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Antonio Navarra
Laurence Tubiana *Editors*

Regional Assessment of Climate Change in the Mediterranean

Volume 2: Agriculture, Forests and Ecosystem Services and People

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Regional Assessment of Climate Change in the Mediterranean

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Editors

Regional Assessment of Climate Change in the Mediterranean

Volume 2: Agriculture, Forests and Ecosystem Services and People

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CIRCE – Climate Change and Impact Research: The Mediterranean Environment

Foreword

CIRCE, co-ordinated by INGV (Istituto Nazionale di Geofisica e Vulcanologia-Italy) and supported by Sixth Framework Programme of European Commission, confirmed the climate change trends in the Mediterranean area indicated in the past IPCC (Intergovernmental Panel on Climate Change) reports, implementing a new generation of climate models for the next decades. These models can be used for simulations on future climate scenarios that are more realistic and detailed. CIRCE realized for the first time a regional assessment of climate change impacts, targeting one of the most complex, socially and physically diverse, region of the world. The coordinate approach showed that climate will significantly impact major economic drivers and affect social dynamics.

Water will become an increasingly precious resource, to be managed both for domestic and industrial usages and for irrigation. New policies will have to be developed to adapt to water scarcity, such as water recycling and innovative global water management approaches. It is a challenge, because water management systems are often deeply entrenched in local traditions and cultures and therefore they cannot be changed overnight. Water scarcity, which is usually well managed in European countries, is still an issue in North Africa and it is a clear example of how climate change could amplify regional inequalities.

Reduced water availability and increased frequency and intensity of heat waves will render ecosystems more vulnerable, since climate change is too fast to allow ecosystems adaptation. Particularly affected are traditional crops (wheat, olives, grapes), both because there is less available time for biomass accumulation and because of higher temperatures and water stress on crops. Forests in the Mediterranean region are also going to be affected. CIRCE has shown, that it is extremely important to set up adaptation strategies in this field, such as biodiversity and habitats preservation, sustainable development and methods to control fires and pests.

The Mediterranean is the most important tourist region of the world. Climate change will affect tourism fluxes by decreasing the tendency to travel from northern countries as they take advantage of hotter and longer summers and in the future the south could be strongly affected by a gradual loss of tourists. The relative differences of temperature and precipitation will shape the toruism patterns of the future and therefore it is important to develop strategic plans both to support tourism resilience and development in new zones and to reduce carbon emissions related to tourist travel.

The analysis of the results produced by the CIRCE economic models showed that the climate change impact on Gross Domestic Product (GDP) might be a decrease of 1% in 2050, or even more (about 3 %) in North Africa and in small Mediterranean islands (Malta, Cyprus), which are expected to be more sensititive to climate change. CIRCE analysis is showing that supporting a “green economy”, can provide employment and sustainable development in the southern Mediterranean, reducing inequalities and creating innovative growth opportunities. In this way, policies that take into account the factor of a changing climate could be the occasion for a long-term social and economic improvement for all the countries in the Mediterranean region.

CIRCE has created a community where physical scientists, ecologist, economist and social scientist have worked together effectively, crossing disciplinary barriers and developing a common language. When we will look back to these years, we will have no trouble to realize that CIRCE has started a new era in climate studies of the Mediterranean region, showing that is possible to join knowledge and expertise from far disciplines to produce a coherent and consistent assessment that can be at basis of effective adaptation and mitigation policies.

Minister for the Environment, Land and Sea Corrado Clini
Italy

CIRCE – Climate Change and Impact Research: The Mediterranean Environment

Preface

The CIRCE project started on 1 April 2007 and ended on 30 June 2011, coordinated by the Istituto Nazionale di Geofisca e Vulcanologia, Italy. The work of the CIRCE project was split into 13 research lines plus one for coordination and communication. Research lines were subdivided into several work packages activities.

The main objectives of CIRCE were to predict and to quantify the physical impacts of climate change in the Mediterranean, and to assess the most influential consequences for the population of the region. The knowledge yielded by the different specialized investigations were linked in an integrated interdisciplinary approach designed to study the total effect of climate change. CIRCE integrated cutting-edge scientific research with the needs of end-users and communities. Thus, CIRCE was able to quantify the impact of global warming on Mediterranean climate variables, while also taking into account the regional, social, economic and policy aspects of the process. That allowed to overcome the imbalance faced by a number of research projects on climate impacts between physical and natural science and social sciences so as to build a new vision of the interactions between climate factors and socioeconomic evolutions.

The impacts of climate change were analyzed and evaluated in their oceanographic, meteorological, ecological, economic and societal dimensions, and the project focused particularly on the direct economic impacts for six crucial sectors for the Mediterranean region: health, tourism, energy demand, agriculture, water and human migration. In this way, CIRCE made a powerful contribution to the definition and evaluation of adaptation and mitigation strategies.

The end products of CIRCE have been published in the open scientific literature and summarized in less technical terms in the final report – Regional Assessment of Climate Change in the Mediterranean (RACCM), a decision support system tool for adaptation and mitigation strategies tailored specifically for the Mediterranean environment.

This report represents the synthesis of the work in the project and also an opportunity for an assessment of the present state of the science results for climate change studies and their impacts in the Mediterranean region. Assessments of climate change and their impact at global level have been performed repeatedly in recent years. The methodology and the process have been established during four reports prepared by the Intergovernmental Panel on Climate Change (IPCC) since 1990 and a fifth global report is under preparation.

The response of the climate system to external perturbation, like the increase of greenhouse gases, is highly variable in space and time. The intricate web of nonlinear processes and interactions that link the various components of the system modulates and modifies the overall trend and average response with an intrinsic variability that can be of the same magnitude as the signal from the greenhouse gases. The tools at our disposal to produce quantitative evaluation and estimation, mostly models, have been continuously developing and they are now reaching a level where that can actually provide information at scales smaller than the traditional global scale. On the other hand, as the full extent of possible climate change on our societies and economies was becoming clear, the interest for climate change impact informations at local and regional level has been steadily growing. Global assessments like those pioneered by the IPCC need to be complemented by Regional assessments that take into account the specific climatological, social and economic aspects of a region. Such assessments are now greatly needed to provide a sound scientific base to draft detailed adaptation strategies, inform policies and evaluate their costs.

The progress of the regional assessments has been slowed by the absence of tools adequate to address regional and local issues. CIRCE is pioneering the development of models tailored for the regional climate, either using limited area models or high resolution global models, taking great care to properly represent processes and dynamics that are particularly relevant for the region under study, like for instance an accurate representation of the dynamics of the Mediterranean Sea. Such models allow the delivery of primary climate drivers to the impact studies that reflect more accurately the specific characteristics of the region and therefore should allow in principle a more accurate analysis of the downstream impacts.

The Mediterranean Sea area is a critical area for political, social and economical reasons, but it is also a critical area from the climate point of view. It has a unique position at the border of the tropical zones and the mid-latitude areas, resulting in a complex interplay of interactions between the mid-latitude atmospheric dynamics and tropical processes. The delicate energy and hydrological balance of the Mediterranean Sea influence the Atlantic circulation and, ultimately, the world ocean circulation. The region has unique vulnerabilities from the climate and societal point of view that can go critical under climate change. And yet, the region has been rather under-investigated in recent years and comprehensive analyses and assessments of the region are rare. This report provides the first comprehensive assessments of climate change and its impacts in the Mediterranean region, covering different sectors, from physical climate drivers as temperature and precipitation, to agriculture, forests, from water resources to social impacts, evaluating policies and determining costs of actions and inaction.

The report contains novel results obtained by the new system developed under CIRCE integrating them with some of the existing body of results for the region to achieve an overall evaluation of the state of scientific knowledge regarding climate change and its impacts in the Mediterranean region.

The report is divided in five parts. Parts I and II are collected in the first volume, Parts III and IV make up the second volume and the case studies are presented in the third volume. Though there is a logical sequence to the volumes, the discussion is sufficiently independent that each volume can be considered on its own.

Part I deals with climate change in the atmosphere and the Mediterranean Sea and it contains six chapters: Chapter 1 *Introduction*. Chapter 2 *Past and Current Climate Changes in the Mediterranean Region* assess the current level of knowledge of the observed climate variability and trends in the Mediterranean, and it includes description of available temperature and precipitation station and gridded data sets, reviewing issues linked to quality control harmonization and homogenization of data; data for the ocean circulation, sea level and waves are also discussed as the changes in extreme events. Chapter 3 *Future Climate Projections* discusses the status of the art of model projections with existing models and with the new CIRCE models and simulations, including an assessment of the uncertainties of the model projections. Chapter 4 *Mechanisms of Climate Variability, Air Quality and Impacts of Atmospheric Constituents in the Mediterranean Region* discusses regional patterns and variability linking them with air quality and direct and indirect impacts on regional climate and associated uncertainties. Chapter 5 *Detection and Attribution* discusses the issues connected with the identification of the climate change signal and its causes and Chapter 6 *Summary and Major Findings* concludes the part.

Part II is dedicated to the impacts of climate change on the hydrological cycle of the region. It contains five chapters: Chapter 7 *Introduction*. Chapter 8 *The Hydrological Cycle of the Mediterranean* discusses the hydrological cycle in the Mediterranean region, discussing the characteristic and mechanism of the hydrological cycle using both observations and models to analyze possible impacts on the water as a resource, also including some preliminary discussion of adaptation strategies. The particularly relevant impact of climate change on fresh water bodies is discussed in Chapter 9 *Impacts of Climate Change on Freshwater Bodies: Quantitative Aspects*, whereas Chapter 10 *Impacts of Climate Change on Water Quality* deals with the impact of climate change on lakes and how nutrients load in rivers are affected. Part II is concluded by Chapter 11 *Summary and Major Findings.*

Part III is devoted to ecosystem services and it is divided in eight chapters: Chapter 1 *Introduction*. Chapter 2 *Vulnerability of Ecosystem Services in the Mediterranean Region to Climate Changes in Combination with Other Pressures* discusses the ecosystems and ecosystem services projected climatic changes and impacts in the Mediterranean, including an analysis of land use changes and a vulnerability assessment. Chapter 3 *Impact of Climate Variability and Extremes on the Carbon Cycle of the Mediterranean Region* discusses observed impacts of climate variability and extremes on the carbon cycle in the Mediterranean. Chapter 4 *Climate Change Impacts on Typical Mediterranean Crops and Evaluation of Adaptation Strategies to Cope With* analyzes the impacts on selected Mediterranean crops, and the impacts on forest are discussed in Chapter 5 *Climate Change Impacts on Forests* *and Forest Products in the Mediterranean Area.* Chapter 6 *Effects of Climate and Extreme Events on Wildfire Regime and Their Ecological Impacts* discusses the impacts of climate change on wildfires regimes. Chapter 7 *Climate Induced Effects on Livestock Population and Productivity in the Mediterranean Area* discusses the effect of climate change on livestock, and finally Chapter 8 *Summary and Major Findings* presents the conclusion.

Part IV contains the analyses on socio-economic impacts of climate change in the region and it is composed of ten chapters: Chapter 9 *Introduction.* Chapter 10 *Integrated Socio-Economic Assessment* (The Economic Point of View) contains an economic assessment of climate change impacts for the Mediterranean region. Chapter 11 *Water and People: Assessing Policy Priorities for Climate Change Adaptation in the Mediterranean* discusses the challenge to water resources with some policy options analyzed through an analysis of the adaptation capacity. General adaptation issues are faced in Chapter 12 *Adaptation Strategies for the Mediterranean*, which discusses how science and scientific results can be used as an input to adaptation strategies, including consideration of uncertainties. Chapter 13 *Health* is devoted to assessing health effects and developing adaptation strategies, whereas energy issues are discussed in Chapter 14 *Energy Demand and GHG Mitigation Options*, which discusses the impacts of climate change on energy markets, discussing options for mitigation and adaptation. The major role of the tourist industry in the Mediterranean region is taken over by Chapter 15 *Mediterranean Tourism and Climate Change: Identifying Future Demand and Assessing Destinations, Vulnerability*, which analyzes how climate change would threaten coastal tourism and the expected consequences of climate change. The issue of migration and how climate change can affect the migratory fluxes of retirement is discussed in Chapter 16 *International Retirement Migration from Northern Europe to the Mediterranean: New Results on the Role of Climate with a Possible Application to Climate Change*. Chapter 17 *Green Growth in the Mediterranean* is an essay on sustainable development path in the Mediterranean. And Chapter 18 *Summary and Major Findings* will close the part.

Part V is dedicated to the results from the case studies that have been performed in CIRCE. They provide interesting additional materials to the assessments in the other parts, and certainly they represent a rare example of integrated analysis of the impact of climate change. The case studies have been chosen to represent urban, rural and coastal environments, drawn from the north and the south of the Mediterranean shore. The part discusses also stakeholders involvement, the level of engagement and the data and knowledge indicators used in the assessment and adaptation strategies.

We are confident that this report will be a significant contribution to the advancement of understanding and knowledge in climate change and its impact in the Mediterranean and it will be a useful contribution to the coming IPCC AR5 IPCC report, but it will also be able to inform national and European policies, in particular the follow-up to the White Paper on adaptation to climate change and the development of common European policies. Its value will also stretch in time to contribute to the path towards the 2015 UNFCCC Review.

Antonio Navarra and Laurence Tubiana

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The research leading to these results has received funding from the 6th Framework Programme (FP6/2002–2006) under grant agreement number 360961 – Project ‘Climate Change and Impact Research: the Mediterranean Environment (CIRCE)’ whose results have given birth to the ‘Regional Assessment of Climate Change in the Mediterranean’.

Intellectual guidance and support over the whole life of this demanding project has been provided by the Project Officers of the European Commission, Georgios T. Amanatidis, Henrietta Hampel, Gerardus Klaassen, Elisabeth Lipiatou, Philippe Quevauviller, Andreas Tilche as well as by the CIRCE Advisory Board composed by Valerio Calzolaio, Juan Carlos Ciscar, Klaus Hasselmann, Martin König, Fedor Mesinger, Evangelos Papathanassiou.

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A number of people contributed to the development of the ‘Regional Assessment of Climate Change in the Mediterranean’ and deserve recognition.

Firstly, we kindly thank the chapter authors for their contributions, whose work on a wide range of scientific and regional case studies form the substantive basis of this book.

Manuscript reviewers Asbjorn Aaheim, Pascale Delecluse, Klaus Hasselmann, Martin König, John Latahm, María Máñez Costa, Fedor Mesinger, Andy Morse, Reimund Schwarze, George Tselioudis, provided thoughtful and high valuable comments that have contributed to the quality, clarity, and scientific rigor of the information herein.

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CLIMATE CHANGE AND IMPACT RESEARCH:
THE MEDITERRANEAN ENVIRONMENT
Circe

SIXTH FRAMEWORK PROGRAMME

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Part III
Agriculture, Forests and Ecosystem Services

Chapter 1
Introduction

Monia Santini and Riccardo Valentini

Abstract This introductive chapter is an overview about the importance of climate impact assessment for ecosystems and the services they provide. It is also highlighted how, in the global change perspective, not only climate but also socio-economic trends affect the vulnerability of ecosystem services and their adaptive capacity. A multidisciplinary research line in CIRCE project was devoted to the evaluation of the vulnerability of ecosystem services in the Mediterranean region to climate change and other forcings, and to the investigation of feedbacks among ecosystems, climate, water and carbon cycle, including consideration of extreme events and disturbances as fires.

Besides immediate global change effects on humans (e.g. sea-level rise or droughts), an important part of human vulnerability to global change is caused by impacts on ecosystems and the services they provide. Following the Millennium Ecosystem Assessment (MEA 2005), the well established concept of "ecosystem services" is used to describe the benefits people obtain from natural or man-made ecosystems, and influencing human well-being and long-term economic success. Ecosystem services include (e.g. Daily 1997; MEA 2005): (i) provisioning services such as food, water, timber, and fiber; (ii) regulating services such as the regulation of climate, floods, disease, wastes and water quality; (iii) cultural services such as recreational, aesthetic, and spiritual benefits; (iv) supporting services such as soil formation, photosynthesis and nutrient cycling.

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Climate change is acknowledged as altering the quantity, quality, and timing of ecosystem services (e.g. Lindner et al. 2010), first of all of fresh water and food (e.g. Schröter et al. 2005); consequently these changes create vulnerabilities for those individuals, communities and sectors depending on those same services. On the other hand, healthy ecosystems can reduce climate change impacts; e.g. vegetation provides climate regulating services by capturing carbon dioxide from the atmosphere (MEA 2005).

In addition, not only climate but also land use changes are acknowledged as potentially alter both ecosystem services and human society (DeFries and Bounoua 2004; Chase et al. 1996, 2000; Bounoua et al. 2002; Geist and Lambin 2002; IPCC 2007; Parmesan and Yohe 2003; Root et al. 2003; Santini and Valentini 2011). Combination and feedbacks between natural (e.g. climate) and anthropogenic (human activities) drivers lead many ecosystem services to be worldwide degraded or in decline (Carpenter et al. 2009); but reversing this degradation could be possible, even if many efforts are required.

Therefore main messages from the MEA can be resumed as follows: (i) humans have radically altered ecosystems in just the last 50 years; (ii) ecosystem changes support human well-being, but at high costs for natural resources; (iii) further unsustainable practices will threaten development goals; (iv) practical solutions are possible, but require major changes in policy.

The focus on ecosystem services has been recently adopted widely among the scientific and policy communities and has resulted in new integrated approaches for research, conservation, and development (Carpenter et al. 2009; Steffen 2009). The advantage of this concept is that most services can be quantified, even if no single metric is applied across their entire range or scales (Schröter et al. 2005; Zhang et al. 2007).

Moreover, even the synthesis chapter (Smith et al. 2001) of the Third Assessment Report by IPCC recognized the limitations of traditional impact assessments, where a few climate change scenarios are used to assess the response of a system at a future time, challenging the scientific community to move toward more transient 'vulnerability' assessments that are functions of shifting both environmental parameters (including climate) and socio-economic trends, and explicitly including the adaptive capacity of ecosystems to the resulting changes (Schröter et al. 2005; Metzger et al. 2008).

In this context, a multidisciplinary and comprehensive Research Line (RL) in the CIRCE project was devoted to the evaluation of the vulnerability of ecosystem services in the Mediterranean region to climate change and other *forcings*, and to the investigation of feedbacks between ecosystems and either biogeochemical or hydrological cycles. The research focuses in particular on the linkages of ecosystems with climate and human well-being addressed by other CIRCE's RLs.

The goal has been assessing the indirect and direct drivers of change in ecosystems and their services, the current condition of them, and how changes in the services have affected or may affect environment and human well-being.

The objectives were providing (a) a vulnerability concept adapted to the Mediterranean region, focusing on ecosystem services and the impacts which are most critical for policy, (b) a set of consistent scenarios, based on climate scenarios from other components of CIRCE as well as land use change scenarios developed elsewhere, (c) a sector-by-sector synthesis of vulnerabilities, and (d) a high-resolution model analysis of vulnerabilities in major ecosystem types.

The research started from the acknowledgement that ecosystem services in the Mediterranean region are particularly sensitive to the following conditions: (i) extreme seasons, in particular exceptionally hot and dry summers and mild winters; (ii) short-duration events such as windstorms and heavy rains; (iii) slow, long term changes in climate leading to general aridification/degradation up to irreversible desertification (Rubio et al. 2009; Santini et al. 2010). Then, relying on analysis of historical trends about the intensity, frequency and timing of disturbance (e.g. drought) events, their relevance for ecosystem services and vulnerability, and the main driving processes involved were investigated.

The research was organized into several main activities: analysis of climate change impacts on the general vulnerability of Mediterranean basin, and on carbon cycle, forests, agriculture, fires, livestock production. First, the key components and processes determining ecosystem **vulnerability** to major disturbances in the Mediterranean has been identified, as future water shortages, losses of agricultural potential and biome shifts. Then, as net **carbon balance** at ecosystem level is hard to predict since a panoply of interacting and partly compensating processes, impacts on biogeochemical cycles has been evaluated focusing on non-linear processes, which trigger instability of ecosystems when a certain stress threshold is passed, not sufficiently described by current biogeochemical models (Reichstein et al. 2002).

Going into detail for specific key ecosystems, first **agriculture** is addressed. Since understanding the potential impacts of climate change has become increasingly important and is of a main concern especially for the sustainability of agricultural system and for policy-making purposes, the assessment and scenarios in crop production using state-of-the-art models and climate scenarios was carried out. Regarding **forests**, the research was based mostly on data and modeling about the impact of human management on Mediterranean forests, as well as on historical trends of forest products in the Mediterranean region, providing related databases. The role of management for forest production under changing boundary conditions, the potential for mitigation by carbon sequestration in forest related activities, and scenarios of forest management and forest products in future conditions have been reviewed (Calfapietra et al. 2001). Still concerning vegetation resources, changes in **fire** regime (frequency, intensity and season) may have different consequences for different species; however, the persistence mechanisms of many species are poorly understood, especially in recurrent and changing disturbance conditions and also ecosystems that were not under fire pressure in the past (and where fire is becoming important) may have no strategy to deal with fire (Pausas et al. 1999). Finally, recognizing that climatic features affect **livestock** both indirectly (grassland, crops, and water availability) and directly (survival of pathogens and/or their vectors), influencing the ability of animals to breed, grow, and lactate to their maximal genetic potential, and their capacity to maintain health, livestock production systems and animal health under stress of global changes have been investigated.

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Chapter 2
Vulnerability of Ecosystem Services in the Mediterranean Region to Climate Changes in Combination with Other Pressures

Holger Hoff

Abstract The Mediterranean is one of the most vulnerable European regions to climate change, e.g. in terms of future water shortages, losses of agricultural potential and biome shifts. South-eastern Mediterranean countries differ significantly in their demographic and economic development and projected climatic changes – in particular aridification – from northern Mediterranean countries, making them generally more vulnerable. Climate change is but one driver of change in the Mediterranean, which interacts with other drivers such as land use change, urbanization, tourism, globalization etc. In combination, these drivers cause increasing pressure and often land and natural resource degradation, most prominently desertification in the south-eastern Mediterranean. CIRCE has assessed the vulnerability of agriculture and forestry as well as other ecosystem services, e.g. water provisioning and carbon storage. A range of different models at different scales have been employed to simulate these ecosystem services under global change for the full Mediterranean basin and sub-regions.

Keywords Vulnerability • Ecosystem services • Desertification • Climate change • Land degradation

2.1 Introduction

The Mediterranean has been identified as possibly the most vulnerable region to climate change in Europe, e.g. in terms of future water shortages, losses of agricultural potential and carbon storage potential, increased fire risks, and shifts in the

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distribution of plant species (Schroeter et al. 2005; EEA 2005). Climate change is likely to magnify differences of Europe's natural resources. Alcamo et al. (2007) confirm that water availability, crop productivity and forest extent and biomass production are likely to decrease in southern Europe.

Southern and eastern Mediterranean countries are even more vulnerable than European Mediterranean countries, due to their projected stronger aridification and lower adaptive capacity compared to the northern Mediterranean – see the concept of "double exposure" by O'Brien and Leichenko (2000), which identifies regions as particularly vulnerable if the climate exposure is accompanied by economic marginalization.

The main goal of determining current and future vulnerability[1] of Mediterranean ecosystems and their services is to provide a basis for adaptation. Ecosystem services[2] provide a key link between biosphere and anthroposphere and with that an entry-point for adaptation of social-ecological systems.

Vulnerability to climate change can be strongly modified by non-climate factors (Carter et al. 2007). Other drivers of change that affect ecosystems include land use change (e.g. land abandonment in the northern Mediterranean, overgrazing and overexploitation in the south-eastern Mediterranean), fire, urbanization,[3] tourism, sea-level rise, or other globalization effects (e.g. economic integration of Mediterranean countries with the EU, world food and energy markets). Main drivers of change are currently economic and demographic development (southern and eastern Mediterranean have persistently high population growth rates), but increasingly also climate change which may become the main driver of change in ecosystem services by the end of the century (MEA 2005). Climate change is also linked with desertification in all scenarios of the Millennium Ecosystem Assessment. Currently 80% of all drylands in the southern and eastern Mediterranean are affected by desertification (Plan Bleu 2005).

Given the large agreement of Global Climate Models on decreasing precipitation in the southern and eastern Mediterranean (different from most other regions in the world where models often disagree even about the direction of change), plus increasing temperatures, climate change is expected to exacerbate aridification, land degradation, and desertification in this region. Also, projected increase in drought frequency and intensity is likely to increase vulnerability to resource overuse, and vice versa. Since vulnerability is determined by a combination of the exposure and sensitivity to climate change and the capacity to adapt land and water management (Falkenmark and Rockström 2008), climate adaptation needs to be closely

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[1] **Vulnerability** has many different definitions, it is understood here as a function of potential impacts and adaptive capacity to climate and other drivers of change, or more specifically: the degree to which an ecosystem service is sensitive to these changes, plus the degree to which the sector that relies on this service is unable to adapt to the changes (from ATEAM report).

[2] **Ecosystem services** are the conditions and processes through which ecosystems, and the organisms that make them up, sustain and fulfill human life (from the ATEAM report).

[3] Note that **urbanization** can in some cases reduce pressures on surrounding ecosystems by providing economic / income opportunities.

coordinated with IWRM.[4] Examples for reducing climate vulnerability by improved land and water management are:

- increased soil water storage through water harvesting, conservation agriculture or other soil and water conservation measures, which can help to cope with dryspells – and as a co-benefit may enhance soil carbon uptake i.e. contribute to climate mitigation and adaptation, and also increase agro-biodiversity;
- adaptive land planning (zoning) can help to avoid urban sprawl into productive rainfed agricultural land (example Amman), which reduces the need for expanding irrigated land and for more irrigation water, which is the typical response to loss of rainfed agricultural land.

Also, cross-sectoral adaptation is important to address tradeoffs between different ecosystem services and to avoid maladaptation, i.e. adaptation that can increase vulnerability – example: new irrigation schemes, designed to bridge more and more severe dry periods, may fail if total precipitation and water availability decrease, while urban water demands increase at the same time.

The CIRCE projected analyses climate impacts as the “joint product” of climate change and socio-economic dynamics. CIRCE Research Line 7 (“Ecosystem Services”) (i) evaluates the vulnerability of ecosystem services in the Mediterranean region to climate change and other forcings, and (ii) investigates feedbacks by ecosystems to biogeochemical and hydrological cycles.

CIRCE RL7 addresses vulnerability across the following main **sectors** and related ecosystems services:

- agriculture: producing crops, livestock and biofuels, carbon sequestration
- forestry: producing timber and biofuels, carbon sequestration
- terrestrial ecosystems: carbon sequestration, regulating water flow, providing biodiversity and aesthetic value and opportunities for recreation (not quantified in RL7)
- water/water provision

For assessing the vulnerability of Mediterranean ecosystems, RL7 aims to quantify the **sensitivity** of the ecosystems and their services to climate and land use changes, and the **adaptive capacity** of sectors that rely on these services.

The vulnerability assessment in RL 7 also aims at identifying **critical thresholds** in the Mediterranean, beyond which sudden/**non-linear changes**[5] of ecosystems and services can be expected (Carter et al. 2007). Examples are:

- temperature thresholds beyond which fires become much more destructive

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[4] **IWRM** (Integrated Water Resources Management) is defined by the Global Water Partnership as “…co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems”.

[5] Non-linear changes: an ecosystem may change gradually until a particular pressure on it reaches a critical threshold, at which point changes occur relatively rapidly as the system shifts to a new state. Some of these nonlinear changes can be very large in magnitude and have substantial impacts on human well-being (MEA 2005).

- precipitation/drought threshold, beyond which rainfed agriculture (in particular perennial crops) fails or biomes change
- livestock stocking capacity, beyond which sudden drops in plant biomass productivity occur
- minimum vegetation required to sustain moisture recycling to the atmosphere and with that the regional biomes

Given the characteristics of the Mediterranean climate, several critical thresholds will fall into the summer period, especially coincide with very dry summers or droughts. These extremes may determine vulnerability more than changes in temperature or precipitation averages.

Critical thresholds also determine the agenda for resilience building, for enhancing the capacity the capacity to recover from shocks and to avoid falling into irreversible new states (e.g. desertified conditions) when transgressing such critical thresholds (Falkenmark and Rockström 2008).

Another goal of the vulnerability assessment in Research Line 7 is the identification and mapping of **vulnerability hotspots** in the Mediterranean, taking into account vulnerability to climate change in the context of other pressures.

The identification of both, critical thresholds and hotspots, as part of vulnerability assessments can help to prioritize adaptation.

In order to address uncertainties when analyzing key ecosystem processes and feedbacks, CIRCE RL7 has adopted a multi-model strategy across scales, which provides somewhat overlapping results from the different types of models.

2.2 Characterization of the Mediterranean, Its Ecosystems and Ecosystem Services

The Mediterranean is characterized by its strong biophysical and socio-economic gradients, in particular the differences between the northern Mediterranean on the one hand and the southern and eastern Mediterranean on the other hand. The Mediterranean climate is characterized by wet winters and dry summers with high interannual variation in rainfall and frequent droughts and dryspells. The southern and eastern Mediterranean is more arid and has a higher climate variability than the northern Mediterranean see Figs. 2.1 and 2.2.

Mediterranean (lowland) ecosystems are dominated by evergreen sclerophyllous shrublands with oaks (*Quercus coccifera*, *Q. ilex*, *Q. suber*) and other tree species. They have been more strongly anthropogenically modified over the past centuries and millennia than most other types of ecosystems – see Fig. 2.3. The long history of different land uses has left a mosaic of vegetation covers, again with strong differences between northern and southern Mediterranean. Nevertheless, biodiversity in the Mediterranean region is still amongst the highest of any world biomes, with a high proportion of endemic species which seem to be particularly vulnerable to environmental change (Allen 2003; Vogiatzakis et al. 2006).

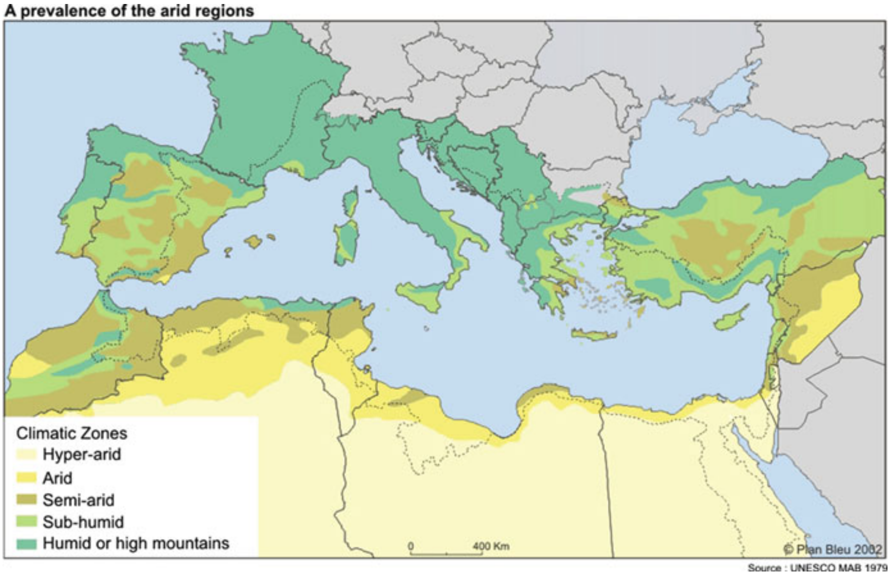

Fig. 2.1 Mediterranean climate (Plan Bleu 2005)

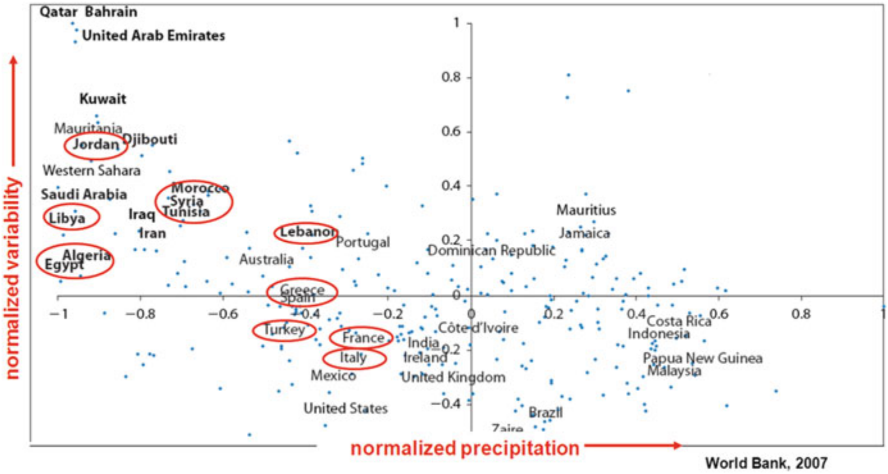

Fig. 2.2 Total precipitation and variability for various Mediterranean and other countries (From World Bank 2007)

While Mediterranean terrestrial ecosystems have been subject to strong anthropogenic change, there are different views about their level of degradation (Allen 2003). Some authors consider Mediterranean ecosystems as being quite resilient to various stresses, despite or maybe because of their long history of modification and resulting adaptation and diverse mosaic of landscapes. In any case, more recently

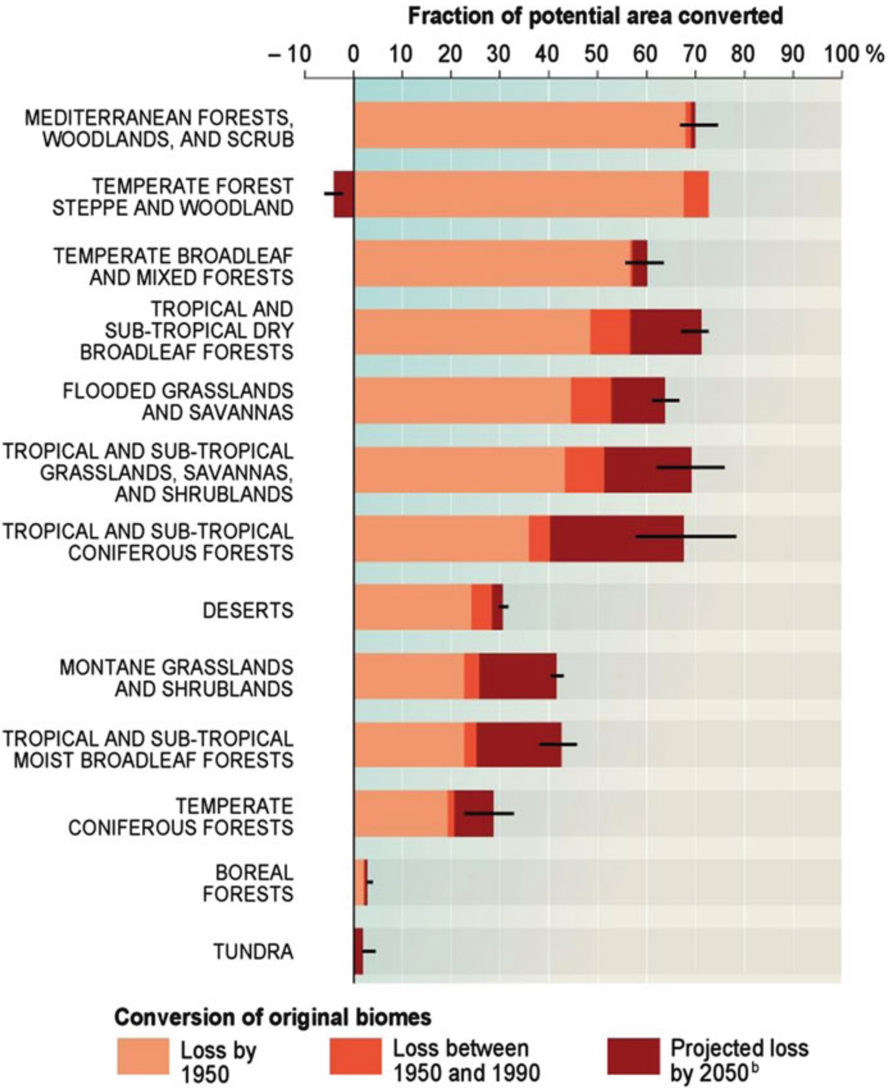

Fig. 2.3 Modification of ecosystems (MEA 2005)

overexploitation and aridification have resulted in erosion, salinization, rangeland degradation and loss of local agro-biodiversity (IAASTD),[6] especially in the southern/eastern Mediterranean – see Fig. 2.4 for decreasing vegetation cover in the MENA region over the past two decades. Land and water quality degradation often coincide, as for example in large scale salinization.

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[6] This information refers to the CWANA (Central and West Asia and North Africa) region, which is somewhat wider than the southern and eastern Mediterranean.

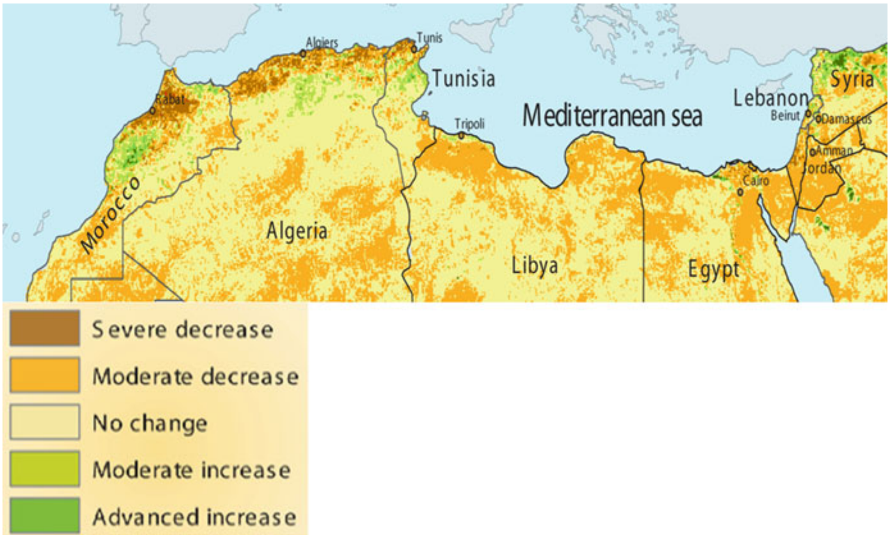

Fig. 2.4 NDVI based vegetation change (degradation) from 1982 to 2003 (GTZ 2008)

There are various definitions for desertification. According to MEA (2005), desertification can be interpreted as a mismatch of demand for and supply of ecosystem services. CIRCE Research Line 7 quantifies the supply of ecosystem services (in terms of water, food, and carbon fluxes and stores), and it also aims at developing a desertification index for the full Mediterranean.

Besides terrestrial ecosystems, also aquatic ecosystems have been seriously impacted by regulation, (over-)abstraction and pollution of water resources. Environmental flow requirements are frequently sacrificed when water scarcity increases, in order to satisfy irrigation or municipal water requirements.

The majority of southern and eastern Mediterranean drylands are occupied by rangelands. Cropland, as well as forest land and population distribution closely follow water availability (either from precipitation or irrigation) – see Figs. 2.5, 2.6 and 2.7. The majority of cropland in the Mediterranean is rainfed, but in most Mediterranean countries irrigation development is accelerating. Egypt is an exception, in that almost all cropland is irrigated.

Irrigation water demand is rapidly increasing, and most of the renewable (blue[7]) water resources are already allocated to irrigation – up to 90% as in Syria. Accordingly, renewable water resources are rapidly exploited, sometimes overexploited. Other demands, in particular from cities, are competing for water with irrigation. So the capacity to buffer shocks such as droughts is decreasing. However, in some countries

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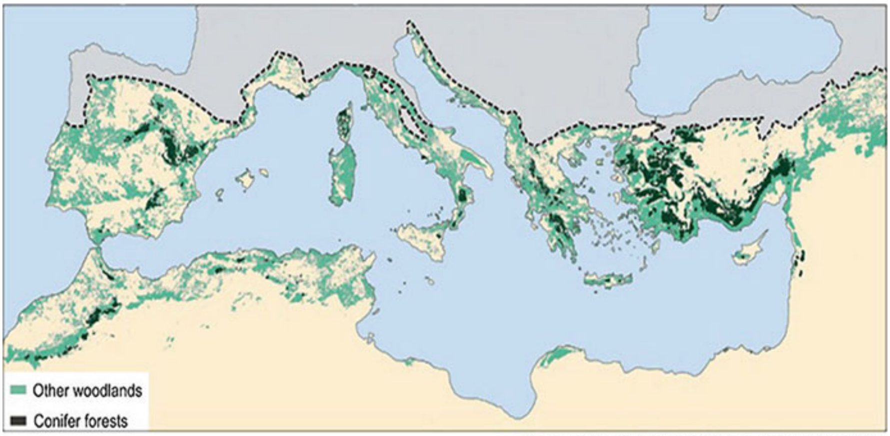
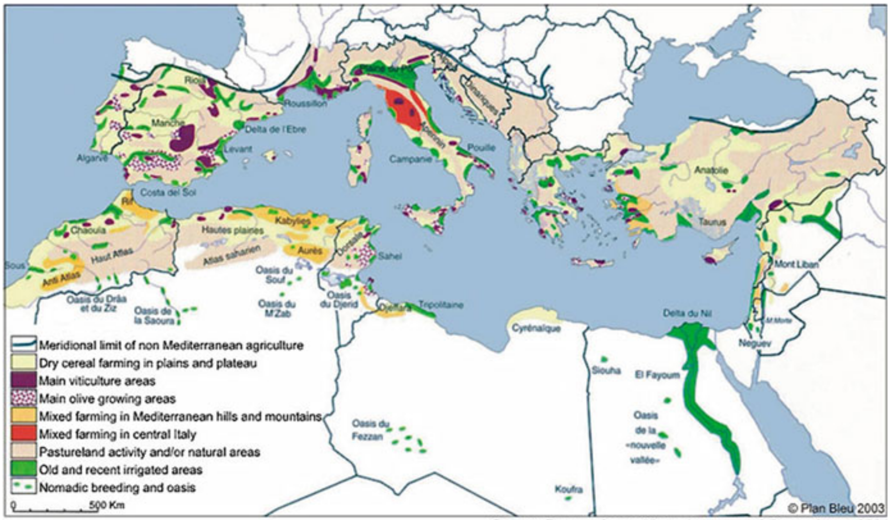
[7] **Blue water** is the runoff in rivers or other surface water and groundwater, available for irrigation and other human uses.



Source : D'après UNEP-WCMC, repris par WWF (2001)

Fig. 2.5 Wood coverage of the Mediterranean Region (Plan Bleu 2005)



Source: Revue géographique des pays méditerranéens, 2001

Fig. 2.6 The Mediterranean's main agricultural and natural systems (Plan Bleu 2005)

irrigation infrastructure is also considered to reduce vulnerability of cities to droughts, because it can also be used to deliver water to cities during critical periods. The gap between water demand and water availability is widening around the Mediterranean due to increasing demands and decreasing availability (climate induced). Water has become a – often the – limiting factor in social and ecological systems. Water quality degradation, e.g. from pollution, overexploitation or increasingly also from seawater intrusion, compounds water quantity constraints.

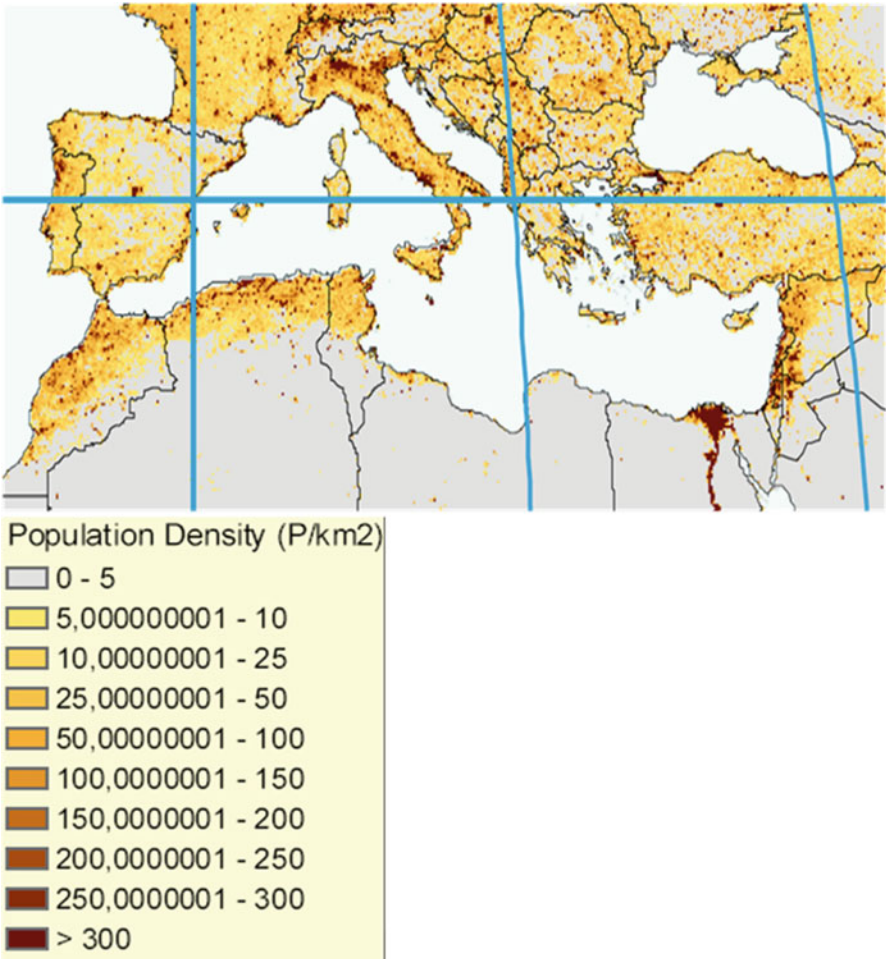


Fig. 2.7 Population density in the Mediterranean (WBGU 2007)

Yield increases and green water[8] productivity in rainfed agriculture in the southern and eastern Mediterranean have generally remained below world average over the past decades, and that gap will probably widen in the near future, as more marginal lands will be cultivated in the region.[9] North African countries have actually seen a sharp decline in per capita rainfed production (IAASTD 2008). Due to their low productivity, accompanied by increasing gaps between demands and availability,

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[8] **Green water** is water in the soil from precipitation, returning to the atmosphere via productive transpiration or unproductive evaporation.

[9] Refers to the CWANA region.

southern and eastern Mediterranean countries have become large net food and virtual water importers. Net virtual water imports generally range from about 20 to 100% of renewable (blue) water resources (Yang et al. 2007).[10] With generally low investments in agriculture, accompanied by further population growth and economic development and climate change, this dependence on virtual water imports is expected to increase further in the region.

Economies, income and employment in the southern and eastern Mediterranean countries (with their high population growth rates) depend more on agriculture and natural resources, in particular water, than in the northern Mediterranean. Similarly, they are more sensitive to any changes in the supporting ecosystem services (see Table 2.1). That largely explains, why GDP in the south-eastern Mediterranean countries closely follows climate variability and extremes (World Bank 2007).

2.3 Projected Climatic Changes and Impacts in the Mediterranean

Besides stronger warming than global average, GCMs quite consistently project a decrease in total precipitation across all emission scenarios for the south-eastern Mediterranean – see Fig. 2.8 a, b, which makes climate projections for this region some of the most negative for any part of the world.

While the region is already very water scarce now (with countries like Jordan having one of the lowest per-capita water availabilities worldwide), the combination of increasing temperatures, decreasing precipitation and increasing plant water demand (due to higher temperatures) will further reduce runoff, groundwater recharge and eventually water availability, e.g. for irrigation (IPCC 2008). Reductions in groundwater recharge may be as high as 70% along the southern rim of the Mediterranean (Doell and Floerke 2005). For a medium climate change scenario (SRES A1B), total water availability in the eastern Mediterranean is projected to be reduced by about 30% by the middle of this century (Menzel et al. 2007).

Reductions in groundwater recharge and increased pumping as a response to drier conditions, will be aggravated by water quality degradation in coastal Mediterranean aquifers (such as in Israel and Gaza) also through seawater intrusion due to sea level rise. This sea level rise will contribute to ongoing salinization in many coastal agro-ecosystems.

Also, climate variability as well as intensity and frequency of extremes, such as droughts and dryspells are projected to increase. Critical parameters, such as the number of consecutive dry days and maximum temperatures are expected to affect ecosystems on top of the overall aridification trends. Moreover, higher precipitation intensities during rainfall-events will lead to higher runoff and lower infiltration, leaving a smaller fraction of the rainfall in the landscape and increasing erosion.

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[10] With the exception of Syria (3%), Jordan (195%), Israel (207%) and Libyia (557%).

