chief. The taboos and obligations, i.e. the “do’s” and “don’ts”, vary among sacred sites, but there are also several common features. For instance, creating shelter belts around the groves through communal labour is an obligation of the entire village community. The strict observance of or adherence to the rules associated with the sacred groves is considered important and cannot be compromised.

However, as culture is dynamic, even belief systems can change over time. Many young people wish to extend their agricultural lands, even if this extension would encroach into the sacred grove. The project therefore re-oriented its activities, with regard to the rehabilitation of degraded lands, around the sacred groves using agro-forestry methods. These permitted cash-crop production (e.g. cashew nuts, mango), and provided an economic income for local people, especially women and young men. At the same time, the vegetation cover restored in these particularly degraded areas was ensured. The establishment of woodlots and fodder banks were additional means to create a “buffer zone” around the sacred groves, which in turn reduces the pressure on the sacred site.

Experience from the Cooperative Integrated Project on Savanna Ecosystems in Ghana showed that any research and dryland rehabilitation efforts must be fully embedded in local cultures and must integrate social science studies so as to benefit local communities through participatory development schemes.

3 Sustainable Management of Marginal Drylands (SUMAMAD)

The third generation project type is the example provided by the Sustainable Management of Marginal Drylands (SUMAMAD) project, which began in 2004 and is ongoing. Its design is based on natural as well as social and scientific research; moreover, it includes a strong component of information exchange across national boundaries so that research findings can be shared in a much wider regional and international context among scientists (see article by Caroline King in this volume).

This project involves nine research sites in eight countries (Fig. 5): five study sites are sponsored by research institutions, while four sites are biosphere reserves, part of the World Network of Biosphere Reserves and internationally recognized by UNESCO. The project study and intervention sites are listed below:

- Hunshandake Sandland/Xilon Gol Biosphere Reserve (HS), China
- Heihe River Basin (HRB), China
- Omayed Biosphere Reserve (OBR), Egypt
- Gareh Bygone Plain (GBP), Iran

Fig. 5 SUMAMAD project sites (C. King. With permission)

- Dingarh/ Lal Sohanra Biosphere Reserve (D/LSBR), Pakistan
- Dana Biosphere Reserve (DBR), Jordan
- Khanasser Valley Integrated Research Site (KVIRS), Syria
- Zeuss-Koutine Watershed (ZKW), Tunisia
- Karnab Chul (KC), Uzbekistan

Furthermore, the project is collectively sponsored and implemented by various institutions, thus pooling dryland expertise and achieving complementary synergy effects: funded by the Flemish Government of Belgium, UNESCO's Division of Ecological and Earth Sciences is the main implementing agency. The United Nations University – Institute of Water, Environment and Health (UNU-INWEH) provides inputs through its academic network of scholars and handles several technical aspects of the project. The International Centre for Agricultural Research in the Dry Areas (ICARDA) supplies valuable information on dryland agriculture.

The SUMAMAD project has three interrelated objectives:

- Assessment of the integration of conservation of natural resources, community development and scientific information in order to elaborate an overall integrated dryland management concept at site level.
- Identification of practices for sustainable soil and water conservation with local communities involving traditional knowledge and modern scientific expertise, or a combination of both, whose aim is to combat environmental degradation.
- Provision of training opportunities, such as inventory techniques, data collection and data analysis, so as to support capacity-building for dryland research.

Several contributions in this publication provide ample information on various SUMAMAD project sites; therefore, detailed information on the study sites is not provided here (see Akram, Al-Qawaba'a Jiang Gaoming, King, Kowsar, Raes, Ouessar, Thomas, Wang Tao above). Suffice to say that several field projects have already gained international recognition, such as the solar-powered brackish water distillation plants that provide clean drinking water to local communities at the Omayed Biosphere Reserve (Egypt). Moreover, the Fars Research Centre for Natural Resources and Animal Husbandry in Shiraz, I. R. Iran, has won the UN-Habitat International Prize for Best Practices to Improve the Living Environment and the UNESCO-Libyan Great Man-Made River International Prize for Water Resources in Arid and Semi-Arid Areas for its work on recharging groundwater through floodwater harvesting techniques.

Annual international SUMAMAD project workshops are held on a rotational basis in the participating countries where scientists report on the results of their dryland studies obtained throughout the year. In doing so, expertise from the various field sites can be exchanged among the scientific community represented from China to Uzbekistan. Study visits and practical field training is also carried out thanks to courses provided by the Ghent University and the Catholic University of Leuven (Belgium). Furthermore, thanks to additional funding by the Flemish

Government of Belgium, the SUMAMAD project site leaders received travel grants to attend and present their research findings at the International Scientific Conference on Desertification and Drylands Research – The Future of Drylands conference held 19–21 June 2006 in Tunis, Tunisia, and the International Conference on Desertification and the International Policy Imperative held 17–19 December in Algiers, Algiers. These fora provided an excellent opportunity for further interaction with the dryland scientific community.

Outreach of the project is ensured through an information brochure, and, more importantly, a regularly updated SUMAMAD project website at http://www.unesco.org/mab/ecosyst/drylands/Sumamad.shtml. To conclude, this third type of UNESCO dryland project encompasses scientific research in the natural and social sciences, which takes into account socio-cultural foundations and information-sharing gained among dryland researchers and practitioners in an inter-regional dryland context.

4 Outreach and environmental Education

Last but not least, UNESCO promotes environmental education at various levels. The results and knowledge gained from dryland studies have been valorized in the hugely successful UNESCO-UNCCD *Education Kit on Combating Desertification* launched in 2001. The kit principally targets primary school teachers and their pupils, aged 10–12 years old, in desertification-affected countries. Its positive approach demonstrates that desertification is not inevitable and that everyone, at his or her own level, has a role to play in the Earth's future. The kit comprises: a teacher's guide informing about the problems of desertification, case studies on successful ways of combating desertification, several copies of the comic *The School Where the Magic Tree Grows*, and a poster depicting the main dryland zones of the world for use in a class-room. The kit is now available in Arabic, Chinese, English, French, German, Hindi, Mongol, Russian and Spanish.