Table 2.1 Vulnerability of ecosystem services

Sector	Ecosystem service	Stresses (climate and others)	Impacts/ sensitivities	Observed/ projected rate of change	Critical thresholds	Hotspots of vulnerability	Adaptive capacity/adaptation (and mitigation) options
Agriculture/ grazing/ agro-forestry	Food (crop and livestock) production	Higher temp., changing prec. patterns, water stress, disease, erosion, urban encroachment	Higher irrigation demand, reduced productivity, crop failure, livestock mortality	–	Precipitation threshold beyond which rainfed systems fail reduced irrigation water allocations below which permanent culturesdie fallow groundwater levels below which irrigation water pumping fails grazing pressure beyond stocking capacity above which productivity sharply declines	–	Crop and livestock selection and breeding, sowing date, conservation agriculture (e.g. mulching, low tillage), intercropping, multi-use systems, agro-forestry, rainwater harvesting and storage, (supplementary) irrigation, improvements in water productivity livestock mgmt to reduce greenhouse gas emissions (mitigation)
Agriculture	Carbon sequestration	Higher temp., changing prec. patterns, water stress, disease, erosion, urban encroachment	Higher irrigation demand, reduced productivity, soil organic matter decomposition	–	Precipitation threshold beyond which rainfed systems fail reduced irrigation water allocations below which permanent cultures die fallow groundwater levels below which irrigation water pumping fails grazing pressure beyond stocking capacity above which productivity sharply declines climatic or land use changes beyond which systems turn into C-sources	–	Crop selection and breeding, conservation agriculture, multi-use systems, agro-forestry, irrigation

(continued)

Table 2.1 (continued)

Sector	Ecosystem service	Stresses (climate and others)	Impacts/ sensitivities	Observed/ projected rate of change	Critical thresholds	Hotspots of vulnerability	Adaptive capacity/adaptation (and mitigation) options
Agriculture/ forestry	Biofuels/ carbon offset	Higher temp., changing prec. patterns, water stress, disease fire, erosion, urban encroachment, overexploitation	Reduced productivity, crop or tree mortality	–	Precipitation change below which biofuels can no longer be produced water or land scarcity below which food security is threatened	–	Multi-use systems, agro-forestry, irrigation
Forestry	Timber production	Higher temp., changing prec. patterns, water stress, disease, erosion fire, overexploitation	Reduced productivity, tree mortality	–	Temperature or management thresholds, beyond which many more/more intense fires occur	–	Forest management, tree species selection and breeding

Forestry/ terrestrial ecosystems	Carbon sequestration	Higher temp., changing prec. patterns, water stress, disease, erosion, fire	Reduced productivity, tree mortality, soil organic matter decomposition	–	Climatic or land use changes beyond which systems turn into C-source	–	Landscape and forest mgmt, ecological restoration
Terrestrial and aquatic ecosystems	Water provision/ regulation	Higher temp., changing prec. patterns, water stress, landcover change, landscape degradation, erosion	Reduced water availability, higher water demand, water quality degradation, sediment yield	–	Precipitation change, below which groundwater recharge fails minimum vegetation cover threshold (climate dependent), below which moisture recycling from land surface to atmosphere fails minimum vegetation cover threshold, below which rapid erosion/ siltation starts	–	Landscape mgmt, conservation agriculture, water demand mgmt, water storage, non-conventional water

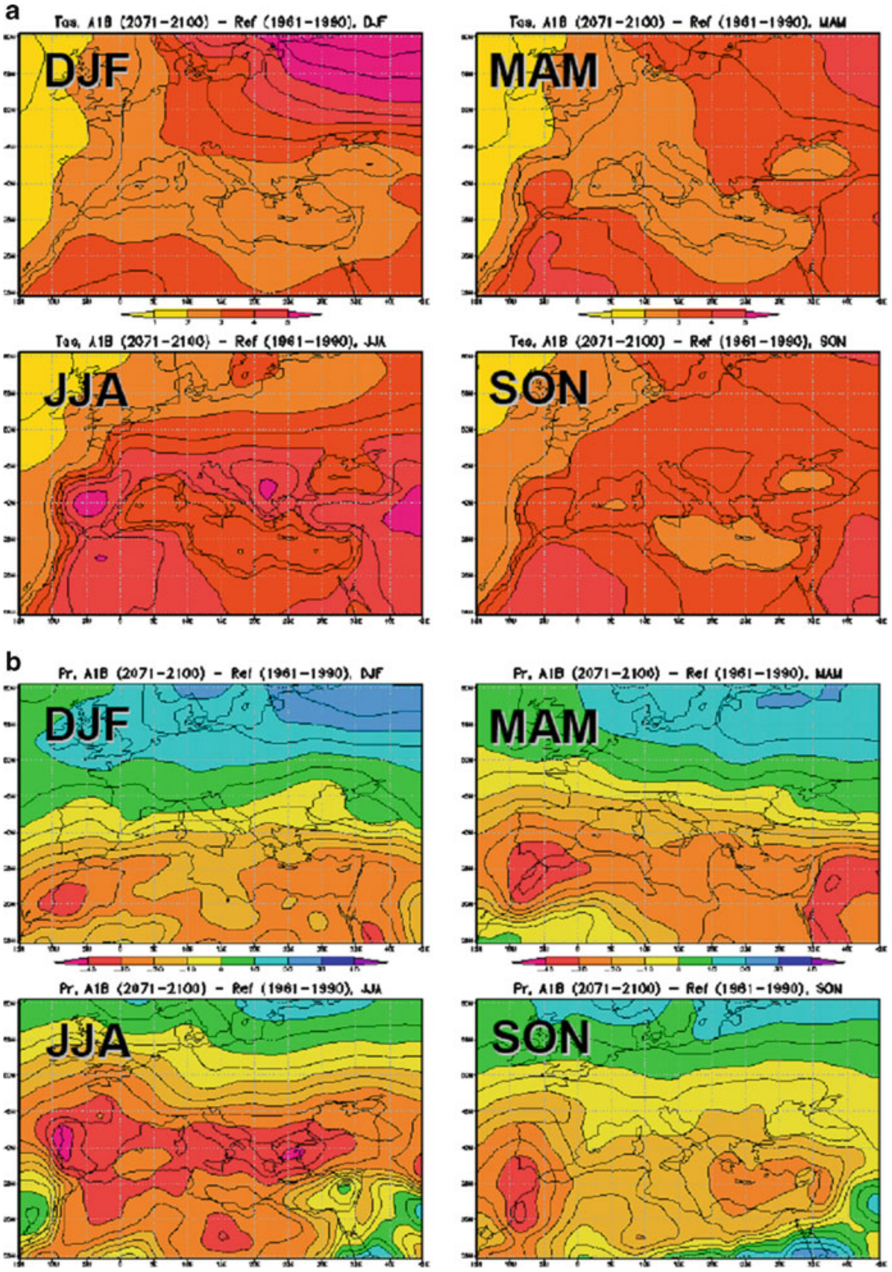

Fig. 2.8 Ensemble GCM simulation of (**a**) temperature change (in degrees) and (**b**) precipitation change (in %) by the end of the century for the different seasons, for A1B scenario (Giorgi and Lionello 2008)

According to IPCC (2007), Mediterranean type ecosystems are among the most impacted and most vulnerable ecosystems under climate change. Given the projected level and rate of further warming and aridification, it is unlikely, that Mediterranean ecosystems will be able to “adapt naturally to climate change” as requested in article 2 of the UN Framework Convention on Climate Change. The southern boundary of evergreen closed-canopy forests is expected to move northwards and forests will diminish in extent, as they are replaced in the southern parts of the Mediterranean basin by low-cover shrublands and grasslands (Allen 2003; Vogiatzakis et al. 2006).

Climate induced changes in dryland ecosystems, often associated with degradation/desertification, may also affect carbon uptake and storage by vegetation and soil, as well as moisture recycling to the atmosphere, both of which can feed back to the regional and global climate. Desertification is a complex phenomenon that entails interacting changes in vegetation, soils, water availability and local climate. MEA (2005) concluded, that desertification in sub-tropical regions leads to feedbacks in water availability through decreasing regional precipitation (from reduced evapotranspiration and increased surface albedo).

Climate change affects (rainfed) agriculture and natural ecosystems alike, through increasing temperatures and heat stress or exceedance of temperature tolerances, and more uncertain rainfall and dryspells and droughts, possibly in some locations also the absence of frost. For temperature response, a general rule is that crop zones migrate about 150 km northwards with every 1° of temperature increase (without any other changes). Hypothesized benefits from increasing atmospheric CO_2 concentrations (increasing water use efficiency), which have been demonstrated in field experiments, may not materialize at landscape scale due to other interacting factors, such as increasing temperatures, exceedance of crop temperature optima, faster growth of weeds that compete for water etc. Bindi and Moriondo (2005) simulate reductions in yields in the southern and eastern Mediterranean countries of about 20–35% for legumes and 5–15% for cereals. Livestock productivity and mortality are negatively affected by a combination of higher temperatures and humidity.

Farmers faced with more uncertain climate and seasonal water supply may chose to reduce risk by planting more resistant but lower yield and less profitable crops.

2.4 Land Use Changes

Northern Mediterranean landscapes are characterized by rural depopulation and abandonment of agricultural – including grazing – land. In Italy, agricultural land has been reduced from 25 to 19.6 million ha between 1970 and 2000 (Coppola 2004). This has lead to an expansion of woodlands with low species richness (Allen 2003).

Spain is currently using irrigation as a tool to prevent rural exodus and maintain cultural landscapes (Varela-Ortega pers comm.), even though productivity and cost-effectiveness in some cases would suggest to re-allocate this water to higher value uses. With projected increasing water scarcity however, agriculture in these rural landscapes may also have to be abandoned.

On the contrary, southern and eastern Mediterranean ecosystems are subject to increasing land (and water) use and overuse, especially from grazing, but also from cropping and harvesting of firewood, largely due to rapid population growth and economic development, but also due to mismanagement. Crop water productivity is generally lower in the southern and eastern compared to the northern Mediterranean, which results in higher water demand per kcal produced.

2.5 Vulnerability of Ecosystem Services and the Sectors They Support

According to the ATEAM (2005) definition, vulnerability is a function of potential impacts of, and adaptive capacity to climate and other drivers of change, or more specifically: the degree to which an ecosystem service is sensitive to these changes, plus the degree to which the sector that relies on this service is unable to adapt to the changes.

Falkenmark and Rockström (2008) suggest an increased vulnerability to climate (and other) stresses when natural ecosystems are changed, due to the "simplified ecosystem configuration in agricultural landscapes", i.e. lower biodiversity and "more sensitive production systems" with fewer, more high-yielding, but stress-sensitive crops. For the Mediterranean the situation may be somewhat more complex. Not only is it more difficult to specify what is meant by "natural vegetation" after several millennia of changing land uses. Also, the resulting anthropogenic mosaic of vegetation cover may have affected vulnerability of ecosystems differently. The sensitivity to fire for example, may have been reduced in spatially highly variable farming landscapes with their high grazing pressure, compared to more homogeneous natural vegetation. The ongoing abandonment of agro-pastoralism – in particular grazing – in much of the northern Mediterranean, which may be viewed as a return of the landscape to more natural conditions, coincides with an increase in fire frequency and intensity.

MEA (2005) identified dryland ecosystems as particularly vulnerable, because of the combination of high variability of environmental conditions, often large and growing populations exerting strong pressure on natural resources, and low levels of human well-being, associated with high sensitivity of people to changes in ecosystem services.

Safriel and Adeel (2008) postulate for dryland ecosystems a chain of non-linear reactions, each of which is triggered by crossing a critical threshold (Fig. 2.9). Continuously increasing population at some stage reaches a threshold beyond which

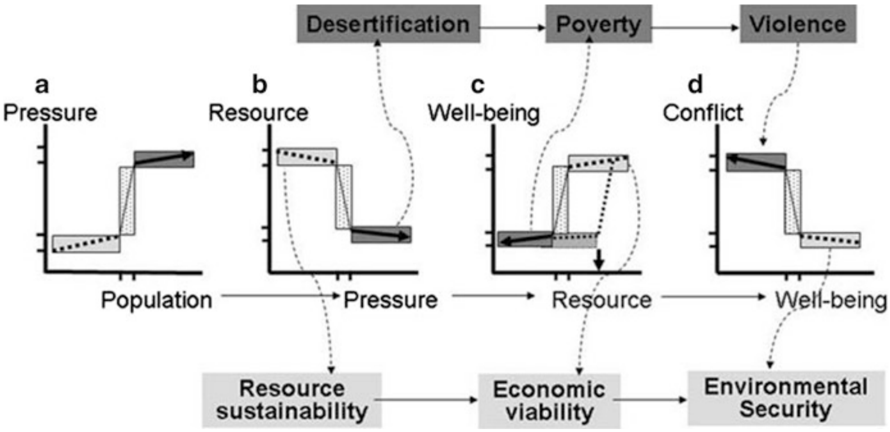

Fig. 2.9 Chain of possible regime shifts when crossing thresholds (Safriel and Adeel 2008)

pressure on natural resources suddenly increases. This pressure on natural resources in turn can push dryland ecosystems to a new (stable) low productivity state (see also Köchy et al. 2008), i.e. to conditions of desertification. They further suggest that a return to a more productive state will be difficult, as long as population increases while land (and water) resources remain finite.

With these pre-dispositions of degradation and poverty especially in the southern and eastern Mediterranean, climate change (with increasing water deficit and length and intensity of dry periods and reduced plant productivity), is likely to increase the vulnerability of social-ecological systems further. Sectors and people who depend on natural resources and ecosystem services may severely suffer, and conflicts – e.g. about water – become more likely, unless appropriate adaptation measures are implemented.

Forest cover has been reduced drastically around the Mediterranean over many centuries. While a re-greening and increase in forest cover has been observed in the northern Mediterranean, there is still large pressure on the remaining forests in the southern and eastern Mediterranean. A lack of effective forest protection in combination with projected climate change and associated increase in fire risk, may suppress productivity (including provision of much needed bioenergy), carbon storage and other forest-based ecosystem services.

Rainfed agriculture in the southern and eastern Mediterranean is generally limited to those (small) parts of the countries that receive sufficient rainfall. Crop failure is common, given the high climate variability in the region. With further increasing variability and overall aridification, compounded by other land use pressures, in particular from urbanization, a decrease in agricultural productivity, food production and other services from rainfed agriculture is likely. There is however large potential for increasing green water productivity in rainfed agriculture, e.g. through rainwater harvesting, supplementary and deficit irrigation, conservation agriculture, changing cropping systems and other improvements in agricultural water management, or generally more adaptive and integrated land and water resources management.

Increasing reliance on irrigation as a response to water scarcity and climate variability may actually increase vulnerability of the agricultural sector, if total water availability is further reduced while demands from all sectors continue to grow. Already now, many irrigation dependent agricultural systems cease production during droughts, due to a lack of available water (Abou-Hadid 2006). For irrigated permanent – e.g. tree – cultures the cut of water supply in the dry season has much more devastating and lasting effects than for annual crop cultures. The climate-related pressure on irrigated production systems is amplified by the increasing competition for blue water from the rapidly growing cities, which will leave less water for agriculture in the future. But, like in rainfed agriculture, there is large potential for water productivity enhancement. Re-use of wastewater (from cities) presents another opportunity for reducing climate vulnerability.

The livestock sector is affected by several interacting pressures. Increasing temperature as observed over the past decades (in combination with humidity) leads to lower productivity or even mortality. Reduced crop productivity in combination with increasing crop demand directly for food makes feed more expensive. On top of climate change, increasing grazing pressure can lead to sharp productivity declines if threshold values of stocking capacity are exceeded, especially in drier environments (Köchy et al. 2008). Moreover, overgrazing and overstocking often cause additional erosion, which reduces soil water holding capacity or green water storage, meaning that an important buffer against dryspells is lost. Again the southern and eastern Mediterranean is more affected than the north (Segnalini 2008).

Vulnerability to climate change can be strongly modified by non-climatic factors, including land use change, fire, urbanization, tourism, and others. The combination of different stresses at different temporal, economic, social and institutional scales cause 'vulnerability complexes' (Galaz et al. 2008), which are the result of interaction between ecosystem change and human activity. Vulnerability complexes threaten economic development in the different sectors and human welfare in many different ways. Population growth in the southern and eastern Mediterranean countries is higher than world average, while economic growth and industrial development are lower and integration in international trade has fallen over the past decades.

Figure 2.10 depicts the aggregate vulnerability of Mediterranean countries, using per-capita-water-availability, % population employed in agriculture and per-capita-GDP as indicators for adaptive capacity. Note that most countries in the southern and eastern Mediterranean are already at or below the Falkenmark threshold for blue water scarcity (1,000 m^3 per capita and year).

Additional indicators or indices that can be used to quantify a country's vulnerability or adaptive capacity, include e.g. water withdrawals relative to water availability, access to safe water, crop water productivity, human development index, literacy rate, governance and political stability or internal conflicts (Alcamo et al. 2008). Table 2.2 lists some of the respective parameters, illustrating major differences between northern and south/eastern Mediterranean countries in terms of adaptive capacity and vulnerability.

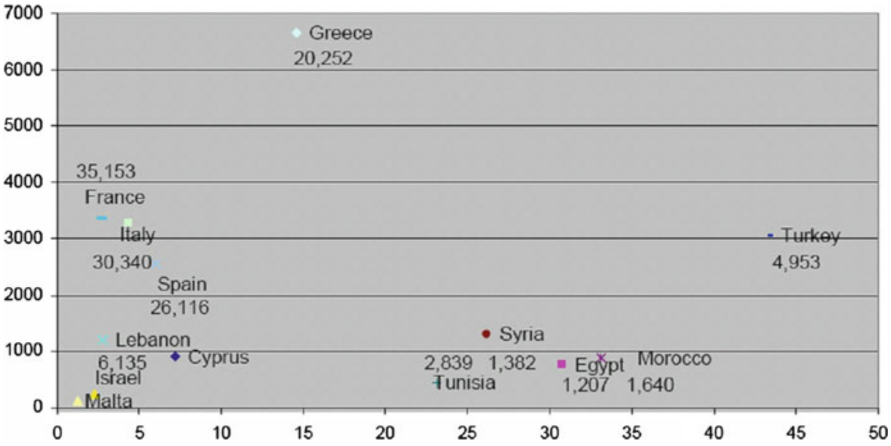

Fig. 2.10 Blue water availability (y-axis, in m^3 per capita and year, data from WRI for 2007) vs. agricultural labor force as a percent of total labor force (x-axis, from WRI for 2004), Per capita GDP (from WRI for 2005) is printed next to each country

Table 2.2 Indicators of vulnerability

	Literacy rate	Population growth rate	Democracy index	CPI	Water withdrawal as % of internal renew. RES.
Algeria	69.9	1.51	3.17	3.0	54.0
Croatia	98.1	0.20	7.04	4.1	–
Cyprus	96.8	1.06	7.60	5.3	30.8
Egypt	71.4	1.76	3.90	2.9	3,800
France	–	0.60	8.07	7.3	22.4
Greece	96.0	0.23	8.13	4.6	13.4
Israel	97.1	1.66	7.28	6.1	273
Italy	98.4	0.33	7.73	5.2	24.3
Lebanon	–	1.05	5.82	–	28.8
Libyan Arab J.	–	1.97	1.84	2.5	711
Malta	87.9	0.69	8.39	5.8	100
Morocco	52.3	1.20	3.90	3.5	43.4
Palestine	92.4	3.18	6.01	–	–
Spain	–	1.52	8.34	6.7	32.0
Syrian Arab Rep	79.6	2.52	2.36	2.4	285
Tunisia	74.3	1.08	3.06	4.2	62.9
Turkey	87.4	1.26	5.70	4.1	16.5

Annual population growth rate for the period 2000–2005 in %, from WRI; CPI the Corruption Perception Index ranging from 0 to 10 (with 10 indicating lowest corruption levels), from Transparency International; Democracy index ranging between 0 and 10 (with 10 indicating highest democracy levels), for 2007, from Economist; Water withdrawals as % of internal resources in 2000, from WRI

Literacy rate is indicated as % of all adults, from WRI

2.6 Results from CIRCE Research Line 7 – Vulnerability Assessment

The concept of multi-functionality (or multi-use systems) as used in the Millennium Ecosystem Assessment (MEA 2005) or more recently in the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD 2008), recognizes ecosystems, including forestry and agriculture as producing multiple benefits/outputs, such as commodities (food, fodder, fibers and bioenergy), but also non-commodity outputs such as landscape amenities and cultural heritages.

Various modeling tools applied in CIRCE RL7 at different scales provide biophysical quantifications of key ecosystem services, in particular food, timber and biofuel production, carbon storage and sequestration, and water provisioning. With that, CIRCE RL7 is producing a basis for economic evaluation of these services, and eventually tradeoff analyses for different interventions, land and water management options and development pathways.

The definition of critical thresholds[11] (see Table 2.1) – through interaction with local partners and stakeholders in RL 11 – provides a basis for calculating backwards acceptable climate or land use changes in order to avoid strong changes.

Table 2.1 summarizes stresses, impacts, sensitivities, rates of change, critical thresholds, hotspots of vulnerability, and adaptation options for the different ecosystem services and the sectors they support.

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[11] e.g. minimum river runoff or groundwater levels, maintaining certain agricultural production systems, avoiding (parts of) the Mediterranean to become carbon sources.

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Chapter 3
Impact of Climate Variability and Extremes on the Carbon Cycle of the Mediterranean Region

Dorothea Frank, Markus Reichstein, Franco Miglietta, and Joao S. Pereira

Abstract The Mediterranean is getting drier and warmer, more frequent and intense summer temperature extremes have been observed. Heat waves and its often associated droughts may strongly impact carbon fluxes and thus the carbon sequestration potential of ecosystems. Drought effects may last longer than the drought event itself due to delayed (ecosystem specific) recovery and/or secondary impacts such as altered mortality, pest and pathogen invasions or increased fire risk. Droughts are the main source of inter-annual variation in terrestrial carbon sequestration and its timing is a crucial factor owing to the strong seasonality of Mediterranean climate. The net carbon balance at ecosystem level to regional climate change is hard to predict since a panoply of interacting and partly compensating processes is affected. It is very likely that increased drought intensity and duration will affect primary productivity of the vegetation, but at the same time respiration processes are also reduced, hence compensating the effects on GPP. The Mediterranean can be considered as one of the "hot spot" areas for recent and projected climate change (Giorgi, 2006). As drought and heat waves are expected to become much more intense, longer lasting and more frequent, the carbon sequestration of Mediterranean ecosystems may be reduced by droughts, or even turning into net carbon sources to the atmosphere.

Keywords Drought • Heat wave • Carbon fluxes • Terrestrial carbon sequestration • Climate change

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3.1 Recent and Ongoing Changes of Mediterranean Climate Change

Mediterranean climate is characterized by hot and dry summers and relatively mild and wet winters. The region around the Mediterranean sea is considered as potentially vulnerable to climate change by increasing greenhouse gas concentrations (Giorgi and Lionello 2008), and even as one of the most prominent and vulnerable "hot spot" areas for recent and projected climate change (Giorgi 2006).

Regional or local extreme weather events may have large impact on natural and man-made systems (Beniston et al. 2007[1]). The record breaking heat wave of summer 2003 in Central and Western Europe is still in public mind for its severe impacts on society, economy and natural systems (Beniston 2004; Luterbacher et al. 2004) such as strongly reduced river discharges (Beniston 2004; Feyen and Dankers 2009), crop failure or reduced crop and fodder yields, and excess deaths (Robine et al. 2007).

In this section we want to briefly summarize recent and ongoing changes of the Mediterranean climate. During the last decade(s) European climate has been very likely warmer than any time during at least the past 500 years (Luterbacher et al. 2004). Within the last decades warm days have been rising drastically, particularly near the Mediterranean coast (Trenberth et al. 2007).

Anthropogenic greenhouse gas (GHG) emissions are expected to cause more frequent and intense summer temperature extremes due to changes in temperature variability, and not only by the mean global warming itself (Fischer and Schär 2009). Exceptionally hot summers in the Mediterranean occurred twice within the last decade: summer 2003 was exceptionally hot in most parts of Central and Western Europe, in 2006 July (Rebetez et al. 2009)[2] and autumn (Cattiaux et al. 2009) anomalies were located more north of the Mediterranean, but again summer 2007 was exceptionally hot in many parts of southeastern Europe, the Balkan peninsula and Greece (Founda and Giannakopoulos 2009) with seasonal means exceeding 4 °C in some of the areas. In Greece it was very likely the warmest summer of instrumental history with record breaking temperatures (Founda and Giannakopoulos 2009).

Overall, the length of summer heat waves over Western Europe has doubled over the period from 1880 to 2005 and the frequency of hot days has almost tripled (Della-Marta et al. 2007), whereas across the eastern Mediterranean region, the mean heat wave number, intensity and length increased by factors of 6.2 ± 1.1,

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[1] Typical impacts associated with extreme events are summarized in Table 2 "Typical impacts associated with extreme events" by Beniston et al. 2007.

[2] The 2006 heat wave affected particularly the Netherlands, Belgium, Germany, Poland, France and Switzerland. The July 2006 anomalies were similar in magnitude to those of June and August 2003, but the discrepancy between minimum and maximum temperature anomalies was larger in 2006 compared to both June and August 2003 (Rebetez et al. 2009).

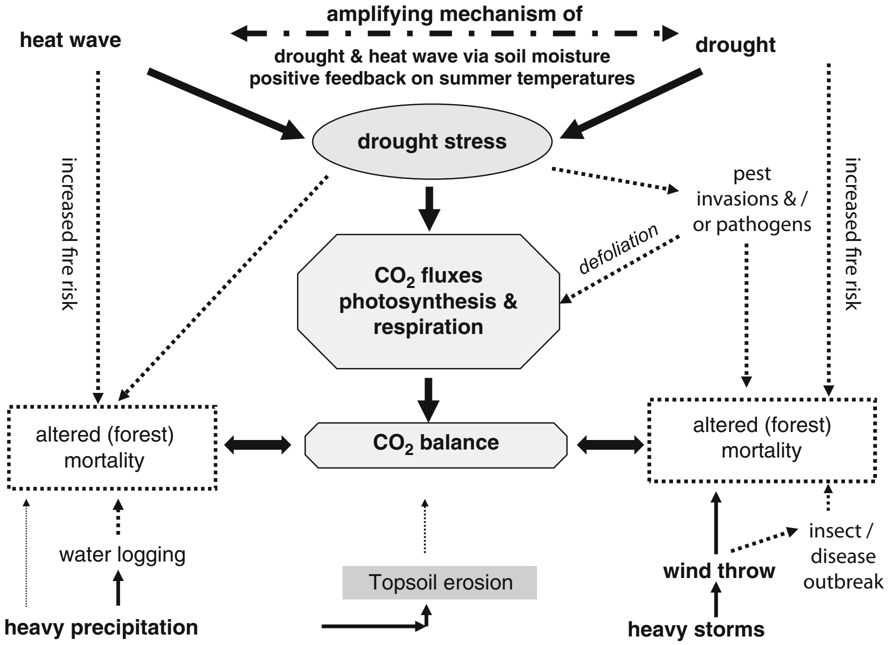

Fig. 3.1 Impacts of climate variability and extremes on the carbon cycling of forest ecosystems. *Dashed arrows* show indirect and lagged effects

7.6 ± 1.3 and 7.5 ± 1.3 respectively, since the 1960s (Kuglitsch et al. 2010). Western Europe's climate has become more extreme than previously thought (Della-Marta et al. 2007); similar findings were detected by Kuglitsch et al. (2010) for the eastern Mediterranean region indicating a higher heat wave increase than previously reported.

The Mediterranean has become drier (Trenberth et al. 2007), the drought period observed in the eastern part of the Mediterranean basin at the end of the twentieth century seems to be the strongest of the last 500 years (Nicault et al. 2008). In Iberia the drought of 2004/05, which affected Western Europe (35°–55°N and 10°W–10°E) was the driest event in the last 140 years. The southern half of peninsula (Portugal and Spain) received roughly 40% of the usual precipitation by June 2005 (Garcia-Herrera et al. 2007). Italian weather stations also showed a tendency towards a decrease in annual rainfall (−5% per century), even if such decrease is very low and rarely significant; spring season precipitation (−9% per century) seems to be the most affected (Brunetti et al. 2006). Extreme rainfall indices show less spatial consistency. Kostopoulou and Jones (2005) found a significant positive trend towards intense rainfall events in the central Mediterranean (represented by Italian stations), contrasted by negative trends in all precipitation indices for the eastern part.

3.2 Observed Impacts of Climate Variability and Extremes on Ecosystems

Impacts associated with extreme events such as heat waves, extreme precipitation or storms, may strongly affect the carbon cycling in agriculture, forestry and natural ecosystems (see Fig. 3.1). The carbon cycle may be affected in manifold ways, e.g. via lower gross primary production (GPP) due to restrictions in leaf photosynthesis, altered mortality of forests through drought related water stress, via wind throw due to heavy storms, or (e.g. drought or wind throw related) pest invasions. Crop damages or complete crop failure and associated changes in the carbon cycling of agricultural systems may be caused through water excess following heavy precipitation events or contrarily through drought related water stress. Heat waves and its often associated droughts impact soil carbon processes – the amplifying mechanism of droughts associated with heat waves, such as soil moisture depletion and the positive feedback on summer temperatures (Beniston 2004; Seneviratne et al. 2006) will be discussed in Sect. 3.4. On the other hand, the concentration of precipitation in fewer but more intense events may cause further carbon losses through topsoil erosion. Often the consequences of extreme events on the carbon cycle go beyond the duration of the extreme event itself (see below) and lag effects – e.g. altered mortality in the next (or in following) year(s) – have to be considered.

Drought is a major driver of the carbon (and water) fluxes in forest ecosystems and impacts annual tree growth (Granier et al. 2007). Severe and recurrent droughts have been identified as a major contributing factor in the recently accelerated rates of tree decline and mortality in (temperate) European Forests (Bréda et al. 2006). The 2003 heat wave strongly affected the hydraulic balance in many forest tree species including Douglas-fir, with symptoms ranging from partial crown necrosis to death (Martinez-Meier et al. 2008). Mediterranean ecosystems and their carbon cycle are adapted to summer droughts as water stress is a defining characteristic of Mediterranean ecosystems (Keenan et al. 2009), but Mediterranean droughts and heat waves are expected to become much more intense and frequent.

Drought can have in fact a strong impact on carbon fluxes and thus on the carbon sequestration potential of ecosystems. Experimental drought and warming resulted in a trend to reduce 33% the biomass of a Mediterranean shrubland (Prieto et al. 2009b). Stem diameter increment of *Quercus ilex* and *Arbutus unedo*, two typical Mediterranean species, were reduced by 41 and 63%, respectively, in an experimental 5-year drought treatment, as well as the increment of live aboveground biomass (by 83%), together with increased mortality rates (Ogaya and Peñuelas 2007). *Quercus ilex* showed strongly decreased net photosynthesis rates (44%) and stomatal conductance (53%) in autumn after a drought treatment (Asensio et al. 2007).

When the precipitation regime was altered in experimental plots in a Mediterranean macchia dominated by *Arbutus unedo L.* permanent down-regulation of stomatal conductance and photosynthesis occurred and was associated to the accumulation of photo-protective pigments. This led to an overall reduction of shoot growth and leaf area index, and an increase in shoot-bearing flowers, so that drought acclimation response prevented the onset of any run-away damage and, thereby reducing the forest vulnerability to drought (Ripullone et al. 2009). Such acclimatory responses may be of relevance while considering the effect of changes in precipitation on the carbon balance of Mediterranean ecosystems as these kind of acclimatory responses to drought reduce the vulnerability of ecosystems, but at the same time their productivity.

Not only droughts also changes in temperature means, extremes and seasonal temperature regime may alter the carbon fluxes of ecosystems. Soil respiration was largely controlled by soil temperature above a threshold value of 10% soil water content (0–15 cm depth) for forest and olive grove and 15% for the abandoned field at in situ measurements in Southeast Spain (Almagro et al. 2009). De Dato et al. (2010) found an increase of soil CO_2 efflux in response to a moderate increase of daily minimum temperature to be unlikely in the semi-arid Mediterranean[3] shrub land, whereas less precipitation can strongly affect the soil processes mainly limited by water availability. In summer larger soil CO_2 emissions in drought plots than in control plots have been found by Asensio et al. (2007). Under decreasing water availability ecosystem respiration was found to be increasingly dominated by heterotrophic soil respiration at in situ observations e.g. by Unger et al. (2009). Hence, soil moisture is a key factor controlling biogeochemical cycles and the release of CO_2 via soil respiration in arid and semiarid shrubland ecosystems of the Mediterranean basin (cf. also de Dato et al. 2010).

A sequence of dry years may have stronger impact on trees than one drought, even a severe one, as the subsoil moisture reservoir may be depleted. The partitioning of the ecosystem transpiration fluxes between trees (holm oak, *Quercus ilex* ssp. *rotundifolia*) and the grass understorey was studied in a southern Portugal oak woodland (Paço et al. 2009). Grass transpiration was estimated as the difference between the transpiration of the ecosystem (eddy covariance) and that from trees (sap flow). Grass transpiration stopped in the summer as the upper soil dried. Trees, however, maintained transpiration throughout the summer due to deep rooting. Tree transpiration represented more than half of ecosystem transpiration, in spite of the low tree density (30 trees ha^{-1}) and crown cover fraction (21%) (Paço et al. 2009). In the short-term, trees showed a high resilience to both seasonal and annual drought, whereas the grassland transpiration showed a strong dependence on rainfall occurrence and on top soil moisture. But if this situation is prolonged, the deep soil water supply may not be renewed and become exhausted leading to widespread tree mortality.

Several studies made in the Mediterranean region reported the occurrence of the so called "Birch effect" on soil respiration (Jarvis et al. 2007): when soils become dry during summer because of a lack of rain and are then rewetted by precipitation, there is a burst of decomposition, mineralization and release of inorganic nitrogen and CO_2. In Mediterranean forests of southern Europe, this effect has been observed with eddy covariance techniques and soil respiration chambers at the stand and small plot scales, respectively. Following such a short-term effect that may last for a few days

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[3] Study site in northeast Sardinia, Italy.

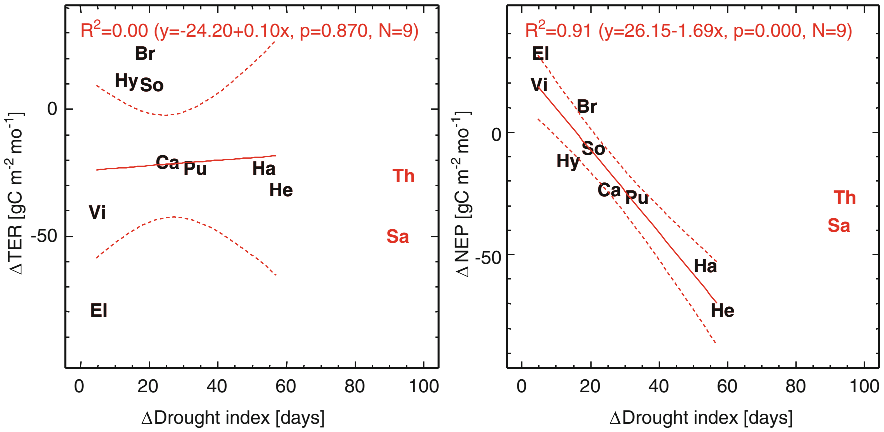

Fig. 3.2 Correlation plot of years 2003–2002; differences of *TER* (Terrestrial Ecosystem Respiration) and *NEP* (Net Ecosystem Productivity) versus Drought index (function of relative extractable soil water (soil water holding capacity) and precipitation distribution)

after late summer of early autumn rains, a significant amount of carbon stored in the soil organic matter can be returned to the atmosphere and thus significantly reducing the annual net carbon gain of Mediterranean forests. A fraction of this carbon may also originate from inorganic substrates, especially in calcareous soils, but recent studies have shown that most of the carbon which is released, actually originates from organic matter (Inglima et al. 2009). The dynamic of those CO_2 efflux pulses may be greatly affected by changes in the precipitation distribution, but the most obvious conclusion is that a possible mean reduction of soil respiration caused by prolonged drought can be rapidly compensated by rapid CO_2 burst following the first rain events after the summer drought period. Moreover, also largely unstudied CO_2 release processes have to be potentially taken into account, such as photo degradation of litter (Austin and Vivanco 2006). Hence, overall, while there is a direct negative effect of drought on soil respiration (and thus a positive on carbon storage), through the mechanisms discussed above the medium term effect is likely to be much smaller or even reverse. This seems to be supported in a combined view of the 2003 heat wave studies by Granier et al. (2007) and Reichstein et al. (2007), as depicted in Fig. 3.2. On a seasonally integrated basis, the ecosystem respiration is barely related to a drought index, while net ecosystem production is (see below).

As net ecosystem productivity (NEP) is a delicate balance between gross primary production (GPP) and ecosystem respiration (Reco), the direct relation between precipitation and GPP is counterbalanced by its relation with respiration, thus leading to a more complex and not single-factor relation with net ecosystem productivity as shown e.g. in Granier et al. (2007) and Alberti et al. (2007).

Net ecosystem production decreased with increasing water stress at all sites investigated by Granier et al. (2007). Transpiration, gross photosynthesis and respiration of trees decreased sharply when the relative extractable soil water[4] dropped below approx. 40%. Net ecosystem exchange was reduced with soil water depletion, but to a lesser extent than gross ecosystem production, as ecosystem respiration decreased as well (Granier et al. 2007). In an experiment made on a Mediterranean forest dominated by *Arbutus unedo L.* NEP was little affected or even slightly declined when soil water availability was increased by drip irrigation (Alberti et al. 2007). The measurements were made using a pair of eddy covariance towers located on a dry and on a wet plot and showed that GPP was increased but that Reco was also stimulated. Such an effect was also confirmed by direct measurements made with automated soil chambers. This result suggests that the net carbon sequestration may not be single-factor affected by changes in precipitation likely following ecosystem-scale homeostatic adjustment driven by accelerated uptake-decomposition rates. However, such conclusion requires some caution as both drought and irrigation treatments used in ecosystem manipulations are made by creating rapid step-changes in ecosystem responses that may finally have a transitory nature.

Nevertheless, droughts are the main source of inter-annual variation in terrestrial carbon sequestration reducing gross primary productivity, ecosystem respiration as well as net ecosystem exchange (Pereira et al. 2007; Ciais et al. 2005). The carbon sequestration of Mediterranean ecosystems may be reduced by droughts, or even turning into net carbon sources to the atmosphere (Pereira et al. 2007). The European heat wave of 2003 reduced the gross primary productivity by 30% over Europe, resulting in a strong anomalous net source of carbon dioxide to the atmosphere and undoing the effect of 4 years of net ecosystem carbon sequestration (Ciais et al. 2005). Also Granier et al. (2007) observed net CO_2 fluxes becoming temporarily positive on sites where drought was most severe. Both Granier et al. (2007) and Reichstein et al. (2007) show that the cause for reduced carbon sequestration during the heat wave 2003 was the lack of water and not directly the high temperatures, thus for the biosphere the 2003 heat wave was rather a 2003 drought spell.

However, in addition to severity and duration, the timing of droughts is a crucial factor owing to the strong seasonality of Mediterranean climate.

There is evidence from recent studies that especially extreme (spring) droughts can substantially alter phenology (such as development of leaves, flowers and fruits) and physiology (e.g. photosynthesis) of Mediterranean *Quercus ilex* forests as shown by Misson et al. (2010, 2011).

The timing of precipitation also influences net primary productivity and net ecosystem exchange (e.g., Jongen et al. 2011), especially if the concentration of precipitation on a few individual rain events increases. Precipitation occurring in the middle of the dry season may result in large pulses of ecosystem CO_2 losses through

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[4] According to Granier et al. (1999), the relative extractable water REW is as followed:
$REW = EW:EW_M$ (with REW being unit less)
EW = extractable water = $W–Wm$; EW_M = maximum extractable water = $W_F–Wm$
(W = available soil water, Wm = minimum soil water, i.e. lower limit of water availability; W_F = soil water content at field capacity; soil water content expressed in [mm H_2O]).

respiration (Reco) (Jarvis et al. 2007). On the other hand, low precipitation at the peak of the growing season may result in decreased carbon sequestration, as occurred in spring 2007 in a Portuguese grassland (Jongen et al. 2011) with substantially reduced GPP and NEE. As another example, in 2003 Western Iberia (incl. Portugal) was hit by the heat wave that affected the whole of Western Europe (Trigo et al. 2006). Adapted to seasonal drought through deep rooting and near isohydric behavior, the woody vegetation in the Iberian Peninsula was barely affected by the heat wave mainly because it rained normally in the first half of the year (Pereira et al. 2007) and the annual precipitation exceeded the 1951–1980 30-year average. However, on the other side the extreme heat of 2003 resulted in the worst fire season ever experienced in Portugal with a total burnt area of (forests and shrublands) twice the average for first 5 years of twenty-first century, i.e. about 5% of the countryside (Trigo et al. 2006; Pereira and Santos 2003), illustrating the complex relationships (cf. Fig. 3.1).

Nine years of eddy covariance measurements over an evergreen Mediterranean forest in southern France showed that the forest acted as a net carbon sink with high seasonal variability since 83% of the net annual carbon sink occurred between March and June (Allard et al. 2008). Considering the predicted mean regional precipitation decrease of around – 22% for the period April to September in the Mediterranean (Giorgi 2006), the timing of the beginning of droughts will be crucial (Unger et al. 2009). During the spring to summer transition, the declining ecosystem sink strength of an open evergreen oak woodland of Southern Portugal was due to a large drought and temperature induced decrease in the carbon uptake (from 56 to 21%) of the understory formed by shallow-rooted annuals (Unger et al. 2009). Increased summer droughts (July–September) would not negatively impact the average carbon budget of this ecosystem, but late spring-early summer droughts (April to June) would dramatically impact the net ecosystem exchange of CO_2 of this ecosystem (Allard et al. 2008).

Drought has manifold impacts on the carbon cycle, e.g. via the phenology of plants (Gordo and Sanz 2010; Jentsch et al. 2009), their physiology, growth and thus their capacity to act as a carbon sink. Nevertheless, the impact of secondary factors such as insect pests, pathogens and fire is often greater than the impact of the original stress and can lead for example to important tree mortality (Rouault et al. 2006) and thus further enhance the impact of drought on the carbon sequestration potential of forest stands. Droughts can favor the occurrence and/or severity of plant diseases, and thus productivity and mortality, with special relevance in long-living species, i.e. in forests. Many studies refer to a positive association between drought and forest disease, i.e. disease favored by drought or synergetic of drought and disease acting on tree health status, with a predominance of canker/dieback diseases (Desprez-Loustau et al. 2006) with intensity and timing of water stress being significant factors affecting the drought-infection interaction. An example is the "charcoal disease" caused by an opportunistic parasite[5] responsible for necrosis on stems and branches of *Quercus* species in the Mediterranean area. This led to

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[5] *Biscogniauxia mediterranea* (De Not.) Kuntze. (syn. *Hypoxylon mediterraneum* (De Not.) Mill.)

serious damages and changing species composition in mixed oak forests in Central and Southern Italy, after one or more seasons of severe drought.

The impacts of droughts may last longer than the respective rainfall deficit itself due to delayed recovery and/or the before mentioned secondary impacts. Drought impacts on the annual tree growth have consequences in the following years (Granier et al. 2007) lasting longer than the drought event itself. Lag effects on the net ecosystem CO_2 exchange have been also described by Arnone et al. (2008) in tallgrass prairie manipulation experiments where warming decreased net ecosystem exchange in the extreme and the following year; drought suppressed net primary productivity in the extreme year and stimulated heterotrophic respiration of soil biota in the following year (Arnone et al. 2008), and therefore reducing the carbon sequestration. Also the type of ecosystem matters. Mediterranean evergreen (savannah like) oak woodland showed different vulnerability, i.e. capacity to resist and/or recover from the impacts of a drought event, compared with Eucalyptus plantations or Mediterranean grasslands (Pereira et al. 2007). In a year with normal rainfall following an extremely severe drought period the Eucalyptus plantation did not reach its net ecosystem productivity values of years before the drought event, whereas the oak woodland and the grasslands reached their maxima (Pereira et al. 2007). Especially if combined with fire, drought may slow down the post-fire succession of Mediterranean shrubland and thus delay ecosystem recovery as shown in the slowed down post-fire transformation from shrub to pine tree dominated vegetation under experimental drought and warming in Spain (Prieto et al. 2009a).

3.3 Projected Changes of Mediterranean

Annual mean temperatures in Europe are likely to increase more than the global mean (Christensen et al. 2007), and in the Mediterranean the warming is expected to be largest in summer (Christensen et al. 2007; Coppola and Giorgi 2010; Giannakopoulos et al. 2009).

Anthropogenic GHG emissions are expected to lead not only to a mean warming, but also causing more frequent and intense summer temperature extremes due to changes in temperature variability that may arise from changes in the interannual temperature variability, the intraseasonal temperature variability and the seasonal cycle (Fischer and Schär 2009). Coppola and Giorgi (2010) show that in Italy increases for extreme hot seasons will be more pronounced than those of mean summer temperatures.

Areas already experiencing strong heat waves could experience even more intense heat waves in the future (Meehl and Tebaldi 2004). Also for the Mediterranean more frequent, intense and longer lasting heat waves and temperature extremes are predicted by many authors (Coppola and Giorgi 2010; Fischer and Schär 2009; Founda and Giannakopoulos 2009; Giannakopoulos et al. 2009; Meehl and Tebaldi 2004). The maximum temperatures recorded in Greece during the exceptional hot summer 2007 could be by the latter part of the century typical summers (Founda and Giannakopoulos 2009). An additional month of summer days accompanied by additional tropical nights, the latter to be largest in the southern and easternmost part and a decrease in the number of frost nights are predicted by Giannakopoulos et al. (2009).

Annual precipitation is very likely to decrease in most of the Mediterranean (Christensen et al. 2007; Giorgi 2006), especially in the warm season (Coppola and Giorgi 2010; Giorgi and Lionello 2008). For the period April to September a large decrease in the mean regional precipitation of around – 22% is predicted for the Mediterranean (Giorgi 2006). Decreased precipitation and enhanced evaporation in spring and early summer will very likely reduce the summer soil moisture and increase the risk of summer drought in the Mediterranean region (Christensen et al. 2007).

Besides the overall trend of decreasing mean precipitation in the Mediterranean (Zaehle et al. 2007), its distribution is also projected to change. A decrease in the number of precipitation days in the Mediterranean area is projected as well as an increase in the length of the dry season/dry spells, i.e. an increase in the risk of summer drought (Christensen et al. 2007; Giannakopoulos et al. 2009). Mediterranean droughts are predicted to start earlier in the year and last longer at the end of this century (2071–2100) compared to 1961–1990 (Beniston et al. 2007), the length of summer drought is predicted to increase by more than 30 days (Hanson et al. 2007). This is consistent with Giannakopoulos et al. (2009) predicting a lengthening of the dry season by a week and its shift toward spring in the south of France and inland Algeria, and autumn elsewhere, together with the extension of droughts in central Mediterranean by a month (starting a week earlier and ending 3 weeks later). The only exception to the overall drying trend is an increase of winter precipitation in some areas of the northern Mediterranean basin (Giorgi and Lionello 2008). This is in agreement with findings by other authors forecasting an increase of winter precipitation over northern Italy contrasting the decreases over the southern parts of the peninsula (Coppola and Giorgi 2010), or the partially compensation of the widespread decline in summer rainfall by an increase of winter precipitation in the northern parts of the Mediterranean (Giannakopoulos et al. 2009).

Inter-annual variability of precipitation is projected to increase in the twenty-first century within the Mediterranean (Giorgi and Lionello 2008; Coppola and Giorgi 2010), whereas intense rainfall events decrease in the Mediterranean (Hanson et al. 2007; Beniston et al. 2007; Oikonomou et al. 2008). Whereas Christensen et al. (2007) predict within the last IPCC report an increase in magnitude and frequency of high winter precipitation extremes to be very likely in northern and central Europe, they state no clear trend for the Mediterranean area and central Europe summers, where extreme short-term precipitation may either increase (due to the increased water vapor content of a warmer atmosphere) or decrease (due to a decreased number of precipitation days, which if acting alone would also make heavy precipitation less common).

The projected climate changes in the Mediterranean area can be summarized as followed: besides an overall trend of decreasing mean precipitation especially in the summer, more frequent, intense and longer lasting heat waves and temperature extremes are predicted, as well as a lengthening of the dry season. Hence, the

Mediterranean can be considered as one of the "hot spot" areas for recent and projected climate change (Giorgi 2006).

3.4 Expected Impacts of the Projected Changes

The projected impacts of climate change and its associated extreme events are discussed within this section focusing on the impacts of heat waves, droughts and extreme precipitation with regard to carbon cycling, being aware that other extreme events such as storms may also in the future affect the carbon cycling e.g. via windthrow in forest ecosystems.

As discussed above, the exact climate impacts are often dependent on relatively subtle characteristics such as timing of precipitation, which are not predicted in a consistent way among different (regional) climate models. Moreover, responses to a certain climate input are often species specific and depend on soil conditions, elements which are unfortunately not well represented by current state-of-the-art models. Hence we briefly summarize the results from a formal model assessment with the LPJ model (Sitch et al. 2003) and otherwise make inferences based on the projections and impacts discussed above. Zaehle et al. (2007) found the ensemble average land–atmosphere flux for large parts of Central Europe close to zero with scenarios agreeing relatively well over large parts of Central Europe and somehow controversial in the Mediterranean[6] region, most notably in mountain areas. All four HadCM3 scenarios predict the strongest decline in soil carbon stocks, and the smallest increase in vegetation carbon due to the pronounced drought in the Mediterranean (Zaehle et al. 2007). Simulations indicate for regions such as the Mediterranean, a higher frequency of periods with pronounced droughts, i.e. with low water-availability relative to the water demand, or temperatures above critical thresholds, and thus the possibility that seasonal phenomena can potentially offset the carbon sequestration of several years in one single year as described by Ciais et al. (2005).

Water stress is a defining characteristic of Mediterranean ecosystems, and is likely to become more severe in the coming decades (Keenan et al. 2009) as in Southern Europe climate change is projected to worsen conditions of high temperatures and drought, and therefore to reduce water availability for natural ecosystems, crop productivity, human and economic uses (IPCC 2007 Summary for Policymakers Tables SPM 2 & 3).

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[6] Zaehle et al. (2007) pp 393f "The differences in land–atmosphere flux shown in Figure 7 in the Mediterranean result mainly from differences between the A2-HadCM3 run and the other three scenarios. On a regional scale, CO_2 induced increases in water-use efficiency more than compensate for the effect of water limitation on photosynthesis in three out of four scenarios (A2-PCM2, A2-CSIRO2, and A2-CGCM2), but not in A2-HadCM3. In A2- HadCM3, drought stress leads to a decline in NPP in the last 25 scenario years, partly masked by substantial interannual variability."

Higher temperatures and more frequent, intense and longer droughts will impact Mediterranean ecosystems carbon cycling, as droughts are the main source of inter-annual variation in terrestrial carbon sequestration reducing gross primary productivity, ecosystem respiration as well as net ecosystem exchange (Pereira et al. 2007; Ciais et al. 2005).

Soil moisture is a key factor controlling biogeochemical cycles and the release of CO_2 via soil respiration in arid and semiarid shrubland ecosystems of the Mediterranean basin (de Dato et al. 2010). The amplifying mechanism of droughts associated with high temperatures (or heat waves), is a positive regional feedback mechanism where decreasing amounts of precipitation lead towards drier soil conditions. The increasing soil moisture deficit lowers evaporation and, thus suppresses evaporative cooling, and leads therefore to hotter and, drier conditions.

According to Beniston (2004), for many purposes in climate impact and policy studies, the 2003 heat wave – undoing the effect of 4 years of net ecosystem carbon sequestration feedbacks (Ciais et al. 2005) – could be used as an analog of future summers in coming decades.

Asensio et al. (2007) indicate that leaf and soil CO_2 exchange of Mediterranean holm oak forest may be strongly reduced (by ca. 44%) by the predicted decreases of soil water availability in the next decades. The projections have big spatial variations within the Mediterranean. At the northern limit of the Mediterranean, Davi et al. (2006) projected even an increase (+34%) of the carbon sink strength for the sclerophyllous evergreen (*Quercus ilex*) ecosystem at Puechabon (France) mainly due to the CO_2 increase. The occurrence of increased NPP, possibly driven by rising atmospheric CO_2 concentrations or, alternatively, by enhanced nitrogen deposition, may also have important implications for additional atmospheric feedback effects. Increased carbon accumulation in forests is in fact strictly associated to increased evapotranspiration (Beer et al. 2009), despite a well-know counteracting and antitranspirant effect of elevated CO_2. This implies that if more carbon is taken up by the plants, more water is injected into the atmosphere, thus altering the ratio between sensible and heat fluxes and consequently the mean height of the planetary boundary layer. These two effects are likely to drive, at the same time, an increase in actual evapotranspiration and an overall decrease in the potential evapotranspiration. On the other hand the decreases of biomass accumulation due to drought reduce the capacity of semi-arid Mediterranean shrubland to remove CO_2 form the atmosphere (de Dato et al. 2010).

Another potential impact of anthropogenic climate change on the carbon cycling is an increased fire frequency risk. Fire offsets within a very short time huge amounts of carbon previously stored within the vegetation. Forest fires are highly sensitive to climate change, as the fire behavior is immediately related to fuel moisture affected by precipitation, relative humidity, air temperature and wind speed (Moriondo et al. 2006).

The projected climate change for the Mediterranean with more frequent, intense and longer lasting heat waves and temperature extremes and a longer dry season will increase fuel dryness and reduce relative humidity, and thus increase the fire risk. The increase in fire risk for the EU Mediterranean countries was greater for the A2 scenario than for the B2 scenario (Moriondo et al. 2006) and may have a very strong impact in areas where forest land cover is high. Mediterranean Europe has been identified as likely to suffer about 2–6 additional weeks of fire risk over all land areas, with a significant proportion being an increase of extreme fire risk, and with a significant increase in the number of days with fire risk of 1–4 weeks (but not in the number of extreme fire risk) at the South of France and coastal areas of the rest of Mediterranean (Giannakopoulos et al. 2009). Future fire activity will increase across Portugal, with area burned and fire occurrence both rising substantially (Carvalho et al. 2010[7]). Mouillot et al. (2006) predicted for Mediterranean ecosystems a decrease of the time interval between two successive fires from 20 to 16 years for maquis shrubland and from 72 to 62 years for forests, and thus via the increased fire frequency towards more shrub-dominated landscapes. The warmer and drier conditions predicted for the Mediterranean, may severely affect plant community (and diversity) recovery after fire disturbance due to lower levels of plant establishment and reduced growth rates and slowing down the succession from shrub to pine tree dominated vegetation (Prieto et al. 2009a), and thus additionally to the fire impact itself altering the carbon sequestration potential. But not only climate change itself also vegetation feedbacks may increase the fire risk in the Mediterranean. Prieto et al. (2009b) suggest that larger accumulation of dead biomass at stand level due to drier conditions combined with higher temperatures, may lead to an increased fire risk in the Mediterranean area.

3.5 Concluding Remarks

In summary, the response of the net carbon balance at ecosystem level to regional climate change is hard to predict since a panoply of interacting and partly compensating processes is affected. It is very likely that increased drought intensity and duration will affect primary productivity of the vegetation. But at the same time respiration processes are also reduced, hence compensating the effects on GPP. The state-of-the-art process model LPJ-DGVM predicts small changes of the net carbon balance of the Mediterranean for the coming century. However, several processes which have the ability to substantially alter the carbon balance are not or not sufficiently represented in DGVMs. These features include climate driven mortality, Mediterranean plant functional types, vegetation adaptation, a variety of soil processes, and fire and post fire effects.

As droughts are the main source of inter-annual variation in terrestrial carbon sequestration, higher temperatures together with more frequent, intense and longer droughts will impact Mediterranean ecosystems carbon cycling and, could turn Mediterranean ecosystems into carbon sources.

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[7] Future area burned is predicted to increase 478% for Portugal as a whole, which equates to an increase from 1.4 to 7.8% of the available burnable area burning annually. Fire occurrence will also see a dramatic increase (279%) for all of Portugal.

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Chapter 4
Climate Change Impacts on Typical Mediterranean Crops and Evaluation of Adaptation Strategies to Cope With

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Abstract Climatic change is expected to have important impact on different economic sectors (e.g. agriculture, forestry, energy consumptions, tourism, etc.). Among human activities, agricultural sector is likely to be particularly exposed to climate change hazard, since animal and crop growth are largely determined by the weather conditions during their life cycles. As a consequence, understanding the potential impacts of climate change on the agriculture has become increasingly important and is of a main concern especially for the sustainability of agricultural system and for policy-making purposes. Climate change is likely to affect agricultural systems very differently in various parts of the world. In the Mediterranean area particular attention should be devoted to climate change impact and adaptation assessments on typical Mediterranean crops like grapevine (*Vitis vinifera* L.), durum wheat (*Triticum turgidum* subs. durum Desf.) and olive (*Olea europaea* L.), since the projected

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global warming may seriously compromise the fragile equilibrium between climate and crops. In this study the impacts on durum wheat and grapevine yields, and olive suitable cultivation area were investigated for two time slices under A1B SRES scenario, at first. Then, some adaptation strategies to cope with these impacts were explored. The results indicated that projected higher temperatures resulted in a general advance of phenological stages with respect to the baseline and in a shorter inter-phase time for both durum wheat and grapevine. Despite the general decrease of time for biomass accumulation, durum wheat took advantage of the positive effect of higher CO_2 concentration, while grapevine resulted more vulnerable to warmer and drier future climate. Adaptation options, aiming at avoiding extremely high temperatures during sensible phases and prolonging the duration of the reproductive stage, resulted as positive strategies to alleviate negative impacts or exploit possible beneficial effects of a changing climate. Finally, the rising temperature will cause a northward and eastward shift of the olive tree suitable area.

Keywords Durum wheat • Grapevine • Olive suitable area • Adaptation strategies • Mediterranean basin

4.1 Introduction

Climatic change is expected to have important impact on different economic sectors (e.g. agriculture, forestry, energy consumptions, tourism, etc.) (IPCC 2007). Among human activities, agricultural sector is likely to be particularly exposed to climate change hazard, since animal and crop growth are largely determined by weather conditions during their life cycles. As a consequence, understanding the potential impacts of climate change on the agriculture has become increasingly important and is of main concern especially for the sustainability of agricultural system and for policy-making purposes.

Climate change is likely to affect agricultural systems very differently in various parts of the world. In Europe, the present climatic trend indicated that in northern Europe climate change may primarily have positive effects through increases in productivity and in the range of species grown (IPCC 2007). In southern areas (i.e. the Mediterranean basin) the disadvantages will predominate with lower harvestable yields, higher yield variability and reductions in suitable areas for traditional crops (Olesen and Bindi 2002). In these areas a particular attention should be devoted to climate change impact assessment on typical Mediterranean crops like grapevine (*Vitis vinifera* L.), durum wheat (Triticum turgidum subs. durum Desf.) and olive tree (*Olea europaea* L.), since the projected global warming may seriously compromise the fragile equilibrium between climate and crops in such areas. Spatial modeling research has indicated potential geographical shifts and/or expansion of both grapevine and olive tree regions with parts of southern Europe becoming too hot to produce high-quality wines and northern regions becoming viable once again (Bindi et al. 1996; Kenny and Harrison 1992; Butterfield et al. 2000).

Adaptation is certainly an important component of any policy response to climate change in this sector (Mizina et al. 1999; Reilly and Schimmelpfennig 1999). Studies show that without adaptation, climate change is generally problematic for agricultural production and for agricultural economies and communities; but with adaptation, vulnerability can be reduced and there are numerous opportunities to be realized (Nordhaus 1991; Rosenzweig and Parry 1994; Smit et al. 1996; Wheaton and McIver 1999).

A number of adaptation strategies have been proposed and tested in simulation studies (Adger et al. 2007) in order to evaluate their efficacy in reducing the negative impact or exploit possible beneficial effects of a changing climate. These strategies included changes in crop species, cultivar and sowing dates (Alexandrov et al. 2002; Tubiello et al. 2002; Adams et al. 2003; Giannakopoulos et al. 2009). These adaptations singly or in combination have the potential to reduce negative climate change impacts and to take advantage of positive ones (Howden et al. 2007).

On these premises, this study aims first to assess the impact of climatic change on typical Mediterranean crops such as grapevine, durum wheat and olive tree considering changes in both mean climate and climate variability. This assessment was then considered as a basis to test the effectiveness of specific adaptation strategies to alleviate the expected adverse impacts or to exploit possible positive effects of climatic change. Specifically, the results of a Regional Climate Model (RCM) were coupled with process-based models to simulate responses of durum wheat, olive tree and grapevine to climate change and variability. With the aim to either alleviate the expected adverse impacts or exploit possible positive advantages of climatic change, the effectiveness of different adaptation options were tested, namely changing in sowing date, shorter or longer cycle varieties and enhanced fertilization.

4.2 Material and Methods

The agriculture in the Mediterranean basin was projected in a future scenario in order to assess the effect of a changing climate over typical Mediterranean crops such as durum wheat, grapevine and olive tree. In particular, changes in yield, with respect to present day, were evaluated for durum wheat and grapevine in 2011–2030 (FP1) and 2031–2050 (FP2) periods, while for olive tree the variation in suitable cultivation area was assessed for the same time slices. Finally, the effectiveness of specific adaptation strategies to alleviate the expected adverse impacts or to exploit possible positive effects of climatic change was tested.

According to the specific target of this paper, process-based simulation models specific for grapevine and durum wheat and an ecological model for olive tree were calibrated and validated over the Mediterranean basin. These models were then used to simulate durum wheat and grapevine yield and olive tree cultivated area for the present period and the selected future time slices under A1B scenario (Nakićenović and Swart 2000).

4.2.1 Study Area: Mediterranean Basin

This region (within 30°–46° Lat N and −5.8°–38° Lon E) represents from a climatic point of view, a transitional area between temperate and tropical climates. Its climate is characterized by wet winters (at least 65% of rainfall occurs between November and April) and very dry summers with average annual precipitation ranging between 400 and 900 mm, and rarely over 1,200 mm or below 400 mm. To the eastward the amount of precipitation is slightly decreasing. Winters are generally mild, with episodic frost periods that however do not last long. Summers are characterized by the presence of the Azores and Saharan anticyclone that determines very high temperatures, especially in the southern and eastern areas. Average temperatures of the warmest month are between 25 and 28°C, those of the coldest month between 6 and 13°C.

4.2.2 Climate Data

Daily meteorological data (minimum and maximum temperature, rainfall and global radiation; Tmin, Tmax, Prec and Rad, respectively) used to drive the process-based simulation models (durum wheat, grapevine) and the ecological model (olive tree) in the baseline and future periods were the results of a dynamical downscaling performed via an atmosphere–ocean regional climate model (AORCM) for the Mediterranean basin (PROTHEUS system) (Artale et al. 2009). The system is composed by the regional climate model RegCM3 as the atmospheric component, and by a regional configuration of the MITgcm model as the oceanic component. The output of the system have an uniform horizontal grid spacing of 30 km on a Lambert conformal projection. The model domain is centered at 41°N and 15°E with 160 grid points in the meridional direction, 150 grid points in the zonal direction and 18 σ-levels. The model was forced over the period 1958–2000, using the boundary conditions over the domain provided by the ERA40 reanalysis. The boundary conditions derived from the SRES scenario A1B of the General Circulation Model (GCM) were used to force the AORCM over the future period 2011–2050.

4.2.3 Selected Crops

4.2.3.1 Durum Wheat

Durum wheat is a rain-fed crop that it is widely cultivated over the Mediterranean Basin. The major climatic constraints to durum wheat yield under Mediterranean environments are both high temperature and drought that frequently occur during the growing cycle of the crop (Porter and Semenov 2005; García del Moral et al. 2003). As a consequence, projected climate changes in this region, in particular rising temperature and decreasing rainfall (Gibelin and Déqué 2003), may seriously compromise durum wheat yields, thus representing a serious threat for the cultivation of such a typical Mediterranean crop.

4.2.3.2 Grapevine

Climatic change is expected to threaten grapevine affecting both yield and quality. The phenology of grapevine is a predominantly temperature-driven process (Jones and Davis 2000; Pearce and Coombe 2004) and warmer temperatures, advancing grapevine phenological stages and shortening growing cycle (Webb et al. 2007), are usually related to lower yield due to a shorter time for biomass accumulation (Bindi et al. 1996; Duchêne and Schneider 2005; Pearce and Coombe 2004).

4.2.3.3 Olive Tree

Nowadays 98% of the olive trees worldwide cultivated are limited to the belt included between 30° and 45° Lat N and it is so typical of the Mediterranean climate that its presence in a territory qualifies the climate of such an area as Mediterranean. Many evidences, deriving from literature, archaeo-botanical investigations and fossil pollen analysis, indicate that during the last two millennia expansions and reductions of olive tree cultivation area depended on warmer or cooler climate conditions (Moriondo et al. 2008).

4.2.4 Model Description

4.2.4.1 SIRIUS Quality v.1.1

Sirius Quality v1.1 (SIRIUS) (Jamieson et al. 1998) is a wheat simulation model that calculates daily biomass production from intercepted photosynthetically active radiation (PAR) and grain growth from simple partitioning rules. The model needs, as inputs, daily weather data consisting of minimum and maximum temperature, rainfall and global radiation. An internal simple soil sub-model takes in account for the dynamics of water and nitrogen (N) in the soil. SIRIUS allows the user to specify management parameters such as sowing date, cultivar genetic coefficients, soil profile properties, fertilizer and irrigation management, atmospheric CO_2 concentration, etc.

Wheat phenology is estimated based on the accumulation of constant thermal time intervals, with the exception of the period from emergence to flag leaf ligule appearance. This phase is calculated from the phyllochrone (i.e. thermal time interval between the appearance of two consecutive leaves) and the final main stem leaf number, set according to the response to day length and vernalization.

From the emergence, daily biomass accumulation is calculated as the product of intercepted PAR and the Radiation Use Efficiency (RUE). This potential growth is then corrected by water and nitrogen limitations, if any, to determine actual daily biomass gain. Grain growth is simulated assuming that all new biomass, produced during grain filling, is allocated to the grain. In addition, a pool of 25% of biomass present at anthesis is transferred to the grain at a constant rate in thermal time. The model accounts for the enhanced CO_2 effect by linearly increasing RUE, so that for a doubling of CO_2 air concentration the RUE is increased by 30% (Jamieson et al. 2000).

The SIRIUS model, originally developed for bread wheat, was calibrated for durum wheat using data from two open-field experimental trials carried out in Florence (Italy, 11.11° E, 43.3° N) in 2003–2005 (Ferrise et al. 2010).

4.2.4.2 Grapevine Growth Model

The grapevine model (Bindi et al. 1997) uses a semi-empirical approach to simulate the main processes regulating development and growth of grapevine and has been already validated for Sangiovese and Cabernet cultivars. Crop development is divided in two periods: vegetative and fruit growth. The vegetative period, included between bud-break and bloom, is calculated on the assumption that bloom occurs when 17 leaves have appeared on the main shoot. The duration of fruit growth, between bloom and maturation, is assumed to be temperature-dependent and it is calculated using the cumulative degree-days approach (i.e. sum of the daily temperatures above a base temperature of 10°C).

Leaf area index (LAI) is calculated from the total number of shoots per unit area, the rate of leaf appearance and leaf expansion. LAI is, in turn, used to calculate the total amount of solar radiation intercepted by the canopy so that the crop biomass can be calculated as the product of this parameter and RUE. The effect of CO_2 on biomass accumulation is considered by linearly increasing the RUE up to +30% for a doubling CO_2 air concentration.

Daily fruit growth rate is calculated assuming that the harvest index (i.e. the ratio of fruit to total biomass) increases linearly during fruit growth. Water stress is included in the model as reducing both LAI growth and RUE (Bindi et al. 2005).

4.2.4.3 Olive Tree Ecological Model

The methodology to reproduce olive tree cultivated area was based on a previous climatic characterization of the area were the plant is currently present (Moriondo et al. 2008) and a following test with which the climatic parameters having major importance in limiting plant expansion in the territory are identified. Through this analysis the climatic variables limiting the olive tree cultivation expansion over the Mediterranean basin were identified. Mean temperature in January and July and total yearly rainfall well described the olive tree cultivated area. In particular, mean temperatures greater than 4°C in January and included between 21 and 30°C in July and at least 240 mm of yearly cumulated rainfall were the climatic delimiters for olive tree cultivation.

4.2.5 Impact Assessment

To evaluate the impact of prospected climate change on the selected crops, the outputs of the models, for two future time-slices (2011–2030 and 2031–2050, respectively FP1 and FP2) were compared with the results of the simulations in the 30-years period 1961–1990 (Pr) chosen as reference period (baseline period).

For durum wheat the analyses were limited to the grid points with more than 200 mm of mean annual precipitation (Zhang and Oweis 1999) and altitude lower than 700 m a.s.l. above which durum wheat is usually not cultivated, while for grapevine only the grid points where the ripeness, in the baseline, has not been forcedly closed by the model were considered, thus excluding the site at higher latitude and altitude.

In this first analysis, no changes, neither in crop management nor in crop cultivar (from here on referred to as Standard Cultivation; STD), were considered in the future time-slices compared to the baseline.

For durum wheat, the model was calibrated to reproduce a general durum wheat cultivar, with medium growing cycle. A climatic criterion was adopted to individuate the optimum sowing date: starting from October 1st and not later than February 15th, the sowing was matched when mean temperature of 5 consecutive days was 14°C or lower and rainfall was lesser than 2 mm. The nitrogen fertilization was set at 120 Kg N ha^{-1} split in two application: 1/3 during tillering and 2/3 at shooting.

For grapevine, the model was calibrated to match the phenological stages of a medium cycle cultivar. A plant density of 3,000 plants ha^{-1} and 14 stems per plant was considered.

For both the crops, a loamy soil (50% sand, 20% clay) with an available water content of 125 mm was considered in all the simulations.

For each grid point, the outputs of the models in terms of phenology and yield, for both durum wheat and grapevine were recorded and averaged over the relevant periods. As concerning the olive tree, the analysis consisted in applying the ecological model all over the domain to evaluate whether or not each grid point of the study area matched the climatic constraints of olive tree cultivation area in present and future periods.

4.2.6 Adaptation Strategies

For durum wheat and grapevine, an analysis of the effectiveness of some adaptation strategies to cope with climate change was performed.

The options evaluated for durum wheat were:

- advancing in sowing date by 15 and 30 days (ADV15 and ADV30, respectively)
- cultivar with longer (+20%) and shorter (−20%) growing cycle (LNG and SHT, respectively)
- enhanced nitrogen fertilization (+30%, corresponding to 180 Kg N ha^{-1}) (HNF).

For grapevine, were analyzed the performances of:

- cultivars with advanced and delayed bud-break (±10% of thermal requirement; ABB and DBB, respectively)
- cultivars with longer (+20%) and shorter (−20%) growing cycle (LNG and SHT, respectively)

4.3 Results

4.3.1 *Climatic Trend*

The picture for the future under the A1B scenario indicates a progressive warming and drying of the Mediterranean region (Fig. 4.1).

In FP2, mean annual temperature was projected to increase from +0.8°C, in the north-eastern regions to more than 1.6°C in south-western and eastern areas of the domain. The highest increases were projected in summer and spring with more than 2.4 and 1.7°C on average, respectively. In contrast, winter warming showed a lower magnitude and a clear longitudinal gradient (from 0.6 to 1.7°C in the western and eastern part, respectively).

Changes in annual precipitation showed different pattern between western and eastern areas of the domain. Precipitations in the western basin, steadily decreased up to −7%, on average, in FP2, while in the eastern zones a slight increase was simulated in FP1 (+5% on average) and a following reduction up to −5.5% was projected in FP2. The driest area resulted the southern Iberian Peninsula (up to −13% in FP2), while the central northern area resulted in almost unchanged precipitation. The highest and widespread reductions were simulated in spring and summer, particularly in southern Iberian Peninsula and Morocco (up to −50% during spring in FP2). Autumn resulted slightly wetter than the baseline (+4.8 and +0.5% in FP1 and FP2, respectively), while rainfall did not show significant variations in winter.

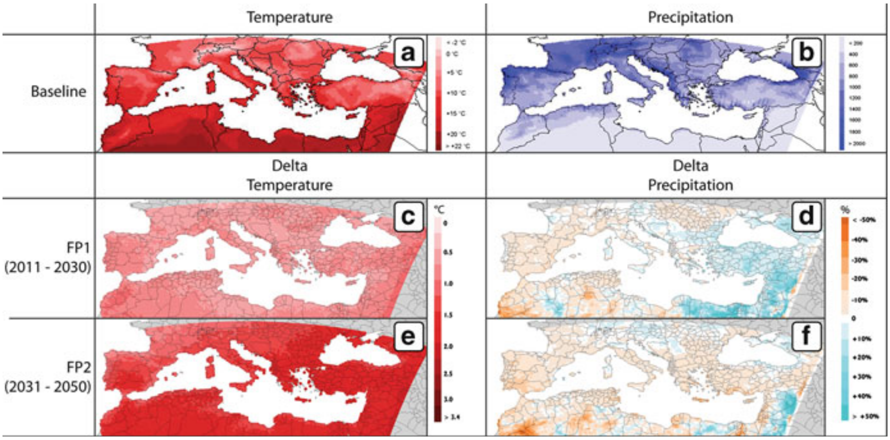

Fig. 4.1 Present and future climate over the study area as simulated by the Protheus system. Mean annual temperature (**a**) and mean cumulative annual precipitation (**b**) are referred to the 1961–1990 reference period (baseline). Changes in mean annual temperature (**c**, **e**) and mean cumulative annual precipitation (**d**, **f**) are expressed as absolute and relative difference, respectively

Table 4.1 Results of SIRIUS validation at regional scale

Regions	Lat	Lon	Observed yield (Mg ha^{-1})	Simulated yield (Mg ha^{-1})
Southern France	43.65	4.96	3.26	3.62
Northern Italy	45.48	11.88	4.88	4.53
Central Italy	42.34	11.73	2.94	3.58
Southern Italy	37.78	12.68	2.17	2.21
Central Greece	39.73	22.19	3.02	2.83
Southern Spain	36.83	–5.34	2.57	3.32

The Pearson's coefficient was 0.88 and RMSE 0.46 Mg ha^{-1}

4.3.2 Model Calibration and Validation

Aiming at analyzing the performance of SIRIUS in simulating yield at regional scale, the model was run for a selected number of places evenly distributed across the Mediterranean Basin (Table 4.1). To run the model in each specific site, a complete series of meteorological data were extracted from the MARS JRC Archive (http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Data-distribution). Downloaded data are the result of daily interpolation of observed meteorological data and are produced with a grid resolution of 50 km lat × 50 km lon.

The outputs of the model were compared with observed yield data for durum wheat, obtained from the Statistical Office of the European Commission (EUROSTAT; http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/). This data-set has different time series according to the country and the crop considered: in general, longer time series were available from 1989 to 2004 but in some cases the series were limited to 6 years.

The comparison between the observed and simulated average yields (Table 4.1) indicates that the model captured the spatial variability of yield very well (0.88 and 0.46 Mg ha^{-1}, Pearson's coefficient and RMSE, respectively) and was thus held to be trustworthy in reproducing the spatial difference in crop yield for present and future climate conditions.

The VITE model has been already calibrated in Tuscany region for the cultivar Sangiovese. This configuration of the model was tested to assess the effectiveness of VITE-model in reproducing grapevine yield spatial variability across the domain. Accordingly, several grid cells of MARS dataset evenly distributed across the basin (Spain, Greece, Italy) and falling over the grapevine cultivated area as derived from CORINE land cover, were selected to provide minimum and maximum temperature, rainfall and global radiation on a daily time step to run the model over the period 1995–2002. The results of the simulations were aggregated at regional level and compared to the relevant regional statistics as obtained from EUROSTAT.

The results indicated a good correspondence between observed and simulated data with a Pearson's of 0.7 and a RMSE of 0.88 Mg ha^{-1}, but the simulation tended to overestimate the observed yields.

To validate the effectiveness of the climatic constraints (i.e. mean temperatures greater than 4 and 20°C respectively in January and July and at least 240 mm of yearly cumulated rainfall) of the olive tree ecological model, this was applied to the Mediterranean domain for the present period (1961–1990) and the resulting map, consisting of grid points identified as cultivated/not-cultivated with olive tree, was compared to the actual map in a confusion matrix scheme. No false negative cases were observed whereas false positive cases resulted in 153 cases corresponding to an error of 8.0% that represents also the overall error of prediction.

4.3.3 Climate Change Impact in STD

4.3.3.1 Durum Wheat

Progressive increasing temperatures, in the future time-slices, resulted in a general advancing of phenological stages with respect to the baseline and in a shorter interphase time. Only sowing time resulted delayed since the optimal temperatures required for sowing occurred later in the winter. On average, crop growing cycle resulted progressively reduced by 7 and 16 days in FP1 and FP2 over the domain. In particular, in FP2, the vegetative period (sowing-anthesis) was shortened by 13 days on average, over the domain, whereas the reproductive phase was less affected (−2.8 dd with respect to the baseline) (Table 4.2).

Despite the lower time for biomass accumulation, wheat yield resulted almost unchanged or slightly increased both in FP1 and in FP2 with the exception of the southern Iberian Peninsula and Morocco where yield resulted progressively reduced up to −26% in FP2 (Table 4.3).

4.3.3.2 Grapevine

The duration of the growing season resulted almost unchanged or slightly decreased as the combined effect of a lengthening of the vegetative phase (from bud-break to bloom) and a shortening of the reproductive stage (from bloom to ripeness). In particular, the reproductive stage resulted progressively reduced from −6 dd to −9 dd, on average, in FP1 and FP2, respectively (Table 4.4).

The response of grapevine to future climate change resulted in a progressive decrease of yield with the exception of some areas at higher latitudes where the yield in FP2 was slightly increased with respect to the baseline. The highest yield losses were recorded in the Iberian Peninsula (up to −11% in FP2) (Table 4.5).

Table 4.2 Changes (No. of days) in the duration of the grain filing phase of durum wheat in FP1 and FP2 (A1B scenario)

	2011–2030						2031–2050					
	STD	ADV15	ADV30	SHT	LNG	HNF	STD	ADV15	ADV30	SHT	LNG	HNF
Portugal	−2.1 ± 0.9	−0.2 ± 0.9	2 ± 0.9	1.7 ± 2.6	−4.3 ± 2	0.8 ± 1.4	−3.8 ± 1.3	−2.3 ± 1.3	−0.6 ± 1.6	−1.4 ± 3.5	−4 ± 1.4	−1 ± 2.1
Spain	−1.3 ± 1.1	0.2 ± 1.2	1.6 ± 1.2	1.1 ± 2.2	−2.8 ± 2.6	1.4 ± 1.6	−3.8 ± 1.3	−2.5 ± 1.1	−1.1 ± 1.1	−1.7 ± 2.3	−3.9 ± 2.3	−1.1 ± 1.8
France	−1.2 ± 1.1	0.3 ± 1.4	1.8 ± 1.5	2 ± 1.3	−4.8 ± 1.9	3.4 ± 0.9	−3.6 ± 1.3	−1.8 ± 1.2	−0.2 ± 1.9	0.4 ± 1.3	−7 ± 2.1	1.3 ± 1.4
Italy	−0.2 ± 0.9	0.8 ± 0.8	1.6 ± 1.1	2 ± 1.4	−0.9 ± 1.3	3 ± 1.4	−1.3 ± 1.2	0 ± 1.2	0.8 ± 1.7	1.4 ± 1.9	−3.1 ± 1.5	2 ± 1.4
Balkans	−0.6 ± 0.7	−0.3 ± 0.8	0 ± 0.9	0 ± 1.5	−0.5 ± 1.6	2.9 ± 1	−1.9 ± 1.4	−1 ± 1.3	−0.7 ± 1.4	0.3 ± 1.6	−2.9 ± 2	1.7 ± 1
Greece	−0.9 ± 0.8	−0.2 ± 0.8	0.5 ± 1	0.4 ± 1.6	−0.3 ± 1.3	1.6 ± 1.5	−1.1 ± 0.9	0 ± 0.9	0.5 ± 1.1	0.8 ± 2.1	−1.5 ± 1.5	1.5 ± 1.3
Turkey	−1.3 ± 1.1	−0.8 ± 1	−0.3 ± 1.1	−0.5 ± 1.6	−1.1 ± 1.8	1.5 ± 1.5	−1.8 ± 1.1	−1 ± 1	−0.8 ± 1.1	0 ± 1.6	−3 ± 2.4	1.1 ± 1.2
Middle East	−2.1 ± 0.4	−1.6 ± 0.6	−1.4 ± 1.1	−2.9 ± 0.7	0.2 ± 0.5	−1.3 ± 0.6	−2.4 ± 0.7	−1.4 ± 0.7	−1.2 ± 1.1	−3 ± 0.9	−0.4 ± 0.7	−1.6 ± 0.7
Morocco	−2.9 ± 1	−0.7 ± 0.8	1.5 ± 0.9	−2.6 ± 1.5	−2 ± 1.2	−2 ± 1.5	−6.3 ± 1.1	−4.3 ± 1.1	−2.9 ± 1.2	−6.5 ± 1.6	−4.2 ± 0.9	−5.3 ± 1.3
Algeria	−0.9 ± 1	0.3 ± 1	1.7 ± 1.3	−1.2 ± 1.9	−0.3 ± 0.8	0.5 ± 1.5	−3.4 ± 1.4	−1.7 ± 1.1	−0.4 ± 1.2	−2.7 ± 1.9	−2.9 ± 1.1	−1.9 ± 1.9
Tunisia	−0.8 ± 0.6	0.9 ± 0.7	1.9 ± 0.8	−2 ± 1.5	−0.2 ± 1.2	0.1 ± 1	−2.9 ± 1.1	−1.4 ± 1	−0.3 ± 0.9	−3.9 ± 1.7	−1.7 ± 0.6	−2 ± 1.6
Libya	−1 ± 0.5	0.8 ± 0.6	1.9 ± 0.5	−3.3 ± 0.6	0.8 ± 0.7	−0.6 ± 0.5	−3.2 ± 0.6	−1.7 ± 0.6	−0.4 ± 0.7	−4.7 ± 0.8	−0.9 ± 0.7	−2.7 ± 0.7
Average	*−1.1 ± 1.1*	*0 ± 1.2*	*1 ± 1.5*	*0.3 ± 2.3*	*−1.8 ± 2.4*	*1.7 ± 2*	*−2.8 ± 1.8*	*−1.5 ± 1.5*	*−0.5 ± 1.6*	*−0.9 ± 2.8*	*−3.5 ± 2.5*	*0.1 ± 2.4*

Changes were calculated, on a grid basis, as the difference between the length of the phase in future and baseline time slices and then averaged at nation level. The standard deviation is also reported. Adaptation options: standard cultivation (*STD*); advanced sowing date by 15 (*ADV15*) and 30 days (*ADV30*); cultivar with longer (*LNG*) and shorter (*SHT*) growing cycle; enhanced nitrogen fertilization (*HNF*)

Table 4.3 Changes (%) in the average yield of durum wheat in FP1 and FP2 (A1B scenario)

	2011–2030						2031–2050					
	STD	ADV15	ADV30	SHT	LNG	HNF	STD	ADV15	ADV30	SHT	LNG	HNF
Portugal	−5.6 ± 3.9	1.6 ± 3.3	5.2 ± 4.7	1.2 ± 8.7	−19.1 ± 5.8	20.5 ± 12.5	−12 ± 13.6	−8.2 ± 11	−4.7 ± 9.3	−6.4 ± 13.6	−17.1 ± 10.5	14.4 ± 26.7
Spain	0.4 ± 4.2	5.8 ± 4.8	8.9 ± 5.8	3.3 ± 7.3	−8.4 ± 10	26.8 ± 11.9	−9.7 ± 10.9	−4.3 ± 9.1	0 ± 8.1	−3.5 ± 9.9	−16.7 ± 10.1	14.9 ± 22.6
France	1.5 ± 5	6.3 ± 5	8.6 ± 6.4	7.8 ± 8.6	−13.9 ± 6.8	48.2 ± 13.7	1.2 ± 5.3	8.7 ± 6.2	10.6 ± 5.7	12.6 ± 9.1	−17.4 ± 7.8	50.2 ± 12.6
Italy	3 ± 6	8.4 ± 5.7	10.7 ± 6.4	7.3 ± 6.4	−6.8 ± 5.6	36.7 ± 12	4.2 ± 6.4	9.4 ± 6.1	10.7 ± 6.8	9.2 ± 7.9	−10.2 ± 9.2	40.6 ± 13.1
Balkans	3.8 ± 7.2	9.3 ± 8.4	11.6 ± 9.3	8.7 ± 8.2	−4.1 ± 7.9	42.3 ± 15.2	2.2 ± 5.2	10.8 ± 6.8	13.1 ± 9.1	13.5 ± 6.7	−10.8 ± 7.1	43.3 ± 11.6
Greece	−0.4 ± 6.3	5.2 ± 7.2	10.3 ± 10.1	8.3 ± 6.7	−11.2 ± 5.9	26.3 ± 13.1	−1 ± 7.7	6.5 ± 6.8	9.7 ± 7.6	10.4 ± 10.2	−15.7 ± 6.8	26.2 ± 17
Turkey	−4.8 ± 6.8	1.4 ± 7.2	5.5 ± 7.2	6.2 ± 8.5	−17.1 ± 6.7	24.2 ± 17	0.2 ± 5.7	6.9 ± 5.3	9 ± 5.7	14.3 ± 8.6	−19 ± 6.4	31.3 ± 14.4
Middle East	−1.4 ± 7	8 ± 6.6	14.6 ± 9.3	11.8 ± 7.3	−13.5 ± 6	9.7 ± 8.6	3.2 ± 7.6	13.2 ± 7	17.8 ± 7.9	18.3 ± 9	−8.5 ± 6.9	14.7 ± 9.6
Morocco	−11.9 ± 8.8	2.6 ± 6.7	16.7 ± 6.2	1.1 ± 6.2	−21.3 ± 13.1	−1.9 ± 13.3	−26.4 ± 10.5	−14 ± 10.7	−2.4 ± 8.9	−14.4 ± 8.6	−33.5 ± 10.9	−17.4 ± 14.2
Algeria	−3.9 ± 9	0.5 ± 10.1	4.6 ± 12.9	−4.2 ± 8.7	−4.7 ± 8	11.6 ± 15.2	1.1 ± 7.5	7.7 ± 6.2	12.1 ± 6.4	4.1 ± 6.4	−3.3 ± 9.1	18.4 ± 10.6
Tunisia	−5.8 ± 5.4	0.4 ± 7.7	4.4 ± 9.9	−7.8 ± 8.2	−7.9 ± 5.6	6.3 ± 8.7	−2.2 ± 5.2	3.7 ± 5.6	9.1 ± 6.9	−3.1 ± 5.7	0.7 ± 6.4	10.8 ± 8.1
Libya	−2.6 ± 6.4	9.4 ± 7	16 ± 6.8	−2.9 ± 6.9	−5.3 ± 8.7	5.8 ± 7.1	−6.9 ± 7.2	−0.9 ± 6.5	5 ± 5.4	−7.9 ± 6.7	−10.1 ± 10.1	2.1 ± 8
Average	*−0.8 ± 7.5*	*5.6 ± 7.3*	*9.5 ± 8.6*	*5.1 ± 9.1*	*−10.6 ± 9.3*	*28.6 ± 19.9*	*−2.2 ± 10.7*	*4.9 ± 10.3*	*8.3 ± 9.4*	*6.7 ± 12.5*	*−14.1 ± 10.8*	*28.4 ± 23.4*

Changes were calculated, on a grid basis, as the difference between the average yield in future and baseline time slices and then averaged at nation level. The standard deviation is also reported. Adaptation options: standard cultivation (*STD*); advanced sowing date by 15 (*ADV15*) and 30 days (*ADV30*); cultivar with longer (*LNG*) and shorter (*SHT*) growing cycle; enhanced nitrogen fertilization (*HNF*)

Table 4.4 Changes (No. of days) in the duration of the reproductive phase of grapevine in FP1 and FP2 (A1B scenario)

	2011–2030					2031–2050				
	STD	ABB	DBB	SHT	LNG	STD	ABB	DBB	SHT	LNG
Portugal	−8.7 ± 3.5	−5.9 ± 4.6	−10.9 ± 3	−21.1 ± 9.9	6.5 ± 5.9	−8.3 ± 4.2	−4.9 ± 5.7	−11 ± 3.3	−18.7 ± 10	5.1 ± 2.4
Spain	−7.2 ± 3.5	−5 ± 4.1	−9.1 ± 3	−21.6 ± 8.6	8.6 ± 5.9	−9 ± 4	−6.5 ± 5.2	−10.9 ± 3	−21.4 ± 9.2	6.1 ± 2.8
Southern France	−10.9 ± 6.8	−9.2 ± 6.4	−12.1 ± 7.2	−37.1 ± 7.4	−4.4 ± 17.2	−13.7 ± 6.1	−12.7 ± 6.3	−15.2 ± 5.8	−37 ± 7.6	7.4 ± 4.6
Italy	−5.3 ± 4.8	−4 ± 5.1	−6.8 ± 5.4	−24.4 ± 7	13.4 ± 6.1	−8.4 ± 5.1	−6.7 ± 5.9	−9.7 ± 5	−24.8 ± 9.6	10.2 ± 2.8
Greece	−2.8 ± 3.4	−1.6 ± 3.5	−4.2 ± 3.2	−19.7 ± 7.4	16.3 ± 5.1	−7.1 ± 6.2	−5.1 ± 7.3	−8.9 ± 5.2	−19.8 ± 10.5	10 ± 2.1
Western Balkans	−6 ± 5.6	−5 ± 5.9	−7.1 ± 6.5	−26.2 ± 6.4	14.5 ± 5.7	−9.5 ± 6	−8.5 ± 6.4	−11.1 ± 6.6	−29 ± 8.4	11.5 ± 3.2
Turkey	−2.7 ± 3.8	−1.5 ± 4.4	−4 ± 4.3	−19.6 ± 7.3	14.1 ± 6	−7.1 ± 6.3	−5.4 ± 6.8	−8.8 ± 6	−21 ± 10.1	9.1 ± 1.8
Average	*−5.8 ± 5*	*−4.1 ± 5.2*	*−7.3 ± 5.3*	*−23.1 ± 9.1*	*10.8 ± 8.9*	*−8.6 ± 5.6*	*−6.6 ± 6.5*	*−10.3 ± 5.2*	*−23.3 ± 10.7*	*8.3 ± 3.3*

Changes were calculated, on a grid basis, as the difference between the length of the phase in future and baseline time slices and then averaged at nation level. The standard deviation is also reported. Adaptation options: standard cultivation (*STD*); advanced bud-break (*ABB*); delayed bud-break (*DBB*); cultivar with shorter (*SHT*) and longer (*LNG*) growing cycle

Table 4.5 Changes (%) in the average yield of grapevine in FP1 and FP2 (A1B scenario)

	2011–2030					2031–2050				
	STD	ABB	DBB	SHT	LNG	STD	ABB	DBB	SHT	LNG
Portugal	−13.6 ± 3.8	−3.7 ± 4.3	−23.4 ± 3.7	−15.5 ± 9.1	−21 ± 3.8	−11.1 ± 4.6	0.2 ± 6.6	−20.8 ± 3.4	−10.1 ± 10.1	−18.1 ± 2.6
Spain	−8.3 ± 5.8	−0.5 ± 5.7	−16 ± 6.9	−16.9 ± 9	−8.4 ± 7.2	−11.2 ± 9	−2.4 ± 9.9	−19.2 ± 9.3	−15.5 ± 12.8	−13.9 ± 7.5
Southern France	−1 ± 9.3	2.1 ± 8.6	−4.1 ± 9.2	−22.3 ± 8	−1 ± 6.1	2.8 ± 11.1	6 ± 9.9	−0.5 ± 12.2	−17.8 ± 8.5	4.6 ± 11.1
Italy	−4.1 ± 5	1.4 ± 5.6	−9.9 ± 4.7	−21.8 ± 7.8	−0.3 ± 5.9	−6.5 ± 7.8	−0.3 ± 9.2	−12.9 ± 6.7	−20.9 ± 12.7	−3 ± 5.8
Greece	−3.1 ± 4.5	5.4 ± 5.3	−11.3 ± 4.4	−14 ± 7.9	−1.7 ± 6.2	−6.1 ± 9.3	3.4 ± 11.1	−15.7 ± 7.9	−11.9 ± 13.5	−5.4 ± 6.4
Western Balkans	−2.8 ± 7.7	3.1 ± 7.3	−8.9 ± 6.6	−22.4 ± 6.4	−1.9 ± 4.7	−5.3 ± 6.8	1.8 ± 7.4	−12.2 ± 6.7	−22.7 ± 7.8	−1.9 ± 5.2
Turkey	0.1 ± 5.9	8.9 ± 4.8	−8.7 ± 7.1	−9.1 ± 5.7	−1.1 ± 6.9	0.2 ± 9.5	8.9 ± 10.4	−8.7 ± 8.8	−7.8 ± 12.3	−1.3 ± 7.5
Average	*−4.8 ± 7.1*	*2.6 ± 6.9*	*−12 ± 8*	*−16.7 ± 9.2*	*−4.7 ± 8.8*	*−5.9 ± 9.9*	*2.1 ± 10.5*	*−13.6 ± 10.1*	*−14.8 ± 13.1*	*−6.5 ± 9.6*

Changes were calculated, on a grid basis, as the difference between the average yield in future and baseline time slices and then averaged at nation level. The standard deviation is also reported. Adaptation options: standard cultivation (*STD*); advanced bud-break (*ABB*); delayed bud-break (*DBB*); cultivar with shorter (*SHT*) and longer (*LNG*) growing cycle

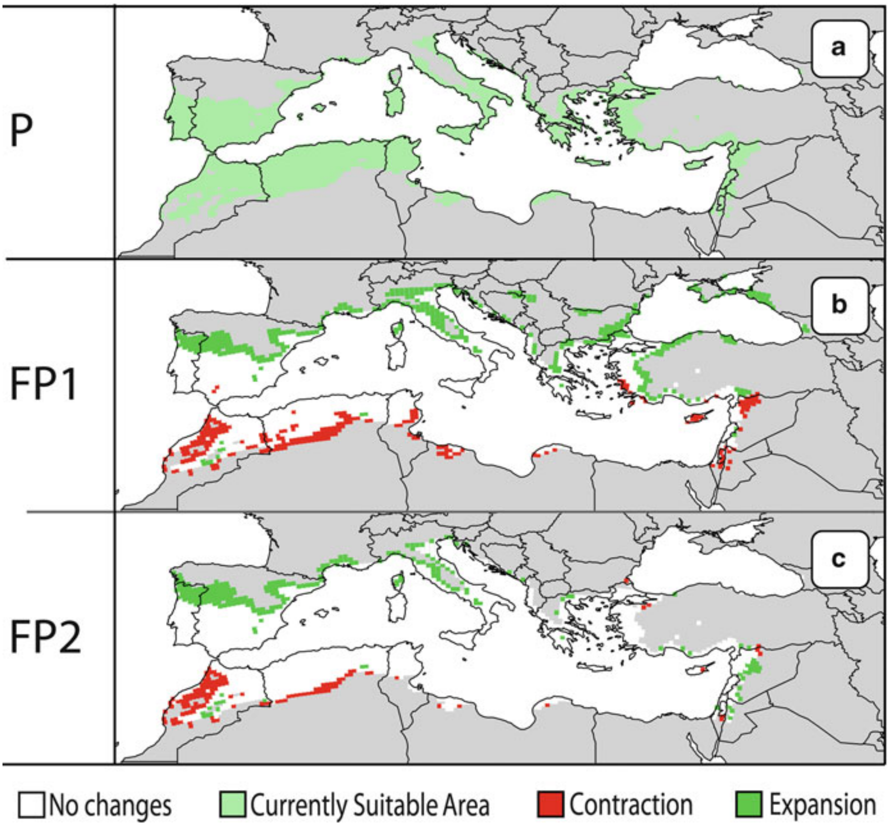

Fig. 4.2 Olive suitable area (*pale green*) in the baseline (A) and simulated in FP1 and FP2 (A1B scenario)

4.3.3.3 Olive Tree

In conjunction with warming, reduction in precipitation will influence the potential olive tree spatial distribution over the Mediterranean basin in the future. The climate projections of PROTHEUS system for FP1 and FP2 under A1B SRES scenario indicated a gradual expansion northward and eastward of the suitable area, while a progressive drawback was observed in North Africa and Near East (Fig. 4.2).

4.3.4 Adaptation Strategies

Different adaptation options were implemented to test their effectiveness in reducing the negative impact of climate change as well as to exploit some advantages that climate change showed in some areas. The results for each adaptation option were compared to the relevant outputs as obtained in the baseline.

4.3.4.1 Durum Wheat: Advanced Sowing

As expected, an advanced sowing time resulted in advanced phenological stages with respect to the baseline, which were more evident in ADV30. Additionally, a general lengthening of the growing cycle was observed in FP1 (+5 dd and +18 dd in ADV15 and ADV30, respectively). In FP2 only ADV30 still resulted in a longer cycle (+9 dd), while ADV15 produced a slight contraction of the growing period (−4 dd). The duration of the grain filling resulted less affected. In FP1 no changes were observed with ADV15 and slight increases were recorded in the western regions with ADV30, while in FP2, small reductions were recorded with higher magnitude in ADV15 (Table 4.2).

In FP1 a widespread increase of yield was simulated (on average +6% in ADV15 and +9% in ADV30, over the domain), while in FP2 increased yield was observed all over the study area with the exception of Southern Iberian Peninsula and Morocco (Table 4.3).

4.3.4.2 Durum Wheat: Shorter and Longer Cycle Varieties

The use of a shorter cycle variety resulted in advanced developmental stages. Anthesis date was advanced by 18 dd in FP1 and 20 dd in FP2, with respect to the baseline and this caused a lengthening or slight reduction of the grain filling duration in FP1 in the central and western regions. In FP2, in the northern shores of Africa and Middle East the shortening of the phase was consistent (Table 4.2). Yield resulted generally increased except that in the southern basin (Table 4.3).

On the contrary, the use of longer cycle variety, delayed the occurrence of the different growth stages (anthesis resulted delayed by 10 and 8 days on average in FP1 and FP2) thus projecting the crop in warmer conditions. The duration of the reproductive phase resulted progressively reduced from eastern areas to north-western areas (−3 and −6 days, respectively, in FP2) (Table 4.2) and yield was progressively reduced up to −14% over the domain, in FP2 (Table 4.3).

4.3.4.3 Durum Wheat: Higher Fertilization

Higher fertilization did not affect the duration of the whole growing cycle, however it slightly increased the length of the grain filling phase, with the exception of the northern shores of Africa and southern Iberian Peninsula (Table 4.2). Yield resulted strongly increased (more than 28% in both time slices), with respect to the baseline (Table 4.3). Nevertheless, in FP2 yield shortfall was recorded in the south-western areas (−17% in Morocco) (Table 4.3).

4.3.4.4 Grapevine: Advanced/Delayed Bud-Break

Advanced bud-break resulted in a lengthening of the vegetative cycle (from bud break to flowering), while the reproductive phase was progressively reduced up to −7 dd in FP2 on average over the domain (Table 4.4). The cultivation in the central and eastern areas took advantage of an advanced bud-break, while in Portugal and Spain yield resulted almost unchanged or slightly reduced (Table 4.5).

The duration of the growing season resulted progressively reduced in DBB, with the reproductive phase shorter than the baseline by 7 and 10 dd in FP1 and FP2, respectively (Table 4.4). DBB resulted in a general reduction of yield all over the basin (on average −12% in FP1 and −14% in FP2) (Table 4.5). Only few areas in the north-western fringes of the domain partially recovered yield losses in FP2 resulting in unchanged yield with respect to the baseline.

4.3.4.5 Grapevine: Shorter and Longer Cycle Varieties

The use of a shorter cycle variety determined a general reduction of the growing cycle and in particular of the reproductive phases (on average −23 dd in both FP1 and FP2) (Table 4.4). A general shortfall in yield was recorded all over the basin in both periods (Table 4.5).

By contrast, a longer cycle variety resulted in a lengthening of the reproductive phase, especially in FP1 (+11 dd), with respect to the baseline (Table 4.4). However, yield progressively decreased in the Iberian Peninsula (−18% in Portugal in FP2), Italy (−3% in FP2) and Greece (−5.4%), while in the remaining part of the domain yield resulted almost unchanged or slightly increased (Table 4.5).

4.4 Discussions

Agriculture inherently depends on climate conditions, and consequently is one of the most vulnerable sectors to the risks of global climate change. Adaptation to climate change is certainly an important component of any policy response in this sector (Mizina et al. 1999; Reilly and Schimmelpfennig 1999).

According to other global and regional studies centered over the Mediterranean (Giorgi and Lionello 2008), the projections of the RCM provides a collective picture of substantial drying and warming of the Mediterranean region in the next future. This trend is expected to greatly affect the performances of typical rain-fed crops, such as durum wheat, grapevine and olive.

Changes in crop yield with respect to the baseline were the result of two main drivers. On one hand the negative impact of increasing temperature and drought, on the other hand the positive effect of enhanced CO_2 concentration.

Higher temperatures, increasing the crop development rate, advanced the timing of phenological stages and reduced the duration of the pre and post-flowering phases (vegetative and reproductive phases, respectively) thus reducing the time for biomass accumulation. The projected decrease in rainfall rate, especially over the southern Mediterranean basin, inevitably leads to more frequent and more intense droughts during the growing season. Conversely, enhanced CO_2 concentration, increasing the efficiency in the use of both water and radiation, is expected to reduce the impact of climatic change on yield arising from a warmer and drier climate (Giannakopoulos et al. 2009; Olesen and Bindi 2002; Kimball et al. 2002). The combination of these factors affected crop growth resulting in different crop fitting capacity to cope with climate change.

Increased temperature in combination with rainfall reductions and longer dry spells, were the main factors affecting crop yield over the Mediterranean basin in the future scenario A1B. However the impact of a warmer climate and lower rainfall may be either reduced or amplified depending on the specific crop growing season.

4.4.1 Durum Wheat

Durum wheat, whose growing cycle is centered on winter-spring, partially escaped the effect of drought and higher temperature of the summer period, and, although the reduction in the grain filling phase, exhibited a general equilibrium or slight increases of yield, with respect to the baseline, due to the effect of increased CO_2. However, in Southern Iberian Peninsula and Morocco, the detrimental effect of the higher increase in temperature and the strong reduction in rainfall (mainly during spring), are predominant and the CO_2 fertilizing effect is not able to recover the yield losses.

Those dynamics resulted amplified in a shorter cycle variety that, even reducing the time for biomass accumulation, shifted the crop cycle in a cooler climate and allow the crop to increase its performances with respect to STD.

Conversely, longer cycle cultivar shifted crop cycle into the warmest and driest period of the year, and although the whole duration of the growing season resulted longer than STD, the grain filling phase showed the highest contraction among all the treatments. The CO_2 effect was insufficient to counterbalance the negative effect of warming and drought and this produced the observed yield shortfall as compared to both baseline and STD.

Earlier sowing date shifted phenological development in cooler conditions that in turn caused a lengthening of the different growth stages. The grain filling phase was moved towards a cooler season than usual and avoided the effect of increasing temperature trends on the duration of the phase, which in some areas resulted even longer than in the baseline. This in combination with the positive effect of rising CO_2 concentration resulted in a consistent increase of yield with respect to the reference period and STD.

As expected, the use of higher nitrogen fertilization resulted into a strong increase of yield, which was the combined effect of a direct stimulus of nitrogen on crop growth and a longer grain filling duration as the consequence of nitrogen-induced delayed leaf senescence.

4.4.2 Grapevine

Grapevine in STD was subjected to the effect of higher temperatures and drought during its growing cycle, which takes place from spring to summer where the highest magnitude of temperature increase and drought were simulated. In the central areas of the basin, rising temperature caused a progressive contraction of the reproductive phase that produced a moderate to severe yield shortfall, despite the fertilizing effect of CO_2.

The strategy involving the use of a variety with ABB, shifted the growth of the crop in a cooler and wetter period, and allowed the enhanced CO_2 to recover the losses due to climate change. In contrast, the use of a DBB, shifted the crop growth in warmer conditions that reduced the duration of the growth stages more than in the present and STD. In such conditions, the negative effect of temperature and drought could not be counterbalanced by increasing CO_2 and yield resulted progressively reduced.

Similarly, the strong reduction in yield observed with a SHT variety, may be ascribed to the lowest duration of the reproductive phase. In contrast, the longer reproductive phase simulated for a LNG variety though prolonging the time for biomass accumulation, likely increased the drought stress of the crop thus leading to strong reductions in yield in the western areas.

4.4.3 Olive Tree

The olive tree (Olea europaea L.) is one of the most ancient cultivated fruit trees in the Mediterranean basin, its cultivation is strictly related to the particular climate conditions, such as warm to hot and dry summers and mild and wet winters, characterizing the Mediterranean climate.

The results of the olive ecological model indicated a progressive expansion northward and eastward of the olive suitable area as the consequence of rising temperature that reduced the occurrence of freezing temperatures during the winter season. On the contrary, extremely high temperatures during summer make the southern borders of the domain no longer suitable for the cultivation.

4.5 Conclusions

Climate projections for the next decades indicate a substantial warming and drying of the Mediterranean region that may threaten the cultivation of typical crops such as durum wheat, grapevine and olive tree.

Rising temperature and reduced rainfall negatively affect yield by both reducing the time for biomass accumulation and increase heat and water stress of the crops during sensible stages of their growth. The enhanced CO_2 air concentration may counterbalance these negative effects by increasing water and radiation use efficiency. As a consequence, the response of the crops to climate change depends on which of these effects is prevailing.

Results indicated that the shortening of the reproductive phase, due to the increasing temperature, strongly affected the final yield of both durum wheat and grapevine, while rising CO_2 may only partially recover the yield losses. Grapevine resulted more vulnerable than durum wheat, due to the longer growing cycle and the timing of the reproductive phase that highly exposed this crop to heat and drought stress.

The strategies that better may cope with negative effect of climate change should consider both the opportunity to advance the timing of phenological stages, aiming at avoiding extremely high temperatures during sensible phases, and prolong the duration of the reproductive stage, to increase the time for biomass accumulation and translocation. Accordingly, in our analysis, the use of grapevine varieties characterized by earlier bud-break or longer cycle resulted in positive strategies causing the crop to advance both flowering and maturity, the former, or increase the lengthening of the ripening phase, the latter. For durum wheat, advanced sowing date as well as the use of shorter cycle varieties shifted the phenological development of the crop in cooler conditions than usual thus increasing the duration of the grain filling and avoiding the heat and drought stress.

Finally, due to the warmer and drier future conditions, olive tree suitable area is expected to shift northward and eastward.

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Chapter 5
Climate Change Impacts on Forests and Forest Products in the Mediterranean Area

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Abstract The Mediterranean Region is defined according to its biogeography and bioclimate. Climate is characterized by mild winters and hot, dry summer. Biodiversity is rich and landscape patterns are complex. Mediterranean forests have historically been subjected to numerous threats (forest fires, over-exploitation, deforestation, degradation), that are today accentuated under climate and land use changes. In this respect, the Mediterranean area appears among the most vulnerable areas to global change. Forest area in the region has increased by 10% between 1990 and 2000. Roundwood nowadays represents 60% and woodfuel 40% of total wood products (125 Mm^3). Sometime non-wood forest products and services are more

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important as they represent 60–70% of total economic value (133 € ha^{-1}) of Mediterranean forests. There are already evidences of impacts of recent climate change on ecophysiology, productivity, dieback and distribution of Mediterranean forests and these impacts will become worse in the future, particularly for increased evaporative demand and repeated extreme events. An interdisciplinary research agenda, integrated with monitoring networks and projection models is needed to provide information at all levels of decision making and to implement a framework of dynamic and adaptive management planning.