UNESCO is currently preparing a new 'Teaching Resource Kit for Dryland Countries'. Targeted at primary and secondary schools, the kit will use a creative approach to environmental education and will be available in Arabic, English, French and Spanish in early 2008 (see also paper by Helene Gille in this volume).

UNESCO's experience of some 50 years of drylands research has shown that the purely scientific study of dryland ecosystems – their structure, functioning and dynamics – cannot be dissociated from socio-economic parameters and cultural values. The interrelationship of humans with their environment must be considered in a holistic manner. The needs of local populations who strive for better living conditions must be put at the centre of any intervention schemes. While a wealth of scientific knowledge now exists on dryland ecosystems and their sustainable management, the implementation of such management schemes can only bear fruit if local dwellers are consulted and if they can help to provide solutions that respect, conserve and valorize dryland areas. With this is mind, education and outreach measures are crucial: land management decisions must be taken fully conscious of the long-term effects they may have.

Bibliography

Schaaf, T. 1998. Sacred groves in Ghana: Experiences from an integrated project. *Conserving the Sacred for Biodiversity Management*. P.S. Ramakrishnan, G. Saxena and U.M. Chandrashekara (eds.). Science Publishers, Enfield.

———. 2001. An overview of UNESCO's activities in the field of dryland conservation, management and rehabilitation. *Integrated Land Management in Dry Areas*, Zafar Adeel (ed.). UNU Desertification Series No. 4. UNU, Tokyo.

———. 2002. Land degradation and rehabilitation in drylands using biosphere reserves. *Proceedings of the International Seminar on Combating Desertification: Freshwater Resources and the Rehabilitation of Degraded Areas in Drylands*, N'Djamena (Chad), 30 October to 4 November 2001. UNESCO-MAB Drylands Series No. 1. UNESCO, Paris.

Skouri, M. (ed.). 1996. *Arid Zones in UNESCO's Programmes.* UNESCO, Paris.

UNESCO. 1985. *Integrated Project on Arid Lands (IPAL)*. Terminal Report. UNESCO, Paris.

———. 1988. *Kenya Arid Lands Research Station (KALRES)*. Terminal Report. UNESCO, Paris.

———. 1992. *Integrated Project on Arid Lands for the Drought-Prone Southern Districts in Lesotho (IPAL-Lesotho)*. Terminal Report. UNESCO, Paris.

———. 1996. *Cooperative Integrated Project on Savanna Ecosystems in Ghana (CIPSEG).* Terminal Report. UNESCO, Paris.

Closing Session

Chapter 1
Mr. Walter Erdelen, Assistant Director-General for Natural Sciences, UNESCO

Your Excellencies,

Honourable participants,

Ladies and gentlemen,

Over the last three days, we have listened to a multitude of speakers from every continent. We have seen the problems of desertification in its different facets and yet, regardless where we are in the world's drylands, we have also learned that we often encounter the same problems when it comes to the sustainable management of arid zones. I was impressed by the accumulation of knowledge and expertise on drylands that is available among our conference participants based on your individual or collective research over many years.

But it is now time to look into the future, which is why we have called this conference 'The Future of Drylands'. Answering a question brought up in the press conference following the Opening Session: yes, drylands do and must have a future! We must all work together for the drylands not to be neglected as remote and peripheral areas or considered as marginal with respect to their economic value. We hope that the *Tunis Declaration* that we have just adopted will be a major step forward on the joint path of the scientific community and decision-makers to help to promote sustainable development in the world's drylands and to achieve the Millennium Development Goals. To this end, we must promote and apply sound science for dryland development.

Honourable Minister of Environment and Sustainable Development, although UNESCO has taken the initiative to organize this conference, it would not have been possible to accomplish such a task without the support of the many international organizations, and regional and national institutions as well as governments and funding partners. For this, UNESCO is immensely grateful.

As they are too numerous to be mentioned here, I wish to single out only the Tunis-based Sahara and Sahel Obsevatory, who have helped us enormously in getting this conference up and running. My particular thanks go the people and the Government of Tunisia for their legendary hospitality in welcoming us here. Sir, your Ministry and all its collaborators were key in making this event a great success for which UNESCO is very grateful. We are all proud that this conference has been placed under the high patronage of His Excellency, Mr. Zine El Abidine Ben Ali, President of Tunisia.

Thank you.

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

Chapter 2
H.E. Nadhir Hamada, Minister of the Environment and Sustainable Development, Republic of Tunisia

Mr. Walter Erdelen, Mr. Youba Sokona,

Distinguished delegates,

Ladies and gentlemen,

It is with great pleasure and emotion that I address you today, distinguished guests and participants, to close the work of this international scientific conference, which I am convinced will be a notable event in the history of combating desertification. In fact, the moment has arrived to say goodbye after three days spent together discussing and exchanging our points of view on the problems faced in the drylands, in a warm and convivial manner.

Ladies and gentlemen,

This conference is held within the framework of the International Year of Deserts and Desertification. The participation of eminent scientists testifies to the interest in issues concerning the livelihoods of dryland populations and their future.

What can we do in fact to respond to the legitimate concerns of these populations faced with desertification, which is becoming increasingly threatening and risks, if nothing is done to mitigate its devastating effects, and that are inevitably expanding to other countries, that up to now have been preserved? Furthermore, early signs of the phenomenon have been recorded in a number of countries on the northern coast of the Mediterranean, the emigration of thousands of people towards Europe who suffer first hand the devastating effects of desertification, are increasingly becoming a veritable challenge to which the international community should rise.