Keywords Forest resources • Forest management • Productivity • Forest distribution • Functionality

5.1 Introduction

The Mediterranean Region is defined according to the biogeographic and bioclimatic classification. Climate is characterized by mild winters and hot, dry summer. Rain is usually concentrated in late Autumn, Winter and early Spring but the rainfall patterns and amount are variable and different, higher on the North Coast (Europe) and lower in the South (Africa) and East coasts (Asia). Year-to-year variability in total rainfall is large and, occasionally, violent precipitation events may occur and dry winds may favor the spread of forest fires (Scarascia Mugnozza et al. 2000a). All regions have relatively mild winters, but summer temperatures are variable. At sea level, temperatures only occasionally reach freezing but, over the several mountain ranges (Alps, Apennines, Pyrenees, North African range) of the area, freezing temperature and snow are common in winter. Furthermore, the Mediterranean region is characterized by an important geographical and topographical variability related to the presence of a variable coastline and of many mountain ranges, often quite high in elevation.

Biodiversity is rich, both for plant and animal species, and it is coupled with a rich variability of vegetation types and land-use forms, giving rise to complex landscape patterns. The climate supports Mediterranean forests, woodlands, and shrub vegetation (*macchia*, *maquis*, *dehesas*). The truly Mediterranean vegetation zone is represented by the plains and the low-elevation valleys all along the sea coasts. It can be subdivided in the Thermo-Mediterranean and Meso-Mediterranean belts (Quezel 1985) corresponding approximately to the area where olive trees are cultivated (Scarascia Mugnozza et al. 2000a). As the elevation increases, vegetation pass from the Supra-Mediterranean to the Montane-Mediterranean and Oro-Mediterranean zones (Quezel 1985) with completely different forest types. Latitude and topographic exposure also affect this vegetational succession, raising the boundaries of the various belts as we move from North to South Mediterranean and from north-to southfacing slopes in mountains (Scarascia Mugnozza et al. 2000a).

Mediterranean forests provide a wide array of services. Wood forest products are surely important but often represent a small part of them and non-wood forest products (such as cork in Portugal and in Tunisia, honey in Lebanon) can sometime be more important (Fabbio et al. 2003; Croitoru 2007; Palahi et al. 2008). Watershed protection, landscape quality, soil conservation, recreation resources are among some of the public goods and externalities provided by Mediterranean forests that are seldom recognized and difficult to evaluate and price (Croitoru 2007). Nevertheless, the multifunctionality of Mediterranean forests has long been recognized, even though forest management is not always optimal and different approaches are adopted in the various part of the Mediterranean area due to the levels of economic development, the pressure on forest resources, the sometimes very different institutional and forest-ownership structures (Scarascia Mugnozza et al. 2000a; Fabbio et al. 2003; Croitoru 2007; Palahi et al. 2008).

Mediterranean forests are subjected to numerous threats such as forest fires, over-exploitation, deforestation and degradation. These threats, historically present, are nowadays accentuated in a context of climate and land use changes (Palahi et al. 2008). Several authors reported that, among all bioclimatic regions, the Mediterranean area appears to be the most vulnerable to global change (Sala et al. 2000; Scarascia Mugnozza et al. 2000a; Walther et al. 2002; Lindner et al. 2010). In this respect, the Mediterranean area is especially sensitive to any climate change because it represents a transition zone between arid and humid regions of the world (Scarascia Mugnozza et al. 2000a). In all climate change scenarios, the increase of temperature is associated to changes in the precipitation patterns, although with a higher uncertainty. If precipitation is forecasted to increase over northern Europe, a decrease up to 20% is expected for the south of Europe, particularly in summer, with severe effects on the frequency and intensity of drought periods, affecting water resources, forestry and agriculture. Higher temperatures and lower precipitation during summer will increase the evaporative demand of the atmosphere on ecosystems that already now can transpire up to 80% of precipitation (Palahi et al. 2008).

Although Mediterranean forest and shrub ecosystems represent only 2% of the world's forest cover (FAO 2006), specific aspects make this region an interesting model system where global change on terrestrial ecosystems can be studied. High sensitivity of productivity to water availability, slow nutrient cycling, fire damages and soil erosion, increasing nitrogen deposition and elevated levels of ozone, high risk from major land-use-changes are all aspects relevant in a global change scenario (Scarascia Mugnozza et al. 2000a).

The chapter will first review the current status and recent (1990–2005) changes of forest resources in the Mediterranean area; the main management option in the area and historical trends in the main forest products as derived from global data sources, presenting the differences between macro-regions (European, Asian and African Mediterranean countries). Then, the evidences of impacts of recent climate change on ecophysiology and productivity, dieback, distribution of tree species of Mediterranean forests will be presented. Finally, the effects of the future climate scenarios on Mediterranean forests will be evaluated using literature surveys and modeling. The chapter will be concluded with some consideration on how management for Mediterranean forests can be adapted to respond to climate change.

Fig. 5.1 Country of Mediterranean Area: North Coast (Europe): Albania, Bosnia and Herzegovina, Croatia, France, Greece, Italy, Malta, Montenegro, Serbia, Slovenia, Spain; South Coast (Africa): Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Tunisia; East Coast (Asia): Cyprus, Israel, Jordan, Lebanon, Syrian Arab Republic, Turkey

The countries that have been selected for the analysis are: Albania, Bosnia-Herzegovina, Croatia, France, Greece, Italy, Malta, Montenegro, Portugal, Serbia, Slovenia and Spain (Europe); Algeria, Egypt, Lybian Arab Jamahiriya, Morocco, Tunisia (Africa) and Cyprus, Lebanon, Israel, Jordan, Syrian Arab Republic, Turkey (Asia) (Fig. 5.1).

5.2 Forest Resources in the Mediterranean Region

Patterns of land-use are different between the northern and southern part of the Mediterranean rim. In the northern part, including Turkey, the shares among Forests, Meadows and Arable land/permanent crops is generally more balanced compared to the southern part (Fig. 5.2). In the south, permanent meadows and pastures are generally prevalent with respect to forest and arable land, with the exception of Israel, Lebanon and, partly, Tunisia. In Egypt, arable land and permanent crops are, by far, the most important land-use (Fig. 5.2).

These differences in land-use patterns may pose different pressures on forest land in the Mediterranean countries, with consequent impact on forest management options. Nevertheless, forest trees represent an important component of the Mediterranean biodiversity; in the area, the number of tree species is quite large compared those living in central Europe (100 vs. 30, respectively). Furthermore, many of the Holarctic and Eurasian tree species survived during the glacial ages in Mediterranean refugia, from where the continent was recolonized at the end of glaciations (Scarascia Mugnozza et al. 2000a).

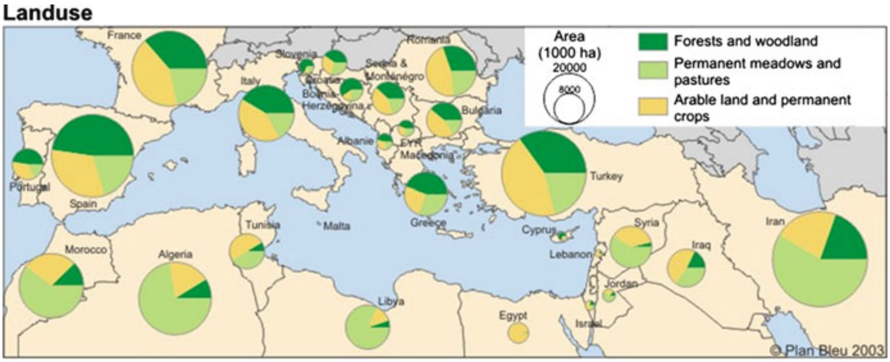

Fig. 5.2 Share of land use options in Mediterranean countries. Forests and woodland, *dark green*; permanent meadows and pastures, *pale green*; Arable land and permanent crops, *yellow*. The size of the circles is scaled according to total area of the three land-uses that sum up to 1 (or 100%). Romania, Bulgaria, Macedonia, Iraq and Iran not included in the present analysis (Source of data: FAOSTAT database, map downloaded from PlanBleu.org)

Basic statistical data on forest resources in Mediterranean countries were derived from the Global Forest Resources Assessment 2005 (FAO 2006) organised every 5 years, by FAO based on common tables and reports provided by 229 countries, grouped in six regions.

In the Mediterranean, the forest cover (for Definitions see caption of Table 5.1) is nearly 80 Mha (79.15 Mha, Table 5.1). Most of the forest area is located in the European side of the Mediterranean (76%), while Mediterranean Africa and Asia contribute respectively for 10 and 14%. There are also 31.5 Mha of other wooded land, to which Mediterranean Europe contributes for 57%. In the case of Asia, it is interesting to note that other wooded land (11.13 Mha), representing 35% of the total cover of this land use in the Mediterranean, is practically equal to that of forest (11.12 Mha).

The percentage forest cover over the total land area is 9.2%, ranging from 1.4% in Africa to 32.6% in Europe. When the country-based percentage cover (third column in Table 5.1) is averaged for all countries, the mean is 21.1%, being 3.6, 11.2 and 33.6% respectively for Africa, Asia and Europe. Country forest cover ranges from 0.1% (Egypt and Lybia) to 62.8% of Slovenia.

In 2005, wood volume in Mediterranean forests sums up to 8,659 Mm^3 (Table 5.2) the largest part being in Mediterranean Europe (nearly 80%, 6,832 Mm^3). African and Asian countries contribute to the total growing stock by 4.7% (408 Mm^3) and 16.4% (1,419 Mm^3), respectively.

The average growing stock in a Mediterranean forest is 109 m^3 ha^{-1}, ranging from 51 m^3 ha^{-1} in Africa to 127.6 m^3 ha^{-1} in Asia (Europe: 113 m^3 ha^{-1}). The Asian value is related to the relevant hectare-based growing stock in Turkey (138 m^3 ha^{-1}) and its large forest cover (see Table 5.1). When the unit growing stock (column 2 in Table 5.2) is averaged for all countries, the mean is

Table 5.1 Forest resources in the Mediterranean region in 2005 [Data are from FRA2005 (FAO 2006)[a]]

Country	Forest area (1,000 ha)	% forest cover	Other wooded land (1,000 ha)	Total area (1,000 ha)
AFRICA				
Algeria	2,277	1.0	1,595	238,174
Egypt	67	0.1	20	100,145
Libyan Arab Jamahiriya	217	0.1	330	175,954
Morocco	4,364	9.8	406	44,655
Tunisia	1,056	6.8	170	16,361
ASIA				
Cyprus	174	18.9	214	925
Israel	171	8.3	85	2,106
Lebanon	136	13.3	106	1,040
Syrian Arab Republic	461	2.5	35	18,518
Turkey	10,175	13.2	10,689	77,482
EUROPE				
Albania	794	29.0	261	2,875
Bosnia and Herzegovina	2,185	43.1	549	5,120
Croatia	2,135	38.2	346	5,654
France	15,554	28.3	1,708	55,150
Greece	3,752	29.1	2,780	13,196
Italy	9,979	33.9	1,047	30,134
Malta	n.s.	1.1	0	32
Portugal	3,783	41.3	84	9,198
Serbia and Montenegro	2,694	26.4	808	10,200
Slovenia	1,264	62.8	44	2,027
Spain	17,915	35.9	10,299	50,599

[a] Definitions: FOREST: Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. OTHER WOODED LAND: Land not classified as “Forest”, spanning more than 0.5 ha; with trees higher than 5 m and a canopy cover of 5–10%, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10%. Both categories do not include land that is predominantly under agricultural or urban land use. For France, the total forest cover is reported. However, only a part of France can be considered as effectively Mediterranean. Forest cover in the French Mediterranean Region is 2.7 Mha (18% of the total), with a percentage cover of 38%, a larger fraction compared to the national average (27–28%) (Montagné et al. 2005)

107 m^3 ha^{-1}, being 60, 64 and 143 m^3 ha^{-1} respectively for Africa, Asia and Europe. Growing stock ranges from 36 m^3 ha^{-1} (Lebanon and Lybia) to 238 m^3 ha^{-1} in Slovenia.

The largest part of the forest (80%) has been reported to be commercially exploitable (or already exploited). The percentage is 63.5% in Africa, 81% in Europe and 85.5% in Asia (with data from Turkey dominating the results). At country level, wood volume of commercial value ranges from 2% of Tunisia to 100% of Morocco. In France and Slovenia wood in “commercial” forest represents more than 90% of total wood volume of the countries (Table 5.2).

Table 5.2 Growing stock in Mediterranean forests in 2005 [Data are from FRA2005 (FAO 2006)[a]]

Country	Growing stock (m^3 ha^{-1})	Total growing stock (Mm^3)	% commercial
AFRICA			
Algeria	76	174	22
Egypt	120	8	–
Libyan Arab Jamahiriya	36	8	–
Morocco	44	191	100
Tunisia	26	27	2
ASIA			
Cyprus	46	8	39
Israel	37	6	70
Lebanon	36	5	–
Syrian Arab Republic	–	–	–
Turkey	138	1,400	87
EUROPE			
Albania	99	78	81
Bosnia and Herzegovina	179	391	80
Croatia	165	352	83
France	158	2,465	94
Greece	47	177	88
Italy	145	1,447	70
Malta	231	n.s.	–
Portugal	93	350	66
Serbia and Montenegro	121	327	–
Slovenia	283	357	91
Spain	50	888	78

[a] Data are in cubic meters overbark. Column 4: percentage that can be commercially exploited

5.3 Forest Management in Mediterranean Forests: Features and Peculiarities

The Global Forest Resources Assessment (FAO 2006) collects also information on the main characteristics of forests in the world. Those information are useful to understand the development of appropriate and efficient silvicultural and management practices to ensure and promote sustainable forestry. Those characteristics are linked to broad management categories (primary forest, natural, semi-natural, plantations, etc.) that may be considered as a starting point in describing the management options in Mediterranean forests. These practices are related to structure and development of forest resources and hence to their ability to provide services. The categories can also be connected to the degree of human impact on forest ecosystems.

The characteristics reported by FRA2005 are listed and described below (FAO 2006):

Primary Forest. land of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. Includes areas where collection of non-wood forest products occurs, provided the human impact is small. Some trees may have been removed.

Modified natural Forest: land of naturally regenerated native species where there are clearly visible indications of human activities. Includes, but is not limited to: selectively logged-over areas, areas regenerating following agricultural land use, areas recovering from human-induces fires and areas where it is not possible to distinguish whether the regeneration has been natural or assisted.

Semi-natural Forest: land of native species, established through planting, seeding or assisted natural regeneration. Includes areas under intensive management where native species are used; naturally regenerated trees from other species than those planted/seeded may be present and may include areas with naturally regenerated trees of introduced species

Productive plantation Forest: land of introduced species, and in some cases native species, established through planting or seeding mainly for production of wood or non wood goods. Includes all stands of introduced species established for production of wood or non-wood goods and may include areas of native species characterized by few species, straight tree lines and/or even-aged stands

Protective plantation Forest: land of native or introduced species, established through planting or seeding mainly for provision of services. Includes all stands of introduced species established for provision of services, such as soil and water protection, pest control, habitat and biodiversity conservation and areas of native species characterized by few species, straight tree lines and even-aged stands.

Data on forest land subdivided in these main categories are reported in Table 5.3.

Mediterranean ecosystems have been subjected to a historical long-term human influence, with both positive and negative effects (Hobbs et al. 1995). Due to this long and strong relationships with humans, the ecosystems of the Mediterranean basin have been defined as “total human ecosystems” (Quezel 1979; Naveh 1987). The long history of manipulation of trees, forests and landscapes is documented also by the current presence of planted forests of *Pinus pinea*, *Cupressus sempervirens* and *Castanea sativa* in areas where these species, introduced and extended since the Greco-Roman times, have become common components of the landscape (Scarascia Mugnozza et al. 2000a). This long history is also reflected into the very limited area of remaining primary forests (2.2 Mha, 2.8% of total forest cover, see Table 5.4). Most of the forest area is under management (modified natural or semi-natural forest, 66.7 Mha, nearly 85%), while 10.3 Mha are productive or protective plantation (13%).

It is interesting to note that there are significant differences in the shares of the management categories between the three continental groups. Whereas primary forests are nowadays totally absent in Africa, in Asia they represent 9% of the forest area (almost all in Turkey) (Table 5.4).

Table 5.3 Main characteristics of forest in Mediterranean countries in 2005, excluding plantations

Country	Forest area (1,000 ha)	Primary forest (1,000 ha)	Modified natural (1,000 ha)	Semi-natural (1,000 ha)
AFRICA				
Algeria	2,277	–	1,206	316
Egypt	67	–	–	–
Libyan Arab Jamahiriya	217	–	–	–
Morocco	4,364	–	3,754	47
Tunisia	1,056	–	320	238
ASIA				
Cyprus	174	22	111	36
Israel	171	–	70	–
Jordan	83	0	37	6
Lebanon	136	0	129	0
Syrian Arab Republic	461	–	198	–
Turkey	10,175	975	5,925	738
EUROPE				
Albania	794	85	621	0
Bosnia and Herzegovina	2,185	2	1,184	857
Croatia	2,135	10	2,063	0
France	15,554	30	–	13,556
Greece	3,752	0	3,618	0
Italy	9,979	106	1,586	8,148
Malta	n.s.	0	0	0
Portugal	3,783	55	–	2,494
Serbia and Montenegro	2,694	4	115	2,536
Slovenia	1,264	119	1,107	38

Data are from FRA2005 (FAO 2006). For definitions see main text

Modified and seminatural forests are nearly 90% in Europe, while they make up approximately 74% and 65% in Africa and Asia. Interestingly, in the countries of the latter two continents, semi-natural forests established through planting, seeding or assisted natural regeneration represent a limited percentage (around 7%) of forest cover. On the other hand, in the same areas, the percentage of forest area that is productive and protective plantations is very relevant being greater than 26%, while, in Europe, the total of planted forests amount to 8.8% (5.2 Mha), largely in the category of productive plantation.

5.3.1 Changes in Total Forest and Other Wooded Land Area

The evaluation of changes occurring in forest cover may provide information on the trend in forest resources and, indirectly, on the sustainability of forestry and other land-use practices in the Mediterranean.

Table 5.4 Importance of the different forest characteristics in Mediterranean region and "continental groups"

Area	Primary forest (%)	Modified natural (%)	Semi-natural (%)	Productive plantation (%)	Protective plantation (%)
Africa	0.0	66.2	7.5	9.1	17.2
Asia	8.9	57.8	7.0	17.2	9.2
Europe	2.0	36.4	52.7	8.1	0.6
Total Mediterranean	2.8	42.4	41.7	9.5	3.5

Calculation based on Table 5.3. For definitions see main text

Changes in forest and other wooded land cover since 1990 are presented in Table 5.5. It is interesting to note that there is an increasing trend in forest cover in almost all countries and, when forest cover is not increasing at least remains constant. Total forest cover increased from 69.13 Mha in 1990 to 76 Mha in 2000, reaching 79.15 Mha in 2005 (Fig. 5.3). Most of the "new" 10 Mha of forest are located in Europe (84%), 10% are in Africa and only 6% in Asia. The percentage increase has been similar in Europe and Africa (around 1%) and lower in Asia (0.4%).

Approximately one third of this increase occurred because the total cover of other wooded land decreased from 34.7 Mha in 1990 to 31.6 Mha in 2005 (−9%, see also Fig. 5.3), indicating a trend of wood encroachment (stand-level cover passed the 10% threshold or the cover of trees became predominant with respect to shrubs and bushes). Natural invasion of abandoned lands, particularly in mountainous regions, and deliberate reforestation and afforestation plans are among the other factors that can be responsible for the increase in forest cover.

Only two countries had a slight negative trend in forest cover between 1990 and 2000 (Albania and Bosnia-Herzegovina) but they reverted (Albania) or stopped (Bosnia-Herzegovina) the trend between 2000 and 2005. Among the countries with a small forest cover, Algeria, Egypt and Syria presented a relevant annual percentage increase between 1990 and 2000 (1.3–4.1%/year) that generally decreased, albeit remaining above 1%, in the 2000–2005 period. In Europe, Italy, Portugal and Spain had annual increases above 1% in the whole 1990–2005 period. In Portugal, the increase is strongly connected to afforestation policies while in Italy the increase in forest cover is mainly related to recolonization of abandoned land. Furthermore, Italy was one of the few countries where also other wooded land increased significantly in the period. In Spain, from 1990 to 2005, total forest cover increased by 4.5 Mha, while other wooded land decreased by 2.2 Mha.

The active policies of afforestation and reforestation are important factor in forest management and in shaping forestry in the different countries. In fact, on one hand, afforestation is a tool to increase forest cover in countries where for climatic or historical reasons it has decreased to very low, unsustainable levels while, on the other hand, afforestation can be used to reduce the exploitation pressure on natural and semi-natural forests. Data on the area of forest plantations and its trend from 1990 to 2005 are presented in Table 5.6.

Table 5.5 Changes in forest and other wooded land area since 1990

Country	Forest area (1,000 ha)			Annual change rate (ha/year)	%	Annual change rate (ha/year)	%	Other wooded land (1,000 ha)		
Year	1990	2000	2005	1990/2000		2000/2005		1990	2000	2005
AFRICA										
Algeria	1,790	2,144	2,277	35	1.8	27	1.2	1,840	1,662	1,595
Egypt	44	59	67	2	3.0	2	2.6	20	20	20
Libyan Arab Jamahiriya	217	217	217	0	0.0	0	0.0	330	330	330
Morocco	4,289	4,328	4,364	4	0.1	7	0.2	407	407	406
Tunisia	643	959	1,056	32	4.1	19	1.9	328	177	170
ASIA										
Cyprus	161	173	174	1	0.7	n.s.	0.2	–	214	214
Israel	154	164	171	1	0.6	1	0.8	16	62	85
Lebanon	121	131	136	1	0.8	1	0.8	–	117	106
Syrian Arab Republic	372	432	461	6	1.5	6	1.3	35	35	35
Turkey	9,680	10,052	10,175	37	0.4	25	0.2	10,905	10,728	10,689
EUROPE										
Albania	789	769	794	–2	–0.3	5	0.6	256	255	261
Bosnia and Herzegovina	2,210	2,185	2,185	–2	–0.1	0	0.0	500	549	549
Croatia	2,116	2,129	2,135	1	0.1	1	0.1	322	338	346
France	14,538	15,351	15,554	81	0.5	41	0.3	2,087	1,814	1,708
Greece	3,299	3,601	3,752	30	0.9	30	0.8	3,212	2,924	2,780
Italy	8,383	9,447	9,979	106	1.2	106	1.1	880	992	1,047
Malta	n.s.	n.s.	n.s.	0	0.0	0	0.0	0	0	0
Portugal	3,099	3,583	3,783	48	1.5	40	1.1	236	84	84
Serbia and Montenegro	2,559	2,649	2,694	9	0.3	9	0.3	820	812	808
Slovenia	1,188	1,239	1,264	5	0.4	5	0.4	44	44	44
Spain	13,479	16,436	17,915	296	2.0	296	1.7	12,447	11,016	10,299

Data are from FRA1990, FRA2000 and FRA2005 (FAO)

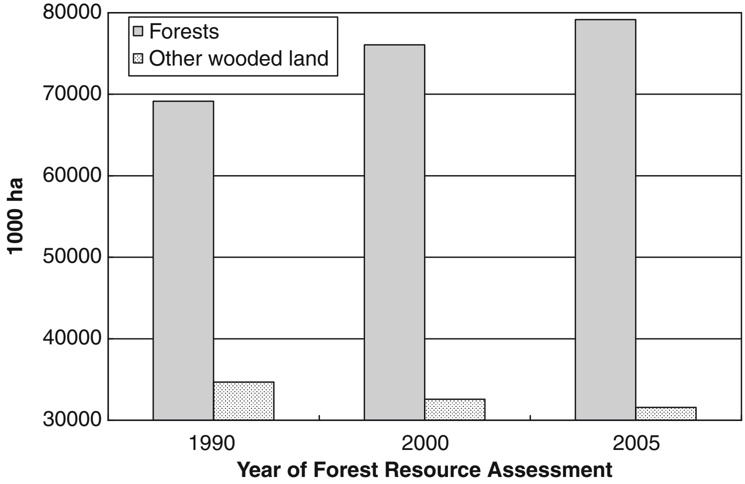

Fig. 5.3 Total area under Forests (*grey bars*) and other wooded land (*hatched bars*) in Mediterranean countries as reported in Forest Resource Assessment reports in 1990, 2000 and 2005 (FAO 2006)

It is worth signaling that, in Asian and African Mediterranean countries, with few exceptions, forest plantations represent a relevant share of total forest area, often above 25–30%. On the contrary, in Europe, only Portugal has more than 30% of forest plantations (not considering Malta).

5.4 Historical Trends for Main Forest Products in the Mediterranean Region

As reported in Sect. 5.3 and Table 5.4, only 2.8% of forest area in the Mediterranean can be classified as "primary forest" with no sign of human intervention. All the rest of the forests are managed and provide different services. Among those, harvested wood is one of the main services and, most probably, the one that is more easily assessed. Coherent and comparable data for the all the Mediterranean countries are available from data sources of international organizations. Generally, international databases put together data coming from reports submitted by single countries following a common reporting format and common definition. Hence, comparability of data among countries is ensured. Data on forest products were compiled from the FAO Statistical Database where forest data are included in ForestSTAT, that contains information on more than 70 products related to forestry. Data are provided annually by Countries to FAO with the cooperation of the International Tropical Timber Organization (ITTO), the United Nation Commission for Europe (UNECE) and the Statistical Office of European Commission (EUROSTAT). A study of the European Forest Institute compared production Statistics for 1998–1999 coming from FAOSTAT, ECE/FAO Timber bulletin and EUROSTAT New Cronos and found very limited differences (1–3%, Wardle et al. 2003).

Table 5.6 Area of forest plantations and changes in the period 1990–2005

Country	Area of forest plantations (1,000 ha)			% of total forest area			Annual change rate (ha/year)	
	1990	2000	2005	1990	2000	2005	1990–2000	2000–2005
AFRICA								
Algeria	620	652	754	34.6	30.4	33.1	3,200	20,400
Egypt	44	59	67	100.0	100.0	100.0	1,500	1,600
Libyan Arab Jamahiriya	217	217	217	100.0	100.0	100.0	0	0
Morocco	478	523	563	11.1	12.1	12.9	4,500	8,000
Tunisia	226	423	498	35.1	44.1	47.2	19,700	15,000
ASIA								
Cyprus	3	3	5	1.9	1.7	2.9	0	400
Israel	84	94	101	54.5	57.3	59.1	1,000	1,400
Lebanon	40	40	40	47.6	47.6	47.6	0	0
Syrian Arab Republic	–	–	8	–	–	5.7	–	–
Turkey	1,839	2,304	2,537	19.0	22.9	24.9	46,500	46,600
EUROPE								
Albania	103	96	88	13.1	12.5	11.1	−690	−1,640
Bosnia and Herzegovina	–	142	142	–	6.5	6.5	–	0
Croatia	56	60	61	2.6	2.8	2.9	400	200
France	1,842	1,936	1,968	12.7	12.6	12.7	9,400	6,400
Greece	118	129	134	3.6	3.6	3.6	1,100	1,000
Italy	289	144	146	3.4	1.5	1.5	−14,500	400
Malta	n.s.	n.s.	n.s.	100.0	100.0	100.0	0	0
Portugal	550	1,034	1,234	17.7	28.9	32.6	48,400	40,000
Serbia and Montenegro	39	39	39	1.5	1.5	1.4	0	0
Slovenia	0	0	0	0	0	0	0	0
Spain	1,126	1,356	1,471	8.4	8.3	8.2	23,000	23,000

Data are from FRA1990, FRA2000 and FRA2005 (FAO)

Table 5.7 Basic statistics of wood removal in the Mediterranean (ForesSTAT database at FAO)

	1990 (Mm^3)	2000 (Mm^3)	2005 (Mm^3)
Industrial roundwood	82.253	90.445	75.238
Wood fuel	57.51	46.805	49.419
Total	139.763	137.25	124.657

The basic data of the two main categories of "raw" forest products (industrial roundwood and woodfuel) derived from FAO ForesSTAT database are reported in Table 5.7 for the 3 reference years of the Forest Resource Assessment reports (1990, 2000, 2005). These data indicate that the amount of harvested wood was nearly constant around 138 Mm^3 between 1990 and 2000 and decreased to 125 Mm^3 from 2000 to 2005 (Table 5.7). Compared to 1990, in 2000 wood harvested for industrial purposes increased by 10% while woodfuel decreased by 18.5%. Between 2000 and 2005, woodfuel increased slightly (5.5%), while industrial roundwood decreased significantly (17%). Overall, industrial roundwood makes up 60–65% of total forest products, while woodfuel, a traditional products of Mediterranean countries contributes for 35–40%. Wood harvested for industrial purposes comes more or less equally from conifer and non-conifer tree species, while the latter made up 80% of woodfuel.

The analysis of data from 1961 to 2007 can provide a deeper insight in historical trends of the two main categories of products harvested from forests in the Mediterranean countries (Fig. 5.4). Overall, wood harvesting increased from 120 Mm^3 in 1961 to 140 Mm^3 in 1990–1991 then, after the crisis in the early 1990s, decreased to an average of 125–127 Mm^3 in 1992–2007. Interestingly, the increase in harvesting up to the 1990s was caused by a constant increase in wood harvested for industrial use (from 45–50 Mm^3 to 80 Mm^3) and a decrease of woodfuel (from 70 Mm^3 to 60 Mm^3, Fig. 5.4), while oscillation of both categories caused changes from 1990 to 2007. Woodfuel harvesting and use changed in three steps, from 70 Mm^3 in the 1960s, to 60 Mm^3 between 1973 and 1993, to 50 Mm^3 in the more recent period. In 1970, wood harvested as industrial roundwood became higher than that harvested for woodfuel. From Fig. 5.4 it is possible to note that the peak in industrial roundwood production in 2000 (see Table 5.7) is an anomaly with respect to the trend of the last 15–20 years. This anomaly was related to the strong damages caused by thunderstorms Lothar and Martin, hitting France at the end of December 1999. The wood recovered from the damaged forests was released to the market in the subsequent years, with a peak in 2000 (10 Mm^3 more industrial roundwood in 2000 compared to 1999). France returned to its pre-storm roundwood harvesting only 3–4 years later. It must be underlined that most of that wood came from the temperate area of France and not directly from the Mediterranean area. The historical changes between 1960 and 2007 reverted the percentage share of the two main products with respect to the total wood exploitation in the Mediterranean: woodfuel, which represented 60% of forest harvest in 1961–1962, steadily decreased to 45% in the period 1973–1985 (Fig. 5.5).

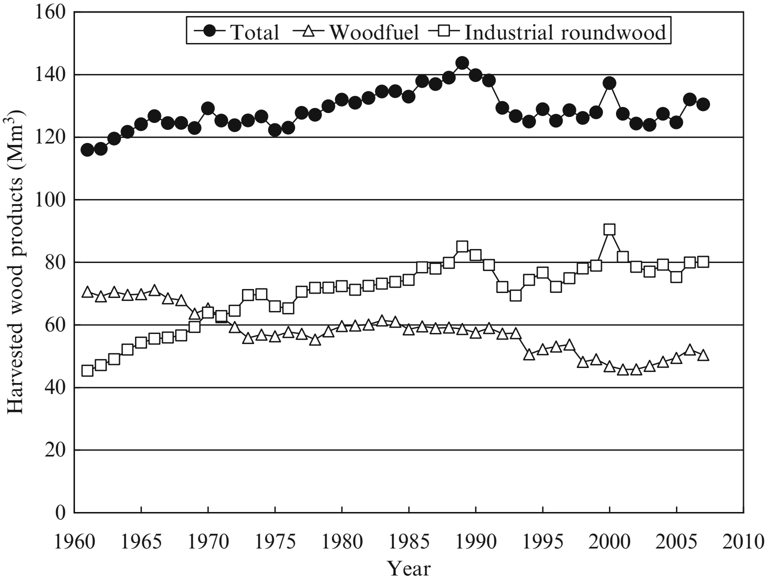

Fig. 5.4 Historical trend (1961–2007) of the main wood products harvested in Mediterranean forests. Total data (*closed circles*); woodfuel (*open triangles*); industrial roundwood (*open squares*). Elaboration based on data from ForesSTAT database at FAO

Nowadays, after some oscillations, woodfuel contributes 40% to wood products. Concurrently, industrial roundwood increased from 40 to 60%, signaling an industrial but also a societal change.

For example, the share of woodfuel production in Mediterranean Europe decreased continuously from 60% in 1960 to 30% in 1980 and, since then oscillated between 30 and 40% of the total (Fig. 5.6).

Between 1960 and 1980, the role of Mediterranean Africa and Asia increased significantly, respectively from 30 to 40% and from 10 to 30% (Fig. 5.6). Since then, the role of Mediterranean Africa kept on increasing, reaching a share of 50–60% of woodfuel production, while in Asia, wood harvested for fuel steadily decreased, reaching 10% of the total production. Hence, in Africa request for woodfuel increased continuously during the last 45 years even if part of that production could be exported to other areas of the Mediterranean. On the other hand, the trend in Mediterranean Asia was different, with a decrease in woodfuel production in the last 30 years. This trend is driven almost exclusively by changes in forest policy in Turkley where 90% of forest cover of Mediterranean Asia is located and where afforestation programs and changes in production objectives favored the more valuable industrial roundwood (see Fig. 5.7).

Industrial roundwood is harvested mostly in Mediterranean Europe (80–90% in the last 50 years, Fig. 5.7), where forest policies promoting more sustainable management, conversion of coppice stands to high forests and societal changes

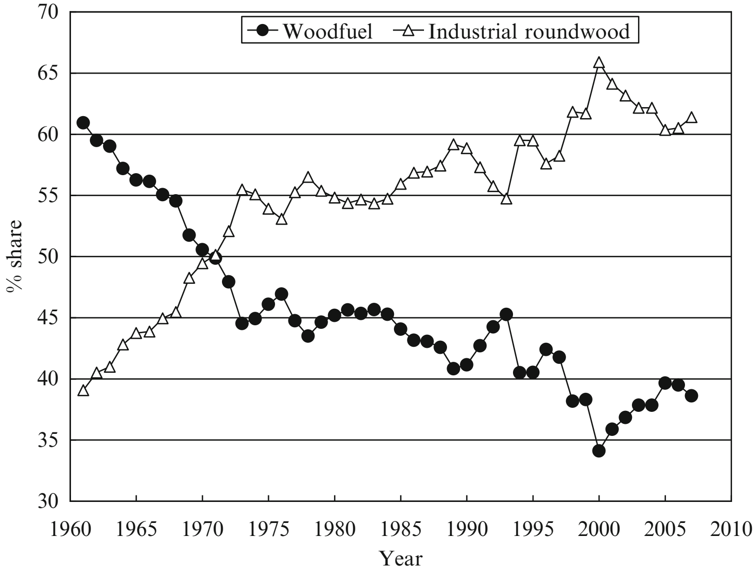

Fig. 5.5 Share of wood products harvested in Mediterranean forests in the period 1961–2007. Woodfuel (*closed circles*); industrial roundwood (*open triangles*). Elaboration based on data from ForesSTAT database at FAO

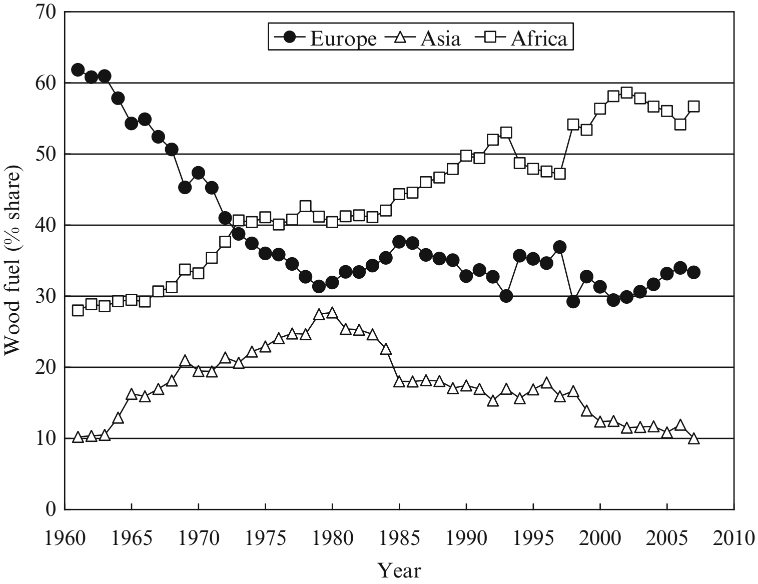

Fig. 5.6 Regional share of woodfuel harvested in Mediterranean forests in the period 1961–2007. Mediterranean Europe (*closed circles*), Africa (*open squares*) and Asia (*open triangles*). Elaboration based on data from ForesSTAT database at FAO

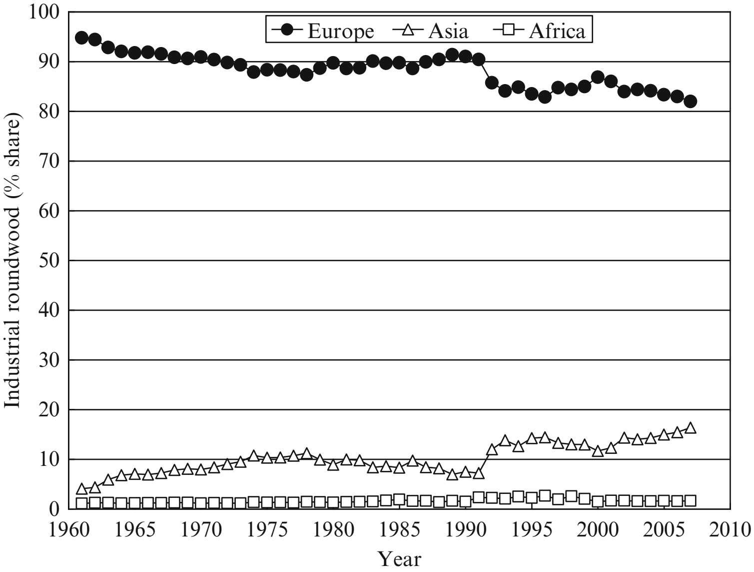

Fig. 5.7 Regional share of industrial roundwood harvested in Mediterranean forests in the period 1961–2007. Mediterranean Europe (*closed circles*), Africa (*open squares*) and Asia (*open triangles*). Elaboration based on data from ForesSTAT database at FAO

caused the changes in trends of the main forest products (see also Figs. 5.4 and 5.5) (Scarascia Mugnozza et al. 2000a; Fabbio et al. 2003). The role of Asia is increasing and roundwood production reached recently 16% of the Mediterranean total production, while the role of Africa is negligible (less than 2%, Fig. 5.7).

5.4.1 Non Wood Products and Externalities in Mediterranean Forests

The multifunctionality of Mediterranean forests and the wide array of benefits provided by them have long been recognized (Scarascia Mugnozza et al. 2000a; Fabbio et al. 2003; Croitoru 2007; Palahi et al. 2008). Levels and trends of the main wood forest products have been described in the previous paragraph and timber and firewood are the products that most readily come to mind but they often represent a small part of the benefits provided by Mediterranean forests. Non-wood forest products (cork in Tunisia and Portugal, honey in Lebanon, mushrooms and truffles in Italy and France, etc.) can sometimes be more important. Furthermore, fundamental are the externalities and public services they provide, such as watershed protection, landscape quality, soil conservation, recreation, carbon sequestration and climate regulation. However, it is not easy to assign a value to externalities and to "indirect" use of forests (Merlo and Rojas Briales 2000; Croitoru 2007). Furthermore, the externalities are often benefited from people that live outside forests or are not directly responsible for forest management and conservation; hence it is difficult to recognize a revenue to forest owners (public or private) (Merlo and Rojas Briales 2000).

Croitoru (2007), reporting results from the MEDFOREX project, calculated the Total Economic Value (TEV) for forests in different areas of the Mediterranean. The average TEV of Mediterranean was calculated to be about 133 € ha^{-1}, with Northern countries having much higher value (173 € ha^{-1}) than Southern (70 € ha^{-1}) and Eastern countries (48 € ha^{-1}). The large differences is partly related to the much larger extension of forest area in the north, as well as to their relatively better conditions (Croitoru 2007). Direct use values (defined as wood and non wood products, grazing, recreation, hunting) represent more than 70% of the average TEV in the region, while indirect use (watershed protection, carbon sequestration) and non-use values (option, bequest and existence value as, for example, biodiversity or landscape conservation) contribute around 15% each (Croitoru 2007).

Even if is not easy to assess the total value of forest services, as many of those have not a direct market price, the results obtained in the MEDFOREX project can lead to some important consideration. First, wood products (roundwood and woodfuel) account for a small portion of total forest benefits. Watershed protection is often much more important. There are also regional differences, with grazing dominating in southern and eastern Mediterranean, while recreation being important in the northern Mediterranean (Croitoru 2007). This multifunctionality needs to be incorporated into forest policy and it is important to develop mechanisms that can internalize these externalities into the economy of Mediterranean forests (Merlo and Rojas Briales 2000). Furthermore, also direct uses may not be optimally managed, resulting in overexploitation and possible degradation of forest resources (Fabbio et al. 2003; Croitoru 2007).

5.5 Climate Change Impacts on Mediterranean Forests

The threats to which Mediterranean forests have been historically subjected, such as drought, forest fires, over-exploitation, deforestation, and degradation can be today accentuated in a context of climate and land use changes (Palahi et al. 2008). Due to the long-term exposure to environmental and anthropogenic stresses, Mediterranean vegetation became adapted to difficult ecological conditions, through response mechanisms that include morphological, phenological and physiological adaptations. Small leaf size, deep root systems, thick bark and high sprouting ability are all morphological features that help Mediterranean ecosystems to thrive under unfavorable conditions. Physiological adaptations include tolerance to tissue dehydration, plasticity of photosynthesis (early spring onset, winter photosynthesis in evergreen species) and ability to recover after a long summer stress period. Mediterranean species have also developed mechanisms of resistance (or resilience) to fire (sprouting, early and large seed production in conifers, serotinous cones)

(Scarascia Mugnozza et al. 2000a). This picture may point out that Mediterranean ecosystems could be less subject to future global changes. However, there is now ample evidence that recent climate change is already causing ecological responses that are clearly visible. In this respect, recent observations corroborated the fact that Mediterranean and Mountains species are disproportionately sensitive to climate change (Walther et al. 2002).

It is then important to review some of the recent findings on how climate change is impacting the main processes in Mediterranean forests.

5.5.1 Ecophysiology, Phenology and Productivity

In the past, ecophysiology was studied at leaf and plant level, providing the knowledge on how photosynthesis was responding to environmental variables and stresses (Ehleringer and Mooney 1983). Nowadays, measurements of carbon exchange at ecosystem level with the eddy covariance technique made possible the analysis of canopy-level processes and responses, that provide a more integrated picture. Furthermore, as the number of sites where this technique is applied is increasing year after year, cross-site comparison or large-scale assessment of canopy fluxes are becoming possible (Ciais et al. 2005; Reichstein et al. 2007).

In a comprehensive analysis of ecosystem fluxes measured between 1998 and 2003 in European forests, the net production of carbon (NEP) resulted more related to variation in gross photosynthesis (GPP) and water availability than to respiration or mean annual temperature (Reichstein et al. 2007). Gross photosynthesis appeared to be related to mean annual temperature at Northern sites, while GPP was linearly dependent on water availability at the more water limited southern sites (not all of them were Mediterranean). Overall, Reichstein et al. (2007) found that water availability was a significant modulator of NEP, while the multivariate effect of mean annual temperature was small and not significant. Furthermore, moisture stimulation effects on respiration may lead to counterintuitive effects on NEP (with lower water availability resulting in higher NEP due to limitation on respiration). So, in Mediterranean ecosystems currently, but also in the future, factors related to the water balance may override temperature effects on ecosystem carbon balances. (Reichstein et al. 2007). More recently, Yi and colleagues (2010), in another analysis using the FluxNet eddy covariance data at 125 sites, found that NEP was strongly related to mean annual temperature at mid- and high-latitudes and to dryness at mid-and low-latitudes. Above 16 °C, a mean temperature that is frequently passed in Mediterranean areas, no further increase of carbon uptake with temperature was observed, with dryness influencing NEP changes (Yi et al. 2010). Decrease of GPP and respiration were also found with a throughfall exclusion experiment in a *Quercus ilex* stand in France (Misson et al. 2010). In the long term, dry climate may cause an adaptive positive response of Water Use Efficiency in Mediterranean tree species. However, this increase may not be sufficient to avoid warming-related growth decline at the southern edge of species ranges (Jump et al. 2006; Penuelas et al. 2008).

Phenological changes are already occurring since some decades. Among the processes that resulted more affected, we may list leaf unfolding in spring, earlier flowering and fruiting and delayed leaf fall in autumn. Furthermore, the response and sensitivity of Mediterranean plants is larger and disproportionate compared to those of more temperate species (Gordo and Sanz 2010). A long-term (1952–2000) field study in NorthEast Spain of plant phenology, appearance of butterfly and arrival of migratory birds reported that leaf unfolding was occurring 16 days earlier, leaves fall 13 days later, butterfly species are appearing earlier but birds later compared to the beginning of the study (Penuelas et al. 2002). While the lengthening of growing season may affect biospheric activity, other changes may have effects on competitive ability, ecology and conservation of ecosystems (Penuelas et al. 2002). For example, during these last decades, insect phenology showed a steeper advance than plant phenology, with possible decoupling of some plant–insect interactions, such as those between pollinators and flowers or herbivorous insects and their plant resources (Gordo and Sanz 2005).

Drought is a strong limiting factor for tree growth. Although species may be adapted to live in climates with periodic water stress, tree growth in those conditions is always lower than growth in more temperate or mesic conditions (Palahi et al. 2008). In Spain, at the southern range and at low altitude, beech forests are showing lower growth compared to higher altitudes, mostly because warming is increasing water consumption and reducing air humidity (Penuelas et al. 2008). Similarly, in Italy, dendroclimatological analyses of old-growth beech forests revealed a moisture limitation of growth on decadal scale since 1970, suggesting that long-term drought stress has reduced the productivity of beech forests in central Apennines, in agreement with similar trends identified in other Mediterranean mountains, but opposite to growth trends reported for many forests in central Europe or, also, in northern Italy (Piovesan et al. 2008).

5.5.2 Dieback, Degradation and Distribution of Forest Ecosystems

Mediterranean ecosystems have been subjected to a historical long-term human influence, with both positive and negative effects (Hobbs et al. 1995). Furthermore, forest fires, over-exploitation and deforestation can lead to ecosystem fragmentation and degradation. Within this framework, the additional impact of climate change can aggravate degradation and make the recovery more problematic.

In the 15 years of crown condition monitoring in Italy over level-I ICP-Forests plots (http://www.icp-forest.org), crown transparency, a proxy of the health status of trees, oscillated between 20 and 35% for the different broadleaved species and between 15% and 30% for conifers. Peaks in transparency occurred in extreme years (2003, 2007), with sometimes carry-over effects in following years. Some of the species showed good recovering capacity (beech, oaks, hornbeam), while other have a continuous trend of increased transparency (Bussotti et al. 2010).

In particular, chestnut reached almost 40% of transparency. Chestnut stands are located in hills and low mountain ranges, with limited capacity to adapt to warming and increased drought also because, historically, for economic reasons, they were frequently planted in sub-optimal condition.

Demographic processes may be sensitive to climate changes, with possible consequences on the diversity and structure of future plant communities. In a 4-years long drought and warming experiment in Spain, species richness of seedlings decreased (Lloret et al. 2004). Drought impacted both the number and the species richness of emerging seedlings. As a result, species that produce fewer recruits are more likely to disappear in drier or warmer scenarios (Lloret et al. 2004).

An analysis of climate in the Region of Valencia, Spain (30 years, 97 stations) showed that precipitation decreased and the variability of rainfall distribution increased inducing conditions that are more favorable for forest fires and high erosivity rainfall events that, on burned lands, may affect ecosystem composition and succession (De Luis et al. 2001). In a protected area in central Italy, decreases in remote-sensing derived vegetation index (NDVI) in pine and oak forests were correlated with decreases in winter rainfall (Maselli 2004).

Respiration rates are temperature-dependent and an increase in temperature produce an exponential increase in the respiration of living tissues of trees. This may results in a depletion of the reserves of mobile carbohydrates, which are used by Mediterranean trees to overcome the dry summer periods. Most of the dieback episodes observed in Mediterranean forests in recent years, are associated to the exhaustion of the reserves of carbohydrates, due to consecutive years of drought and warm climate. As a consequence, weakened forests ecosystems can be subject to pest attacks (Palahi et al. 2008).

A recent analysis over west Europe, including areas of the Mediterranean mountains, along the entire elevation range (0–2600 m a.s.l.) showed that climate warming between 1985 and 2005 resulted in a significant upward shift in species optimum elevation, averaging 29 m per decade (Lenoir et al. 2008). Shift was larger for mountain and grassy species, characterized by faster population turnover. Climate change is then already affecting not only species at the margins (Jump et al. 2006) but also the spatial core of the distributional range of plant species (Lenoir et al. 2008).

5.6 Effects of Future Climate on Forest Functionality and Productivity in the Mediterranean Region

In Sect. 5.5, we have presented some of the evidences of the impacts that the already occurring climate change is causing to Mediterranean ecosystems. Unfortunately, climate change, if not properly mitigated, is a process that will proceed in the next decades. Climate change scenarios are available from several international institutes and also CIRCE has produced scenarios tailored for the Mediterranean (see part 1, chapter 2 of RACCM). In all climate change scenarios, the increase of temperature is associated to changes in the precipitation patterns, although with a higher uncertainty. If precipitation is generally forecasted to increase over northern Europe, a decrease up to 20% is expected for the south of Europe, particularly in summer, with severe effects on the frequency and intensity of drought periods, affecting water resources, forestry and agriculture. Higher temperatures and lower precipitation during summer will increase the evaporative demand of the atmosphere on ecosystems that already now can transpire up to 80% of precipitation.

Concurrently to change in climate, atmospheric concentration of CO_2 will increase. As CO_2 is the primary substrate for photosynthesis, increases in CO_2 concentration could be beneficial to forest production. However, a key role will be played by resource availability such as nitrogen and, above all, water.

Results obtained in Free Ambient Carbon dioxide Enrichment (FACE) experiments, which exposed portion of tree stands to elevated CO_2 concentrations (generally 550 μmol mol^{-1}) indicated that Net Primary Productivity increases under elevated CO_2 compared to current concentration and forest response is maintained over a broad range of productivities (Norby et al. 2005). However, those experiments did not include warming and, in most cases, irrigation and fertilization was applied.

Simulation results obtained with a process-based forest growth model (GOTILWA) applied in the Mediterranean region on *Quercus ilex*, *Pinus halepensis*, *P. pinaster*, *P. sylvestris* and *Fagus sylvatica* forests over the period 1961–2100 indicated that changes in rainfall and increasing atmospheric CO_2 concentration will promote higher production in the region (Sabaté et al. 2002). However, temperature increase, causing a longer growing season, would have different consequences for production, with *F. sylvatica* showing higher production, when water is not limiting. Conversely, more Mediterranean species such as *Q. ilex* and *Pinus* spp. would invest more carbon in maintaining and producing leaves. Forest management will play an important role in regulating stand density and leaf area index and hence water availability for the remaining trees (Sabaté et al. 2002).

At Sect. 5.5.1 we have reported that phenology is already changing in the Mediterranean. For the future, modeling exercises which considered projected changes in temperature predicted an increase of the growing season by 2080 of 50 days for the Mediterranean region (Palahi et al. 2008). A longer growing season will imply a greater water demand, only partially mitigated by the increased CO_2 concentration (Penuelas et al. 2008), while the climate projections predict less precipitation and changes in its distribution regimes. In Swiss alps, under future climate conditions, melt-out of snow and onset of growth were projected to occur on average 17 days earlier by the end of this century than in 1971–2000. As a result, plant height and biomass production were expected to increase by 77 and 45%, respectively (Rammig et al. 2010).

The evaporative demand may increase in the future, increasing the frequency and impact of dry periods. Under these conditions, the response of Mediterranean tree species may be different. Along a 5-years-long drought experiment in a mixed holm oak forest, *Q. ilex* showed the highest mortality rates (18%), while *Phillyrea latifolia* the lowest (3%). Drought strongly reduced biomass increment of *Arbutus unedo*

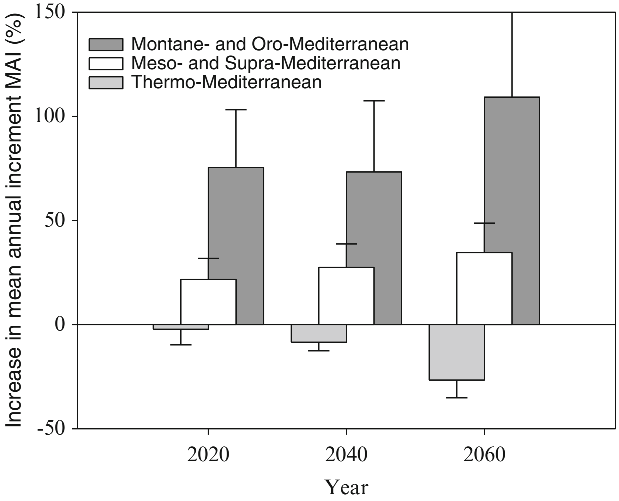

Fig. 5.8 Changes in mean annual increment (*MAI*) under climate change scenarios for pine species in Italy. Results obtained by modeling simulations with the HYDRALL model (Magnani et al. 2002). For explanations see text

and *Q. ilex*, but not that of *P. latifolia* (Ogaya and Penuelas 2007). Drier conditions could thus have strong effects on structure (species composition) and functioning (carbon uptake and biomass accumulation) of these Mediterranean forests (Ogaya and Penuelas 2007).

A modeling exercise on pine species occurring in different vegetation zones (Thermo-Mediterranean zone: *Pinus halepensis*, *P. pinaster*; Meso and Supra Mediterranean zone: *Pinus pinaster*; Montane and Oro-Mediterranean zone: *Pinus sylvestris*) was performed in Italy using the HYDRALL model (Magnani et al. 2002). Growth was assessed in 2020, 2040 and 2060 using climate data and scenarios for ten sites in Italy: four in the Thermo-Mediterranean zone and three for each of the other two zones (Scarascia Mugnozza et al. 2000b). According to modeling results, effect of climate change on pine forest mean annual increment will be neutral in 2020 and then slightly negative for Thermo-Mediterranean zone, moderately positive in Meso and Supra Mediterranean zones and clearly positive in Montane and Oro-Mediterranean zone (Fig. 5.8).

Negative effects in the Thermo Mediterranean zone are to be related with the impact of drought.

Multispecies functional models can be used to study complex interactions among climate, tree species and fire regimes. An application of the model SIERRA in Mediterranean type ecosystem indicated the lack of drastic changes in the succession process but relevant changes in the water budget and drought periods, enhancing the susceptibility to extreme events (Mouillot et al. 2002). Furthermore, climate changes may result in an increase in fire regimes, with more frequent return of fires both in macchia (20–16 years) and forest (72–62 years). This may result in changes in dominating ecosystem type towards shrub-dominated landscape (Mouillot et al. 2002), with potential impact on recreation.

Concerning biodiversity, several drivers are currently impacting species richness and variability and will do so in the future. In general, land-use change will probably have the largest effect, followed by climate change, nitrogen deposition, biotic exchange among ecosystems and changes in CO_2 concentration. In this respect, Mediterranean zone and grassland ecosystems will most probably experience the greatest change in biodiversity because of the substantial influence of all drivers impacting biodiversity (Sala et al. 2000).

5.7 Effects of Future Climate Scenario on the Potential and Effective Distribution of Forest Ecosystems and Tree Species

Climate change will not only affect functionality or productivity of forests but also their distribution. We have illustrated that changes in species distribution are already occurring (see Sect. 5.5.2) but climate changes will enhance the trends that Mediterranean ecosystems are currently experiencing (Scarascia Mugnozza et al. 2000b).

Large areas of ecosystems in Europe are likely to be affected already under a climate stabilization scenario at 2 °C. Most of the impacts should be in northern countries, with a net increase of plant species number, and in Mediterranean countries, with a decrease (Bakkenes et al. 2006). Under future climate scenario, the distribution of typical Mediterranean tree species is likely to decrease in the region, but could expand to new areas where Mediterranean like climatic conditions will appear (Palahi et al. 2008). However, the possible positive changes in distribution (e.g. increased species ranges) will collide with current ecosystem fragmentation and physical barriers imposed by human land-use. In this respect, habitat fragmentation is a threat to the survival of species and may cause population decline, as isolated populations are more susceptible to demographic and genetic stochasticity. This should be compensated for by sufficient spatial connectivity between habitat patches to allow dispersal of individuals among populations (Smulders et al. 2009).

Modeling exercise on European beech, using statistical and process-based models, indicated that, under future climate scenario, beech has the potential to expand its northern edge and loose habitat at the southern edge of its distribution (Kramer et al. 2010).

In central Italy, a general increase of the species average potential altitude was found by a bioclimatic modeling exercise (Attorre et al. 2008). Only the true Mediterranean species are likely to be favored by the predicted climate change, while for other chorological types (Sub-Mediterranean and Eurosiberian) the response seems to be species-specific, depending on the ecological characteristic of each species, with the more thermophilous and xerophilous species that should benefit from the predicted drought in terms of area and mean abundance, while mesophilous species may suffer a strong reduction (Attorre et al. 2008). A more in-depth analysis at national scale, with improved model and land-use matrix, confirmed the shift in tree species distribution towards higher altitudes but found also a reduction of forest cover (Attorre et al. 2011). Species like *Pinus sylvestris* and *Tilia cordata* were found to be at risk of local extinction, while other species could find potential new, suitable areas at the cost of a rearrangement of forest community composition and increasing competition. However, final rearrangements and distribution of species in the Mediterranean basin in response to climate change will depend on multiple factors, among which the geographical and topographical regional characteristics have a noticeable influence (Attorre et al. 2011).

Climate change, together with trends of land-use change (e.g. rural abandonment) are likely to diminish forested areas within the Mediterranean basin, with possible replacement with more fire prone shrub communities (Resco de Dios et al. 2007). This could be favored by outbreaks of pathogens, fire and other large scale disturbances that could be exacerbated under climate change, while landscape fragmentation is expected to limit species migration (Resco de Dios et al. 2007).

5.8 Responding to Climate Change: Adaptive Management for Mediterranean Forests

The Mediterranean basin has maybe the longest history of human presence in the earth. Humans began to modify significantly Mediterranean ecosystems 8,000 years ago, starting already at that time to impact global climate (Ruddiman 2003). Today, the Mediterranean can be considered a test area for studying global change (Scarascia Mugnozza et al. 2000a; Palahi et al. 2008). Historically, forests have been able to adapt to slow-rate changes in mean climate variables but the current rate of changes is much faster than in the past and, furthermore, variability has increased, with greater risk of extreme weather events, such as prolonged drought, storms and floods.

Can the Mediterranean populations apply management options that may prepare or adapt forests to the expected impacts of climate changes?

The degree of adaptation will depend both on the inherent adaptive capacity of trees and forest ecosystems but also on the socio-economic factors that will drive the capability to implement planned adaptation strategies. Socio-economic factors are particularly limiting in the Mediterranean region, where large forest areas are only extensively managed or unmanaged (Fabbio et al. 2003; Lindner et al. 2010). Therefore, a dynamic conservation approach is urgently required and it should be based on sustaining the mechanisms allowing the maintenance of biodiversity (natural disturbance, gene flows, regeneration) (Palahi et al. 2008). Re-afforestation policy are necessary to ensure that forest species and their site-specific varieties are best adapted to future climatic conditions and ecosystem functioning is maintained (Resco de Dios et al. 2007). Fire prevention is also fundamental, as well as grazing control in burned and degraded areas where the re-establishment of a minimum texture of ground vegetation and tree cover is the only feasible way of restoration (Fabbio et al. 2003). Adaptive management should also try to implement solutions for reduced water use and long-term soil preservation (Palahi et al. 2008).

5.9 Concluding Remarks

Although Mediterranean forest and shrub ecosystems represent only 2% of the world's forest cover (FAO 2006), specific aspects make this region an interesting model system where global change on terrestrial ecosystems can be studied. In fact, Mediterranean forests are subjected to numerous threats such as forest fires, over-exploitation, deforestation and degradation. These threats are nowadays worsened by climate and land use changes (Palahi et al. 2008). Among all bioclimatic regions, the Mediterranean area appears to be the most vulnerable to global change (Sala et al. 2000; Scarascia Mugnozza et al. 2000a; Walther et al. 2002; Lindner et al. 2010). In this respect, recent observations corroborated the fact that Mediterranean and Mountains species are disproportionately sensitive to climate change (Walther et al. 2002).

- In all climate change scenarios, the increase of temperature is associated to changes in the precipitation patterns, with possible decrease of 20% over the Mediterranean. Higher temperatures and lower precipitation will increase the evaporative demand of the atmosphere on ecosystems where water is already now a severe limiting factor.
- Mediterranean forests sum up to 80 Mha, most of which are located in the European side of the Mediterranean (76%), while Mediterranean Africa and Asia contribute for 10 and 14%. Forest area in the region has increased by 14% between 1990 and 2005 due to wood encroachment, natural invasion of abandoned lands and deliberate reforestation and afforestation plans.
- Roundwood nowadays represents 60% and woodfuel 40% of total wood products (125 Mm3). Industrial roundwood is harvested mostly in Mediterranean Europe (80–90% in the last 50 years). The role of Asia is increasing and roundwood production reached recently 16% of the Mediterranean total production, while the role of Africa is negligible (less than 2%).
- The average TEV of Mediterranean was calculated to be about 133 € ha^{-1}, with Northern countries having much higher value (173 € ha^{-1}) than Southern (70 € ha^{-1}) and Eastern countries (48 € ha^{-1}) (Croitoru 2007). Non-wood forest products and services are more important as they often represent 60–70% of total economic value.
- There are already evidences of impacts of recent climate change on ecophysiology, productivity, dieback and distribution of Mediterranean forests and these impacts will become worse in the future, particularly for increased evaporative demand and repeated extreme events.
- Gross Primary production and Net Ecosystem Production are related to water availability (Reichstein et al. 2007; Yi et al. 2010). So currently, but also in the

future, factors related to the water balance may override temperature effects on ecosystem carbon balances.

- Productivity of forests may increase in areas where water is not limiting, while decrease in growth and possible dieback of ecosystems is predicted to occur in drier locations (Scarascia Mugnozza et al. 2000b; Sabaté et al. 2002). Drier conditions could also have strong effects on structure (species composition) and functioning (carbon uptake and biomass accumulation) of holm oak Mediterranean forests (Ogaya and Penuelas 2007).
- Phenological changes are already occurring since some decades. While the lengthening of growing season may affect biospheric activity, other changes may have effects on competitive ability, ecology and conservation of ecosystems, (Penuelas et al. 2002).
- Climate changes may result in an increase in fire regimes, with more frequent return of fires both in macchia (20–16 years) and forest (72–62 years). This may result in changes in dominating ecosystem type towards shrub-dominated landscape (Mouillot et al. 2002), with potential impact on recreation.
- Under future climate scenario, the distribution of typical Mediterranean tree species is likely to decrease in the region, but could expand to new areas where Mediterranean like climatic conditions will appear (Palahi et al. 2008). However, the possible positive changes in distribution (e.g. increased species ranges) will collide with current ecosystem fragmentation and physical barriers imposed by human land-use.

Currently, the planning situation in the Mediterranean basin is very diverse. Periodical planning, when applied, is static but challenges and constraints impose a change toward a dynamic process which allows up-dating or re-planning (Palahi et al. 2008). Climate change and competing demands for timber, food, biofuels and other ecosystem services will pose severe challenges to forest governance in the future (Agrawal et al. 2008). Understanding of adaptive capacity and regional vulnerability to climate change in Mediterranean forests requires focused research efforts. An interdisciplinary research agenda integrated with monitoring networks and projection models is needed to provide information at all levels of decision making, from policy development to the management unit (Lindner et al. 2010).

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Chapter 6
Effects of Climate and Extreme Events on Wildfire Regime and Their Ecological Impacts

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Abstract Fire regime has been affected by climate changes in the past, and is expected to do so in relation to the projected climate warming in the near future. For the Mediterranean Basin, higher fire risk, longer fire season, and more frequent large, severe fires are expected. The projected increased drought for the Mediterranean Basin would make ecosystems more vulnerable to fire, and more difficult to restore after fire. Ecosystem vulnerability is assessed considering soil susceptibility to post-fire erosion, and vegetation capacity to recover after fire.

In the perspective of a more severe fire regime and harsher climate, two main strategies are proposed: (1) mitigation strategies to reduce fire impacts; and (2) adaptation strategies to improve ecosystems capacity to cope with the new climate and fire regime. The focus of adaptation will be on strategies for vegetation management to reduce fire hazard, and increase ecosystem resilience, especially in highly vulnerable areas.

Restoration techniques are proposed to increase ecosystem resilience to fire by using resprouting woody species, and by increasing the diversity of species in post-fire afforestation/reforestation projects. To face increased drought, several techniques to improve water availability and water use efficiency for introduced seedling are discussed.

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Finally, the landscape dimension of fire prevention and restoration is addressed through a spatial decision support system, including a fire propagation model combined with an ecosystem vulnerability model in GIS format. The system allows assessing fire risk, identifying values at risk, and prioritizing fire prevention and post-fire restoration actions.

Keywords Fire regime • Vulnerability • Fire resilience • Plantations • Fire modeling

6.1 Climate and Fire Regime During the Last Decades in the Mediterranean Area

Fuel availability (i.e., plant biomass) and weather conditions (i.e., wind, temperature, air humidity and precipitation) are the drivers of wildfires, and both are directly or indirectly controlled by climate (Pausas 2004; Krawchuk et al. 2009). For instance, the fire regime of Mediterranean ecosystems is attributed to their seasonal climate, that is, mild temperatures and abundant rainfall in spring (which promote fuel production) followed by high temperatures and low precipitation in summer (resulting in severe water deficit, Viegas and Viegas 1994; Pausas 2004). At a longer temporal scale, changes in regional fire regimes have been associated to changes in climate through both long-term paleoecological evidence (Clark 1990) and correlation data from the twentieth century (Beer et al. 1988; Piñol et al. 1998; Westerling et al. 2006). However, neither the direct link nor the interactions between fire regime and climate are well understood because of the complexity of the underlying mechanisms. For instance, while dry conditions increase flammability and fire hazard (Piñol et al. 1998), they may also reduce plant production as well as fuel loads and continuity (Pausas and Bradstock 2007). In fact, there is currently a strong controversy with respect to the relative role of fuel and climate in the fire regime of Mediterranean ecosystems. The "fire mosaic model" proposes that catastrophic fires are due to unnatural fuel accumulations produced as a consequence of fire-suppression policies (Minnich 1983, 2001). On the other hand, the "fire weather model" states that large fires are due to extreme climatic conditions (e.g., severe drought, dry winds) and that fire is independent of the fuel type/age (Keeley et al. 1999; Keeley and Zedler 2009). Whereas in the first model, fires are fuel-limited, in the second one, fires are climate-driven. These two models have strong implications on land management; while the "fire mosaic model" suggests that fire risk may be significantly lowered by reducing fuel loads, the "fire weather model" suggests that fuel management has a limited role in reducing catastrophic fires. The large fires that occurred in the Mediterranean Basin in the last decade were related not only to extremely warm and dry weather (supporting the "fire weather model", Founda and Giannakopoulos 2009), but also to positive anomalies in the previous wet season which promoted plant growth and fuel build-up (Trigo et al. 2006).

It has recently been suggested that fire-climate relationships are climate-dependent in such a way that the relative role of weather and fuel load varies along climatic

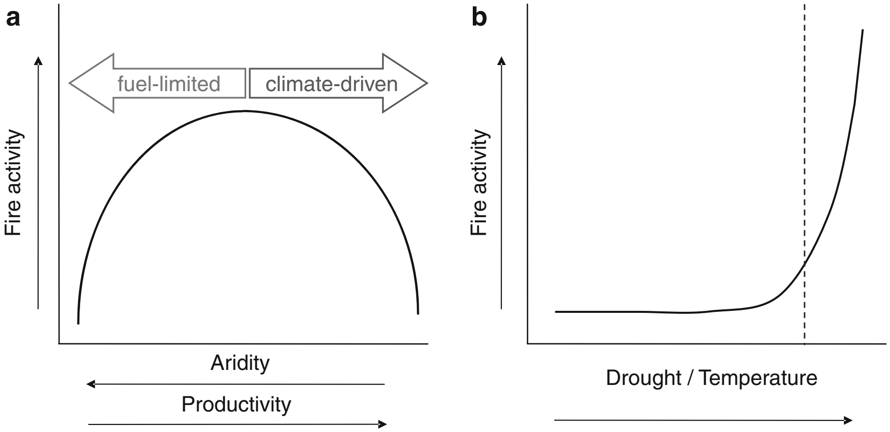

Fig. 6.1 Hypothetical fire – productivity relationship at spatial (**a**) and temporal (**b**) scale (Adapted from Pausas and Bradstock 2007)

gradients (Pausas and Bradstock 2007; Westerling and Bryant 2008; Littell et al. 2009; Fig. 6.1a). Specifically, in moist and productive ecosystems, dry conditions are needed to burn the existing fuel (vegetation), and thus the fire regime is climate-driven. On the other hand, in dry and unproductive ecosystems, fire spread is limited by both low fuel availability and low fuel continuity, even when climatic conditions are adequate for ignitions. These patterns, described for California (Westerling and Bryant 2008), seem to be applicable to the Mediterranean Basin (Pausas 2004). However, fuel load (amount and continuity) is dependent not only on climatic conditions, but also on land-use and management (Pausas and Lloret 2007). Therefore, the fire-climate relationship would be more complex in Mediterranean Basin ecosystems, where a longer and stronger human pressure has generated both fragmented landscapes and high fire ignitions (e.g., Pausas 2004).

The increase in fire activity detected in the Mediterranean Basin during the last decades has been explained by the abandonment of rural activities and the consequent fuel accumulation and increased fuel connectivity (Moreira et al. 2001; Pausas 2004; Bajocco et al. 2010). In addition, there is evidence that fire activity is linked to the climatic conditions controlling fuel availability (Viegas and Viegas 1994; Pausas 2004). All these results suggest that the fire regime in Mediterranean Basin ecosystems is globally fuel-limited (Fig. 6.1a). However, when a long time-series is considered for areas productive enough to sustain continuous fuels, a switch in the fire activity has been detected: before the 1970s, fires were small and weakly related to climate, while after this date fires were larger and strongly related to climate (Pausas and Fernández-Muñoz 2012). Before the switching point, landscapes were shaped by agriculture, livestock and other land uses, which maintained low and fragmented fuels. But the progressive land abandonment due to rural exodus to the cities resulted in burnable landscapes (i.e., fire non-limited by fuel); in such conditions, the area burnt was strongly driven by climatic conditions. Therefore, progressive changes in human land use abruptly changed from a fuel-limited fire regime to a climate-driven fire regime (Pausas and Fernández-Muñoz 2012).

The role of fuel in determining fire regimes does not depend on the amount alone, but also on its quality, type, and structure, which in turn may also be linked to climate and previous fire regimes. Therefore, fire modifies fuel amount and structure, plant composition and vegetation functioning, which in turn affect fire activity. These feedback processes can be depicted during early post-fire conditions, where lower average rooting depth may diminish plant moisture and thus increase fire susceptibility (Mouillot et al. 2002). This is especially relevant in plant communities dominated by seeders, that is, non-resprouter species whose post-fire regeneration relies exclusively on seedling recruitment (Pausas et al. 2004). At a longer time scale, flammable dry and poor communities become dominated by seeders, which in turn increase the flammability of the community (Saura-Mas et al. 2010). However, the distribution pattern of post-fire response groups along the fire gradients is still unclear because of the complexity of fire-climate spatial interactions (Clarke et al. 2005; Pausas and Bradstock 2007; Fig. 6.1a), and, thus, feedback processes are still difficult to predict.

Similarly, at the temporal scale, fire-climate interactions are not straightforward either; rather, they show a threshold effect, that is, the existence of a critical climatic value above which the probability of fire increases dramatically (Flannigan and Harrington 1988; Good et al. 2008; Westerling and Bryant 2008; Fig. 6.1b). Therefore, whereas small changes in climate conditions may seem to have little effect on ecosystem functioning, they may end up having a great impact through their effect on the fire regime, because fire may act as an amplifier of climate changes impacts. Determining the (spatial and temporal) variability of this climatic threshold is our current challenge.

6.2 Changes in Fire Regime According to Projected Climate Change in the Mediterranean

6.2.1 What Would Be New in the Forest Fire Regime?

Climate change affects variables such as air temperature, precipitation, relative humidity and wind speed, all of which influence fuel moisture and, thus, fire behavior (Moriondo et al. 2006). The fact that all the attributes describing fire regime (i.e., frequency, size, intensity, seasonality, type and severity) are highly dependent on weather and climate (Swetnam 1993; Flannigan et al. 2000) explains the rapid response that fire regimes have to changes in climate. It has even been suggested that the impacts of climate change on fire regimes might be more important than the direct impacts of climate change on species because fire can rapidly change a vegetation landscape that will fall more readily into a new equilibrium with climate (Weber and Flannigan 1997).

The inference often found in assessments of the future impact of climate change on fires is that increased drought (due to global warming) will also cause an increase in fire occurrence (Williams et al. 2001; Moreno 2005). Increases in extreme climate events, in particular, are expected to have a great impact on fire risk (Flannigan et al. 2005a). Global change has the potential to affect not only the meteorological fire hazard, but also many other interrelated components of the total fire hazard, especially its societal components (i.e., land use changes and policy, fire management strategies).

Climate-induced changes in the production of available fuel and in the overall flammability of the plant material may alter fire frequency, intensity and severity, which in turn will influence the structure and composition of ecosystems (Flannigan et al. 2000; Mouillot et al. 2002). With a climate-mediated disturbance such as fire, very complex responses to climate change may be expected (Swetnam 1993). It is likely that changes in climate will have different fire effects in different climatic conditions depending on critical thresholds of combustibility (Fig. 6.1). It has been observed, for instance, that the effect of anomalously wet years on fuel accumulation is relatively more important in dry, sparsely vegetated areas (Kipfmueller and Swetnam 2000), whereas anomalously dry conditions have a greater effect on fire danger in forested areas, where heavy fuels tend to accumulate over long periods (Agee 1993; Swetnam and Betancourt 1998; Donnegan et al. 2001).

Furthermore, changes in fire regime may have different consequences for different species (Zedler et al. 1983), and changes in species composition may have consequences on landscape combustibility and flammability, which may feed back to the fire regime. Moreover, at ecosystem level, other impacts and responses determined by plant communities as well as soil characteristics (e.g. erodibility) and post-fire events (e.g. heavy post-fire rains) may also take place.

Wildfires are already a major natural hazard in Mediterranean and other climates of the world (Westerling et al. 2006; Pausas and Keeley 2009). Wildfires include a wide range of fire regimes and affect a great diversity of ecosystem types over a large range of climates. Therefore, in principle, climate change would not introduce completely new phenomena, but it could change the trends in fire regimes and affected areas.

Studies investigating the likely effects of projected climatic changes on fire regimes began appearing around 1990 (Brown et al. 2004; Flannigan et al. 2005a), but few attempts have been made to quantify the potential impact of climate change on fire risk in ecosystems of the Mediterranean Basin (Mouillot et al. 2002; Moriondo et al. 2006). All these studies are based on a simulation approach and most of them use the outputs (climate data) obtained from General Circulation Models (GCM) run under different scenarios of fire danger indices (Brown et al. 2004; Moriondo et al. 2006).

Results generally show an increase in fire risk, burned area, fire intensity and/or frequency of fires as a result of projected climate changes (Fried et al. 2004; Moriondo et al. 2006; Flannigan et al. 2009). However, global or regional decreasing trends have also been reported (Beer and Williams 1995; Flannigan et al. 1998; Scholze et al. 2006). A decrease in fire frequency has been suggested by some studies, for instance in boreal forests (Bergeron and Flannigan 1995), indicating that the large regional variability around the world precludes any generalization about an overall increase in fire occurrence with global warming (Williams et al. 2001).

Some studies project a significant increase in fire frequency (of 40%, or even higher) under drier scenarios in relation to the reference scenario, and they suggest that these climate-change-induced modifications to fire frequency will probably be relevant for plant communities (Cary and Banks 1999). Other studies project that higher temperatures will extend the typical fire seasons, with more fires occurring earlier and later in any given year (Wotton and Flannigan 1993). The annual area burned is expected to strongly increase in some regions (Price and Rind 1994; Flannigan et al. 2005b), as are the fire danger levels (Flannigan and Van Wagner 1991; Stocks et al. 1998), the number of potential catastrophic fires (i.e. high-severity fires), and related economic losses (Fried et al. 2004). The impact of climate change differs according to vegetation fuel types, due partly to the effect of fuel type on fire intensity but mainly to the greater importance of wind speed on fire spread rate for grass fuels, as compared to brush and forest (Torn and Fried 1992). Increased fire frequency and severity could also increase the risk of losing some rare species and ecosystem types.

As for Mediterranean-type ecosystems (MTEs), fire occurrence strongly depends on the drought that drastically increases flammability during summer, on the temperature reached during this period, and on the amount of fuel load (Mouillot et al. 2002). Aiming to improve the projections of GCM-based assessments, which are somewhat hampered by coarse spatial and temporal resolutions (Stocks et al. 1998), Moriondo et al. (2006) investigated the effects of climate change on the fire risk in EU Mediterranean countries by using the output of a regional circulation model (HadRM3P) as an input to the Canadian Forest Fire Weather Index (FWI) for the current and two future IPCC scenarios (A2 and B2). Regional models are more suitable for local impact studies such as those on forest fires, especially in areas like the Mediterranean with a complex topography (Giorgi 1990). Results suggested a general increase in fire risk throughout all Mediterranean countries, with an especially strong impact likely in areas where forest land cover is high (Alps region in Italy, Pyrenees in Spain, and mountains in the Balkan region). In this study, as in others reporting similar results (Flannigan et al. 2000 for North America; Williams et al. 2001 for Australia), the higher fire risk was a direct consequence of increases in maximum temperatures and decreases in both rainfall and relative humidity during the summer period (Moriondo et al. 2006). In Spain, all GCM-based projections, under all scenarios, show a significant increase in the average monthly fire danger index, which will probably result in a lengthened fire season (Moreno 2005). Higher fire danger index values will also likely result in longer and more frequent extreme situations, even assuming that the frequency distribution of such situations remains the same, thus increasing the probability of large and severe fires. The same author suggests that impacts are expected to be higher in temperate-climate areas bordering Mediterranean ones.

Model-based climate-change assessments generally disregard various feedbacks and report a best-case forecast. Although fire-induced changes in vegetation composition, structure or distribution could create conditions that favor subsequent wildfires (Fried et al. 2004; Fulé 2008), model-based predictions do not generally consider the indirect effects of climate change on plant-growth and vegetation-distribution rates (Westman and Malanson 1992), or on community structure and composition (Ryan 1991; Mouillot et al. 2002), nor do they deal with the direct effects of increased lightning on ignitions (Price and Rind 1994). Nevertheless, despite the uncertainties in climate projections, the limitations of the modeling approaches (Pitman et al. 2007) and the complicated interacting factors, there still appears to be no reason to doubt that fire will globally increase in the coming decades (Fulé 2008; Lloret 2008).

Based on the projected climate changes described in previous chapters, we summarize below the main fire-regime changes and their impacts in Mediterranean and circum-Mediterranean countries:

- Most model-based studies tend to indicate that the projected impacts of climate change on fire regimes in Mediterranean countries (i.e., likely increases in fire frequency, intensity and severity) would have direct and significant effects on MTEs and the services they provide (Fried et al. 2004; Moriondo et al. 2006).
- Wildfires are expected to increasingly affect northern latitudes beyond the Mediterranean regions and higher elevations in mountain ranges in the Mediterranean countries. Therefore, wildfires would increasingly affect fire-sensitive ecosystems. Vulnerable forest ecosystems, such as the varied endemic Mediterranean mountain conifer forest types, could be severely endangered (Regato 2008).
- Increased land abandonment would contribute to increasing fuel load and continuity in the landscape. This would combine with more frequent extreme events to generate an increased probability of large and intense wildfires. Increased drought occurrence would also lead to higher fire frequency, especially in highly populated regions (high fire ignition probability) and the rural-urban interface.
- Both plant water stress and plant mortality will very likely increase (Rambal and Hoff 1998). Increasing amounts of decaying vegetation in drier environments are expected to enhance fuel and landscape hazardousness (Fulé 2008) by temporarily increasing dead fuels in the mid-term. This process would increase the probability of high intensity fires.
- Increasing fire recurrences will likely decrease the resilience of many MTEs (Díaz-Delgado et al. 2002; Delitti et al. 2005). In the case of forests, post-fire vegetation will less likely return to its pre-fire state because severe fires often favor alternative stable states, such as grasslands or shrublands (Fulé 2008).
- Increased drought would increase the difficulty of afforestation and reforestation in post-fire degraded lands because of the higher water stress for introduced plants.

6.3 Approaches and Methods to Identify Fire-Vulnerable Ecosystems

In the context of integrated fire management strategies aimed towards minimizing fire risk and promoting resilience to fire and biodiversity in the landscape, it seems crucial to predict how ecosystems may evolve in the short to long term after a fire.

Vulnerability has many different definitions. Based on the definition proposed by IPCC (2007), it is understood here as the degree to which a system is susceptible to, and unable to cope with, adverse effects of any driver of change (fire, in this case). Vulnerability to a given driver is a function of the character, magnitude, and rate of the driver-caused changes to which a system is exposed, its sensitivity, and its adaptive capacity. Although vulnerability aspects are frequently considered in assessment systems for most natural hazards, they have generally not been included in operational fire danger indices, which are mostly based on factors determining the fire risk conditions (Chuvieco et al. 2010).

It is known that different temporal scales may be required for analyzing different ecological processes. The post-fire soil degradation caused by water erosion, for instance, is mostly expected to occur from fire extinction up to a few months after it, when the recovery of the vegetation cover is still low (Pausas and Vallejo 1999), whereas the reestablishment of pre-fire plant communities through successional dynamics may span over several years, even decades, depending on the pre-existing vegetation types, fire severity and the environmental conditions (Keeley 2009). Therefore, the assessment of an ecosystem's vulnerability to fire should take into account the response of its various components (soil and vegetation) at different time scales.

An abundant body of literature documents the effects of fire on soils and the vegetation dynamics after fire in Mediterranean-type ecosystems, sometimes considering the interactions of fire with various other factors (Moreno and Oechel 1994; Trabaud 1994; Giovannini and Lucchesi 1997; De Luís et al. 2003; Duguy et al. 2007b; Baeza and Vallejo 2008; Duguy and Vallejo 2008). Nevertheless, integrated approaches considering the short-to-long-term response of the whole ecosystem to fire are still rare. This can be explained by the great difficulty of setting up long-term field-based experiments that would be appropriate for monitoring and documenting such responses. Given the lack of suitable field data, theoretical and modeling activities appear to be the only methods available for exploring the ecological vulnerability to forest fires in the short-to-long term for a wide range of ecosystems.

In this context, an innovative methodology aimed at assessing the ecological vulnerability to fire and based on the use of geographic information technologies (a geographic information system and remote sensing) has been developed for Mediterranean ecosystems in Spain (Duguy et al. 2012; Chuvieco et al. 2010).

This theoretical and modeling approach is structured in three stages: (1) short-term, less than 1 year after the fire, focused on soil degradation risk (Fig. 6.2); (2) medium-term, 25 years after the fire, focused on permanent changes in plant community structure and composition; and (3) integration of the short- and medium-term vulnerabilities to evaluate the overall ecological vulnerability to fire. At each stage, the variables that are considered are expressed in cartographical format and their qualitative values are successively combined by applying a matrix method. The model has been implemented in several sites: the regions of Madrid (centre Spain) Aragon (inland north-eastern Spain) and Valencia (eastern Spain). In each case, a regional-scale cartography of the ecological vulnerability to fire was obtained (Fig. 6.3). The short-term vulnerability maps facilitate the identification of the most erodible areas, which would be in greater need of short-term post-fire mitigation

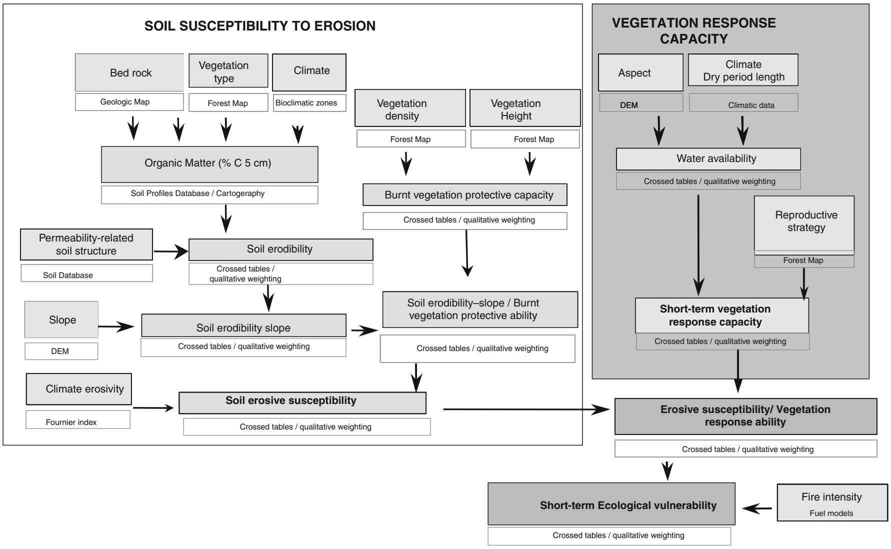

Fig. 6.2 Scheme for the short-term vulnerability analysis. Early post-fire ecosystem response depends on both physical and biotic factors, which determine post-fire soil erosion risk. The methodology considered the physical factors related to the soil susceptibility to erosion after a fire and the factors influencing the plant community response in the short term after fire. We evaluated the vegetation capacity for rapidly protecting bare soil in terms of the speed of the post-fire vegetation reestablishment

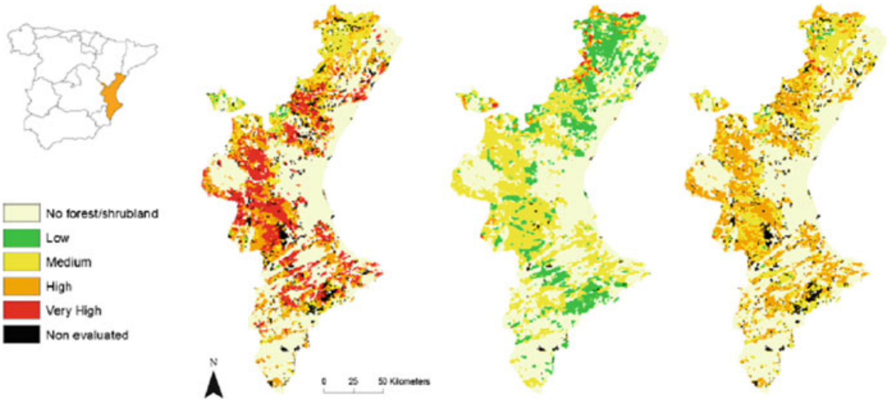

Fig. 6.3 Maps of short-term, medium-term and overall ecological vulnerability to fire (from *left to right*) for the Valencia Region (indicated in *orange* within Spain in the *upper left* localization map)

actions, whereas the medium-term vulnerability maps identify areas where permanent changes in the vegetation structure and composition can be expected in the medium term after a fire. Finally, the overall vulnerability maps indicate the most problematic situations in relation to the risk of degradation of the whole ecosystem in the medium term as a consequence of fire (Fig. 6.3).

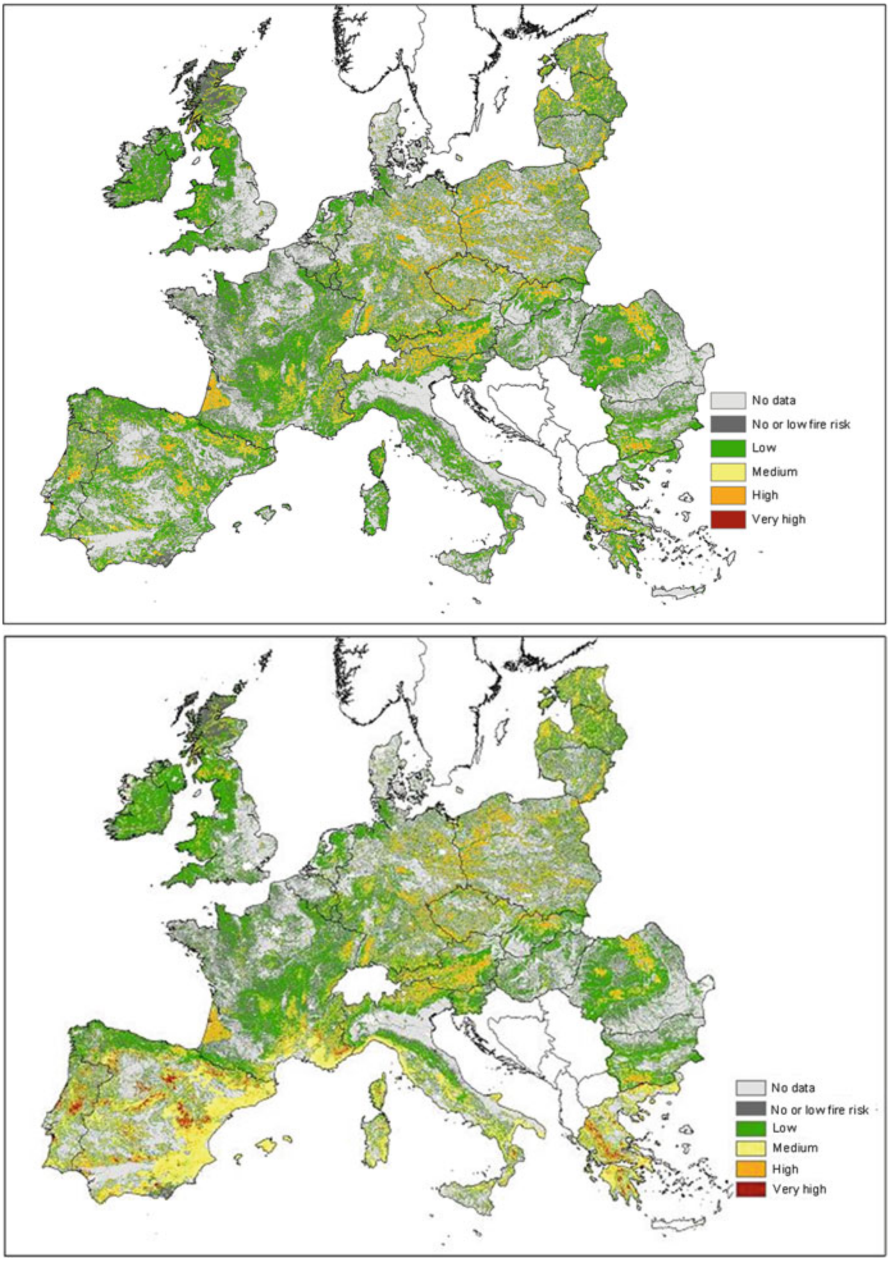

Fig. 6.4 Fire vulnerability in Europe. *Above*: Current situation. *Below*: Projection according to IPCC (2007) projections for wildfires and drought occurrence. See the text for more details

The model has been partially validated in the Ayora (Valencia) test site by comparing the overall-vulnerability values predicted by the model with field observations of medium-term post-fire ecosystem recovery. Our validation protocol used the 1979 Ayora vegetation map, corresponding to the pre-1979 fire situation (Röder et al. 2008), to run the vulnerability model. A set of previously-corrected Landsat images (Röder et al. 2008) allowed us to monitor the post-fire evolution of green biomass (NDVI) up to the year 2000, that is 21 years after the fire, in areas that had been covered by *Pinus halepensis* forests before 1979. In this way, we were able to compare the predictions of the model with real NDVI data obtained from the images. The areas of higher predicted vulnerability to fire were always associated with larger observed decreases in the green biomass (NDVI). Moreover, the model predictions were consistent for any given plant community (for each type of pine forest, in this case).

A simplified version of this approach to assessing fire vulnerability was applied to Southern and Central Europe using the CORINE2000 map for vegetation types (modified with the European Forest Genetic Resources Programme – EUFORGEN-maps) and the PESERA model (http://eusoils.jrc.ec.europa.eu/ESDB_Archive/pesera/pesera_data.html) for soil erosion risk assessment (current situation, Fig. 6.4). The regional IPCC (2007) projections on drought and forest fires risk were used to estimate changes in fire vulnerability for the end of the twenty-first century (Fig. 6.4).

6.4 Confronting Fire Impacts in Light of Climate Change

6.4.1 Post-fire Restoration Techniques to Reduce Fire Risk

In general, long-term forest fire impacts requiring restoration actions are caused by: (a) Wildfires affecting fire-sensitive ecosystems in regions where natural fires are uncommon; (b) Unprecedented fire frequency or severity – altered fire regime – over fire-dependent ecosystems; (c) Unprecedented combination of fire regime and other disturbances over fire-dependent ecosystems.

Fire impacts on ecosystems should be analyzed in terms of the interactions between direct fire-induced processes and previous human-induced degradation processes. And post-fire rehabilitation should include a long-term perspective on recuperating ecosystem integrity according to ecological restoration concepts (van Andel and Grootjans 2006). In addition, as fire hazard is inherent in Mediterranean and other ecosystems of the world, fire prevention principles should be incorporated into post-fire rehabilitation strategies in order to anticipate new fire events that will probably occur sooner or later.

In a general sense, restoration may be applied to stop ecosystem degradation after fire and to promote its regeneration. The scope of the strategies presented further on concentrates on the conservation and recovery of natural ecosystems, thus excluding from the discussion the use of exotic species or the change of land use.

In Mediterranean ecosystems affected by wildfires the main objectives of restoration programs could be (Vallejo and Alloza 1998):

1. To conserve the soil, because in terrestrial ecosystems, soil is a non-renewable primary resource which may be exposed to the risk of degradation and erosion after fire. This objective includes hydrological cycle regulation.
2. To improve ecosystem resistance and resilience in relation to fire
3. To promote mature forests, especially hardwood forests, which are scarce in Mediterranean Basin landscapes.

In the context of climate change, these objectives can be grouped into two main strategies:

(a) Mitigation strategies, which include all actions taken to reduce and reverse the impacts caused by fires (soil and water conservation), and
(b) Adaptation strategies, which encompass all approaches taken to adjust, prepare, and accommodate to the new conditions created by climate change and a new fire regime (to promote biodiverse, mature, and more resilient forests).

Mitigation techniques aim at reducing fire impacts, and adaptation strategies and methods aim at reducing fire hazard and promoting ecosystem conservation in the perspective of new fire regimes. The focus of adaptation will be on strategies for fuel and vegetation management to reduce fire occurrence and severity, and increase ecosystem resilience, especially in highly vulnerable areas.

Strategies to cope with a more severe fire regime and harsher weather conditions should address both the social and the technical components of fire management. On the social side, emphasis should be placed on improving awareness and preparedness with the aim to reduce human-caused ignitions, especially at the rural-urban interface. On the technical side, several approaches should be considered on the basis of the various threats projected with respect to fire regimes and droughts (Table 6.1).

6.4.1.1 Mitigation Strategies

Post-fire rehabilitation measures are short-term actions designed to mitigate soil degradation until natural vegetation regeneration covers the burned area. The treatments mainly aim at controlling soil erosion and runoff and preventing off-site impacts of sediments and floods. The most common post-fire rehabilitation measures are grass seeding, mulching, and contour-felled logs, as hillslope measures, and check dams (straw bales, log, and rock dams) as channel measures (Napper 2006; Cerdà and Robichaud 2009).

Emergency Seeding

Emergency seeding consists of herbaceous seeding with or without application of a mulch layer designed to promote a rapid plant cover for soil protection until the

Table 6.1 Main strategies to face a more severe fire regime and increased drought

New threats linked to changing fire and climate	Prevention	Post-fire restoration
Uncertain response of species to climate change and fire regime	Specific fire prevention measures targeted to fire-sensitive ecosystems	Increasing plant species diversity in restoration projects – application of adaptive management principles
Increased land abandonment driving increasing old field colonization by pioneer seeder plant species	Fuel control combined with the introduction of resprouting woody plant species	Introduction of resprouting woody species (see Sect. 6.4.1.2 below)
Newly affected forests	Specific fire prevention measures targeting fire-sensitive ecosystems	Reintroduction of fire-sensitive species
Increased high-intensity fire occurrence	Fuel control in the landscape to try to prevent megafires	Promote landscapes with low combustibility
Increased drought	Improve early warning at high spatial resolution for fire danger	Application of techniques to improve water inputs and water use efficiency in restoration projects

natural regeneration stabilizes the burned area. Seed mixes often include grass and legume species selected for their rapid growth rate. These mixes combine annual species to provide quick cover, and perennial species to establish longer-term protection.

The effectiveness of emergency seeding on erosion control and vegetation recovery has been widely discussed (e.g., MacDonald 1989; Beyers et al. 1998; Keeler-Wolf 1995). Robichaud et al. (2000) reviewed a number of post-fire emergency rehabilitation projects conducted in USA from 1973 to 1998, and based on the same data, Beyers (2004) discussed the effectiveness of post-fire seeding and its impacts on plant communities. According to the available data, the effect of the seeding treatment on plant cover strongly depends on both the climatic conditions and the pre-fire vegetation community.

Mulching

Together with post-fire seeding, mulching is the most widely used post-fire rehabilitation treatment, and it is mainly aimed at providing a rapid soil protection. Mulches protect the soil from rainsplash, reduce overland flow, create mini-sediment dams, reduce compaction and crusting, and increase water infiltration (Abad et al. 2000; Robichaud et al. 2000). They may also benefit plant germination and growth by changing the microclimatic conditions at the soil surface, increasing soil moisture retention (Bautista et al. 1996). Mulches mimic the role of litter. In conifer forests, low and moderate severity burned sites often have trees that are only partially consumed by fire, leaving dead needles in the canopy that fall to the ground shortly after the fire and provide a natural mulch ground cover. Pannkuk and Robichaud (2003) showed that a 50% ground cover of dead needles reduced the interrill soil erosion by 60–80%. Thus, post-fire rehabilitation treatments should exclude areas where needles provide sufficient ground cover.

The main advantages of using mulches as a post-fire emergency treatment are: they are effective immediately after installation; they reduce erosion during the critical first post-fire year; mulch materials are readily available in most areas; and thick mulch can suppress the invasive weeds that commonly appear after fires.

A study in eastern Spain (Bautista et al. 2009) tested the effectiveness of new rehabilitation treatments (seeding, mulch, and seeding plus mulch) to mitigate soil degradation and enhance vegetation recovery in the short and medium term under Mediterranean climate in burned, highly degraded woodlands. The seeded mix included several native species from different functional groups aimed not only at protecting the soil from erosion and degradation but also at enhancing ecosystem function and resilience. The species selection consisted of native herbaceous, subshrub and shrub species. The applied mulch was chopped wood from forest pruning activities, which mimics the effect of in-situ chopped charred wood.

The combined Seeding plus Mulching treatment enhanced total plant cover throughout the two post-fire years studied, with plant cover values being around 50% higher than for the control (untreated) plots. However, neither the Seeding nor the Mulch alone influenced the vegetation recovery.

The plant cover increase in the Seeding plus Mulch treatment was due to the germination and growth of the seeded herbaceous species. Mulch cover highly increases seed germination probably by improving soil moisture retention. The mulch layer could also play an important role in reducing seed loss downslope. Subshrub and shrub species also germinated and survived as part of the Seeding plus Mulching treatment, but their contribution to plant cover were low due to their relatively low percent germination and growth rate; nevertheless, as these plant species rapidly sprout after fire, surviving individuals may greatly contribute to ecosystem resilience in case of further disturbances.

In contrast to other works reporting a decrease in native species richness due to seeding (e.g., Keeley 2004) or mulching (e.g., Kruse et al. 2004), in this case there was no adverse effect of seeding or mulch treatment on the number of native species. But the Seeding plus Mulch treatment tended to decrease the total plant cover of some of the most common obligate-seeder shrub species that constitute fire-prone communities and are target species for fuel control programs (Baeza et al. 2003).

With respect to soil protection, the treatments with mulch (seeding + mulch and mulch alone) greatly reduced soil surface compaction and enhanced water infiltration. Nearly 2 years after fire and treatment application, these effects were still significant. The mulch layer also greatly reduced post-fire soil loss: the non-mulched sites showed about 20 Mg ha year-1 of soil erosion during the first post-fire year while the mulched sites had negligible losses (Bautista el al. 2009).

6.4.1.2 Fire Adaptation Measures

Adaptation strategies include all restoration actions taken to assist natural resources (species, habitats, forest, watersheds) in accommodating the new conditions imposed by climate change.

Degraded ecosystems have lost some components of the original ecosystem; some of these are evident (certain structural species: main tree and shrub species and directly associated macrofauna) but most of them are unknown or uncertain (infrequent plant species, microorganisms, etc.). In addition, degraded ecosystems have modified some functions or their rates. The main restoration strategies suggested to face the new fire regime and climate change projections are (Vallejo and Alloza 1998; Vallejo et al. 2009):

- Planting of resprouting shrubs and trees to improve adaptation (resilience and/or resistance) in fire-prone shrublands (often old fields) dominated by seeders, which are usually fuel accumulators. These areas have a high degradation risk after repeated fires. Resprouting shrubs and trees are not only very resilient to fire; they also confer resilience to the ecosystem (Ferran et al. 1991). A number of native tall shrub species considered resilient to fire were introduced with success (Vallejo 1996) in subhumid and semi-arid conditions, where they were not present, to reduce fire hazard and to improve the resilience and structure of the ecosystem.
- Combined planting of pines and hardwoods (holm oak) for mature forest restoration (Pausas et al. 2004). This is intended to combine the fast growing features of pines in degraded lands with the high resilience provided by oaks. In the forestry tradition, this operation is envisaged sequentially (Montero and Alcanda 1993): to introduce first the pines and later on the hardwoods. We have investigated the simultaneous planting of both types of species to reduce the restoration costs and to facilitate the feasibility of these operations.
- Selective clearing of highly flammable shrublands combined with the planting of resprouter species to reduce fire hazard and to improve ecosystem resilience (Valdecantos et al. 2009).

According to the proposed strategy, restoration techniques should enhance the adaptation of burned areas to both new fire regimes and climate change. The main environmental limitation for a successful introduction of plants on degraded Mediterranean sites is water stress (Vallejo et al. 2000), and this is, of course, also applicable to other arid regions of the world. In Mediterranean regions, the most critical situations are located in the transition between semi-arid and dry subhumid climates, where high water stress is combined with a high disturbance rate, especially fire.

Plantations in drylands frequently show poor results, especially when species other than pines are used. Planted seedlings often show high mortality rates, particularly when significant rainfall events are absent for more than 3 months (Alloza and Vallejo 1999). During the last decades of the twentieth century, climatic conditions in the Mediterranean basin have been exceptionally adverse, with record high global temperatures (Castro et al. 2005). Hence, drought spells may have been major drivers in the large-scale plant mortality observed. As adverse climatic conditions are likely to persist in the near future (Millan et al. 2005), current restoration techniques must be updated to make them more efficient against future climate scenarios. In addition, there is a large body of evidence indicating that a key obstacle to plantation success is transplant shock, which is the intense short-term stress experimented by seedlings as they are transferred from favorable nursery conditions to the adverse field environment (Burdett 1990).