Our conference has attempted to respond to a number of the issues, notably the approaches presented by scientists; and also, thanks to our firm determination, to reach a consensus on the possible avenues that need to be explored to confront the problems that arise. In fact, the conference was an occasion to look back over 50 years of research that have helped to develop the zones affected by aridity and desertification. These three days of dialogue and exchanging viewpoints and experiences between researchers from different countries have likely led to consensus on the future priority of research on the subject and to evaluate the avenues that have yet to be explored with a view to situating the much needed development of these zones on a solid base.

C. Lee and T. Schaaf (eds.), *The Future of Drylands*.

While formulating the hope that international cooperation will help us to realize the recommendations stipulated in the *Tunis Declaration* that crowns this conference and that translates the concerns of everyone in the face of this phenomenon, we should, at the same time, celebrate their hope finally to see the establishment of international solidarity working to conclude the programmes and strategies that attenuate the seriousness of desertification.

Ladies and gentlemen,

Tunisia has relentlessly worked to contribute in an effective and resolute manner to the promotion of ideas and initiatives aimed at the best approaches to the questions related to combating desertification.

Once again, welcome to Tunisia, and enjoy the rest of your stay.

Thank you for your attention, and I hope to see you again soon.

Chapter 3
Vote of Thanks to His Excellency, Zine El Abidine Ben Ali, President of the Republic of Tunisia

We, the representatives of the scientific community and international organizations participating at the International Scientific Conference on *The Future of Drylands* held in Tunis on 19–21 June 2006, within the framework of the International Year on Deserts and Desertification, wish to convey our gratitude to His Excellency, the President Zine El Abidine Ben Ali, and to the Government and the people of Tunisia for their warm welcome, the good organization and all the care received during our stay in Tunisia, land of hospitality and friendship.

We wish to reiterate to His Excellency, the President Zine El Abidine Ben Ali, our deep gratitude for having agreed to place the conference under his High patronage and for his distinguished contribution in promoting international solidarity in favour of sustainable development of the drylands.

Signed in Tunis on 21 June 2006.

Motion de remerciements à Son Excellence Zine El Abidine Ben Ali, Président de la République tunisienne

Nous les représentants de la communauté scientifique et des organisations internationales réunis à l'occasion de la Conférence scientifique internationale sur "l'Avenir des terres sèches" qui s'est tenue à Tunis, du 19 au 21 juin 2006, dans le cadre de l'Année Internationale des Déserts et de la Désertification, adressent leur profonde gratitude à Son Excellence le Président Zine El Abidine Ben Ali, au Gouvernement et au peuple tunisiens pour le chaleureux accueil, la bonne organisation et pour toutes les attentions dont ils ont été entourés durant leur séjour en Tunisie, terre d'accueil et d'amitié.

Nous tenons à exprimer à Son Excellence le Président Zine El Abidine Ben Ali notre profonde gratitude pour avoir bien voulu placer cette conférence sous son haut Patronage et pour sa contribution distinguée à promouvoir la solidarité internationale en faveur du développement durable des zones sèches.

Fait à Tunis le 21 juin 2006.

International Scientific Conference

'The Future of Drylands'

Tunis (Tunisia), 19–21 June 2006

Declaration on Research Priorities to Promote Sustainable Development in Drylands, or the *Tunis Declaration*

We, the participants of the international scientific conference on 'The Future of Drylands', assembled in Tunis (Tunisia) from 19 to 21 June 2006:

Expressing our gratitude to the Government and the people of Tunisia for having hosted the conference in Tunis under the high auspices of the President of Tunisia, His Excellency Zine El Abidine Ben Ali;

Appreciating that the United Nations Educational, Scientific and Cultural Organization (UNESCO) has taken the lead in organizing the conference in collaboration with its partner organizations including the Tunisian Ministry for Environment and Sustainable Development, the Sahara and Sahel Observatory (OSS), ICARDA and ICRISAT representing the Consultative Group on International Agricultural Research (CGIAR), the Convention on Migratory Species (CMS), the United Nations Food and Agricultural Organization (FAO), the Secretariat of the Global Environment Facility (GEF), the International Council for Science (ICSU), the International Fund for Agricultural Development (IFAD), the Union du Maghreb Arabe (UMA), the United Nations International Strategy for Disaster Reduction (UN-ISDR), the United Nations Convention to Combat Desertification (UNCCD), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), the United Nations University (UNU), the World Meteorological Organization (WMO), and benefiting from the financial support of The Christensen Fund (TCF), the Flemish Government of Belgium, the Norwegian Agency for Development Cooperation (NORAD), and the German Technical Cooperation (GTZ);

Acknowledging that the conference has been organized in the context of the 2006 International Year of Deserts and Desertification and commemorating fifty years of dryland research in the UN system;

Considering that the world's drylands is home to more than 2 billion people with rich cultures and provide habitats to unique plant and animal species that need to be preserved for present and future generations;

Being concerned however, that many drylands are subject to land degradation and desertification as a result of extended droughts, climate change and human activities that exacerbate poverty and food insecurity;

Bearing in mind that while our scientific knowledge on dryland environments and the socio-economic dimensions of dryland development have increased over the past fifty years, important knowledge gaps still remain today and that new challenges and opportunities have emerged that need to be addressed in order to promote sustainable development through a holistic approach and action plans to combat desertification;

Urge civil society, national authorities and the international community to place combating desertification and development of drylands as a major priority and to create an enabling environment for the successful implementation of the multilateral environmental agreements and to achieve the Millennium Development Goals;

Call upon governments and multilateral environmental agreements to use sound scientific knowledge to formulate and implement policies, laws, regulations and action programmes vis-à-vis environmental issues stressing integrated management of natural resources and conservation practises;

Request the scientific community to ensure its findings are made available and understandable to decision-makers and local dryland communities so that research can help shape sound policies and good governance as well as education on an interactive basis for sustainable dryland management and improved livelihoods;

Encourage public, private, national and international institutions to step up their efforts in providing funding for demand driven, integrated and application-oriented research in both the natural and social sciences for a better understanding of human-environment interrelations in the drylands;