In the long-term, newly planted forests in strategic locations might produce a positive feedback on rainfall. At regional scale, precipitation may be affected by vegetation cover. Decreasing forest cover reduces evapotranspiration and this may cause precipitation to decrease in climate conditions with high regional water circulation, for example in Moist Tropical regions – e.g., Amazonia (Correia 2006), and in coastal areas around the Mediterranean under a dominant breeze circulation regime (Millan et al. 2005). For these situations, increasing forests might increase precipitation at regional scale.

Facing Increased Drought in Plantations

The options considered to reduce water stress in plantations are (Chirino et al. 2009):

- Increase water inputs in the ecosystem (Fig. 6.5)

  Irrigation. At present, irrigation is usually conducted for plantations in arid regions at the establishment stage, but this is unusual in the Northern Mediterranean countries. Reduced and highly cost-effective irrigation systems, especially passive irrigation techniques, have been developed and applied in warm deserts all over the world (see Bainbridge 2007).

  Fog collection. Foggy areas in drylands offer the possibility of a highly valuable and inexpensive water resource which could be used for several purposes, among them for creating water points in remote areas for combating fires and for irrigating plantations (Estrela et al. 2009).

  Runoff harvesting. Runoff harvesting is an ancient passive irrigation system employed on desert hillslopes. Soil preparation involves constructing microcatchments which collect and concentrate runoff in the plantation hole (De Simón et al. 2004; Fuentes et al. 2004; Chirino et al. 2009), thus increasing seedling survival and growth.

- Increase soil water availability – soil water holding capacity

  Soil water infiltration could be improved in degraded fine-textured soils by means of mechanical soil preparation techniques (transient improvement) and by the application of mulch (Valdecantos et al. 2009).

  Both the available soil water and the soil water holding capacity can be increased by means of mechanical soil preparation and additions of organic matter

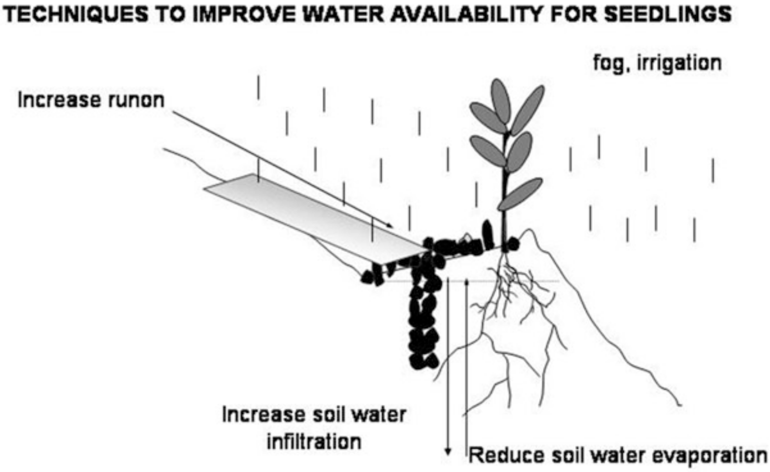

Fig. 6.5 Alternative/complementary techniques to improve water availability for seedlings in forest plantations

(e.g., biosolids, composted or uncomposted refuses: Querejeta et al. 2000), and hydrogels (Choudhary et al. 1995; Hüttermann et al. 1999). Hydrogels are probably more effective in coarse-textured soils (Seva et al. 2004). Biosolid application could have negative effects on seedling survival in relation to increased salinity and, if using semi-liquid sludges (slurry), physical problems in the soil as the sludge dries out (Valdecantos et al. 2004).

- Improvement of seedling atmospheric microhabitat: Tree-shelters

  High radiation levels and high evaporative demand characterize dry environments. Under these conditions, seedling survival is usually higher under the protection of a canopy than in open areas (Espelta 1996; Vilagrosa et al. 1997; Vallejo et al. 2006), but exceptions are not uncommon (Vilagrosa et al. 2001; Pérez-Devesa et al. 2004). The use of tree shelters may ameliorate harsh conditions and improve species survival and growth. These positive effects have been attributed to the fact that tree shelters modify the plant environment: they create a greenhouse microclimate with increases in temperature, relative humidity, and carbon dioxide levels (Burger et al. 1992).

  Most of the species tested under Mediterranean conditions showed a positive response to tree shelters (Costello et al. 1996), with the effect of tree shelters being more relevant, in terms of survival, in the driest regions.

- Improvement in seedling water use efficiency

  – Plant species selection
  – Plant quality manipulation

Plant Species Selection

Restoration usually consists of introducing one or several keystone species. These species, typically trees or tall shrubs, are supposed to play a critical role in determining ecosystem structure and functioning, acting as 'ecosystem engineers' (Jones et al. 1994) which are able to modify the habitat. It is assumed that these species would improve soil properties, create a forest floor habitat, improve the microclimate, indirectly facilitate the importation of seeds by birds and so on. Finally, the introduction of a woody species would not be enough for its complete establishment if symbionts, pollinators or dispersers were lacking (Hobbs and Norton 1996). Mycorrhiza and/or rhizobacteria inoculation in the nursery is a way to ensure efficient symbiosis for seedlings to be introduced (Barea and Honrubia 2004).

Within the set of native species found to be suitable for restoring a given habitat, we have to select the ones that best fit the management objectives proposed. In the case of post-fire restoration we would select woody resprouters according to the above-stated objectives of increasing fire ecosystem resilience and reducing fire risk. Moreover, given the projection of increased drought we would prioritize the use of drought-resistant native woody resprouter species, ecotypes, and genotypes, especially for very degraded sites and dry microclimates.

Plant Quality: Nursery Cultivation

Suitable restoration techniques may help the seedlings to get through the transplant shock and the first summer drought, and thus establish successfully. These include several nursery techniques that take into account the morpho-functional characteristics of seedlings to promote their resistance to drought and increase their acclimation to the reforestation site.

The main technical elements in the nursery culture are:

- Substrates or growing media.
- Containers.
- Drought preconditioning.

Substrates or Growing Media

The characteristics of the growing media are important for good root development, which is considered a key step in the success of a plantation (Peñuelas and Ocaña 1996). Nowadays, the growing media recommended for use include standard components like peat moss or other alternative organic materials such as coconut fiber, composted

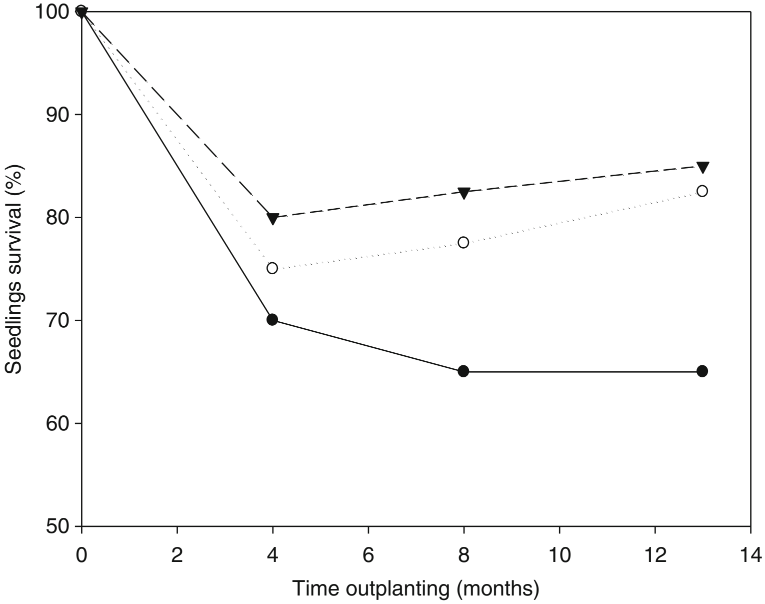

Fig. 6.6 Survival of *Quercus suber* seedlings after 13 months in outplanting (Control substrate: *black circle* and *solid line*; hydrogel stockosorb – 0.7%: *white circle* and *dotted line*; hydrogel stockosorb – 1.5%: *black triangle* and *long dashed line*) (Chirino et al. 2009)

sawdust, bark, or composted sewage sludge in combination with a mixture of aeration materials like perlite, sand, vermiculite, tuff or polystyrene (Landis et al. 1990).

A mixture with low proportions of other substances like hydrogels or some clays (sepiolite) can increase the water holding capacity of the plug, thus providing the seedlings with higher water availability for a longer period of time in the field. This fact can be especially important in climates with high rainfall variability, like the semi-arid climate. Field results ratified the beneficial effects that mixing hydrogels into the substrate had on seedling performance (Fig. 6.6).

Containers and Root Systems

Several studies have related the planting stock quality of the seedlings to the type of container used (Landis et al. 1990; Peñuelas 1995; Vilagrosa et al. 1997; Dominguez et al. 1999). An appropriate container should have a shape and dimension that allow the seedling to develop correctly, especially its root system. In general, high-volume containers (300 cm^3 or more) are recommended for reforestations in dry and semi-arid climates and for species with high root-to-shoot ratio, because they enable the good root system development that is critical during the first stages after plantation. According to our experience, long containers are preferred for species that develop a tap root, like *Quercus* sp., whilst wider containers are recommended for species that show important secondary-root development.

Drought Preconditioning

Drought preconditioning is one of the main techniques used to precondition seedlings against drought stress by means of induction of mechanisms for drought resistance. However, because Mediterranean plant species have ontogenetically high resistance to stress conditions, the common techniques of drought preconditioning (i.e., short-term preconditioning) applied to species characteristic of humid or subhumid climates are not very effective when applied in Mediterranean dry or semiarid species (Fonseca 1999; Vilagrosa et al. 2003). Experiments carried out by CEAM showed that long-term drought preconditioning in the nursery promotes higher benefits to plant morpho-functional characteristics than short-term preconditioning (Rubio et al. 2001; Chirino et al. 2003). On the other hand, the response of species to drought preconditioning seems to depend on the plant species. For example, species like *Pistacia lentiscus* are very responsive to preconditioning whilst species like *Quercus coccifera* are not. Probably, this type of response is related to the drought strategies developed for each species (Vilagrosa et al. 2003).

The main responses obtained in drought preconditioning experiments are higher root-shoot ratio in the nursery (Chirino et al. 2003), changes in allocation patterns (i.e., higher fine-root colonization in the plantation hole and lower above-ground development) (Rubio et al. 2001; Chirino et al. 2003), higher tolerance to drought conditions through higher elasticity of cell membranes (Rubio et al. 2001) or better photochemical efficiency (Vilagrosa et al. 2003), drought-avoidance mechanisms like higher root hydraulic conductivity to supply water to leaves, higher leaf capacitance to water and lower transpiration rates (Villar-Salvador et al. 1999; Vilagrosa et al. 2003). Although drought preconditioning does not improve survival, seedlings are generally better adapted to field conditions (Rubio et al. 2001). For example, preconditioned seedlings of *Q. suber* and *P. lentiscus* showed lower biomass reduction due to summer drought than well irrigated seedlings.

6.4.2 Landscape Dimension in Fire Prevention and Restoration

Efficient and sustainable fire management policies (and particularly those related to fire prevention and post-fire restoration) need to be planned at regional and landscape levels (Fernandes 2006; Finney 2007; Schmidt et al. 2008), and their effects should also be evaluated at wider spatial and temporal scales than those resulting from single fire events (Lloret 2008). Such upscaling-based approaches may also allow better analyses of the interactions between wildfires and the environmental changes that take place at a global scale.

One of the main questions that current fire-related research needs to address is how to manage fire-prone landscapes under climate change in order to reduce both the future fire risk and the vulnerability of landscapes to fire (i.e., to increase their resilience to fire). The hypothesis underlying this research is that appropriate landscape-level fuel management (resulting in the long-term modification of the structure, composition and spatial configuration of plant communities) could alter both the ecosystem-level successional trajectories and the landscape structure, facilitating a dynamics towards more resistant (less flammable) and resilient ecosystems and landscapes.

It is broadly accepted that not only the nature of fuels and their moisture content, but also their spatial distribution in the landscape, among other factors, have a strong influence on fire spread and behavior (Turner and Romme 1994; Mouillot 2001; Duguy et al. 2007a, b), and, thus, on potential fire impacts. Higher degrees of landscape fragmentation (i.e., a more fine-grained landscape) have often been observed to limit fire propagation and moderate fire behavior (Minnich 1983; Knight 1987; Duguy et al. 2007a, b). Traditionally, it is believed that disturbances are more likely to spread across a homogeneous area (Wiens et al. 1985), but the opposite also occurs (Turner 1987). It has likewise been proposed that, in highly fragmented landscapes, disturbances require a higher boundary-crossing frequency and a more convoluted route and, therefore, spread less easily (Turner and Romme 1994; Forman 1995). In the case of fires, it is generally accepted that greater landscape heterogeneity retards fire propagation (Minnich 1983; Wiens et al. 1985; Knight 1987), although landscape pattern may have little influence on crown fire behavior when burning conditions are extreme (Turner et al. 1994: Keeley et al. 1999), which might become more frequent in the future. Indeed, no universal correlation has been found between fire propagation rate and landscape heterogeneity (Morvan et al. 1995).

In the last decades, the intense land abandonment that took place in most northern Mediterranean landscapes generally caused the disappearance of the former mosaic-like landscape structure, conformed by small patches of natural vegetation in the matrix of agricultural-dominated land (Lloret et al. 2002; Duguy 2003). The increase in the continuity of natural vegetation patches led to a loss of landscape heterogeneity and fragmentation (Lloret et al. 2002), which, in turn, favored the spread of large and intense fires which have often resulted in a further homogenization of these landscapes (Debussche et al. 1987; Vos 1993; Vázquez and Moreno 1998; Lloret et al. 2002). These trends will likely be maintained, or even enhanced, under future conditions (Moreno 2009), and interconnected highly-flammable patches of increasing size might result in a strong increase in the risk of large fires.

An effective fuel management policy in relation to fire control requires the development of models and procedures that optimize its effectiveness, both spatially and temporally, and that minimize the arbitrariness in its planning process (Hiers et al. 2003; Fernandes 2006). The temporal efficiency should aim to extend the interval between treatments (Baeza and Duguy 2009), whereas the spatial efficiency should aim to minimize the ratio of area treated in the landscape to the expected benefits (i.e., decrease the risk of large fires) (Loehle 2004).

Fire management has to be assessed through costs, benefits and damages in the long term (Pausas and Vallejo 2008). Given the potentially high costs of landscape-level fuel treatments for fire control or for enhancing fire resilience, it is essential to plan these actions through spatial optimization procedures (Hiers et al. 2003; Finney 2004). In the context of climate change, it will be particularly crucial to apply cost/benefit analyses to optimize the resources needed for fire mitigation and restoration actions (Martell 2001; Moreno 2005).

Forman and Collinge (1996) described the "aggregate-with-outliers" model as an effective landscape structure in relation to fire spread control and biodiversity enhancement. To reduce both fire occurrence and fire spread, while promoting the expansion of forest in the landscape, these authors proposed three main approaches focused on landscape pattern:

1. Minimize the sites that are especially susceptible to fire ignition
2. Increase landscape spatial heterogeneity
3. Increase barriers or filters that inhibit fire spread.

Given the difficulty and obvious limitations in implementing large-scale and long-term experiments on fuel treatment, and in assessing their performance in relation to real fires, our indications as to the effectiveness of this "*aggregate-with-outliers*" model, or of any other proposed landscape structure in relation to fire control, mostly come from recent theoretical and modeling studies (Hirsch et al. 2001; Hiers et al. 2003; Finney 2004; Finney et al. 2007). Many questions related to fuel treatments, such as their optimized placement in the landscape or their potential effectiveness under alternative climate change scenarios, can only be addressed through modeling approaches (Finney 2001b).

Most modeling-based studies confirm that fuel treatments need to be designed and implemented at a landscape level in order to significantly modify the spatial pattern of fire spread and behavior (Finney 2001a, b; Stratton 2004; LaCroix et al. 2006; Duguy et al. 2007a, b). A strategic placement of theoretical treatments in the landscape results in a more effective reduction of fire propagation and a more moderate fire behavior than a random or arbitrary arrangement of treatments (Finney 2001a, 2003, 2007; Loehle 2004; Duguy et al. 2007a, b; Schmidt et al. 2008). The overall efficiency of the action is also improved, i.e. we obtain a larger ratio of area saved (non-burned) to total area treated in the landscape (Loehle 2004).

Real landscapes are characterized, however, by their complexity and fine-scale variability in terms of fuels, topography, and weather, which produce complex patterns of fire behavior and effects (Finney 2004). Analytical solutions to the optimization of fuel treatment placement on real landscapes are still under investigation.

The combination of spatial technologies (GIS) and fire modeling, and their integration with ecological principles, multi-criteria decision methods and other models (vegetation, landscape, watershed, treatments) have led to the development of spatial decision support systems (SDSS) to aid in the complex multi-objective process of forest management in fire-prone ecosystems (Hiers et al. 2003; Sisk et al. 2006). SDSSs can help land managers in designing dynamic and sustainable landscape-specific prevention and restoration plans under different scenarios of global change. We present here an innovative GIS-based procedure for fuel treatment optimization in the landscape, which we developed in the framework of the SDSS ForestERA (http://www.forestera.nau.edu/). We implemented the spatial procedure in a test area (Ayora, Valencia) for which we had previously parameterized the FARSITE model (Duguy et al. 2007a, b) in relation to a set of management objectives (i.e., minimization of fire risk, promotion of landscape resilience to fire, promotion of biodiversity, conservation of soil and water). We then carried out a preliminary exploration of the effectiveness of various fuel scenarios for controlling fire propagation and moderating fire behavior (Duguy et al. 2009).

We first carried out an assessment of the risks that the studied landscape might face from the threat of catastrophic wildfire and its consequences. We identified Fire Hazard (assessed through the variable Heat per unit of area, in kJ m^{-2}), Crown Fire Behaviour and Ecological Vulnerability to Fire (which included post-fire erosion potential) as the three key risk factors. The latter variable was assessed through a model of ecological vulnerability to forest fires in Mediterranean ecosystems (Duguy et al. 2012), as explained in Sect. 6.3. These three layers were combined in ArcGIS to create a composite risk layer (the layer *Risks*, Fig. 6.7). We then identified and prioritized features or areas of particularly high importance in the landscape, i.e., areas in critical need of protection from catastrophic wildfires (Fig. 6.8a). We combined this information with the previous assessment of the risks through overlay and buffering processes to create the final layer *Values* (Fig. 6.8b). A final overlay was generated through the combination of the *Values* and *Risks* layers. The various resulting combinations were evaluated through an expert knowledge-based decision table, leading to the final prioritization map (Fig. 6.9). We finally created various fuel scenarios aiming to minimize fire hazard through the reduction of fuel loads in some of the areas that the previous analysis had identified as most in need of management attention. We simulated both extensive hazardous fuel removals (fire prevention treatment) and the introduction of wooded patches in different successional stages (fire restoration action). We modeled fire behavior with FlamMap (Finney 2006) and FARSITE (Finney 1998) in all scenarios and compared them using four outputs from those programs: the rate of fire spread ($m.min^{-1}$), the fireline intensity (kW m^{-1}), the heat per unit of area (kJ m^{-2}), and the crown fire activity.

Preliminary results confirm that fuel spatial distribution is a key parameter influencing fire propagation and behavior across the landscape. Minor or moderate changes in the spatial pattern of fuels may cause substantial changes in fire behavior.

In the studied landscape, concentrating fuel reduction treatments on heavy surface fuel types, such as fuel model 4-type shrublands, which favor the spread of intense fires (Anderson 1982), allowed us to substantially moderate fire behavior and, thus, to reduce potential fire-caused damages to the aboveground vegetation and to the whole ecosystem.

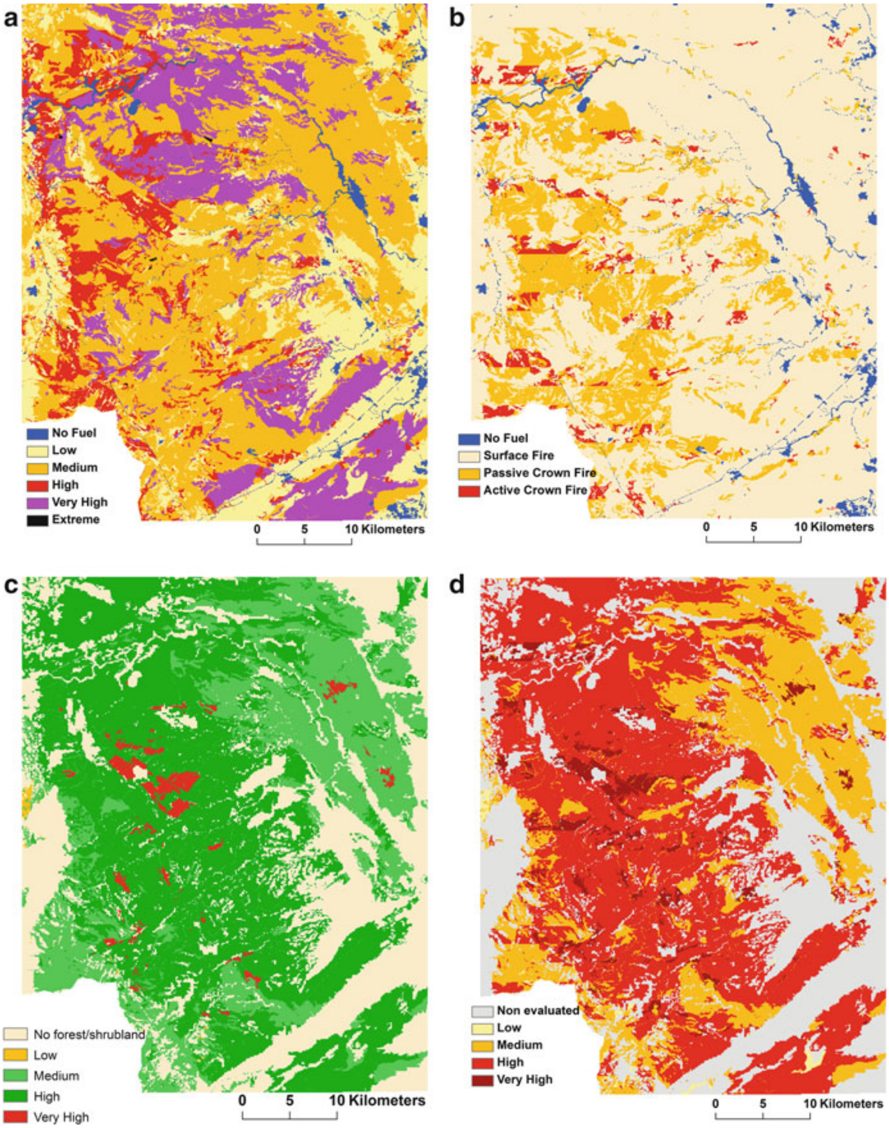

Fig. 6.7 Composite Risk layer (**d**) developed by overlaying Fire Hazard, or predicted Heat per Unit Area in kJ m^{-2} (**a**), Crown Fire Behaviour (**b**) and Ecological Vulnerability (**c**) layers. In (**a**): Low (<3,000); Medium (3,000–10,000); High (10,000–20,000); Very high (20,000–32,000); Extreme (≥32,000) kJ m^{-2}

Simulations confirmed that the creation of a more fine-grained landscape through the fragmentation of large fire-prone areas (fuel model 4) with woodlands in different successional stages could be very effective for reducing fire size and, in most cases, burning conditions. However, habitat fragmentation may have negative effects on biodiversity; therefore both fire prevention and biodiversity conservation should

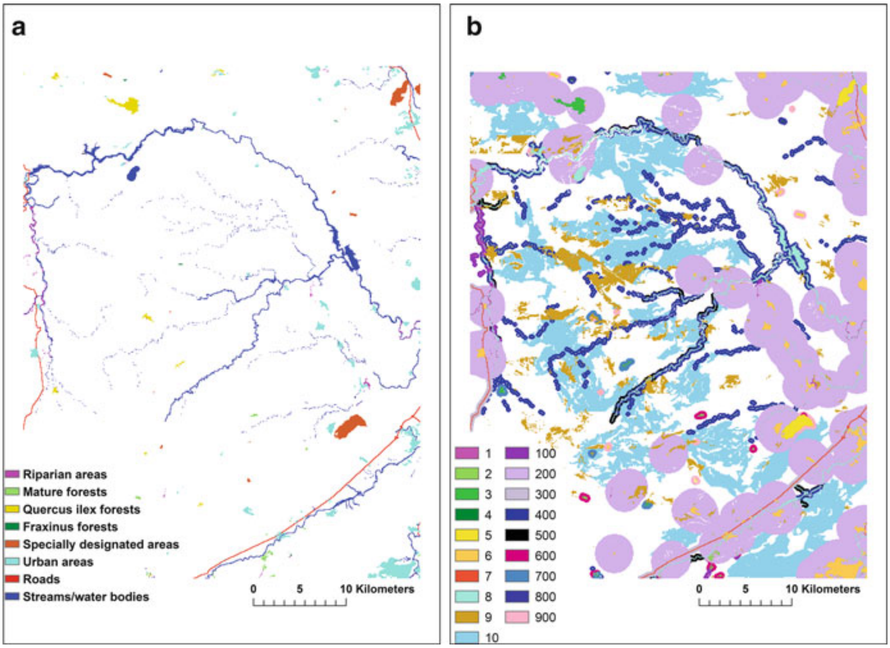

Fig. 6.8 Critical features in need of protection from wildfire (**a**) and Areas of importance generated through overlay/buffering processes (**b**). In (**b**), we include critical features (from (**a**)) and their buffers, adding all areas at very high risk and the largest continuous areas (>1,000 ha) at high risk, after the composite risk map (categories 9 and 10, respectively). The first 8 legend numbers in (**a**) correspond to those in (**b**). Buffered areas in (**b**): 100: Riparian; 200: Urban; 300: Road; 400: Water body; 500: Stream; 600: Mature forest; 700: *Quercus ilex* forest; 800: *Fraxinus* forest; 900: Specially designated areas

be integrated in the planning process. In the absence of fire, the landscape structure that would result from these actions would probably enhance the extension of woodlands in the medium-to-long term, thus promoting biodiversity.

6.5 Concluding Remarks

Climate change is expected to trigger a more severe fire regime and more difficult conditions for ecosystem restoration after fire. At present, strategies and techniques are available to address the long-term ecological restoration of degraded ecosystems/landscapes after wildfires. Nevertheless, the restoration process is subject to many uncertainties as the restorationist cannot foresee all the possible environmental circumstances that might affect the success of a restoration, nor is all the knowledge available on the ecosystem to be restored or on the potential multiple interactions between introduced plants, soil properties, extant organisms and so on. Climate Change introduces new uncertainties both

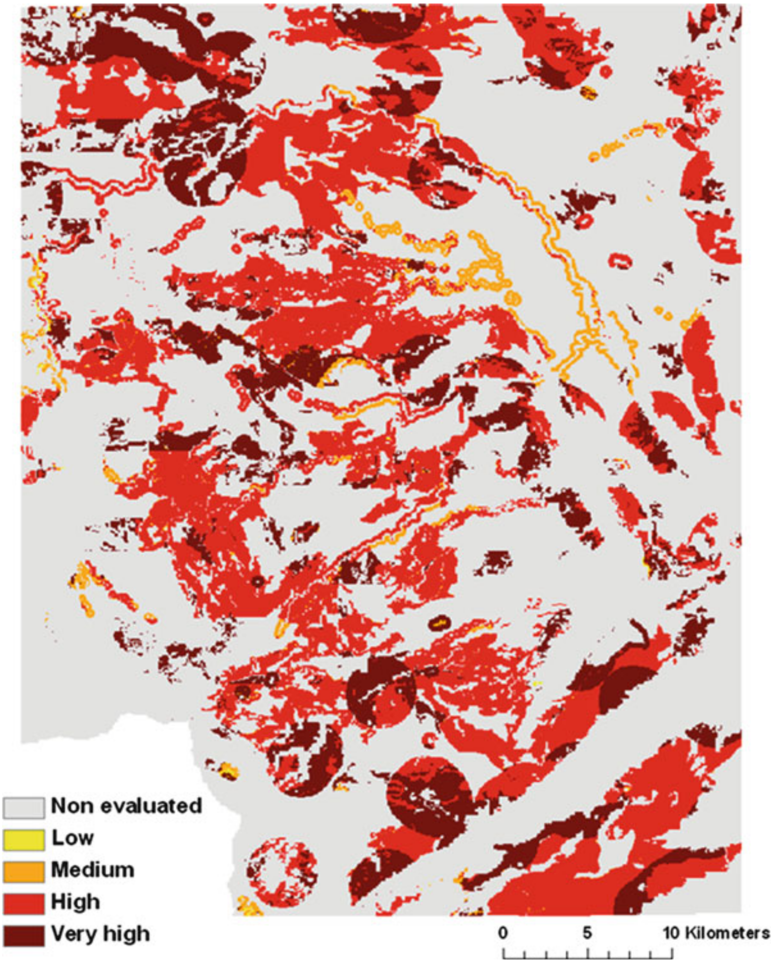

Fig. 6.9 Priority areas for management attention. Non fuel areas (urban, roads, streams and water bodies) were excluded as well as specially designated areas

in its magnitude and in its consequences on wildfires and organisms. Therefore, restoration projects should follow adaptive management principles (Whisenant 1999), including monitoring and the possibility of rectifying or amending the restoration actions as we learn from the dynamics of the restored land. The shortcoming of this approach is that it requires further and longer-term funding.

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Chapter 7
Climate Induced Effects on Livestock Population and Productivity in the Mediterranean Area

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Abstract The ability of livestock to breed, grow, and lactate to their maximal genetic potential, and their capacity to maintain health is affected by climatic features. Climate affects animals both indirectly and directly. Indirect effects include those that climate exerts on grassland and crops, and on water availability. Additionally, climate may also affect survival of pathogens and/or their vectors, which may cause risks for health in animal and human populations. Analysis of

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Nicola Lacetera, Maria Segnalini, Umberto Bernabucci, Bruno Ronchi, Andrea Vitali and Alessandro Nardone wrote the whole chapter with the exception of the Sect. 7.3. The Sect. 7.3 was co-authored by Annelise Tran, Helene Guis, Cyril Caminade, Carlos Calvete, Andrew Morse and Matthew Baylis.

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meteorological and entomological data indicate that climate has favored invasion of *Culicoides imicola* into new regions of the Mediterranean basin where it was previously absent. The meteorological complex has not been studied precisely to determine the optimal combination for normal physiological functions and behavioral actions, health, welfare, and maximal performance of livestock. An index for measurements of environmental warmth and its direct effects in livestock is the Temperature Humidity Index (THI). The THI combines values of temperature and humidity and has been widely used as a bioclimatic indicator of thermal stress in livestock. Studies carried out within the CIRCE project permitted to characterize the Mediterranean basin in terms of THI and to establish its strong heterogeneity even if most of the area is at risk of heat stress for farm animals during summer. The same studies also indicated that the area will be also subjected to warming and extreme climate events, which may aggravate the consequences of hot weather in livestock. Comprehensive frameworks need to be developed to identify and target adaptation options that are appropriate for specific contexts.

Keywords Livestock • Mediterranean basin • Temperature humidity index • Health • Productivity

7.1 Introduction

In the last decades the livestock sector has significantly evolved worldwide. Global meat and milk production increased significantly mainly due to a growing demand of food of animal origin, especially in the developing countries (Boyazoglu 2002; http://www.fao.org/worldfoodsituation/en/).

An analysis of data on stock of farm animals and meat and milk production in the Mediterranean basin reveals a strong heterogeneity of the area for the ruminant sector (FAOSTAT 2010). The Mediterranean area we refer to is delimited by the 10° West and 40° East meridians, 28° and 48° North parallels, and includes fully or partially over 20 countries that are part of three continents: Europe, Asia and Africa. These territories are strongly dissimilar from a socio-economic (size of population, food consumption and alimentary habits, culture, and technological development) and geophysics (temperature, rainfall, altitude, etc.) point of view (Frei and Schär 1998; Nardone 2000; de Rancourt and Mottet 2006), and this contributes to explain the heterogeneity of the livestock sector.

In the following sections we will discuss results from recent studies which were aimed at characterizing the Mediterranean area on the basis of a bioclimatic index in order to establish whether the direct effects of climate on animal physiology, behavior and health may at least partially explain the heterogeneity of the livestock sector in the basin, and also to evaluate whether bioclimatic constraints may limit the expansion, efficiency, profitability and sustainability of the livestock industry in the basin.

7.2 Indirect Effects of Climate on Livestock

The ability of livestock to breed, grow, and lactate to their maximal genetic potential, and their capacity to maintain health is strongly affected by climatic features.

Climate may affect animal production both indirectly and directly. Indirect effects include primarily those that meteorological factors exert on growth and quality of grassland and crops, and on water availability (Ringler et al. 2010). Additionally, climate may also affect survival of pathogens and/or their vectors, which may cause risks for health in animal and human populations (Nardone et al. 2010). In the following Sect. (7.3) the impact of climate features and climate changes on the emergence of vector-borne diseases will be emphasized by presenting the case of bluetongue in the Mediterranean basin.

The ruminant industry is deeply linked to land use and it furnishes about 60% of the total protein production in the whole Mediterranean area (Nardone et al. 2004). In terms of ruminant production there are strong differences between the northern and southern Mediterranean countries (Tables 7.1 and 7.2). The favorable climate of the northern part of the basin leads to have cattle herd in the northern countries greater than in southern countries where dry climate and poor grassland are more suitable to small ruminants production (sheep and goats). Furthermore, it must be considered that the expected climate change will surely worsen the existing problems of desertification, water scarcity, forages or crops production, and will also introduce new threats to animal and human health. Livestock production is likely to suffer from deterioration in the quality of rangeland associated with higher concentrations of atmospheric carbon dioxide and to changes in areas of rangeland as climate boundaries move northwards. The most serious impacts are likely to be observed in North African and eastern Mediterranean countries. In the Mediterranean basin, the area of unproductive shrubland is expected to expand, while in North Africa and the Near East, most of the steppe rangeland could give way to desert by 2050 or earlier (Ragab and Prudhomme 2002). At the scale of the Mediterranean basin, it is estimated that by the end of the century the increase of temperature will range between about 2 and 6.5 °C (IPCC 2007).

7.3 Impact of Climate Change on the Emergence of Vector-Borne Diseases – The Case of Bluetongue in the Mediterranean Basin

Over recent decades, a great number of emergences or resurgences of vector-borne diseases have been described across the world: some arthropod-borne infections have been recognized for the first time, some have become of considerable public health importance, and others have spread geographically (Gratz 1999). Climate change is often cited among the factors involved in the emergence of vector-borne

Table 7.1 Stock of ruminants in countries of the Mediterranean region (year 2008)

	Cattle (head)	Buffaloes (head)	Sheep (head)	Goats (head)	Camels (head)
Albania	577,000[a]	120[a]	1,853,000[a]	876,000[a]	–
Bosnia and Herzegovina	459,218	13,000[a]	1,030,510	70,392	–
Croatia	467,077	–	645,992	91,902	–
France	19,887,458	–	8,187,329	1,224,391	–
Greece	628,000[b]	1,392[a]	8,904,000[b]	5,455,000[b]	–
Italy	6,283,000	294,000	8,237,000	920,000	–
Malta	19,442	–	12,315	6,227	–
Montenegro	109,300	–	222,200	–	–
Portugal	1,442,800	–	3,144,600	495,900	–
Serbia	1,057,000	–	1,605,000	154,575	–
Slovenia	479,851	–	131,180	28,228	–
Spain	6,020,200	–	19,952,300	2,959,300	–
European zone	***37,430,346***	***308,512***	***53,925,426***	***12,281,915***	***0***
Cyprus	54,900[a]	–	267,300	318,400	–
Israel	416,000	–	430,000	90,000	5,300[a]
Jordan	79,380	100[a]	2,300,000[a]	1,083,330	5,000[a]
Lebanon	77,400[a]	–	330,000[a]	450,000[a]	440[a]
Syrian Arab Republic	1,168,330[a]	5,200[a]	22,865,400[a]	1,561,260[a]	24,500[a]
Turkey	11,036,753	84,705	23,974,600	5,593,560	1,057
Asian zone	***12,832,763***	***90,005***	***50,167,300***	***9,096,550***	***36,297***
Algeria	1,650,000[a]	–	20,000,000[a]	3,800,000[a]	290,000[a]
Egypt	5,023,162	3,560,000	4,672,000	4,237,270	107,372
Libyan Arab Jamahiriya	130,000[a]	–	4,500,000[a]	1,265,000[a]	47,000[a]
Morocco	2,814,000	–	17,077,700	5,117,900	45,000[a]
Tunisia	694,660	–	7,300,940	1,496,290	232,000[a]
African zone	***10,311,822***	***3,560,000***	***53,550,640***	***15,916,460***	***721,372***
Mediterranean region	**60,574,931**	**3,958,517**	**157,643,366**	**37,294,925**	**757,669**

Source: FAOSTAT (2010)
[a] Estimated and calculated data
[b] Semi-official and mirror data

diseases (Purse et al. 2005; Patz and Olson 2006). Indeed, insect vectors (or more generally arthropod vectors) are very sensitive to their environments, which determine their presence, density and behavior. As a consequence, meteorological (e.g. temperature, rainfall, humidity) as well as landscape factors may greatly influence the spatial distribution of vectors and the diseases they transmit.

Bluetongue virus (BTV) is transmitted by some species of biting midges of the Culicoides genus (Diptera: Ceratopogonidae). BTV infects all ruminant species, but only improved breeds of sheep and cattle and some species of deer tend to develop severe signs. Owing to its widespread distribution, its ability to spread rapidly and

Table 7.2 Meat and milk production from ruminant species in countries of the Mediterranean region (year 2008)

	Cattle and buffalo meat (tons)	Sheep and goat meat (tons)	Camel meat (tons)	Cow and buffalo milk (tons)	Sheep milk (tons)	Goat milk (tons)	Camel milk (tons)
Albania	49,775[a]	22,000[a]	–	890,010[a]	75,000[a]	73,000[a]	–
Bosnia and Herzegovina	26,335	1,622	–	737,199	18,774	–	–
Croatia	35,700[b]	2,716[a]	–	826,000	8,000	14,000	–
France	1,479,300	97,400	–	24,516,320	247,190	572,600[b]	–
Greece	68,115[b]	146,000[b]	–	800,110[a]	785,000[b]	505,000[b]	–
Italy	1,059,314	59,699	–	11,505,910	564,550	48,520	–
Malta	1,479	140[a]	–	39,910	2,020[b]	1,428	–
Montenegro	2,845[a]	674	–	168,600[a]	9,420[a]	–	–
Portugal	108,540	25,889[a]	–	1,961,000	92,000	28,310	–
Serbia	99,000	23,000	–	1,580,000	14,400	–	–
Slovenia	36,944	2,078[a]	–	666,472	418	1,412	–
Spain	658,334	166,233	–	6,339,900	441,400	592,800	–
European zone	***3,625,681***	***547,451***	***0***	***50,031,431***	***2,258,172***	***1,837,070***	***0***
Cyprus	4,248	7,208	–	151,400	15,670	23,665	–
Israel	116,554	9,302[a]	80[a]	1,293,770	18,200	20,480	–
Jordan	14,000[a]	22,620[a]	240[a]	260,000[a]	87,000[a]	21,000[a]	–
Lebanon	46,530[a]	12,139[a]	–	183,600[a]	24,700[a]	34,000[a]	–
Syrian Arab Republic	65,783[a]	212,995[a]	333[a]	1,707,460[a]	873,673[a]	96,967[a]	–
Turkey	371,953	317,000[a]	14	11,286,622	746,872	209,570	–
Asian zone	***619,068***	***581,264***	***667***	***14,882,852***	***1,766,115***	***405,682***	***0***
Algeria	123,000[a]	201,000[a]	3,850[a]	1,500,000[a]	220,000[a]	230,000[a]	12,500[a]
Egypt	590,000[a]	60,500[a]	34,900[a]	5,852,002	93,000[a]	15,100[a]	–
Libyan Arab Jamahiriya	6,300[a]	34,000[a]	3,700[a]	130,000[a]	56,000[a]	15,400[a]	2,000[a]
Morocco	172,000	142,000	2,200[a]	1,700,000	27,000[a]	34,000[a]	3,800[a]
Tunisia	53,000	62,700	1,400[a]	1,046,000	18,500[a]	13,200[a]	1,000[a]

(contiuned)

Table 7.2 (continued)

	Cattle and buffalo meat (tons)	Sheep and goat meat (tons)	Camel meat (tons)	Cow and buffalo milk (tons)	Sheep milk (tons)	Goat milk (tons)	Camel milk (tons)
African zone	***944,300***	***500,200***	***46,050***	***10,228,002***	***414,500***	***307,700***	***19,300***
Mediterranean region	**5,189,049**	**1,628,915**	**46,717**	**75,142,285**	**4,438,787**	**2,550,452**	**19,300**

Source: FAOSTAT (2010)

[a] Estimated and calculated data

[b] Semi-official and mirror data

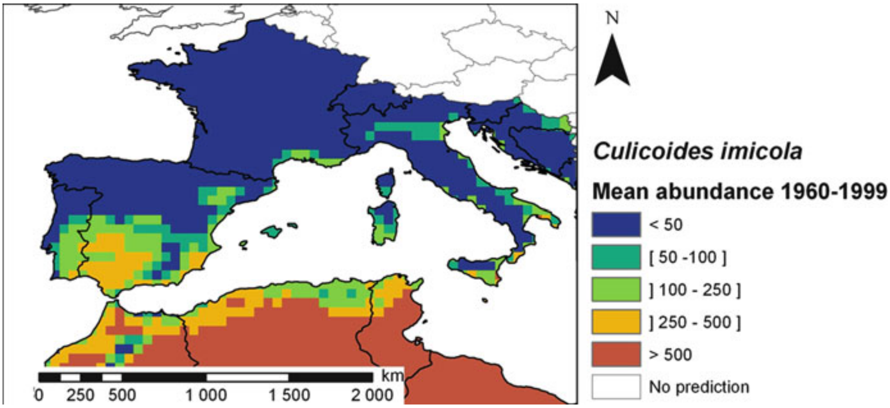

Fig. 7.1 Abundance of the biting midge *Culicoides imicola* derived from climatic data, 1960–1999, Western Mediterranean basin

its major direct economic consequences, BT is a notifiable disease to the OIE (World Organisation for Animal Health).

The disease, which seems to have originated from the African continent, is believed to have been confined in Africa for several decades. Until recently Europe was BT-free. The year 1998 saw the first of a number of BTV introductions into Europe which altogether have caused the most severe outbreak of BT on record (Gomez-Tejedor 2004), resulting in the death of more than 1.5 million sheep (FAO 2006).

In the Mediterranean Basin, BT emergence is thought to have been largely fuelled by the northward extension of the main Afro-Asian BTV vector *Culicoides imicola* (Mellor and Boorman 1995; Purse et al. 2005) from North Africa to Southwest Europe. Indeed, passive dispersal by winds of Culicoides individuals may reach several hundreds of kilometers overseas and has a strong impact on the spread of BTV (De Liberato et al. 2003; Alba et al. 2004; Gerbier et al. 2008).

Predictive maps of *C. imicola* presence or abundance can be derived from statistical analyses of entomological data (Culicoides are usually sampled in the field using light traps) and environmental variables related to temperatures, precipitation and vegetation (e.g. Wittmann et al. 2001; Calistri et al. 2003; Tatem et al. 2003; Calvete et al. 2008).

For example, using data provided by the Spanish bluetongue national surveillance program on Culicoides trap catches set in livestock holdings from 2004 to 2006, detection and abundance models of *C. imicola* were developed following the methods of Calvete et al. (2008). The model, based on four climatic variables (mean annual temperature, annual precipitation, their variation coefficients), allows mapping the geographic distribution of *C. imicola* across the Mediterranean Basin.

Figure 7.1 represents the abundance of *C. imicola* (number of insects/trap) averaged on the 1960–1999 period. This map reproduces well the past situation in Spain and Portugal, the only parts of southwest Europe in which the species was known to

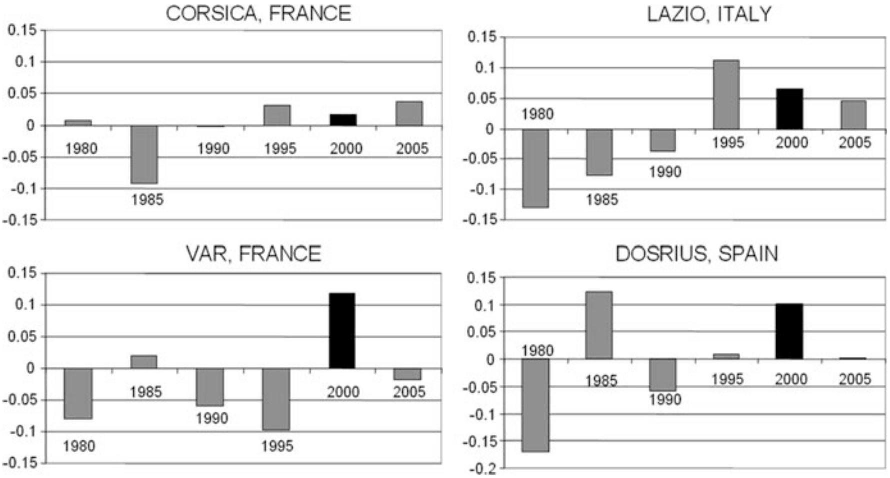

Fig. 7.2 Changes in the modeled abundance of *Culicoides imicola*, bluetongue vector, in four sites (Corsica and Var, France; Lazio, Italy; Dosrius, Spain) where it was detected for the first time between 2000 and 2005. The changes are expressed as relative anomalies with respect to the reference mean (1960–2009) for different 5-years periods. In *black*: 5-year period in which *C. imicola* was first detected

occur before 1998 (Mellor et al. 2008), as well as in the Maghreb region, where *C. imicola* was known to occur in Morocco and Algeria (Baylis et al. 1998).

Climate models have been developed within the CIRCE project to simulate past and future climatic data sets. For example, the METEO-FRANCE model, based on one global atmospheric model and two oceanic models allows the simulation of monthly temperatures and precipitation on a 50 km grid (Somot et al. 2008, 2009).

Integrating the simulated rainfall and temperature data into the statistical model of *C. imicola* abundance allows the visualization of the evolution of the probability of presence of this species in recent decades.

For example, Fig. 7.2 illustrates the changes since 1980 in the probability of presence of *Culicoides imicola* (compared to the 1960–2009 average) in four sites, two in France (Corsica and Var), one in Italy (Lazio) and one in Spain (Dosrius, Barcelona). In these sites, the insect has been described for the first time in 2000, 2004 and 2002, respectively (Delécolle and de La Rocque 2002; Baldet et al. 2005; De Liberato et al. 2003; Sarto i Monteys and Saiz-Ardanaz 2003).

According to the simulations, the anomaly of abundance (difference to the 1960–2009 mean abundance) was positive for the 5-year period corresponding to the first detection of *C. imicola* in the four areas. In most cases, a significant increase of the anomaly of abundance occurred between 1980 and 2009 in these four sites and the abundance anomaly became positive a few years before the species was detected. These results suggest that climatic factors have favored the invasion of *C. imicola* into new regions where it was previously absent.

The retrospective study of variation of abundance of *C. imicola*, the main BT vector in the Mediterranean Basin, provides strong evidence that climate has played an important role in the recent emergence of the disease, by favoring the geographical spread of *C. imicola* to new areas. Recent works on the phylogeny of *C. imicola* sustained these conclusions (Calvo et al. 2009). To improve the predictions, entomological studies are needed to assess the accuracy of the model and if necessary to develop more precise abundance models for the whole Mediterranean region.

Integrating regional climatic model projections (2010–2050) will allow study into the effects of future regional changes on *C. imicola* abundance. Using different regional models will provide an estimate of the variability and consistency of the predictions. Then, the areas identified at risk for an increase (positive anomaly) of *C. imicola* abundance may be used for entomological or veterinary surveillance. Models of abundance of the vector at a local scale using landscape factors could help targeting such surveillance (Guis et al. 2007).

Nevertheless, one must consider that the risk of the disease not only depends on the abundance of the vector, but also on others factors determining the transmission of the disease (vector competence, vector to host ratio, vector lifespan relative to incubation duration, feeding frequency). To study the impact of climate changes on BT risk, a modeling framework such as the basic reproduction ratio (R0) could be used (Gubbins et al. 2008).

7.4 Direct Effects of Climate on Livestock

The direct effects of climate on animal production depend on the ability of animals to maintain a normal body temperature under unfavorable meteorological conditions. In other words, cold or heat stress result from an imbalance between the net amount of energy flowing from the animal to its surrounding environment and the amount of heat energy produced by the animal. This imbalance may be caused by changes of a series of meteorological factors (air temperature, humidity, wind, and solar radiation), animal proprieties (age, rate of metabolism, etc.), and by the efficiency of thermoregulatory mechanisms (conduction, radiation, convection and evaporation). For each species, strain and individuals within species, there is a range of environmental temperature, defined as Thermoneutral Zone (TZ), within which the metabolic heat production is unaffected by a temperature change and homeothermic animals can maintain a fairly constant body temperature (heat loss = heat gain) and an efficient level of growth, reproduction and lactation (Bligh and Johnson 1973). The TZ is bounded at its lower and upper end by the lower critical temperature and upper critical temperature, respectively. When the animal is faced with an environmental temperature below the lower critical temperature, it reduces heat dissipation, and when the heat-retaining mechanisms are no longer adequate to maintain a fairly constant body temperature, it must increase heat production to avoid hypothermia. When the environmental temperature is above the upper critical temperature, animals avoid the hyperthermia by increasing heat loss and/or decreasing heat production. Therefore, thermal stress resulting in increased energy maintenance requirements, physiological and metabolic adjustments and modification of feed intake can be responsible for high neonatal mortality rate, reduced growth, reproductive performance and milk production and can cause sizeable economic losses to the livestock industry (Johnson 1987).

7.5 The Temperature Humidity Index

The ability to predict the direct effects of climate variables on livestock is therefore important to guarantee animal welfare, performances and health. Air temperature provides a measure of the sensible heat content, but there are limitations considering temperature alone as a measure of the thermal environment because, for example, high humidity reduces the potential for evaporative heat loss, while solar radiation adds heat to that deriving from metabolic processes. Conversely, strong winds, especially in combination of precipitation, amplify the adverse effects of cold temperatures.

The total meteorological complex has not been studied precisely to determine the optimal combination for normal physiological functions and behavioral actions, health, welfare, and maximal performance of livestock. Extensive effort has been given to developing an index to describe a given meteorological environment (temperature, humidity, solar radiation, etc.) and to assess its effects in terms of physiological and productive responses (Hahn et al. 2003). However, the development of an acceptable single index to describe these climatic parameters is not presently available. A good index for measurements of environmental warmth and its effects was developed for cattle and is called Temperature Humidity Index (THI). This index, and in particular its significance in terms of physiological and productive responses, needs to be established for all breeds and categories of livestock, beef and dairy types, swine, sheep, goats, etc. (Johnson 1987).

The THI combines the effect of temperature and humidity into a single value and has been widely used as a bioclimatic indicator of thermal stress in livestock (Bouraoui et al. 2002; West 2003; Vitali et al. 2009). The THI may be calculated by different formulas (Bohmanova et al. 2007) each of which is more or less suitable to be applied in different climate condition (arid, humid, tropical, etc.).

According to THI, the following livestock welfare categories have been identified for environmental management decision in bovine species. A $\text{THI} \le 68$ generally does not cause safety problem for healthy animal. Under mild discomfort condition ($68 \le \text{THI} < 72$) and discomfort condition ($72 \le \text{THI} < 75$) heat stress begins to cause first problems. Under alert condition ($75 \le \text{THI} < 79$), producers can expect some decrease in the rate of weight gain. Under danger conditions ($79 \le \text{THI} < 84$), animals show noticeable decreases in weight gain and, when handled, transported or overcrowded, may be severely affected. Under emergency conditions ($\text{THI} \ge 84$) without management intervention, animal mortality can occur, especially when such conditions are prolonged.