Request both the national decision-making bodies and the scientific community to increase their efforts in implementing research for development projects in close collaboration with and for the benefit of local dryland communities, integrating modern technologies with traditional knowledge with a view to achieving sustainable development in drylands;

Identify the following themes as priority issues in our attempt at defining future paths of dryland research for sustainable development:

- Interdependence and conservation of cultural and biological diversity;
- Integrated management of water resources in the context of a looming water crisis;
- Assessing and forecasting dryland ecosystem dynamics in order to formulate adaptation strategies in the context of global change and to alleviate poverty so as to achieve the MDGs;
- Agriculture and pastoralism as opportunities for sustainable land use;
- Coping with and management of natural and man-made disasters;
- Formulating and implementing scenarios and policy options for good governance in the context of global change;
- Identifying viable dryland livelihoods and policy options for the benefit of dryland dwellers (such as ecotourism);
- Educating for sustainable development and knowledge sharing;
- Reversing environmental degradation and promoting rehabilitation;
- Costs related to *inaction* in the field of land degradation;

- Renewable energies suitable for dryland development;
- Evaluation of dryland ecosystem services and their trade-offs;

Invite the scientific community to increase the involvement of youth and women in research, innovation and education programmes so as to facilitate gender equity;

Invite the organizers of the conference, as well as all participating institutions and individuals, to make special efforts for the wide dissemination of this Declaration through appropriate channels, such as national and international fora, publications and Internet.

Summary Report on the UNESCO-Organized International Scientific Conference *The Future of Drylands*

Introduction

1. Under the leadership of UNESCO, the international scientific conference on *The Future of Drylands* was held in Tunis (Tunisia) from 19 to 21 June 2006. The conference was placed under the high auspices of H.E. Zine El Abidine Ben Ali, President of Tunisia. The Tunisian Ministry of Environment and Sustainable Development was the national organizer of the conference; the conference also benefited from valuable logistic and technical support provided by the Tunis-based sub-regional organization Observatoire du Sahara et du Sahel (OSS). UNESCO also wishes to acknowledge gratitude to the generous financial Conference sponsors namely Oasis, a system wide program of the Consultative Group on International Agricultural Research (CGIAR) jointly convened by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); the Flemish Government of Belgium; The Christensen Fund and the Global Environment Facility (GEF).

Preparatory Work for the Conference

2. As lead organization, UNESCO arranged for several inter-agency meetings for the preparation of the conference. The first meeting was held at UNESCO Headquarters in Paris from 14–15 February 2006 and was attended by representatives of the following organizations: Convention on the Conservation of Migratory Species of Wild Animals (CMS), Food and Agriculture Organization of the United Nations (FAO), International Council for Science (ICSU), International Fund for Agricultural Development (IFAD), Sahara-Sahel Observatory (OSS), United Nations Convention to Combat Desertification (UNCCD), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), and United Nations University (UNU). At this meeting, the title of the conference, the venue (Tunis) and the dates of the conference (19 to 21 June

2006) were retained, in particular as the conference was to be embedded into the 2006 International Year of Deserts and Desertification, and was to be held in close proximity to World Desertification Day observed every year on 17 June (which happened to be a Saturday in 2006; for convenience purposes, the conference, therefore, started on Monday, 19 June 2006). A phased time-schedule leading up to the conference itself was also elaborated.

3. The first inter-agency preparatory meeting identified the three large conference objectives:

   - To commemorate 50 years of dryland research in the UN System in the context of the 'International Year of Deserts and Desertification'
   - To review the current state-of-knowledge of dryland ecosystems and the socio-economics of dryland development in order to provide scientific and technical advice to decision-makers and for the implementation of the UNCCD
   - To identify important knowledge gaps for defining future paths of research into drylands, in particular to promote application-oriented science for the sustainable development of dryland regions and to reach the Millennium Development Goals

It was agreed at the first inter-agency meeting hat the conference focus on three inter-related clusters of topics:

(a) Research and science issues related to drylands and desertification
(b) Policy requirement to combat desertification
(c) Interventions/implementation issues related to sustainable dryland development

4. The second inter-agency preparatory meeting took place in the sidelines of the UNCCD 3rd session of the Committee for the Review of the Implementation of the Convention (CRIC-3) in Bonn (Germany) on 2 and 3 May 2005. Representatives of the following organizations took part in the 2nd meeting: Convention on the Conservation of Migratory Species of Wild Animals (CMS), Global Environment Facility (GEF), Food and Agriculture Organization of the United Nations (FAO), International Centre for Agricultural Research in the Dry Areas (ICARDA), Observatoire du Sahara et du Sahel (OSS), United Nations International Strategy for Disaster Reduction (UN-ISDR), United Nations Convention to Combat Desertification (UNCCD), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations University Institute for Water, Environment and Health (UNU-INWEH), United Nations University Institute for Environment and Human Security (UNU-EHS), World Meteorological Organization (WMO), as well as the University of Arizona. While all above-mentioned UN bodies and international institutions were to form the Organizing Committee for the Conference, an Executive Committee was also created composed of UNESCO, FAO, UNEP, UNU and OSS, which was entrusted to take *ad hoc* decisions related to the preparation of the conference (while major decisions would be taken in consultation with the entire Organization Committee).

5. The second inter-agency meeting decided that an international Scientific Committee, consisting of 12 members from all world regions, be established with the mandate of assisting with the 'Call for Papers' for the conference, review paper abstracts for selection at the conference, and edit the conference proceedings after the conference.
6. The second meeting also worked out the conference structure with three keynote presentations and eight working group sessions. The keynote presentations would target the following topics:

   - Keynote Presentation 1: Research and science related to drylands and desertification
   - Keynote Presentation 2: Policy-related issues in drylands
   - Keynote Presentation 3: Interventions and implementation needs for sustainable dryland development

7. The eight working groups would address the following issues:

   1. Conservation of biodiversity, cultural and natural heritage in drylands
   2. Dryland hydrology and water management
   3. Monitoring and forecasting on dryland ecosystem dynamics
   4. Sustainable land use and agriculture
   5. Disaster and risk management in drylands
   6. Policy, governance and socio-economic dynamics in changing drylands
   7. Viable dryland livelihoods and policy options
   8. Education and knowledge sharing in drylands

8. By e-mail consultations among the members of the Organizing Committee, the members of the Scientific Committee were identified. All selected persons are renowned scientists in the field of drylands research and desertification control:

19 June 2006	20 June 2006	21 June 2006
Morning session (Plenary)	**Morning session** (2 parallel working groups):	**Morning session** (2 parallel working groups):
Opening Session Keynote presentation on cluster 1; Keynote presentation on cluster 2; Keynote presentation on cluster 3	WG 3 WG 4	WG 7 WG 8
Afternoon session (2 parallel working groups): WG 1 WG 2	**Morning session** (parallel working groups): WG 5 WG 6	**Afternoon session** (Plenary): • Summary presentations on working groups; • Closing session.
Evening: Poster exhibition & film sessions	**Evening:** Poster exhibition & film sessions	**Evening:** Poster exhibition & film sessions

The final agenda with names of presenters is attached in Annex 1 to this report.

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Professor Riccardo Valentini
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9. The third inter-agency preparatory meeting convened in Tunis (Tunisia) from 19 to 20 January 2006 with a view to select the conference venue and to discuss organizational and logistic matters with the local counterparts, in particular the Tunisian Ministry of Environment and Sustainable Development and OSS. Representatives of the following organizations took part in this technical preparatory meeting: Consultative Group on International Agricultural Research (CGIAR); Food and Agriculture Organization of the United Nations (FAO, Tunis Office); International Crops Research Institute for the Semi-arid Tropics (ICRISAT); Institut des Régions Arides, Tunisie (IRA); Ministry of Environment and Sustainable Development of Tunisia (DGE/MEDD); Observatoire du Sahara et du Sahel (OSS); United Nations Convention to Combat Desertification (UNCCD, Regional Coordination Unit for Africa), United Nations Environment Programme (UNEP); United Nations Educational, Scientific and Cultural Organization (UNESCO); United Nations University, Institute for Environment and Human Security (UNU-EHS); as well as the University of Arizona.
10. In order to facilitate communication and information about the conference, UNESCO prepared a conference website in English and in French (http://www.unesco.org/mab/ecosyst/futureDrylands.shtml for English version), as well as a conference brochure in English and in French, which was widely distributed *inter alia* through Permanent Delegations at UNESCO.

The Conference

11. The conference was attended by over 400 participants (and thus exceeded initial expectations by 100%!) from all continents. A total of 20 organizations (UN bodies, international and regional organizations, national governments and

funding agencies as well as private foundations) took part in the conference by providing intellectual, technical and/or financial support. The following organizations were involved with the conference (in alphabetic order of acronyms):

- CMS (Convention on Migratory Species or Bonn Convention)
- FAO (Food and Agriculture Organization of the United Nations)
- Flemish Government of Belgium
- GEF-World Bank (Global Environment Facility)
- GM at IFAD (Global Mechanism at the International Fund for Agricultural Development)
- GTZ (German Technical Cooperation)
- ICARDA (International Centre for Agricultural Research in the Dry Areas)
- ICRISAT (International Crops Research Institute for the Semi-arid Tropics)
- ICSU (International Council for Science)
- NORAD (Norwegian Agency for Development Cooperation)
- OSS (Observatoire du Sahara et du Sahel)
- TCF (The Christensen Fund based in the United States of America)
- UMA (Union du Maghreb Arabe)
- UNCCD (United Nations Convention to Combat Desertification)
- UNDP (United Nations Development Programme)
- UNEP (United Nations Environment Programme)
- UNESCO (United Nations Educational, Scientific and Cultural Organization)
- UN-ISDR (United Nations International Strategy for Disaster Reduction)
- UNU (United Nations University)
- WMO (World Meteorological Organization)

12. Thanks to the Tunisian Ministry of Environment and Sustainable Development and UNESCO's Press office more than 50 journalists were present at the opening ceremony, which included Tunisian media as well as representatives of the international press agencies such as AFP, AP, Reuters, EFE, DPA. During the 3-day conference, a number of interviews were given with the high-ranking participants to the conference by the Tunisian and international media (TV, radio et paper press), such as Jeune Afrique, AFP, AP, BBC, RFI, Radio Canada International. Accordingly, the conference benefited from excellent worldwide media coverage.
13. High-ranking officials at the Opening Session included H.E. Mr Nathir Hamada (Minister of Environment and Sustainable Development of Tunisia); H.E. Mr Habib Ben Yahia (Secretary-General of the Union du Maghreb Arabe); Mr Walter Erdelen (Assistant Director-General for Natural Sciences, UNESCO); Mr Hama Arba Diallo (Executive Secretary, UN Convention to Combat Desertification); Mr Ahmed Djoghlaf (Executive Secretary, UN Convention on Biological Diversity); Dr William Dar (Director-General, ICRISAT, statement made on behalf of the CGIAR system); Mr Mustapha Sinaceur (UN Resident

Coordinator a.i. and FAO Sub-Regional Representative for North Africa and FAO Representative in Tunisia); Mr Salvano Briceno (Director of the UN International Strategy for Disaster Reduction); and Ms Claudia Cardinale (UNESCO Goodwill Ambassador). Representatives from UNEP and UNU also enriched the Opening Session with statements of their organizations. The conference programme is attached as Annex 1 to this report.