7.6 The THI Characterization of the Mediterranean Area

The Mediterranean basin has been already characterized by focusing the attention on air temperature and precipitation dynamics (Klein Tank and Können 2003; Xoplaki et al. 2005). Previous animal biometeorology studies have utilized THI to characterize the region of Córdoba in central Argentina (De la Casa and Ravelo 2003), and the north-east region of Thailand (Somparn et al. 2004).

A series of studies carried out within the CIRCE project permitted to characterize also the Mediterranean basin in terms of THI, and a recent study (Segnalini et al. 2011) described the THI dynamics over the Mediterranean area for the period 1951–2007. The formula used in these studies is reported below, and has been already utilized for THI calculation in previous animal biometeorology studies carried out in Mediterranean countries (Bouraoui et al. 2002; Vitali et al. 2009). Furthermore, Bohmanova et al. (2007) indicated this formula as the one to be preferred for calculation of THI in regions with a subtropical climate:

$$\mathrm{THI} = \left(1.8 \cdot \mathrm{AT} + 32\right) - \left(0.55 - 0.55 \cdot \mathrm{RH}\right) \cdot \left[\left(1.8 \cdot \mathrm{AT} + 32\right) - 58\right]$$

where AT is the air temperature (°C) and RH the relative humidity. The dataset utilized for these studies was made available for the Circe community from the Centre National de la Recherche Scientifique and Institute Pierre Simon Laplace (CNRS-IPSL).

Figure 7.3a, b show the isolines of the mean annual and seasonal THI, respectively, referred to a 30 years reference period (1971–2000) known as CliNo (Climate Normal). CliNo is the conventional 30-year period utilized for climatologic analysis and confrontation adopted by the World Meteorological Organization. For the seasonal characterization of the study area, the months of December, January, and February were defined as winter (DJF); March, April, and May, as spring (MAM); June, July, and August, as summer (JJA); and September, October, and November, as fall (SON).

Mean annual THI ranged from 45 to 72, and showed a north–south gradient (Fig. 7.3a).

The analysis of mean seasonal THI data indicates that THI ranged from 35 to 65 in DJF, from 45 to 75 in MAM, from 55 to 80 in JJA, and from 45 to 75 in SON, and that also in this case, a north–south gradient may be observed (Fig. 7.3b).

Previous studies documented a general tendency of the average annual temperature in the Mediterranean area to increase (Xoplaki et al. 2006; Klein Tank and Können 2003; Brunetti et al. 2002). In terms of THI, Segnalini et al. (2011) reported that, during the period 1951–2007, THI increase in the Mediterranean basin, and also that the THI dynamics in the study area were not spatially and temporally homogeneous. Figure 7.4a shows the anomalies of annual THI calculated by comparing CliNo (1971–2000) versus the 30-year period 1951–1980. Considering the basin in its complex, a general warming in the area was detected (+0.16 THI units). In details, supporting the large heterogeneity of the area, the anomalies ranged

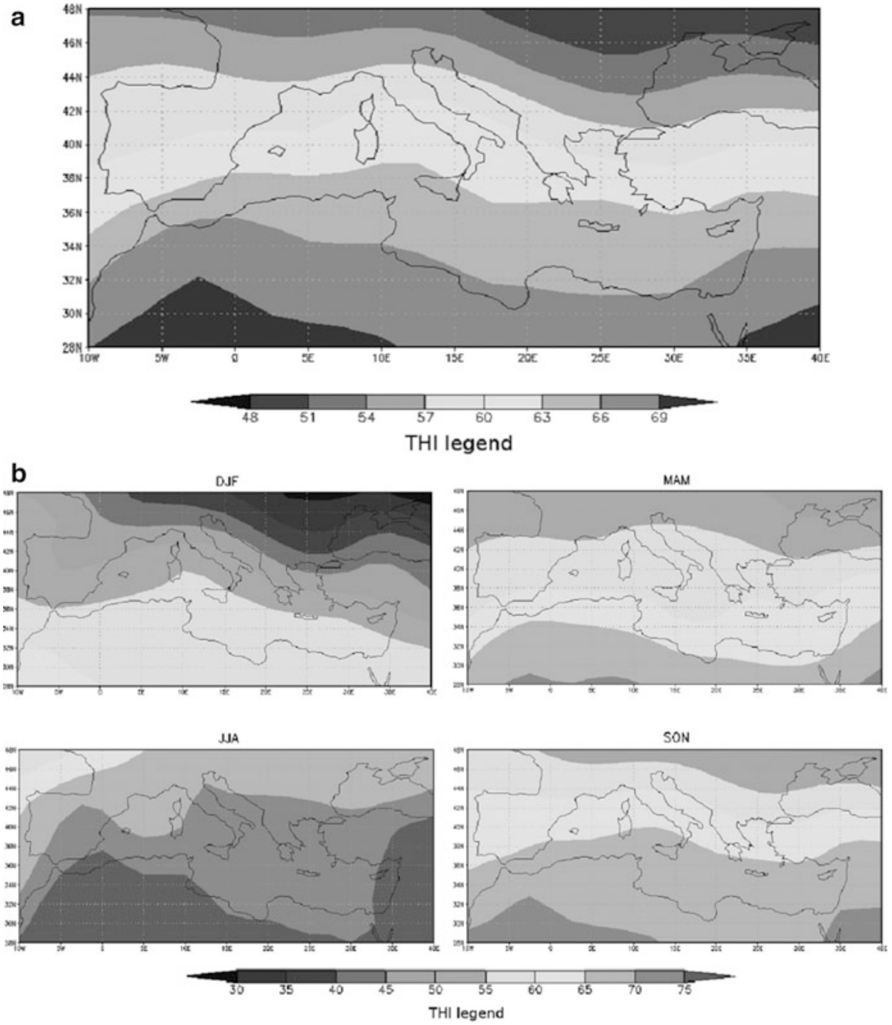

Fig. 7.3 Regional variability of the mean annual (panel **a**) and seasonal (panel **b**) temperature humidity index (*THI*) for CliNo (Climate normal, 1971–2000 period) in the Mediterranean basin. The months of December, January, and February were defined as winter (*DJF*); March, April, and May, as spring (*MAM*); June, July, and August, as summer (*JJA*); September, October, and November, as fall (*SON*)

from −1.5 to +1.2 units of THI: the largest negative and positive anomalies were observed over eastern Turkey, and in the north-eastern part of the Black Sea, respectively. The same anomalies study carried out by considering the four seasons separately, pointed out that only in the winter season a small negative anomaly was detectable (−0.03 THI units), whereas in the remaining three seasons the area was subjected to an overall warming (MAM +0.22, JJA +0.27 and SON +0.14 THI

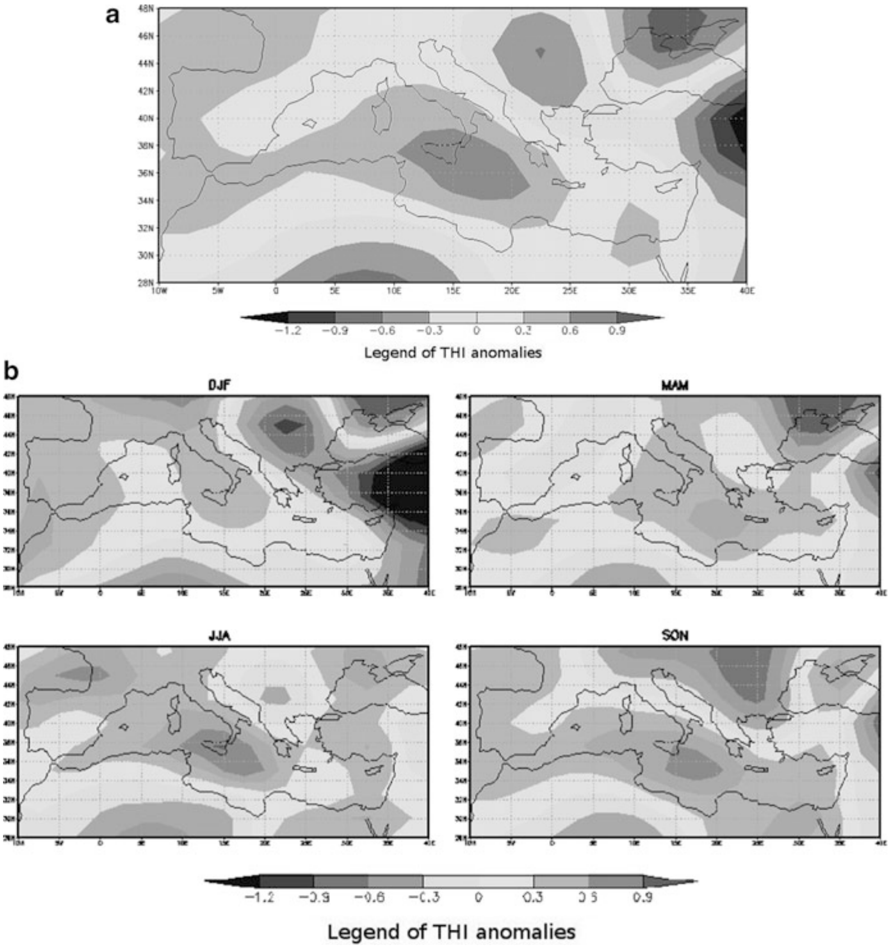

Fig. 7.4 Regional variability of the annual (panel **a**) and seasonal (panel **b**) temperature humidity index (*THI*) anomalies versus CliNo (Climate normal, 1971–2000 period) for the 30 year period 1951–1980. The months of December, January, and February were defined as winter (*DJF*); March, April, and May, as spring (*MAM*); June, July, and August, as summer (*JJA*); September, October, and November, as fall (*SON*)

units increases) (Fig. 7.4b). Furthermore, the analysis of the summer season reveals that the THI increase was particularly marked in the central part of the basin.

Previous studies carried out considering climate features different from THI indicated that the Mediterranean basin is also subjected to extreme climate event (Klein Tank and Können 2003). Figure 7.5 shows the isolines of winter and summer THI anomalies of year 2007 versus CliNo. The year 2007 was considered for an anomalies study because previous papers referred to Mediterranean countries indicated that it was characterized by abnormal warm summer and winter. In particular, in this

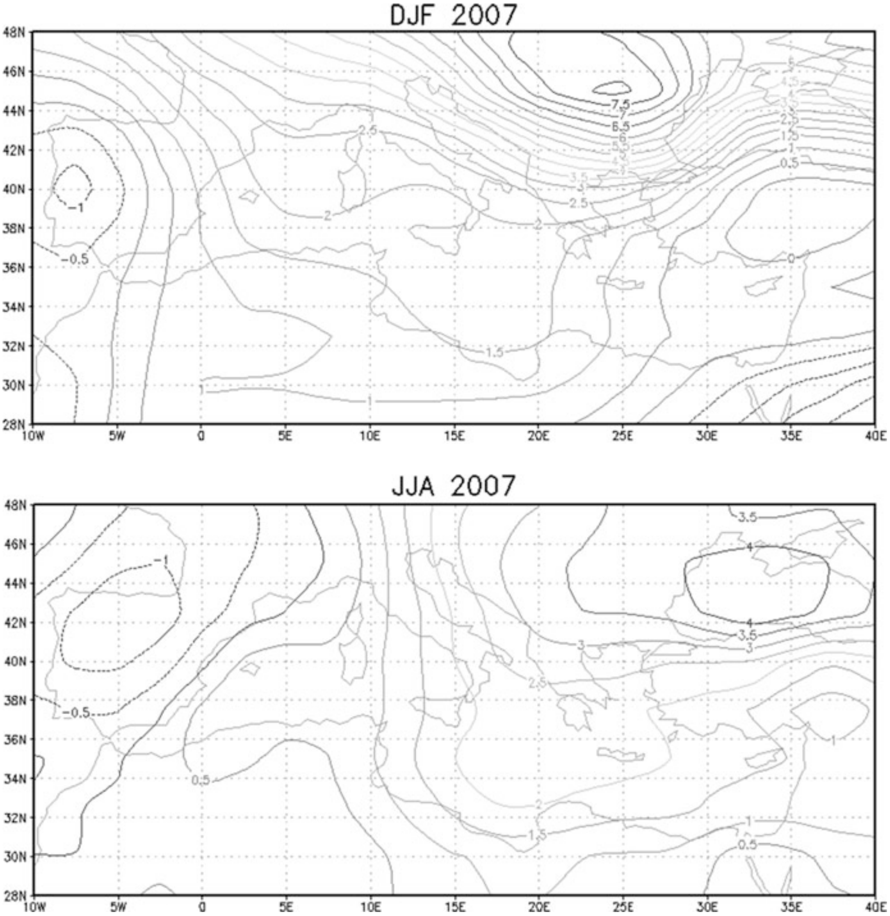

Fig. 7.5 Isolines of winter (*DJF*) and summer (*JJA*) temperature humidity index (*THI*) anomalies for the year 2007 versus CliNo (Climate normal, 1971–2000 period)

year the winter season was the warmest in the last 50 years, and in the Balkan area and parts of Asia Minor summer value of mean temperature was 4 °C higher with respect to CliNo (Founda and Giannakopoulos 2009). First of all, the analysis of isolines referred to THI (Fig. 7.5) outlines a west–east gradient. Furthermore, providing additional evidence for a significant heterogeneity of the area, the same isolines show that summer anomalies ranged between −1 (Iberian Peninsula) and + 4 (Balkan area) THI units, whereas winter anomalies ranged from −1 (western part of the basin) to + 8 (in the north east) THI units.

As already reported above, the THI has been widely utilized to predict the effects of environmental warmth in farm animals. In a study carried out in Tunisia, Bouraoui et al. (2002) indicated that exposure of dairy cattle to mean daily THI higher than 69 would be responsible for impairment of milk yield, and that the extent of milk yield decline would be proportional to the number of units the THI is above this threshold. Our analysis indicated that in several regions of the Mediterranean basin, mean values of summer THI is already largely above this threshold, that the area is undergoing an overall warming and also that the area is subjected to extreme climate events. Therefore, environmental warmth surely represents a major challenge for the livestock industry and for its tendency to expand and increase its efficiency. In particular, the strong north–south gradient indicates that animals reared in the countries of the central and south regions of the basin are likely to experience conditions of severe heat stress during summer months, which may severely compromise their performances, health and survival.

7.7 Relationships Between THI, Productivity and Health

Several regional studies carried out in the Mediterranean area pointed out negative effects of environmental warmth on reproductive performance, growth, milk yield and health parameters of farm animals reared in the region (Bouraoui et al. 2002; Yeruham et al. 2003; Aharoni et al. 2005; Atasever and Erdem 2009; Santolaria et al. 2010; Marai and Haeeb 2010; Shehab-El-Deen et al. 2010).

Heat stress reduces the expression of estrus behavior, alters follicular development and the growth and function of the dominant follicle, compromises oocyte competence, and inhibits embryonic development in cows and sows. Fertility of heat stressed males is also severely compromised. In all species, dry matter intake and rate of gain in growing animals are lower under heat stress conditions compared to thermoneutrality. In dairy cows, heat stress is associated with a decline of colostrum and milk yield and also with significant worsening of their quality (immunoglobulin content, fat and protein percentages, fatty acids composition, protein fractions) (Lacetera et al. 2003).

Health and survival of farm animals may be affected by climate in three different ways: heat-related diseases and stress, extreme weather events, and emergence or re-emergence of infectious diseases, especially vector-borne diseases critically dependent on environmental and climatic conditions. In a recent regional scale study carried out in Italy within the CIRCE and CLIMANIMAL projects, we performed a retrospective analysis on mortality data of dairy cows to establish the relationships between THI and risk of death (Vitali et al. 2009). The study was carried out in the Po Valley (Italy), which has a high concentration of dairy farms (approximately 60% of the Italian dairy cow population). Results of that study indicated that 80 THI is the value above which the number of deaths in dairy farms starts to increase significantly (Fig. 7.6). Furthermore, in the same study, we also reported that the number of summer deaths in dairy cow farms was dramatically higher in the summer 2003, which has been widely recognized as one of the hottest summer in the last half millennium (Xoplaki et al. 2005). That heat stress may increase mortality in farm animals is not novel, even if thresholds in terms of THI had not been indicated before either in dairy

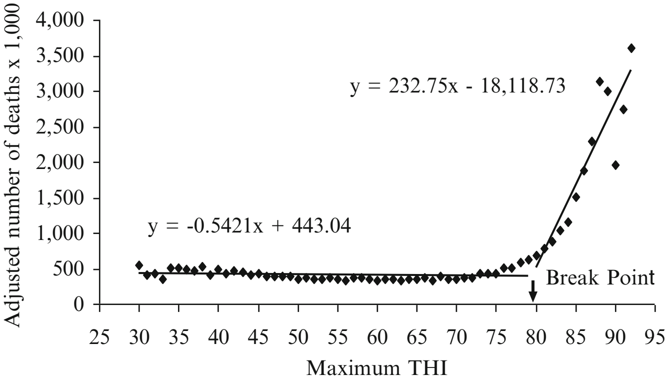

Fig. 7.6 Adjusted number of deaths (*AND*) in relation to maximum temperature humidity index (*THI*). A break point was detected at 79.6 THI. Below the break point the AND was constant across THI values, whereas above 79.6 THI the AND rose sharply with THI (From Vitali et al. 2009)

cows or in other species. With regard to similar events registered in Mediterranean countries, it has been reported that during the severe and prolonged heat waves that occurred in Europe during the summer of 2003, over 35,000 people, and thousands of pigs, poultry, and rabbits died in the French regions of Brittany and Pays-de-la-Loire (http://lists.envirolink.org/pipermail/ar-news/weekof-Mon-20030804/004707.html).

Risk management, by considering perceived thermal challenges, then assessing the potential consequences and acting accordingly, may strongly reduce the impact of such challenges in the livestock industry (Nienaber and Hahn 2007). Appropriate adaptation measures, which may help animals to face with conditions of environmental warmth, include set up of meteorological warning systems, revision of feeding plans, shade, sprinkling, air movement, or active cooling. In synthesis, the most important element of proactive environmental management to reduce risk is preparation: be informed, develop a strategic plan, observe and recognize animals in distress, and take appropriate tactical action.

7.8 Scenarios

Mediterranean basin has been identified as one of the most prominent “Hot-Spots” in future climate change (Giorgi 2006), in that it is considered particularly vulnerable to present and future climate variability and change. In other words, at the scale of the Mediterranean basin, it is likely that the growth of the average annual temperature will be slightly higher than that of the rest of the world (Hallegatte 2009; Van Grunderbeeck and Tourre 2008).

Results obtained within the CIRCE project testified that the area is also likely to undergo an increase of the THI values. These studies were carried out by using the

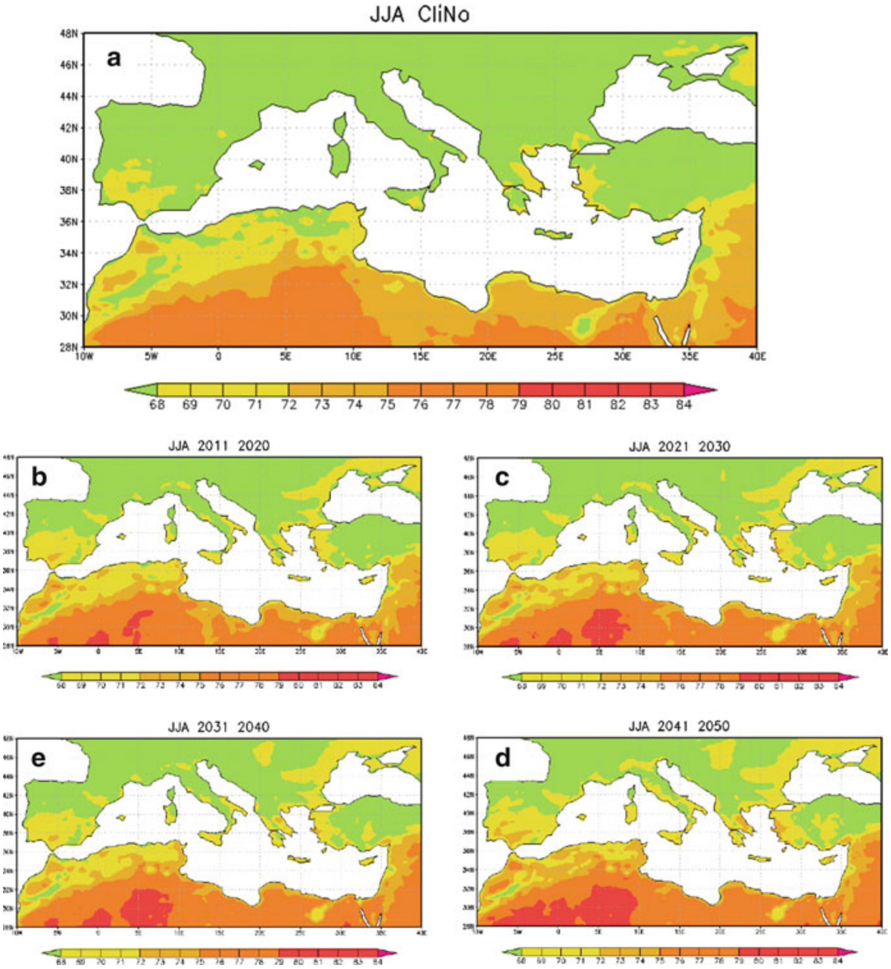

Fig. 7.7 Summer temperature humidity index (*THI*) values related to livestock welfare categories: CliNo period (1971–2000), (**a**); 2011–2020, (**b**); 2021–2030, (**c**); 2031–2040, (**d**); and 2041–2050, (**e**). Different colors identify the different livestock welfare categories: THI ≤ 68, 68 ≤ THI < 72, 72 ≤ THI < 75,75 ≤ THI < 79, 79 ≤ THI < 84, and THI ≥ 84

dataset simulation of the CNRS-IPSL, which was produced within the same project and made available to the CIRCE community.

Summer THI values predicted for the decades 2011–2020, 2021–2030, 2031–2040, and 2041–2050 are reported in Fig. 7.7 where different colors identify the different livestock welfare categories (see above). The maps relative to the four decades (Fig. 7.7b–e) are very similar, but differ significantly from CliNo (Fig. 7.7a). Firstly, CliNo map (Fig. 7.7a) shows that approximately the 36° latitude North marks a border line between category that does not cause safety problem for healthy

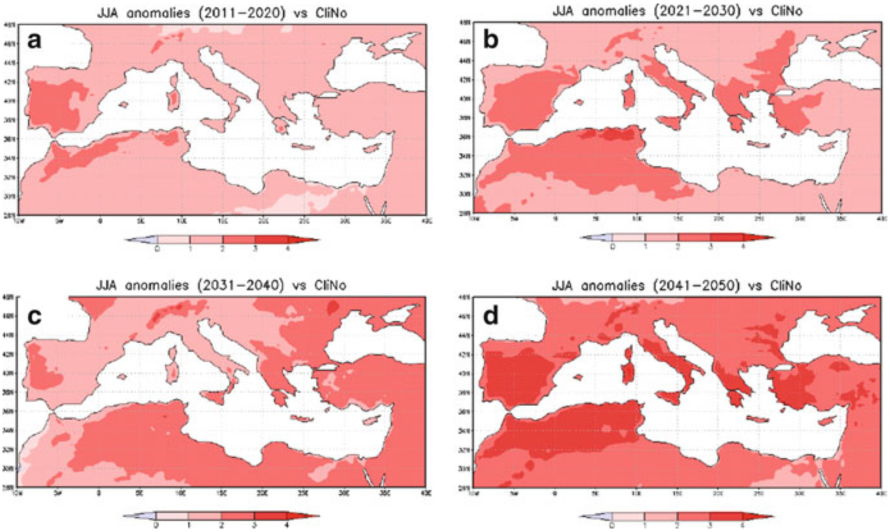

Fig. 7.8 Summer anomalies of the temperature humidity index (*THI*) for the decades 2011–2020 (**a**), 2021–2030 (**b**), 2031–2040 (**c**) and 2041–2050 (**d**) compared to CliNo (1971–2000)

animal (THI ≤ 68), and the others (THI ≥ 68); instead, such border line moves at approximately 40° North when considering scenario maps. In particular, it may be noticed an increase of the risk for animals health, welfare and productivity (danger condition) in the south-west area, and also that the Balkan area and the Italian coasts and islands will shift from the category indicating no risk to the one with mild discomfort condition.

Figure 7.8 reports the summer anomalies for the four decades. Considering the basin in its complex, a general warming in the area will be detected (all positive anomalies) even if it will not affect to the same extent the different countries. With regard to the first decade considered (2011–2020, Fig. 7.8a), the increase of THI values ranges from 1 to 2 units in most of the basin and from 2 to 3 units only in the western part (Iberian Peninsula, Algeria and Morocco). In the period 2021–2030 the increase from 2 to 3 units of THI will expand and cover the entire Italian territory (Fig. 7.8b). Finally, the anomaly map referred to the period 2041–2050 (Fig. 7.8d) indicates an increase from 3 to 4 units of THI in Iberian Peninsula, North Africa, Italy, Greece, Turkey and Balkan area.

7.9 Conclusions

The Mediterranean area is widely heterogeneous and land-sea interactions, latitude, altitude and orography are the physico-geographical factors which influence its climate system. Some patterns, such as the North Atlantic Oscillation (NAO), may affect the atmospheric circulation in terms of air temperature, precipitations and pressure distribution, particularly in winter, even if this index is certainly an important feature of atmospheric variability throughout the year. The importance of NAO is mainly due to its effects in deviating the storm track, which may explain the differences in climatic features between western and eastern areas of the basin. Changes of atmospheric circulation create a strong spatial and temporal variability. Moreover Pokrovsky (2009) observed that climate warming over the last century resembles the surface temperature anomalies associated with the value of this index.

The heterogeneity of the basin may be also highlighted in terms of THI even if most of the basin has to be considered at risk of heat stress for farm animals during summer season. The same area is and will be also subjected to warming and extreme climate events, which may surely aggravate the consequences of hot weather on animal welfare, performances, health and survival. This underlines the importance to develop appropriate adaptation strategies to attenuate the negative effects of heat stress in farm animals in the Mediterranean basin, considering that the subsistence economies of many countries of the south Mediterranean basin are strongly engaged in that sector. Comprehensive frameworks need to be developed to identify and target adaptation options that are appropriate for specific contexts, and that can contribute to environmental sustainability as well as to economic development and poverty alleviation.

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Chapter 8
Summary and Major Findings

Monia Santini and Riccardo Valentini

Abstract This chapter resumes major and common findings among chapters 2 to 7. Focus is given to the spatial heterogeneity of Mediterranean region in terms of ecosystem vulnerability to climate change impacts. Further, the role of spatio-temporal scale of evaluation is noteworthy, as well as taking into account extreme events and thresholds in the interaction among climate and its effects.

Part III of the Regional Assessmnt of Climate Change in the Mediterranean is divided into eight chapters:

1. Introduction
2. Vulnerability of Ecosystem Services in the Mediterranean Region to Climate Changes in Combination with Other Pressures
3. Impact of Climate Variability and Extremes on the Carbon Cycle of the Mediterranean Region
4. Climate Change Impacts on Typical Mediterranean Crops and Evaluation of Adaptation Strategies to Cope With
5. Climate Change Impacts on Forests and Forest Products in the Mediterranean Area
6. Effects of Climate and Extreme Events on Wildfire Regime and Their Ecological Impacts
7. Climate Induced Effects on Livestock Population and Productivity in the Mediterranean Area
8. Summary and Major Findings

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In line with RL7 from CIRCE, this Part III was focused on assessing the vulnerability of ecosystem services starting from the main above messages of the Millennium Ecosystem Assessment (2005). To this aim, first of all the *vulnerability* in general for ecosystem and their services had to be defined. In agreement with the ATEAM approach (Metzger et al. 2008), vulnerability can be considered as the product among the exposure and the sensitivity of the ecosystem, representing the potential impact, and its adaptive capacity (Anav et al. 2010; Chase et al. 1996) to climate change. Starting from this definition of vulnerability, the *hot-spots* are then assumed not simply as those areas highly responsive to climate change, as in the Regional Climate Change Index (Giorgi 2006) but, more comprehensively, as those regions highly vulnerable, for which potential climate change impacts on the environment, on different activity sectors and ecosystem services can be particularly pronounced.

In dealing with vulnerability of ecosystem services, changes in climate and changes in socio-economic forces have been acknowledged as strongly interacting, highlighting the land use changes, among others, as a main factor affecting vulnerability (e.g. DeFries and Bounoua 2004; Chase et al. 1996), and recalling the theory of double-exposure (O'Brien and Leichenko 2000) and vulnerability complexes (Galaz et al. 2008), which exacerbate the criticality of ecosystems. Given the interaction of multiple factors, another basilar concept included in Part III contributions is introduced in Anav et al. (2010): i.e., often abrupt/non linear processes trigger new degraded irreversible states when overcoming critical thresholds (e.g. Carpenter et al. 2009; Safriel and Adeel 2008). As highlighted thus in Bounoua et al. (2002), Calfapietra et al. (2001), and Chase et al. (1996, 2000), this vulnerability-hotspot-threshold assessment is a basis for elaborating adaptation strategies (Lavorel et al. 2006), focusing on more critical areas. At the same time, the feedback evaluation from the multidisciplinary approach offered by Part III is a strong starting point for successively verify the effectiveness of adaptation (e.g. avoiding maladaptation and/or dis-services; e.g. Zhang et al. 2007), considering that often different sectors compete for the same resource (e.g. agriculture and urban lands for blue water) (e.g. Steffen 2009) and that for several sectors interventions are more urgent.

After above mandatory definitions, several common key-points can be evinced from chapters in Part III.

In most cases the analysis is divided into assessment of past conditions/impacts vs. future projections, relying both on well assessed recent literature (Anav et al. 2010; Bounoua et al. 2002; Carpenter et al. 2009) and on process-based (Bounoua et al. 2002; Calfapietra et al. 2001; Carpenter et al. 2009; Chase et al. 1996) and statistical (Calfapietra et al. 2001; Chase et al. 2000) models (simulating water and carbon cycle, crop growth and yield, fire danger propagation and livestock diseases) or indicators (proxies of livestock health and productivity in (Chase et al. 2000), of water scarcity in (Anav et al. 2010), of fire vulnerability in (Chase et al. 1996) even based on CIRCE climate predictions (Calfapietra et al. 2001; Chase et al. 2000).

Then, after recognizing Mediterranean as an hot-spot of both climate change (Giorgi 2006), land use changes (Falcucci et al. 2007), and desertification (Rubio et al. 2009), Mediterranean sub-regions of European (North Mediterranean) and

Middle East-North Africa (MENA) countries, are acknowledged as suffering from vulnerability in different ways. In particular, MENA region already appeared in the past more vulnerable from different points of view, particularly for faster aridification and lower adaptive capacity (Anav et al. 2010), but also in terms of water (Anav et al. 2010; Bounoua et al. 2002) and land (Carpenter et al. 2009) resources, and either direct or indirect effects on livestock (Chase et al. 2000). This spatial variability across the basin is projected worsening in future conditions mainly in MENA, jointly with a northward shift of fragile conditions for different sectors/processes: water (Anav et al. 2010), agriculture (Calfapietra et al. 2001), forests (Carpenter et al. 2009), fires (Chase et al. 1996), and livestock diseases (Chase et al. 2000).

The importance of spatial scale is highlighted in (Bounoua et al. 2002) and (Chase et al. 1996), where different consequences of climate change are discussed when thinking on regional, landscape, ecosystem, stand or species level. What evinced from (Bounoua et al. 2002) and (Chase et al. 1996) is also the importance of the temporal scale to evaluate climate variability and its effects over short- to long-terms (erosion or permanent vegetation changes in the case of fires and lag effects on CO_2 exchanges in the case of carbon cycle). But in particular differences of impacts are related to the ecosystem type and, also, the same climate trends can have different and contrasting effects, when occurring on the long period or as isolated events.

Instead of just considering mean climate change, a special attention is given to the extremes events (Anav et al. 2010; Bounoua et al. 2002; Chase et al. 1996) or years (Chase et al. 2000), focusing in particular on the role of droughts/heat waves on carbon cycle (turning ecosystems from carbon sinks to sources; (Bounoua et al. 2002), fires (depending on droughts; Chase et al. 1996), livestock (Chase et al. 2000). Still in terms of temporal variability, also the intensity and timing of event is of great importance, affecting in particular the forest NEE (Bounoua et al. 2002), the crop growth (Calfapietra et al. 2001), the recovery and re-growth after fires (Chase et al. 1996), as well the timing of adaptation (Calfapietra et al. 2001; Chase et al. 1996) and/or mitigation strategies (Chase et al. 1996).

Another key-point emerging from Part III, and often related to extremes, is the concept of *threshold*, representing the reaching of critical conditions above which, for example, forest ecosystems collapse (Bounoua et al. 2002), agriculture fails (Calfapietra et al. 2001), vegetation burns or does not recover after fires (Chase et al. 1996), and livestock stops productivity or dies (Chase et al. 2000).

Often non linear changes leading to a threshold are due not only to single isolated factors, but by a combination of them or, better, by their feedbacks, e.g. when changes in vegetation impact either climate (Anav et al. 2010; Bounoua et al. 2002; Chase et al. 1996; Anav et al. 2010) or fires (Chase et al. 1996). Another example is when human intervention implements inadequate adaptation strategies altering natural ecosystems, and increasing rather than decreasing vulnerability, as when for example water is used for irrigation in case of very strong decrease of the recharge (Anav et al. 2010).

The main conclusion is that, even if Mediterranean basin was often considered easily flexible to adaptation thanks to its long history of former adaptations, in reality the level of projected changes suggests that this region will be no more able to adapt by itself (Anav et al. 2010; Chase et al. 1996). In this sense, the evaluation of integrated vulnerability, non-linear processes and feedbacks could help in evaluating the feasibility of separated mitigation and adaptation strategies (to reduce impact and risk, respectively), combined adaptations and adaptation/mitigation (Calfapietra et al. 2001; Chase et al. 1996, 2000).

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Part IV
People

Chapter 9
Introduction

Ana Iglesias

Keywords Climate change • Adaptation • Mediterranean • Society • Economics • Health • Water • Tourism

The challenge of characterizing the social and economic impacts of climate change is an extremely complicated one given the multitude of uncertainties that multiply and plague efforts to model future climates. And yet, for all these difficulties, the crucial importance of succeeding in this task is intuitively grasped. Should we fail to appraise the consequences of climate change or indolently decide to leave the challenge unheeded, the burdens and hazards for future generations will be seriously aggravated.

International cooperation has produced reasons for hope: the IPCC has become a global forum for discussion, analysis and proposal on action. Indeed, it is within the context of the IPCC that the twin strategies of adaptation and mitigation have been put forward. Facilitating adaptation has taken a more central role and the agreement reached at the Conference of the Parties of the UNFCCC in Copenhagen in December 2009, specifically mentioned the commitment of resources by developed countries for this cause. Although a new international framework to succeed the Kyoto Protocol has not yet been agreed upon, numerous developments aimed at mitigating the effects of climate change such as the EU's unilateral commitment to reduce CO2 emissions by at least 20% by 2020 and the steps being taken by emerging economies are promising signs.

As an example of such international cooperation, CIRCE plays a centre role in the development of mitigation and adaptation strategies. The models, projections and scenarios that the project has developed are of the highest scientific quality and

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relevance. CIRCE's analysis of climate change impacts in the areas of air, sea, and precipitation, water, agriculture, forests and ecosystems, collected in the other volumes of the RACCM are an example of enthusiasm, seriousness, and cooperation to the scientific and policymaking communities throughout the globe. But CIRCE is not merely an effort for scientists and politicians. On the contrary, the project facilitates and encourages the widespread participation and inclusion of all levels of society. The endeavor to prepare societies for climate change is an inclusive one precisely because the impacts will affects us all. It is only through the inclusion of multiple voices that viable strategies and solutions will be promoted.

Volume IV of the RACCM takes the work of the other volumes as its starting point. Each chapter takes into account the projections for future climates that CIRCE experts have developed in order to analyze what the socioeconomic consequences of future scenarios might be. Thus, the achievements of this volume are twofold: First of all the chapters here presented evaluate how climate change influences people and analyses the changes it implies for their social and economic activities and institutions. Secondly, the chapters are concerned with conceptualizing and proposing strategies for improving the region's the capacity to cope with climate change. Not least, when formulating strategies, the work here presented takes into consideration the different levels of vulnerability that exist at a regional and country level, providing an analysis that is both sensitive and relevant to local conditions.

In sum, this volume considers these experiences and combines them with current methods for evaluating climate impacts in order to propose ways for people to respond to climate change in the Mediterranean.

Chapter 10
Integrated Socio-Economic Assessment (The Economic Point of View)

Francesco Bosello and Mordechai Shechter

Abstract This section introduces the main methodologies used by the climate change impact science to assess economically the consequences of climate change. Furthermore it presents the main findings of this literature focusing specifically on possible future economic consequences of climate change in the Mediterranean area emphasizing the new knowledge in this field brought by the CIRCE project. The robust finding of the literature points out a low economic vulnerability of Euro-Mediterranean countries (with losses ranging from −0.25 to −1.4% of GDP for extreme temperature scenarios or even slight gains), and a higher vulnerability of North African and Eastern-Mediterranean countries (of roughly 2% of GDP by the mid of the century). Against this background the CIRCE project proposes one of the first attempts to perform a detailed integrated impact assessment exercise focusing on the Mediterranean area. With the IPCC A1B SRES scenario as reference, impacts related to energy demand, sea-level rise and tourism, have been economically assessed by a general equilibrium model. The Mediterranean as a whole loses 1.2% of GDP with the Northern-Mediterranean countries clearly less vulnerable than the Southern-Mediterranean ones. Among the former the average loss in 2050 is 0.5% of GDP, while among the latter this more than doubles. Particularly adversely affected are Cyprus, Albania and the Eastern Mediterranean region (−1.6, −2.4, −1.5%

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of GDP respectively in 2050). In terms of impact types, tourism and sea-level rise are clearly the most threatening, while GDP impacts induced by demand re-composition of energy use is less of an issue and often positive.

Keywords Climate change • Economic impacts and modeling • Integrated impact assessment • Top-down • Bottom up approaches

10.1 Introduction

This section introduces the main methodologies used by the climate change impact science to assess economically the consequences of climate change. It will highlight problems and criticalities of the economic quantification and the different evaluation approaches used. Furthermore it will present the main findings of this literature, focusing specifically on the Mediterranean area. Given the strict economic and quantitative angle of the section, information on the physical dimension and relevance of climatic impacts will be kept to a minimum. These are amply treated by other sections of this book. By the same token, quantitative economic assessments of past impacts will be given also a marginal role. This section indeed aims to shedding light on future possible economic consequences of climate change. Assessment of what happened and/or of what is happening will be reported only if needed to complement or integrate lacking information on future trends.

In what follows: Sect. 10.2 describes integrated assessment as the main methodological approach used to investigate the climate change issue, Sect. 10.3 explains how the economic dimension is represented within the integrated assessment approach, Sect. 10.4 presents the main finding from the literature, Sect. 10.5 describes innovations and steps forward proposed by the CIRCE project, finally Sect. 10.6 concludes.

10.2 Integrated Assessment (IA) and the Climate Change Problem

In its general definition, Integrated Assessment (IA) is a process aimed at combining, interpreting and communicating knowledge from diverse scientific fields in order to tackle a problem comprehensively by stressing its cause-effect links in their entirety (Rotmans and Dowlatabady 1998).

Due to the multidimensionality of climate change, which involves the climatic, the environmental and the social domains, an Integrated Assessment approach has been increasingly applied to its analysis. Especially after the beginning of the 1990s, IA models (IAMs) boomed. Already in 1996, 26 of such models were officially censed (Weyant 1996). Since then, the number of models in which the feedback between the economic and the climatic-environmental dimension is explicitly considered has easily quadrupled.

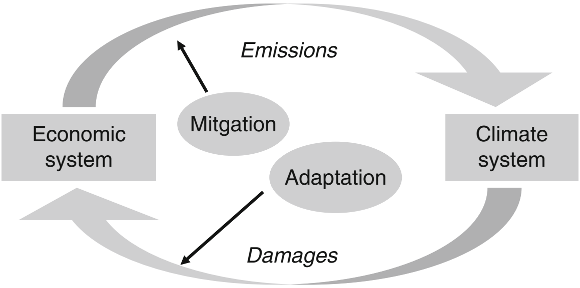

Fig. 10.1 Exemplifying hard-linked IAMs structure

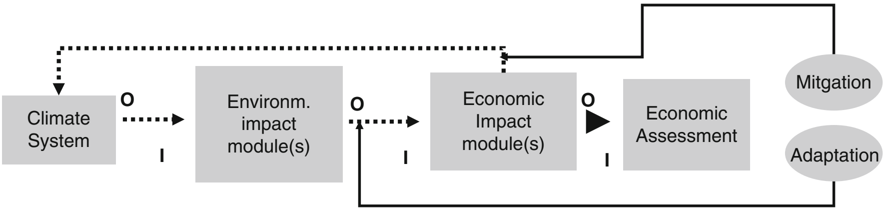

Fig. 10.2 Exemplifying soft-linked IAMs structure

It is beyond the scope of this report to provide an in depth survey of the different models within the wide family of IAMs (for this we address the interested reader to Bosello et al. 1998 and Warren et al. 2006). It is however useful to recall the broad distinction between hard-linked and soft-linked IAMs.[1]

In hard-linked IAMs (Fig. 10.1) the climate and economic dimensions are treated as a "unified" system represented by a consistent set of differential equations. Emissions build CO_2 concentrations and temperature. A (more or less refined) damage function translates temperature increase into GDP losses. Examples of well known hard-linked models are the RICE model family (see Nordhaus and Yang 1996; Nordhaus and Boyer 2000), the MERGE model (Manne et al. 2004), the FUND model (Tol 2002), the WITCH model (Bosetti et al. 2006, 2009).

In soft-linked IAMs (Fig. 10.2), climate, environmental and economic variables belong to two or more separated modeling exercises, which are then connected in a sort of sequential chain process: outputs of climate models are inputs to environmental impact modules whose outputs on their turn are inputs to economic models which finally provide an economic assessment (examples of this kind of exercises are the IMAGE (Image team 2001), the SGM (Prinn et al. 1999), the AIM (Kainuma et al. 2003) models).

These approaches show symmetric pros and cons: the main advantage of hard-linked IAMs is the internal consistency (of the mathematical structure above all, but also through time and space), which in addition allows researchers to perform full optimization exercises. In other words, the model can replicate the choices of a fully

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[1] This definition is still broadly valid, however it is also increasingly blurring, especially because of the growing flexibility of software packages and of the computational power of computers.

rational, perfectly farsighted, decision maker (or set of decision makers). This situation albeit non reproducible by the real world offers the "ideal benchmark" on which public or private choices should be shaped. Their major shortcoming is that to represent the climate and economics within a same mathematical framework requires strong simplification. On the contrary, soft-linked models can reach a high detail in the representation of different domains, but then the links between the different parts may show inconsistencies and non converging solutions. In addition, the computational burden is high. This often prevents the possibility to performing fully intertemporal optimization exercises, as some feedbacks could not be closed.[2]

10.3 The Role and Representation of the Social-Economic Dimension in IA

Offering a satisfactory description of the social-economic component and of its reactions to climatic pressures is probably the major challenge in IA modeling. This originates the so called economic impact assessment literature addressing this specific step of wider IA exercises.

Modeling social and economic relations is per se problematic due to unpredictability of human behavior, but many features of climate change contribute to magnify the role of uncertainty.

Its long time dimension often requires to push the analysis to the far future. In doing so the uncertainty on climatic pressures is accrued by the uncertainty related to the future development of present societies. This is not neutral obviously as the characteristics of the impacted society – e.g. its technology, its institutional setting, its economic structure, its wealth – determine its sensitivity and capacity to adapt to climate pressures. Accordingly, they contribute to determine the final impact itself (see on this the debate on the IPCC SRES scenarios and on the choice of using a market exchange rate rather than a purchasing power parity metrics to measure GDP (Castles and Henderson 2003a, b; Castles 2004; Henderson 2005)). This allows at best to build "storylines". This word is on particularly appropriate as it refers exactly to narratives of possible futures that, even though plausible, are not at all "forecasts" to which a "probability" can be associated. The long-term time dimension has another implication: it imposes subjective judgments. This unavoidably occurs when something happening in the future has to be evaluated today. Implicitly or explicitly

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[2] The distinction between hard and soft linked models somehow translates into the distinction between policy optimization vs. policy simulation. Policy optimization IAMs perform "normative" exercises: basically they answer the question on what would be the optimal (utility-maximizing) level of environmental externality (say GHG emissions and thus climate change damage), given the cost and benefits of climate policies or of available strategies to reach a given environmental target. Policy simulation IAMs perform "positive" if-then exercises by assessing the (direct and higher order) costs of environmental policies.

some weights on different times, or, said differently, on different generations are placed. This is another non neutral choice: inflating or deflating future damages it determines the convenience and the size of resources to be devoted to climate policies. This is the well known and never settled debate on "discounting" recently reinvigorated by the Stern Review (Stern 2007; Nordhaus 2007; Weitzman 2007, 2009). Discounting thus becomes "the" issue when policies have to be decided, optimally weighting respective costs and benefits in a world of smooth climatic damage. Nonetheless, when discontinuous and irreversible events are possible, like catastrophic climatic events, standard cost benefit criteria may not be appropriate and precautionary targets can be set. A recent example is provided by the temperature increase stabilization target for the century of +2°C, considered by the EU a threshold for acceptable risk. In this case discounting is less of an issue.

Its global scale imposes a global analysis. This is needed firstly for a correct quantification of the impact generated by anthropogenic emissions. One unit of GHG in the atmosphere damages the world as a whole irrespectively on where it has been emitted. Therefore the related damage is a "sum" of all the induced negative impacts. This is required secondly, for the analysis of mitigation policies. The public good nature of emission reduction, the associated free riding and leakage effects[3] ask for an explicit modeling of international relations and strategic behavior to design effective, efficient and self sustainable international environmental mitigation strategy. Due to the many specificities and asymmetries characterizing economic systems this exercise is clearly complex, data intensive and uncertainty prone.

Finally, some impacts of climate change entail consequences which are very difficult to reconcile with an explicit economic measurement. This happens because they are partly or totally unrelated to markets exchanges. Typical examples are human life, biodiversity or ecosystem losses. In these cases prices, the typical market indicators of scarcity and indirectly of value, are inappropriate or non existing. This makes the economic assessment extremely troublesome.

Notwithstanding these complexities, some representation of the economic dimension is needed if an assessment of the cost of climate change and of climate change policies has to be determined (Table 10.1).

A partial and a general equilibrium perspective can be first of all identified.

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[3] Benefits of emission reductions are non excludable. They are felt not only by who is abating and bearing the costs, but also by others. This creates an incentive to understate the willingness to abate hoping to charge the burden of abatement on other parties. This is the "free riding" mechanism, one of the major obstacles in the practical implementation of a stringent and largely participated international mitigation agreement. Strictly intertwined to this is the "leakage" effect. This relates to the fact that when a country or group decide an abatement policy, emissions in non abating countries increase. Two are the reasons: part of the polluting productions processes are re-located abroad to escape the stringent environmental regulation; products of the abating countries tend to become more costly in international market as charged by the cost of the cleaning activities. Thus demand shifts to cheaper products of non abating countries which accordingly produce and pollute more.

Table 10.1 Methodological approaches in the economic assessment of climate change

	Market value based assessments	Non market values based assessments
Partial equilibrium	"Direct costing" and partial equilibrium	"Direct costing" + non market evaluation
General equilibrium	"CGE modeling"	"CGE approach" + non market evaluation

The first offers an economic assessment which does not take into account the feedback that an economic perturbation into a sector or activity exerts on the rest of the systems. Albeit the many differences in direct costing techniques, its final result can be described with the process below:

(Economic cost of climate change) = ("Quantity with Climate Change" – "Quantity without Climate Change") × ("Price").

These methodologies are largely diffused in the literature focusing on specific impacts (see e.g. Fankhauser 1994; Yohe et al. 1996; Yohe and Schlesinger 1998; Volonte and Nicholls 1995; Gambarelli and Goria 2004 for sea-level rise; Hamilton et al. 2005a, b; Amelung et al. 2007; Elsasser and Bürki 2002; Scott et al. 2004; Scott and McBoyle 2007; OECD 2007 for tourism, the survey of Viscusi and Aldy 2003 for health). They are however generally endorsed also by those modeling exercises compounding climate change costs in single damage functions. Usually their parameterization is based on a "simple" sum of direct costs translating into GDP losses related to a given temperature increase scenario. They are easier to apply, however they do not capture possible rebounds on costs that a changing economic context can impose.

In fact, sectors within the economy are not isolated and markets are linked by flows of input, goods and services domestically and internationally. Thus, economic perturbations like those induced by a changing climate can spread their effect outside the area initially impacted and, more importantly, can induce a reallocation of resources that can smooth or amplify the initial effect.

To capture these processes a systemic perspective is necessary. This concept is made operational by Computable General Equilibrium (CGE) models.

At the beginning, CGE models were developed mainly to analyze international trade policies and to a lesser extent public sector policies. But, soon, due to their great flexibility, they started to be applied to climate change impact and policy assessment. The peculiar feature of CGE models is market interdependence. All markets are linked, as supply and demands of factors of production, goods and services are mobile between sectors, domestically and internationally. These flows are determined by change in relative prices which signal where profit or saving opportunities are. In this way CGE models can capture and describe the propagation mechanism induced by a localized shock onto the global context. Moreover they are able to assess the "systemic" effect of these shocks, that is the final welfare or general equilibrium outcome which is determined after all the adjustments at play in the economic system operated. The final summarizing indicator of these "higher order" effects is the change in GDPs which is usually very different from the initial impacts.

Recently, a growing CGE literature assessed the costs of single impact categories such see e.g. Deke et al. (2002), Darwin and Tol (2001), Bosello et al. (2007) on sea-level rise; Bosello et al. (2006) on health; Tzigas et al. (1997), Darwin (1999), Calzadilla et al. (2008), Ronneberger et al. (2009) on agriculture, Calzadilla et al. (2008) on water scarcity.

CGE models have been also used to investigate the interactions of multiple impacts, although the techniques are still in development. For example, Bigano et al. (2008) analyzed the joint effect of adverse climatic impacts on sea-level rise and tourism activity for the 12 macro-regions in which the world was divided, showing that the interactions usually tend to exacerbate the negative effects. Bosello et al. (2009a, b), Aaheim et al. (2009), Aheim and Wey (2010), present the first combined assessment of an extended set of climate change impacts (health, tourism, agriculture, energy demand and sea-level rise).

The second important differentiation in the economic impact assessment methodologies is induced by the presence of non market goods and services. In some cases a use value can be directly or indirectly associated. If so, a market value can be also identified. This way not only a monetary value can be attached to an impact, but it can be also modeled as a change in an appropriate market transaction. But often, use values are not at hand or constitute just a part of the true value of an item. In these cases the only way to proceed to an economic valuation is to create fictitious markets. These techniques belong to the family of the so-called “stated preferences” exercises. Trough interviews, educated respondents are called upon to explicit their willingness to pay to restore or accept a compensation for the loss of a given non market good or service. Non market (climate change impact) assessments are by their nature direct costing or partial equilibrium exercises. They allow to “price” an item and accordingly its changes in quality or quantity. They do not evaluate all the extended implications of the change for the whole economic system.

Partial and general-equilibrium, market and non market-based approaches can finally endorse a static or a dynamic perspective. In the first case time does not really play a role. In the second, time changes. Albeit more realistic, as economic inertias and cumulative growth processes can be modeled, the introduction of dynamics implies to define how agents’ form their expectation. Assuming they are myopic, fully informed or bounded rational is not neutral to the final outcomes and introduces a further bias.

10.4 Economic Assessments of Climate Change Impacts for the Mediterranean Region

10.4.1 Sea-Level Rise

Coastal erosion and sea floods impacts on often densely populated and infrastructure-rich river deltas, wiping out of entire islands and island nations (Nicholls et al. 2007) make sea-level rise one of the most prominent assessments in the climate change impact literature.