14. Three keynote presentations were also made during the Opening Session:

- *Keynote Presentation 1*
  - Research and science related to drylands and desertification given by Prof. Charles Hutchinson, Director of Office of Arid Lands Studies, University of Arizona, USA
- *Keynote Presentation 2*
  - Policy-related issues in drylands given by Dr Youba Sokona, Executive Secretary of the Observatoire du Sahara et du Sahel (OSS)
- *Keynote Presentation 3*
  - Interventions and implementation needs for sustainable dryland development given by Dr William Dar, Director-General of ICRISAT and former Minister of Agriculture of the Philippines

15. Prof. Charles F. Hutchinson also presented the UNESCO commissioned book *The Future of Drylands – Revisited* which discusses the current state of scientific knowledge on dryland ecosystems. Some 50 years after the publication of Gilbert F. White's book *The Future of Arid Lands*, a team from the Office of Arid Land Studies (OALS) at the University of Arizona in Tucson has taken this unique opportunity to look back in time and assess where we are now relative to then.
16. A total of 64 scientific papers in eight thematic sessions (see paragraph 5) were dedicated to relevant dryland issues (the conference papers and poster abstracts are currently being edited. The publication of the conference proceedings is planned for 2007).
17. Over 30 scientific as well as institutional posters were displayed throughout the conference informing on drylands research and development issues. Moreover, several organizations used the conference to showcase their dryland activities with publications and information brochures distributed at their specific stands (such as FAO, ICARDA, OSS, UNESCO). A Norwegian company featured its latest soil compacting technology (using kaolinite) to prevent soil erosion in drylands. Japanese artist Ms Kyoko Kobori prepared for the conference Japanese calligraphy on the theme of deserts. Two post-conference excursions informed on dryland research activities in the specific Tunisian context.
18. Several organizations used to the conference as a platform for side events and satellite meetings, such as:

- Joint Flanders-UNESCO-UNU-ICARDA project “Sustainable Management of Marginal Drylands” (SUMAMAD)
- UNESCO-IHP: Arab Region Committee of the WADI project
- UNESCO-IHP: G-WADI Steering Committee
- UNU: master course graduation ceremony
- World Bank – GEF Secretariat: measuring impact of SLD – drylands
- IRD: Hydrological changes in the Mediterranean region
- ROSELT/OSS: results of the long-term ecological observation network
- UNU-INWEH: IYDD Algiers conference preparatory meeting

Conference Outcomes

19. Summary presentations of the eight thematic sessions are appended as Annex 2 to this report.

    Conference participants adopted by acclamation a “Declaration on Research Priorities to Promote Sustainable Development in Drylands” (the *Tunis Declaration*) which calls for putting science at the service for drylands research and development, and which identifies twelve scientific priority themes for dryland development (full text of Declaration attached as Annex 3). In essence, the Declaration calls upon governments to use sound scientific knowledge to formulate and implement policies, laws, regulations and action programmes vis-à-vis environmental issues. The scientific community is requested to ensure its findings are made available and understandable to decision-makers and local dryland communities so that research can help shape sound policies and good governance as well as education on an interactive basis for sustainable dryland management and improved livelihoods.
20. Twelve priority issues should be addressed in future paths of dryland research for sustainable development:

    1. Interdependence and conservation of cultural and biological diversity
    2. Integrated management of water resources in the context of a looming water crisis
    3. Assessing and forecasting dryland ecosystem dynamics in order to formulate adaptation strategies in the context of global change and to alleviate poverty so as to achieve the MDGs
    4. Agriculture and pastoralism as opportunities for sustainable land use
    5. Coping with and management of natural and man-made disasters
    6. Formulating and implementing scenarios and policy options for good governance in the context of global change
    7. Identifying viable dryland livelihoods and policy options for the benefit of dryland dwellers (such as ecotourism)
    8. Educating for sustainable development and knowledge sharing
    9. Reversing environmental degradation and promoting rehabilitation

10. Costs related to *inaction* in the field of land degradation
11. Renewable energies suitable for dryland development
12. Evaluation of dryland ecosystem services and their trade-offs

21. The conference was also a fine example of inter-agency collaboration among 20 UN bodies, international and regional organizations as well as private and public funding partners in a synergistic manner. By bringing together scientists from all world regions, the conference helped to increase awareness on dryland issues, and the need of using scientific expertise in reaching the Millennium Development Goals.
22. UNESCO wishes to thank all the contributing conference speakers as well as the scientific committee, conference organizers and partner organizations that helped make this conference a success. With special thanks to Oasis, the Flemish Government of Belgium, The Christensen Fund and GEF for their generous financial contribution. Finally, we reserve a special mention to all those who work tirelessly to ensure that drylands remain special places and in doing so ensure that drylands remain unique and viable regions for future generations.

The Future of Drylands International Scientific Conference Tunis (Tunisia), 19–21 June 2006

Agenda

Monday, 19 June 2006: 9:30–13:00 hrs.

Opening Session

Room: Sidi Bou Saïd

- H.E. Mr. Nadhir Hamada, Minister of Environment and Sustainable Development of Tunisia
- H.E. Mr. Habib Ben Yahia, Secretary General of UMA (Union du Magreb Arabe)
- Mr. Walter Erdelen, Assistant Director-General for Natural Sciences, UNESCO
- Mr. Hama Arba Diallo, Executive Secretary, UN Convention to Combat Desertification (UNCCD)
- Mr. Ahmed Djoghlaf, Executive Secretary, Convention on Biological Diversity (CBD)
- Dr. William Dar, Director-General, ICRISAT, on behalf of the CGIAR system
- Mr. Mustapha Sinaceur, UN Resident Coordinator a.i. and FAO Sub-Regional Representative for North Africa and FAO Representative in Tunisia
- Mr. Salvano Briceno, Director, UN International Strategy for Disaster Reduction
- Mr. Zafar Adeel, United Nations University (UNU)
- Ms Gemma Shepherd, UNEP
- Ms Claudia Cardinale, UNESCO Goodwill Ambassador

11:15–11:30 hrs.: Coffee/tea break

Keynote Presentations

Room: Sidi Bou Saïd

- Prof. Charles Hutchinson, Director of Office of Arid Lands Studies, University of Arizona, USA:
- Research and Science Related to Drylands and Desertification
- Dr. Youba Sokona, Executive Secretary of the Observatoire du Sahara et du Sahel (OSS):
- Policy Requirements to Combat Desertification

- Dr. William Dar, Director General of ICRISAT and former Minister of Agriculture of the Philippines:
- Interventions and Implementation Needs for Sustainable Dryland Development

***

Monday, 19 June 2006: 14:30–18:00 hrs.

Session I: Conservation of biodiversity, cultural and natural heritage in drylands
Room: Top Hat
Chairperson: Prof. Riccardo Valentini
Rapporteur: Prof. Charles Hutchinson

Presenting author	Title of paper
Iwao Kobori	Fifty years of personal experience in arid land studies
Beate Scherf	Livestock genetic diversity in dry rangelands
Roseline C. Beudels-Jamar	The role of megafauna restoration in dryland, natural and cultural heritage conservation
Mohammed Al-Qawaba'a	Learning from nature and culture to manage nature reserves: Experience from the Dana Biosphere Reserve, Jordan

16:00–16:30 hrs.: Coffee/tea break

Presenting author	Title of paper
Pietro Laureano	Traditional knowledge and the world databank for safeguarding ecosystems
Ingrid Hartmann	Cultural diversity in Ethiopia and its impact on local economies and biodiversity
Durgadas Mukhopadhyay	Indigenous knowledge and sustainable natural resource management in the Indian desert
Mohamed Neffati	The medicinal and aromatic plants sector in the drylands: A promising alternative for sustainable development and combating desertification in Tunisia

Monday, 19 June 2006: 14:30–18:00 hrs.
Session II: Dryland hydrology and water management
Room: Sidi Bou Said
Chairperson: Prof. Houcine Khatteli
Rapporteur: Prof. Donald Gabriels

Presenting author	Title of paper
Howard S. Wheater	G-WADI – UNESCO's global network for water and development information for arid lands
Bo Appelgren	Towards sustainable dryland development in Africa: Integrating groundwater and land management
Mohamed Meddi	Evolution of the pluviometric regimes in various stations of the northern Algerian Sahara
Stefan Saradeth	AQUIFER – Remote sensing as support for the management of internationally shared transboundary aquifers in Africa

16:00–16:30 hrs.: Coffee/tea break

Presenting author	Title of paper
Sayyed Ahang Kowsar	Desertification control through floodwater harvesting: The current state of know-how
Dirk Raes	Modeling the effects of floodwater spreading systems on the soil water balance and crop production in the Gareh Bygone Plain of southern Iran
Mohamed Ouessar	Future of drylands – An overview of evaluation and impact assessment tools for water harvesting
Michel Malagnoux	Degraded arid land restoration for afforestation and agro-silvo-pastoral production through a new water harvesting mechanized technology

Tuesday, 20 June 2006: 9:00–13:00 hrs. and 14:30–16:00 hrs.
Session III: Monitoring and forecasting of dryland ecosystem dynamics
Room: Top Hat
Chairperson: Dr. Gisela Alonso Dominguez
Rapporteur: Dr. Gertjan B. Beekman
Introduction by the Observatoire du Sahara et du Sahel/Sahara-Sahel Observatory

Presenting author	Title of paper
Mohamed S. Abdel Razik	Plant diversity changes in response to environmental drivers and pressures at El Omayed 'ROSELT/OSS Observatory, Egypt
Mongi Sghaier	Integrated environmental and socio-economic modeling using LEIS for desertification monitoring and assessment in Menzel Habib observatory (South Tunisia)
Jesse T. Njoka	Experiences in the Establishment of Long Term Ecological Observatory Network (ROSELT) in Eastern Africa
Moussa Karembé	Effets des gradients climatique, anthropique et sol sur la production ligneuse du Parc du Baoulé, Mali

11:00–11:30 hrs.: Coffee/tea break

Presenting author	Title of paper
Freddy Nachtergaele	The Land Degradation Assessment in Drylands (LADA) Project: Reflections on indicators for land degradation assessment
Adbi Jama	A new toolkit for monitoring and forecasting forage supply in the grazing lands of Eastern Africa
Mohamed Ismail	Conception and implementation of a desertification monitoring system in Tunisia
Ryan L. Perroy	Chararcterizing dryland post-grazing change trajectories on Santa Cruz Island, CA, with multitemporal landsat data

13:00–14:30 hrs.: Lunch break

Presenting author	Title of paper
Raghuvanshi Ram	Decision support system for water resources management in Dudhi and Bewas micro-watersheds, Madhya Pradesh, India
Abdoulaye Saley Moussa	Soil indicators of rangeland degradation in a semi-arid communal district in South Africa
Vieri Tarchiani	Monitoring drylands ecosystem dynamics for sustainable development policies: The Keita experience

Tuesday, 20 June 2006: 9:30–13:00 hrs. and 14:30–16:00 hrs.
Session IV: Linking sustainable indices and climate variability
Room: Sidi Bou Saïd
Chairperson: Dr. Mekhlis Suleimenov
Rapporteur: Prof. Sayyed Ahang Kowsar

Presenting author	Title of paper
Ronald Bellefontaine	Vegetative propagation at low cost: A method to restore degraded drylands
Asamoah Larbi	Developing high-yielding, nutritious feed legumes for dryland agriculture in Central and West Asia and North Africa
Humberto Alves Barbosa	Linking sustainable indices and climate variability in the State of Ceará, Northeast Brazil
Bunyamin A. Ola-Adams	Conservation of biodiversity of Nigerian drylands

11:00–11:30 hrs.: Coffee/tea break

Presenting author	Title of paper
Abule Ebro	Impact of land use conflict on livelihood and range condition in the Awash Valley of Ethiopia
Mohammed Karrou	Adoption of integrated natural resources management packages, a potential mean for the sustainable development of rainfed agriculture in the Maghreb region: The case of Morocco
Muhammad Akram	Desertification control for sustainable land use of the Cholistan Desert – Pakistan

13:00–14:30 hrs.: Lunch break

Presenting author	Title of paper
Zhang Qian	Policy analysis in grassland management of Xilingol Prefecture, Inner Mongolia
Nagwa H.K. Elnwishy	Combating desertification through fish farming
Lugman Mohamedein Mohamed	Assessment of management models of *Acacia seyal* as a means for the rehabilitation of drylands, Sudan
Boubaker Raddaoui	Participatory monitoring and evaluation of a project to combat desertification in drylands (Case study in Central Western Tunisia)

Tuesday, 20 June 2006: 16:30–18:00 hrs.
Session V: Disaster and risk management in drylands
Room: Top Hat
Chairperson: Dr. Gertjan Beekman
Rapporteur: Dr. Mary Seely

Presenting author	Title of paper
Nacif Rihani	Issues and options for the livestock sector in responding to droughts
Dusan Sakulski	Implementation of the water sensor web for floods and droughts in South Africa
Ibrahim M.G. Phiri	The impact of changing environmental conditions on vulnerable communities of the Shire Valley, southern Malawi
Braulino Lapinel Pedroso	Drought, aridity and desertification – a case study from the eastern part of Cuba

Tuesday, 20 June 2006: 16:30–18:00 hrs.
Session VI: Policy, governance and socio-economic dynamics in changing drylands
Room: Sidi Bou Saïd
Chairperson: Prof. Boshra Salem
Rapporteur: Dr. Mekhlis Suleimenov

Presenting author	Title of paper
Mélanie Requier-Desjardins	Social costs of desertification in Africa: The case of migration
Pierre Gerber	With the back against the wall – Issues and options regarding livestock production in African drylands
Olivier Barrière	Legal aspects of the co-viability of social and ecological systems in African arid zones: A legal anthropology approach to environmental law
Ian Watson	Integration of regulation, extension, science, policy and monitoring improves land management in arid Western Australia

Wednesday, 21 June 2006: 9:30–13:00 hrs.
Session VII: Viable dryland livelihoods and policy options
Room: Top Hat
Chairperson: Prof. Dali Najeh
Rapporteur: Dr. Marc Bied-Charreton

Presenting author	Title of paper
Gemma Shepherd	An ecosystem approach to natural resource management in the Sahel
Richard Thomas	An integrated livelihoods-based approach to combat desertification in marginal drylands
Moncef Ben-Hammouda	A conservation agriculture based on direct sowing

11:00–11:30 hrs.: Coffee/tea break

Presenting author	Title of paper
Tanveer Arif	Viable options for improving livelihoods in Tharparkar Desert District, Pakistan
Mohamed Ahmed Elfadl	Improving the traditional agroforestry for sustainable livelihood in the drylands of Sudan
Ahmed A. El Obeidy	Introducing new crops with high water use efficiency in the Middle East and North Africa

Wednesday, 21 June 2006: 9:30–13:00 hrs.
Session VIII: Education and knowledge sharing in drylands
Room: Sidi Bou Said
Chairperson: Dr. Mary Seely
Rapporteur: Prof. Boshra Salem

Presenting author	Title of paper
Zafar Adeel	Findings of the global desertification assessment by the millennium ecosystem assessment – a perspective for better managing scientific knowledge
Mary Seely	The unmet challenge of connecting scientific research with community action
Krishna Prasad	Development and management of drylands: The need for adapted education and knowledge sharing
Mark S. Reed	Participatory land degradation assessment

11:00–11:30 hrs.: Coffee/tea break

Presenting author	Title of paper
Hélène Gille	Environmental education within the perspective of sustainable development: A teaching resource kit for dryland countries
Farida Khammar	Environmental education: An alternative to development in drylands
Caroline King	Sustainable Management of Marginal Drylands (SUMAMAD): Sharing success stories from indigenous, adaptive and innovative approaches
J. Justin Pious	Innovations of an Indian non-governmental organization in building the capacity of people inhabiting the drylands
Thomas Schaaf	UNESCO's experience of fifty years of drylands research and outreach

Wednesday, 21 June 2006: 15:00–17:00 hrs.
Closing Session (in plenary)
Room: Sidi Bou Saïd

Summary presentations on the eight thematic sessions by the Session Chairpersons

Session I – Chairperson: Prof. Riccardo Valentini

Rapporteur: Prof. Charles Hutchinson

Session II – Chairperson: Prof. Houcine Khatteli
Rapporteur: Prof. Donald Gabriels

Session III – Chairperson: Dr. Gisela Alonso Dominguez
Rapporteur: Dr. Gertjan B. Beekman

Session IV – Chairperson: Dr. Mekhlis Suleimenov

Rapporteur: Prof. Sayyed Ahang Kowsar

Session V – Chairperson: Dr. Gertjan Beekman
Rapporteur: Dr. Mary Seely

Session VI – Chairperson: Prof. Boshra Salem
Rapporteur: Dr. Mekhlis Suleimenov

Session VII – Chairperson: Prof. Dali Najeh
Rapporteur: Dr. Marc Bied-Charreton
Session VIII – Chairperson: Dr. Mary Seely
Rapporteur: Prof. Boshra Salem

- Presentation of children's texts on deserts
- Declaration on research priorities to promote sustainable development in drylands, the *Tunis Declaration*
- Closing remarks by Mr. Walter Erdelen, Assistant Director-General for Natural Sciences, UNESCO
- Closing remarks by H.E. Mr. Nadhir Hamada, Minister of Environment and Sustainable Development of Tunisia
- Vote of thanks by a conference participant: Dr. Marc Bied-Charreton

Future of Drylands Conference

Tunis, 19–21 June 2006

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