In 1991 the IPCC already proposed methodologies and estimates of the cost of sea level rise and of the benefit of coastal protection (IPCC CZMS 1991). The following and very large body of literature was dominated by engineering researches and on Geographical Information Systems (GIS) use to determine areas, people and activities at risk to which an economic value was attached.

In a different vein, a thinner literature attempted to assess the "higher-order" cost of sea-level rise through the use of CGE models.

The Mediterranean area has been the focus of both types of investigations and the related economic assessment has been provided with different degree of detail.

Like the majority of economic impact assessments, also in the case of sea-level rise, information are mainly available for the European part of the-Mediterranean. The North African coastal area is almost uncovered. This said, assessments for the large areas or with a country detail are provided by both global engineering and general equilibrium exercises. The second usually start from the information provided by the first and enrich their direct costing estimation with the description of the wider economic implication of sea-level rise. Assessments performed on specific sites necessarily offer indications only on direct costs (Table 10.2).

Among direct cost estimates we found results presented by the PESETA project (Richards and Nicholls 2009). The DIVA engineering model (Nicholls et al. 2007; Vafeidis et al. 2008) is used to calculate the impacts of sea-level rise on EU coastline, including direct coastal erosion, coastal flood impacts, changes in wetlands, flood effects in river mouths, sea water intrusion and salinization. Then the economic costs due to land and wetland loss (related to erosion and flooding) and the number of people flooded are computed in an economic module also included in DIVA. Results specific to the Mediterranean EU highlight potentially high absolute costs (Eur 1.2 Billion in 2080 for a medium sea-level rise scenario). The study also emphasizes the role of coastal protection: it appears a cost effective strategy to curb damages from sea-level rise. In terms of impacts on economic activities, sea-level rise is expected to be a moderate concern though. PESETA also offers a general equilibrium assessment of the related GDP implication (Nicholls et al. 2009). In 2085 for the more pessimistic climatic and sea-level rise scenarios, GDP in Southern Europe is expected to decline the 0.005%. These costs are much smaller than direct cost assessment. This is partly explained by market adjustments that usually smooth initial negative impacts; partly because the general equilibrium assessment in PESETA analyzes only the effect induced by land losses in the agricultural sector. Moreover it is performed with a static economic model that cannot represent correctly inertias in the economic system. For instance, using a dynamic CGE and including also productive capital losses from sea-level rise, Bosello et al. (2009a) find that negative impacts can amount in 2050 to 0.012% of GDP in the Mediterranean Europe. This study also depicts the possible future impacts in North Africa and Middle East highlighting losses of the 0.016 and 0.006% of GDP respectively.

A general equilibrium approach has been used also by Deke et al. (2002) which restrict their study to the costs of coastal protection, ignoring land loss and its wider economic consequences. The costs of coastal protection are subtracted from investment; this essentially reduces the capital stock, and hence economic output. They

Table 10.2 Economic impacts of sea-level rise in the Mediterranean. Selected studies

	Climate or Sea level scenario	Protection level	(Annual) Protection cost		(Annual) Residual damage	
			Million $	% of GDP	Million $	% of GDP
PESETA project (Nicholls et al. 2009)						
Croatia	A2 medium 0.44 m in 2080	0			30	
Greece		0			449	
Italy		0			149	
Spain		0			620	
Croatia		“Optimal”	17		0.9	
Greece		“Optimal”	46		8.4	
Italy		“Optimal”	74		10.9	
Spain		“Optimal”	72		11.5	
Southern Europe	A2 high 2085	0			356	–0.005
Deke et al. (2002)						
Western Europe (direct cost)	0.13 m in 2030	Total	688	0.003		
Middle East North Africa (direct cost)			57	0.01		
Western Europe (welfare impact)			1,376	–0.006		
Middle East North Africa (welfare impact)			496	–0.087		
Bosello et al. (2009a)						
Mediterranean Europe	0.25 m. in 2050	0			783	–0.012
North Africa		0			3,594	–0.016
Middle East		0			332	–0.006
Gambarelli and Goria (2004)						
Fondi Plain (Italy)	1 m	0			130–260 (Cumulated discounted 2002–2100 3% dr)	

Source: Our elaboration from the quoted studies estimate a direct protection costs against 13 cm. of sea-level rise in 2030 ranging from 0.003% of GDP in Western Europe to 0.01% in North Africa and Middle East, and a final GDP loss ranging from 0.006% of Western Europe and the 0.087% of North Africa and Middle East with respect to the no protection case.

These macro-regional or country-level assessments have a major shortcoming. They hide hot spots for coastal vulnerability. These can only be addressed with site-specific investigation. In this vein Gambarelli and Goria (2004) estimate the cost of sea-level rise in the Fondi plain in Lazio (Italy). This is a low lying area inhabited by 30,000 people facing a particularly high flooding risk. It is characterized by an important wetland ecosystem, greenhouse activities and potential for coastal tourism. Uncontrolled sea-level rise can entail a cumulated discounted loss ranging from Eur 130 to 260 Million. Figures are expected to boom when densely populated coastal areas are involved. El-Raey (1997) estimated that in the cities of Alexandria, Rosetta and Port Said on the Nile delta coast of Egypt, a sea-level rise of 50 cm could result in over two million people abandoning their homes, the loss of 214,000 jobs and the loss of land valued at over US$ 35 Billion.

10.4.2 Extreme Events

In 2005, 17 of the 20 most costly insured losses were represented by weather related extreme events amounting to a total of over $ 74 billions, $ 45 billions of which provoked by the Katrina hurricane alone. A similar picture can be drawn stretching the analysis backward to 1970. Extreme weather events like storms, typhoons and hurricanes are recorded 18 times in the top 20 most costly insured losses where hurricanes Andrew, Wilma and Ivan generated losses in excess of $ 22 billion, 13 billion and 10 billion in 1992, 2004 and 2005 respectively (Swiss Re 2006)

Losses related to climate changes induced extreme events are not confined to hurricanes and storms: change in precipitation patterns for instance may lead to droughts in some areas, thereby increasing the risk of brush and forest fires. In some other areas increased precipitations can increase floods risk (EcoSecurities 2005). For instance in 2005 rain, floods and landslides in Europe induced an insured loss of more than $ 1.8 billion (Swiss 2006). Finally, crop diseases, losses for the tourism or the energy industry, negative impacts on human health are also expected (Mills et al. 2005; Mills and Lecomte 2006).

Without any adaptation, losses related to extreme events are likely to increase: on the one hand climate change can increase their frequency and intensity; on the other, the intrinsic trend of economic development to increase the value and density of human and physical capital implies higher vulnerability.

The Mediterranean does not differ from this general picture: it will be exposed to more frequent extreme hot period, with the corollary of droughts, forest fires, peaks

Table 10.3 Potential changes in insured risk capital to cover US hurricanes, Japanese typhoons and European windstorms under a low and high emission scenario for 2080

Storm type	Approximate current risk-capital requirement	Additional capital required with low emissions[b] (%)	Additional capital required with high emissions[b] (%)
US hurricane[a]	$ 67 bn	+20	+90
Japanese typhoon[a]	$ 18 bn	+10	+80
European windstorm[a]	$ 33 bn	No change	+5

Source: ABI (2005)

[a] Capital requirements to cover 1-in-250-year loss

[b] Percent changes from baseline (2004 prices)

in heat-related mortality, but also to more frequent intense precipitations leading floods, landslides, etc. The first will be a generalized concern for the whole area, while the second will be more an issue for Euro-Mediterranean countries.

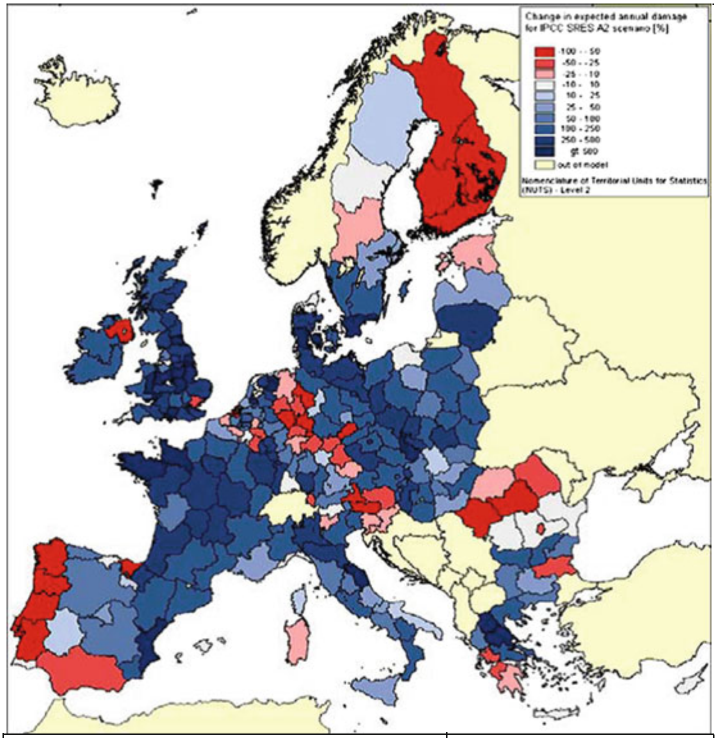
Assessing economically the associated expected losses is very difficult, quantitative information is very thin, and when available it covers only the Mediterranean Europe.

As a general indication it can be observed from past trends that every 10 years economic losses due to natural disasters double worldwide. These have reached almost $ 1 trillion over the past 15 years. Each year now brings 4-times as many weather-related natural disasters as 40 years ago, resulting in 11-times the insurance losses (equivalent to $ 10 billion per year over the course of the 1990s). If current trends persist, the annual loss amounts will, within the next decade, come close to $ 150 billion (Innovest 2002).

The Association of British Insurers (2005) provides some information more specific to Europe. It estimates that today to cover the vast majority of European windstorm claims, except those occurring less than once in 250 years on average, risk capital totals approximately $ 33 billion (Table 10.3). Under a high emissions scenario where carbon dioxide emissions double by the end of the century, modeling from this study suggests that the risk capital requirement could increase by 5%.

This projection relates to insured capital at risk. Increase in damages can in fact be much higher. Feyen and Dankers (2009) within the PESETA project provide an estimate of change in expected annual direct damage from river flooding (Fig. 10.3).

Feyen and Dankers (2009) show that flood damages, reflecting regional patterns in flood hazard, are projected to rise across much of western, central and Eastern Europe, but also in Mediterranean regions like Italy as a whole, the north-eastern parts of Spain and northern Greece. In these areas direct economic losses are projected to increase between the 25 and the 100% with some peaks of the 250% in the mountainous regions of Italy and Greece. The strongest decrease in flood damage is projected for the North-Eastern parts of Europe, but also in southern Spain and Greece.



	1960-1990 (Million Eur/year)
Northern Europe	578
British Isles	806
Central Europe North	1,555
Central Europe South	2,238
Southern Europe	1,224
EU	6,402

Fig. 10.3 Relative change in expected annual direct damage from river flooding (averaged over administrative level NUTS2) between scenario (2071–2100) and control period (1961–1990 see *right table*) for a +3.9 °C temperature increase scenario (Source: Feyen and Dankers 2009)

10.4.3 Energy Demand

It is reasonable to assume that an increased mean temperature will increase the amount of energy demanded for cooling purposes and decrease that for heating purposes.[4]

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[4] Although adaptation to warmer temperature does not necessarily have to be through extra energy consumption, i.e. it can be partially implemented through passive building cooling, design, behavioural change, etc.

It is also reasonable to assume that at low level of temperature change the increased spending on cooling should be dominated by saving from reduced heating expenditure, but that the situation reverses at some point, at high enough levels of temperature change. It can thus be expected that the relationship between energy demand and mean global temperature might be "U" shaped.

An important question is whether we are already to the right of the minimum of such a curve, in which case global energy consumption will rise with higher global mean temperature, or whether we are still on the left-to-the-minimum portion of the curve, in which case global energy consumption will first decline and then eventually rise as global mean temperature increases (Hitz and Smits 2004).

An important role in this analysis is played by wealth or income effects. Indeed if – as it seems – air conditioning is strongly correlated with income, even if we had the same climate in future years the demand pattern between heating and cooling would change because of income changes. This introduces uncertainty on the analysis of adaptation cost in the energy sectors and greater care must be taken in assuming on which branch of the curve we are, based on current energy consumption.

In our knowledge there are few studies that estimated the effects of climate change on the demand for energy and none of them is specific to the Mediterranean Europe. Tol (2002), based his extrapolations on a UK-specific model that relates the energy used for heating or cooling to degree days, per capita income, and energy efficiency. Tol hypothesized that both relationships are linear. Economic impacts were derived from energy price scenarios and extrapolated to the rest of the world. Energy efficiency is assumed to increase, lessening costs. According to Tol's (2002) best guess parameters, by 2100, benefits (reduced heating) are about 0.75% of GDP and damages (increased cooling) are approximately 0.45%. The global savings from reduced demand for heating remain below 1% of GDP through 2200. However, by the twenty-second century, they begin to level off because of increased energy efficiency.

For cooling, the additional amount spent rises to just above 0.6% of GDP by 2200. Thus throughout the next two centuries, net energy demand decreases, suggesting we are on the downward sloping part of the energy demand- temperature curve.

These finding are somehow confirmed by Berrittella. They conducted a dynamic panel data econometric estimation of the demand for coal, gas, electricity, oil and oil products by residential, commercial and industrial users in OECD and (a few) non-OECD countries, to derive long-run elasticities for temperature. The main findings highlighted that residential demand responds negatively to temperature increases, pointing at a prevalence of heating needs in determining residential demand. By contrast, industrial demand is insensitive to temperature increases. In the case of the service sector, only electricity demand displays a mildly significant negative elasticity to temperature changes. The estimated elasticities range from the −0.6 of electricity to the −3 for oil product. Transposed to a scenario of 1°C increase in mean global temperature, this may configure a decrease in households' demand ranging from the −1.5 to the −7% for electricity and from the −6 to the −40% for oil products, depending on the region.

However, studies for the US provide mixed results. With the exception of Rosenthal et al. (1995), Cline (1992) and Fankhauser (1995) found a net increase in electricity expenditure for a 2.5°C increase in mean global temperature amounting to 9,900 and 6,900 US $ billions respectively, and more recently, Mendelsohn (2001) showed that energy costs will increase even with an approximate 1°C increase. Since the United States consumes about one fourth of global energy, this may be an indication that global energy demand will increase immediately as temperatures rise.

Concluding, the still limited quantitative evidence does not allow assessing with certainty the impact of climate change on energy demand and consequently the cost of the associated demand shifts especially in the Mediterranean. However it can be noted that, when these costs are positive, they appear to be a tiny percentage of GDP. All the cited studies however have been obtained in partial equilibrium. The rebound effects on the overall economic context of the re-composition of demand have not been taken onto account. These effects can be potentially very large and need to be carefully assessed. This is one of the aim of the work undertaken within the CIRCE project which will be reported below.

10.4.4 Health

The impacts of climate change on human health are many and complex. Global warming would increase heat-related health problems, which mostly affect people with pre-established cardiovascular and respiratory disorders. On the other hand, global warming would reduce cold-related health problems, again most prevalent in people with cardiovascular disorders. Climate change would affect the range and abundance of species carrying diseases, and would affect the virulence of those diseases as well (McMichael 2004); could increase the number of people suffering from death, disease and injury from floods, storms, fires and droughts (Confalonieri et al. 2007).

Quantifying these impacts is extremely difficult though. Firstly, it is in general problematic to record changes in health status actually occurred as yet in response to observed trends in climate over recent past. Some studies estimated that in 2000, climate change caused the loss of over 150,000 lives and 5,500,000 DALYs (Campbell-Lendrum et al. 2003; Ezzati et al. 2004; McMichael 2004). Secondly, when future estimations are involved, there is the crucial complication to include correctly possible autonomous acclimatization processes be they physiological, behavioral or driven by social economic conditions which are also fundamental in determining final vulnerability (Tol et al. 2007). This translates in the difficulty to assess economically health impacts.

An economic assessment of direct cost of climate change impacts on human health for the EU with some detail on the Mediterranean area is provided by the PESETA project (Watkiss et al. 2009). Firstly, projected mortality from temperature changes for the 2020s and the 2080s across Europe are estimated.

The projections are based on temperature-response functions, providing the relationships of daily mortality against daily temperature derived from epidemiological

Table 10.4 Change in death rate per 100,000 due to heat related mortality: projections for 2080

	2.5°C	3.9°C	4.1°C	5.4°C
Northern Europe	8	15	9	14
British Isles	4	8	7	10
Central Europe North	12	24	19	33
Central Europe South	17	31	31	52
Southern Europe	11	18	18	28
EU	12	22	19	33

Source: Our adaptation from Watkiss et al. (2009)

Table 10.5 Change in death rate per 100,000 due to cold related mortality: projections for 2080

	2.5°C	3.9°C	4.1°C	5.4°C
Northern Europe	−8	−13	−11	−16
British Isles	−27	−48	−57	−75
Central Europe North	−14	−25	−26	−37
Central Europe South	−20	−37	−39	−53
Southern Europe	−28	−52	−49	−64
EU	−21	−37	−39	−52

Source: Our adaptation from Watkiss et al. (2009)

studies (mainly drawn on the EU-funded cCASHh project, Menne and Ebi (2006) and Kovats et al. (2006)).

Separate functions represent heat and cold effects. Acclimatization is also considered.

In PESETA the impacts quantified do not fully represent the effects of urban zones (for example, elevated temperatures in urban areas and possible interactions with air quality, especially ground-level ozone), and do not include heat-waves. Tables 10.5 and 10.6 report changes in mortality due to heat and cold stress.

According to Table 10.4 the estimated increase in heat-related mortality rates in the EU is between 12 deaths/100,000 population per year for the lowest warming scenario to 33 for the highest warming case, which leads to an estimate of increase in mortality of 50,000 to 160,000 cases per year, respectively.

The highest increase in relative mortality is projected to occur in Central and Southern Europe.

Warmer projections show also cold related reduced mortality (Table 10.5). The range is between 100,000 and 250,000 per year. The British Isles and the Southern Europe regions are estimated to be the areas with the highest fall in mortality.

Then, mortality changes are economically assessed using two alternative approaches (Table 10.6). The first, values mortality results using the value of a statistical life (VSL) metric which is directly applied to the numbers of cases (deaths) estimated. The second approach considers the value of a life year lost (VOLY), which provides a means of explicitly recognizing the loss of life expectancy involved.

Table 10.6 Direct impacts of climate change on health in Europe

	European total number of deaths	Valuation using VOLY central (€ 59 k)	Valuation using VSL central (€ 1.11 M)
Heat-related deaths			
(a) Climate-dependent functions			
2020s	27,337	12,903	30,344
2020s with acclimatization	3,978	1,878	4,416
2080s 2.5°C scenario	50,665	23,914	56,238
2080s 2.5°C scenario with acclimatization			
2080s 3.9°C scenario	106,419	50,230	118,125
2080s 3.9°C scenario with acclimatization	17,080	8,062	18,959
(b) Country-specific functions			
2020s	26,372	12,448	29,273
2020s with acclimatization	3,938	1,859	4,371
2080s 2.5°C scenario	58,508	27,616	64,944
2080s 2.5°C scenario with acclimatization			
2080s 3.9°C scenario	107,339	50,664	119,146
2080s 3.9°C scenario with acclimatization	19,449	9,180	21,588
2080s 4.1°C scenario	95,822	45,228	106,362
2080s 4.1°C scenario with acclimatization	19,346	9,131	21,474
2080s 5.4°C scenario	161,694	76,320	179,480
2080s 5.4°C scenario with acclimatization	73,322	34,608	81,387
Cold-related deaths			
(a) Climate-dependent functions			
2020s	−50,272	−23,728	−55,802
2020s with decline in sensitivity of mortality to cold	−19,422	−9,167	−21,558
2080s 2.5°C scenario	−57,823	−27,292	−64,184
2080s 2.5°C scenario with decline in sensitivity of mortality to cold			

2080s 3.9°C scenario	−86,291	−40,729	−95,783
2080s 3.9°C scenario with decline in sensitivity of mortality to cold	−18,835	−8,890	−20,907
(b) Country-specific functions			
2020s	−98,529	−46,506	−109,367
2020s with decline in sensitivity of mortality to cold	−6,893	−3,253	−7,651
2080s 2.5°C scenario	−101,112	−47,725	−112,234
2080s 2.5°C scenario with decline in sensitivity of mortality to cold			
2080s 3.9°C scenario	−184,222	−86,953	−204,486
2080s 3.9°C scenario with decline in sensitivity of mortality to cold			
2080s 4.1°C scenario	−189,742	−89,558	−210,614
2080s 4.1°C scenario with decline in sensitivity of mortality to cold	−5,645	−2,664	−6,266
2080s 5.4°C scenario	−255,696	−120,689	−283,823
2080s 5.4°C scenario with decline in sensitivity of mortality to cold	−62,679	−29,584	−69,574

Source: Watkiss et al. (2009)

For the 2020s without acclimatization, the heat-related effects are valued at € 13 billion when applying the VOLY method and at € 30 billion applying the VSL approach (assuming that on average, 8 years of life is lost per case), though drop to € 2–4 billion when acclimatization is included. The benefit due to the reduction of cold-related deaths are valued at € 23–46 billion according to the VOLY method and € 55–110 billion with the VSL method.

By 2100 under an A2 projection, the values range from € 50 to 180 billion without acclimatization, and € 8–80 billion per year with acclimatization. Similar or higher benefits are projected for the reduction in cold-related mortality. Watkiss et al. (2009) caution against a simple summing up of effects however note that the benefits from the reduction in cold-related deaths can be at least as large, and under many scenarios, larger than the increase in heat-related deaths.

The economic impact on GDP of climate change related changes in health status is estimated by Bosello et al. (2009a). They translate data on mortality and morbidity changes associated to six classes of diseases (malaria, schistosomiasis, dengue, gastro-enteric, cardio vascular and respiratory) derived by Tol (2002) into changes in labor productivity and in health care expenditure. These on their turn are used as inputs to a world CGE model that computes the economic consequences. In general the Mediterranean area is marginally affected in economic terms. Southern Europe, North Africa and the Middle East are expected to lose respectively the 0.02, 0.13, and 0.1% of GDP in 2050 for a temperature increase of 3.1°C. Figures are however relevant in absolute terms amounting to $ 130, 2,920, 5,539 million respectively. This is the net effect of climate change which takes into account the decrease in mortality and morbidity related to the reduced cold stress.

10.4.5 Agriculture

Climate change impacts on crops productivity can be substantial. Easterling et al. (2007) summarize in a meta-analysis the extended literature on this topic: moderate degree of warming can be beneficial mainly due to positive CO_2 fertilization effect. However, a given threshold trespassed, impacts become negative and rapidly worsening.

This pattern is common to main cereal cultivations worldwide, but much more concerning at the lower latitudes where the majority of developing countries is. At the mid to high latitudes, to which the Mediterranean area belongs, slightly negative to moderately positive effects are estimated until +3.5°C for wheat and rice and until +2°C for maize.

Starting from those data the few economic assessments available in the literature tend to highlight small losses from climate change impacts on agriculture especially in Mediterranean Europe where the sector also accounts for only a small part of gross domestic production (GDP). Against this background, the PESETA project (Ciscar et al. 2011) applying a EU CGE model reports for Mediterranean Europe almost no economic losses from climate change impacts on agriculture for a 2.5°C temperature increase scenario. These become positive for a 5.4°C temperature increase scenario but equal to the 0.1% of GDP. Bosello et al. (2009a, b) analyzing climate-change induced changes in land productivity with a world CGE model concludes that Mediterranean Europe could in fact gain slightly (+0.2 to +0.5% of GDP in 2050 with respect to the baseline) due to effects on international agricultural markets. The direct climate change effect on land productivity is negative worldwide, however it is less negative in the Mediterranean Europe than elsewhere, especially South Asia, Africa and Latin America. Increase in agricultural prices and re-shuffling of international demand then bring an advantage to EU agricultural exports and overall GDP. On the contrary North Africa is much more vulnerable and final impact on regional economic performances range from the −0.6 to the −2.5% of GDP in 2050.

However, these economic assessments are based on inputs that consider the effects of projected changes in temperature and CO_2 fertilization, but do not fully consider issues of water availability, rarely consider extreme events and impacts outside cereal cultivations (EEA 2008). All these climatic stressors are expected to increase the exposure of Mediterranean countries agricultural sectors with negative impacts on yields, employment and revenue generation (IPCC AR4 2007).

Some indications of the economic magnitudes potentially involved are provided by studies assessing the direct economic losses sustained by agricultural sectors in the past because of extremes climatic events.

In this vein EEA (2004) estimates that European droughts of 1999 have caused losses of more than € 3 billion to agriculture in Spain; COPA-COGECA (2003) estimates that the hot summer of 2003 have led to € 810 million in economic losses to agriculture in Spain and up to € 4–5 billion in Italy; Munich re (2008) estimates a total of € 10 billion losses for the whole EU agricultural sector in 2003 consequence of impact on farming, livestock and forestry.

These figures do not obviously take into account future adaptation policies nor improvement in agricultural practices and farming technologies. However they provide important information on potential future costs if nothing will be done.

It is finally important to consider that impacts on agricultural production are only a part of expected consequences of climate change in agriculture: this is much more important in terms of area occupied and land management, and of social aspects like the conservation of traditional production, farmer income and employment.

10.4.6 Ecosystems

Economic assessments of the impact of climate change on ecosystem services are extremely scarce. In the Mediterranean context, in our knowledge they are limited to Chiabai et al. (2011) and Bosello et al. (2009b).

Chiabai et al. (2011) quantify the potential impact of climate change on some services provided by EU ecosystems. In particular: the land productivity service associated to biodiversity in agricultural soil, the wood provisioning and the carbon sequestration services of forest ecosystems.

Table 10.7 Climate change impacts on ecosystem services (% change wrt 2000, reference year 2050)

	+1.2°C T wrt 2000		+3.1°C T wrt 2000	
	Agricultural land productivity	Forest productivity (timber)	Agricultural land productivity	Forest productivity (timber)
Med_Europe	−2.30	−6.08	−5.94	−15.70
North_Europe	−0.93	15.09	−2.39	38.97
East_Europe	−1.42	4.48	−3.67	11.56

Source: Adapted from Chiabai et al. (2011)

Table 10.8 Climate change impact on GDP with (W Es) and without (W/o Es) ecosystem/biodiversity effects

	Climate change indirect impact NPV 2001–2050 (dr–3%) Million US$					
	+1.2°C T wrt 2000			+3.1°C T wrt 2000		
Region	W/o ES effect (1)	W ES effect (2)	Difference (impact on ES services) (2) − (1)	W/o ES effect (1)	W ES effect (2)	Difference (impact on ES services) (2) − (1)
Med_Europe	−33,979	−43,733	−9,754	−65,084	−97,631	−32,548
North_Europe	488,420	490,350	1,929	1,360,399	1,366,058	5,659
East_Europe	−20,808	−28,046	−7,238	−101,529	−123,787	−22,258

Source: Bosello et al. (2009b)

As shown by Table 10.7 consequently to climate change land productivity is expected to decline for Europe as whole as a consequence of soil biodiversity loss, while forest timber productivity may decline in the Mediterranean, but increase in other EU areas especially in the Northern part.

Adding these information to an initial climate change impact scenario and comparing economic effects with a world CGE model, Bosello et al. (2009b) are able to disentangle the economic impact of climate change on those ecosystem services (Table 10.8).

Calculated over 2000–2050 (3% discount rate) they imply a higher loss for Mediterranean EU ranging from $ 9.7 to 32.5 billion; a higher loss for Eastern EU ranging from $ 7.2 to 22 billion, but a slight gain for Northern EU ranging from $ 2 to 5.6 billion. The total net discounted loss for the three regions ranges between 15 and 49 billion $ over the 50 years.

Finally, climate change also impairs the ability of EU forest to stock carbon. Depending on the climate change scenario, the loss of this carbon sequestration can be worth a net annuity of $ 553 to 1,736 million when calculated over the 2001–2050 period. These figures monetize the additional negative GDP performances imposed at the world level by the higher temperature increase consequent upon the lower CO_2 sequestered by EU forests.

10.4.7 Tourism

Climate change plays an obvious role in tourist destination choice. Although climate is by no means the only determinant (Crouch 1995; Witt and Witt 1995; Gossling and Hall 2006; Bigano et al. 2006a; Rosselló et al. 2005), the "amenity of climate" is recognized as one of the major determinants of tourism flows (Maddison 2001; Lise and Tol 2002; Bigano et al. 2006b). The Mediterranean in particular benefits from this determinant, being close to the main holidaymakers of Europe's wealthy, but cool and rainy, Northwest. Climate change would alter that, as tourists are particularly footloose. Recent researches (Hamilton et al. 2005a, b; Hamilton and Tol 2007; Amelung et al. 2007; Amelung and Moreno 2009) point out that Mediterranean countries, both in Southern Europe and North Africa, currently popular holiday destinations, may become "too hot" and less attractive under the climatic point of view. This is primarily relevant for summer tourism. But can be a concern also for winter tourism as a reliable sky season could not be guaranteed anymore in low ski resorts which are particularly vulnerable to warmer climate (Elsasser and Bürki 2002; Scott et al. 2004; Scott and McBoyle 2007; OECD 2007). This can be an additional source of negative economic impacts in those Mediterranean regions where winter tourism is particularly important in the production of value added like in Northern Italy, in some region of Spain and in the Balkans. The overall economic implications can be substantial. Just consider that about 10% of world GDP is now spent on recreation and tourism, and that recent contributions highlight the importance of tourism in stimulating economic growth (Lee and Chang 2008).

Studies addressing directly the economic impact of climate change on tourism activity are quite scarce though and reported in Table 10.9.

The emerging picture is a damage for Mediterranean Europe that can be economically relevant. Depending on the temperature scenario and on the flexibility that tourists can have in adjusting their holiday decisions, this can range from € 824 million to € 12.6 billion of direct losses according to Amelung and Moreno (2009). They compute the decrease in tourism expenditure estimating lower "bed nights" on the basis of changes in Tourism Climatic Index (TCI) between the 1970 and 2080. Losses could reach € 224 million just in the winter tourism segment in Northern Italy according to Bosello and Marazzi (2008). Their calculation is based on the estimate that for a temperature increase of 4°C the 80% of Italian ski resorts will run out of business not being able to operate due to the insufficient snow cover. Some indication on the overall impact on GDP is provided by Bosello et al. (2009a). In their exercise they use changes in tourism flows as a response to climate change computed by a world tourism model (see Bigano et al. 2005a, b), to decrease the demand addressed to the tourism and recreational services sector of a world CGE model. In a 3.1°C temperature increase scenario the negative performance of the tourism sector is reflected in a flexion of GDP of the 0.25, 0.65 and 2.8% in Southern Europe, North Africa and Middle East respectively. The general equilibrium assessment for Mediterranean Europe thus confirms the direct cost estimates, but in addition it shows that in term of climatic attractiveness North Africa and Middle East are even more vulnerable.

Table 10.9 Economic consequences of climate change impacts on tourism industry in the Mediterranean (in parenthesis the temperature increase scenario)

PESETA project (Amelung and Moreno 2009)	
Southern Europe[a]	–824 Million Eur (2.5°C) allowing seasonal adjustments; –12583 Million Eur (5.4°C) without seasonal adjustments
Bosello and Marazzi (2008)	
Northern Italy[b] winter tourism	–52 Million Eur (1°C); –224 Million Eur (4°C)
CLIMCHALP project (Bigano and Bosello 2007)	
Northern Italy Alpine Regions[c]	–694 Million Eur (average of A1, A2, B1, B2 IPCC SRES scenarios)
Bosello et al. (2009a)	
Southern Europe[d]	–0.25 (3.1°C)
North Africa[d]	–0.65 (3.1°C)
Middle East[d]	–2.80 (3.1°C)

Source: Our adaptation from the cited studies

Notes:

[a] Only Spain, Italy and Greece. Data expressed as absolute variation of direct tourism expenditure wrt present

[b] Only four Italian regions: Valle d'Aosta, Piedmont, Alto Adige, Friuli Venezia Giulia. Data expressed as absolute variation of ski resorts revenues wrt present

[c] Data for Valle d'Aosta, Piedmont, Lombardy, Veneto, Trentino Alto Adige, Friuli Venezia Giulia expressed as absolute variation of direct tourism expenditure wrt the baseline without climate change in 2030

[d] Data expressed as percentage changes in GDP wrt the baseline without climate change in 2050

10.4.8 Overall Assessment of Economic Impacts of Climate Change in the Mediterranean

The studies cited so far assess impacts by category. But are there estimates of economic impacts of climate change as a whole in the Mediterranean area? One source of information is provided by damage functions embedded in hard-linked IAMs. As said, these are reduced form equations liking temperature increase to GDP losses calibrated to reflect the latest available knowledge. One among these damage functions is that proposed by Nordhaus and Boyer (2000). It is embedded in the RICE model, but it has been used as reference by other modeling exercises (see e.g. Bosetti et al. 2006). As shown by Table 10.10, Nordhaus' study does not disentangle the Mediterranean region. This is covered by different geographical aggregations though, and at least a very rough indication of climate-change costs imposed to the area can be obtained.

According to these estimates, total damage for the Non EU Mediterranean regions as a whole, could range between the 2 and the 4% of GDP, that of

Table 10.10 Climate change impacts in different world regions encompassing the Mediterranean area under a 2.5°C increase in global temperature above 1990 level (% of GDP)

	Agriculture	Other vulnerable markets	Coastal	Health	Non market time use	Catastrophic events	Settlements	Total
West. Europe	0.49	0.00	0.60	0.02	–0.43	1.91	0.25	2.83
High income OPEC	0.00	0.91	0.06	0.23	0.24	0.46	0.50	1.95
Africa	0.05	0.09	0.02	3.00	0.25	0.39	0.10	3.91

Source: our adaptation from Nordhaus and Boyer (2000)

Mediterranean Europe should be no less than the 2.83%.[5] Major concerns for EU economies are impacts on agriculture and those driven by catastrophic events. The rest of the Mediterranean area is more affected by health and other market impacts. In Nordhaus and Boyer (2000), the estimate of the total damage is the sum of single impact types. Thus it does not take into account possible impact interactions, moreover behavioral changes driven by changes in prices (market driven adaptation) are not explicitly modeled.

Some recent exercises try to do so: Eboli et al. (2010), Bosello et al. (2009a, b), Aaheim et al. (2009) within the ADAM project, Aaheim and Wey (2010) within the ENSEMBLES project, Ciscar et al. (2011) within the PESETA project. All use world (static or dynamic) CGE models and analyze the final effect on GDP or on welfare of a wide range of impacts.[6] Only Bosello et al. (2009a, b, c) report results for the whole Mediterranean (Northern, Southern and Eastern area), other studies offer indications just for its EU part. Table 10.11 summarizes the findings also reporting some results for non-Mediterranean regions that can offer an interesting comparison. In the light of the differences in quality and quantity of impacts considered, in the model baselines and specifications,[7] and in the geographical detail, the results are comfortably robust.

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[5] We assume that "Africa and High Income OPEC" are partly representative of North African countries; and that Western Europe indicates the minimum impact that Southern Europe can experience due to its higher exposure compared to the Northern part.

[6] On sea-level rise, agriculture, health, energy demand, tourism flows, Eboli et al. (2010); on sea-level rise, agriculture, health, energy demand, tourism flows, forestry, Bosello et al. (2009a); on sea-level rise, agriculture, health, energy demand, tourism flows, forestry, fisheries, extreme events, electricity supply Aaheim and Wey (2010); on sea-level rise, agriculture, tourism, river floods Ciscar et al. (2011).

[7] Probably the most important difference across the quoted studies, all making use of CGE models, is that pertaining to static and dynamic exercises. In the first case no transitions, dynamics and inertias of the economic system and linking the economic system to climate impacts are captured. In the second they are taken into account. Accordingly, studies results would not be immediately comparable. It can be noted that, typically, dynamic model results are larger than those of static models as inertias tend to amplify both positive and negative effects.

Table 10.11 Climate change impacts in different Mediterranean regions (% differences wrt baseline)

	Final impact on GDP %	Direct cost (% of GDP)
Eboli et al. (2010)[a]		
Italy	−0.16 (1.2°C)[b]	
Bosello et al. (2009a)[c]		
Northern Europe	1.8 (2°C)[b]	5 (2°C)[b]
Mediterranean Europe	0.2 (2°C)[b]	−2.3 (2°C)[b]
North Africa	−1.7 (2°C)[b]	−5.4 (2°C)[b]
Middle East	−1.9 (2°C)[b]	−4.0 (2°C)[b]
ENSEMBLES project (Aaheim and Wey 2010)[c]		
Europe	0.6 (2°C)[d]	Na
AFRICA	−3.8 (2°C)[d]	Na
ADAM project (Aaheim et al. 2009)[a]		
Southern Europe	−0.05 (2°C)>−<−0.4 (4°C)[d]	−0.4 (2°C)>−<−1.75 (4°C)
Iberia	−0.1 (2°C)>−<−0.5 (4°C)[d]	−0.7 (2°C)>−<−3.2 (4°C)
PESETA project (Ciscar et al. 2011)[a]		
Northern Europe	0.55 (2.5°C)>−<0.7 (5.4°C)[e]	Na
Southern Europe	−0.25 (2.5°C)>−<−1.4 (5.4°C)[e]	Na

Source: Our adaptation from Eboli et al. (2010), Bosello et al. (2009a), Aaheim and Wey (2010), Aaheim et al. (2009), and Ciscar et al. (2011)

Notes:

[a] Static exercises

[b] Reference year 2050

[c] Dynamic exercises

[d] Reference year 2100

[e] Percent of welfare change compared to current situation (2010)

According to all studies Northern Europe is expected to gain from climate change, while in the Mediterranean Europe small losses or slight gains are expected. Losses will be moderate for moderate temperature increases; they can be rather relevant, even though not catastrophic, for quite extreme temperature increase scenarios. This points out a relatively low climate change vulnerability of the EU region even though this is higher in its Southern part. Both Bosello et al. (2009a) and Aaheim et al. (2009) emphasize the role of market driven adaptation. For instance, for a 2°C temperature increase scenario, climate change impacts would entail a direct cost ranging from the 0.4 to the 2.3% of GDP.[8] This is a combination of a reduction in agricultural productivity, lower tourism inflow, contraction of the energy sector and land loss to sea-level rise. But once markets adjust the final impact on GDP is much smaller. In Bosello et al. (2009a) the dynamics of agricultural and energy markets are sufficient to turn losses into gains. The lower energy demand induced in Europe and worldwide by higher temperatures reduces energy prices. This is particularly beneficial for a heavy energy importer like the EU. Similarly, gains in trade are associated to higher prices of agricultural commodities consequent

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[8] Note that these estimates obtained through a direct cost methodology are closer to Nordhaus and Boyer (2000) estimates.

the decline in crops' productivity. Mediterranean EU can thus export relatively more as its agricultural sector is damaged, but less than that of other countries, and at higher prices. This is a long-term effect though. Indeed these market forces are not sufficient to outweigh negative climate change effects before 2030.

Also in North Africa and in the Middle East, market forces smooth initial negative impacts, however not completely. Vulnerability remains high and losses are considerable. Those regions highlight a higher exposure, sensitivity and lower capacity to adapt.

10.5 The Integrated Impact Assessment Performed by CIRCE Project

The CIRCE project proposes one of the first attempts to perform a detailed integrated impact assessment exercise focusing on the Mediterranean area.

The scheme of the exercise is very similar in spirit to what depicted by Fig. 11.2. A climate scenario is firstly taken as reference for the whole evaluation. This is the A1B IPCC SRES scenario whose detailed downscaled characteristics have been defined by CIRCE climatic work packages. Consistently with that scenario, a set of impact-specific studies have been performed estimating effects on tourism attractiveness, on energy demand, on sea-level rise, on agriculture, on ecosystem services, on migration flows and on water demand and supply. Finally, the results of those studies compatible in scope and in output characteristics have been used as inputs to a CGE model (Bosello et al. 2010).

This allowed assessing the effects of climate change for the Mediterranean economies related to energy demand, sea-level rise and tourism.[9]

Climate-change impacts on energy demand have been derived from CIRCE D10.5.3: "Energy demand and temperature changes: econometric estimation" (Bosello and De Cian 2009). This study estimates household energy demand on a macro dynamic panel dataset spanning from 1978 to 2000, for 31 countries. Then it computes the demand elasticity to temperature of different energy vectors for cold, mild and hot countries. A cluster analysis placed Mediterranean economies within the mild region. For this area, the study highlights the presence of a cooling and heating effect (Table 10.12). Summer temperature leads to higher annual electricity demand (an almost uniform 0.7% in the Mediterranean area) to feed a higher usage

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[9] Although climate change impacts on agriculture are presently not part of the CGE assessment, CIRCE deliverable D10.9.5: "Economic evaluation of climate change impact on agriculture in the Mediterranean region – a CGE versus partial equilibrium analyses" will provide these inputs. In addition, work performed by CIRCE WP10.9 allowed to build inside the CGE model and estimate a new and more realistic description of agricultural production. By the same token climate change impacts on migration flows will be included as long as results from WP10.3 will be completed.

Table 10.12 Direct impact of climate change A1B SRES scenario: % changes wrt baseline in 2050

	Households' energy demand				Tourism	
Country/region	Natural gas	Oil products	Electricity	Land loss to sea-level rise[a]	Demand shift	Expenditure flows[b]
Italy	−12.48	−15.61	0.73	−0.07	−1.26	−9.87
Spain	−12.45	−15.52	0.73	−0.02	−2.32	−7.78
France	−13.08	−16.45	0.78	−0.06	−0.64	−5.31
Greece	−12.00	−15.09	0.70	−0.17	−2.39	−1.97
Malta	−12.48	−15.61	0.73	0.00	−3.83	−0.07
Cyprus	−13.11	−17.38	0.74	−0.27	−3.67	−0.42
Slovenia	−12.48	−15.61	0.73	0.00	−0.55	−0.07
Croatia	−12.48	−15.61	0.73	−0.04	−3.16	−0.93
Fyug	−12.24	−15.35	0.71	−0.42	−1.04	−0.42
Albania	−12.00	−15.09	0.70	−0.27	−3.25	−0.33
Turkey	−13.11	−17.38	0.74	−0.08	−0.04	−0.15
Tunisia	−12.48	−15.61	0.73	−0.25	−4.87	−1.21
Morocco	−12.45	−15.52	0.73	−0.17	−4.19	−1.20
RoNAfrica	−12.51	−15.90	0.72	−0.07	−3.14	−13.24
RoMdEast	−13.11	−17.38	0.74	−0.42	−3.25	−56.83
RoNME	−13.72	−15.54	−2.09	−0.79	1.30	40.34
RoA1	−12.26	−16.17	0.11	−1.31	2.80	188.31
ChInd	Nss	nss	20.37	−1.82	0.07	0.39
RoW	Nss	−1.8262	15.69	−0.92	−1.88	−129.26

[a] Percent of total land
[b] $ billions

of air conditioners. On the contrary gas and oil product demand, mainly addressing heating needs, respond negatively to temperature increases, especially when occurring in fall, spring or winter (−12% on an annual basis).

Information on land losses have been provided by CIRCE D.10.6.2: "Updated version of the DIVA−Med database" (Vafeidis 2009) which reports the most recent findings from the Dynamic Integrated Vulnerability Assessment (DIVA) model. This, carried out simulations for IPCC A1B, A2 and B2 scenarios until 2500, with detailed results at coastal level (regular grid with a spatial resolution of 5°, with 5-year time steps until 2100 and 100-year time steps from 2100 to 2500). For each scenario, both a "with adaptation" and a "without adaptation" cases have been run, and the corresponding land losses have been assessed. Consistently with the social economic benchmark of the CGE model, land losses in 2050 from the A1B "without adaptation" scenario have been used as input data.

To estimate climate change impacts on the tourism sector, tourism flows by region have been obtained from the Hamburg Tourism Model (HTM), (Bigano et al. 2005a, b; Hamilton et al. 2005a, b) an econometric simulation model of tourism flows in and between 207 countries, run on the A1B SRES scenario. Climate is represented by the annual mean temperature. A number of other variables, such as country size, were included in the estimation, but these factors are held constant in the simulation. International tourists are allocated to the different countries on the basis of a general attractiveness index, climate, per capita income in the destination countries, and the distance between origin and destination. Again, other explanatory variables were included in the regression for reasons of estimation efficiency, but these are held constant in the simulation. The number of international tourists to a country is the sum of international tourists from the other 206 countries. See Bigano et al. (2005a) for further details. Total expenditure is calculated multiplying the number of tourists times an estimated value of the average individual expenditure.

To determine with the CGE model the economic consequences of the different impacts assessed, these need to be translated first into changes in economic variables existing in the model.

Land losses to sea-level rise have been modeled as percent decreases in the stock of productive land by region. In this case, the modification concerns a variable, land stock, which is exogenous to the model and therefore is straightforwardly implemented.

Changes in regional demand for oil, gas and electricity have been modeled as exogenous shifts in the demand by the different economic sectors for the output of the oil, gas and electricity industries. As demands are endogenous variables to the model, a final demand adjustment is then determined by the model itself.

Changes in tourism attractiveness have been implemented as changes in regional demand addressing market services sectors. This has been done rescaling the change in tourism and recreational services demand (expenditures) to the wider market services demand which includes tourism services.

Table 10.12 summarizes the results of the direct impact assessment exercises once they have been translated into suitable inputs for the CGE model.

As long as direct impact are concerned, it is possible to note that, on an annual basis, consistently with the cooling summer and heating winter effects, electricity demand in the Mediterranean area is expected to increase by roughly the 0.7% in 2050; heating demand however is estimated to decrease by an almost uniform 12 and 15% for natural gas and oil products. Sea-level rise is negative for all the regions considered. The amount of land loss is however a tiny percent of total regional land. The highest losses are expected for Tunisia and Morocco followed by Malta and Cyprus, nonetheless the loss is lower than the 5% of total national surface. Finally impacts on tourism demand are clearly negative for all the Mediterranean (except a very small gain for Turkey), becoming "too hot", and positive for the non Mediterranean EU whose climatic attractiveness increases. The higher losses are again experienced by Tunisia and Morocco (−4.9 and −4.2% respectively) followed by Malta, Cyprus and Croatia, which are not only warmer, but also where the tourism share on services value added is higher. Among the Euro-Mediterranean countries the bigger looser are Greece, Spain and Italy.

Final GDP impacts are reported by Fig. 10.4. In terms of aggregate impact the whole Mediterranean area losses the 1.2% of GDP with the Northern-Mediterranean countries clearly less vulnerable than the Southern-Mediterranean ones. Among the former the average loss in 2050 is the 0.5% of GDP, while among the latter this more than doubles. Particularly adversely affected are Cyprus, Albania and the Eastern Mediterranean region (−1.6, −2.4, −1.5% of GDP respectively in 2050). In terms of impact types, tourism and sea-level rise are clearly the most threatening, while GDP impacts induced by demand re-composition of energy use is less of an issue and often positive. Again, a difference emerges between the North and the South Mediterranean. In the former, impacts associated to sea-level rise and tourism are rather balanced, while in the latter, losses of the tourism industry dominate. Summarizing, CIRCE confirms the quite good adaptive capacity against climate change of Euro-Mediterranean countries and the higher vulnerability of North African and Middle East countries. This is driven not only by higher negative impacts on average, but by an economic structure where the tourism activity contributes with an higher share to the production of value added. It is also worth stressing that the impacts considered are just a small subset of those that climate change can originate. Thus total negative impact can be expected to be quite higher than those here estimated.

Finally the analysis is completed by the description of the more relevant economic adjustments triggered by climatic impacts. Figure 10.5 highlights effects on world prices. Three clusters can be identified: that of energy prices which decline, as the net effect on household energy demand is negative; that of industry and services prices which remain roughly constant; that of agricultural prices, which increase after 2020.

This has an implication on international competitiveness as typically measured by terms of trade effects (see Fig. 10.6).

North Africa and Middle East countries, as energy exporters are particularly damaged, while EU countries which are heavy energy importers and food exporters benefit. These "second order" effects thus hamper the negative impacts in the Southern and Eastern Mediterranean countries, but smoothen that in the Euro-Mediterranean ones, although not turning them into gains.

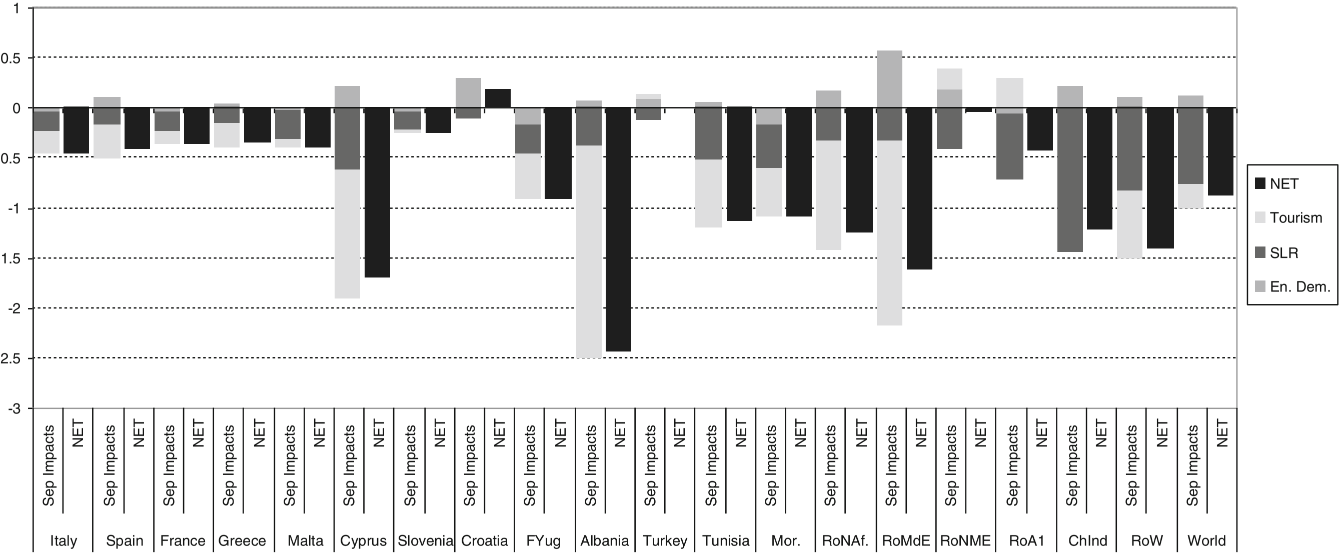

Fig. 10.4 Climate change impact on GDP: % change wrt baseline in 2050 (Source: Bosello et al. 2010)

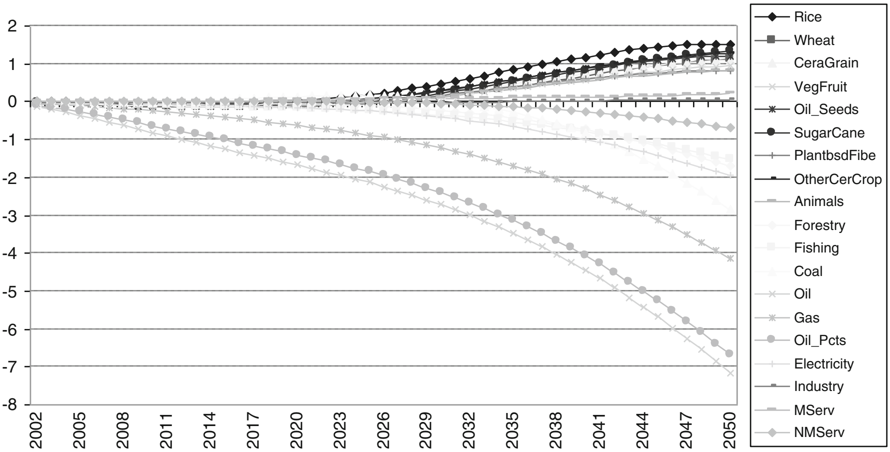

Fig. 10.5 Climate change impacts on world prices: % change wrt baseline (Source: Bosello et al. 2010)

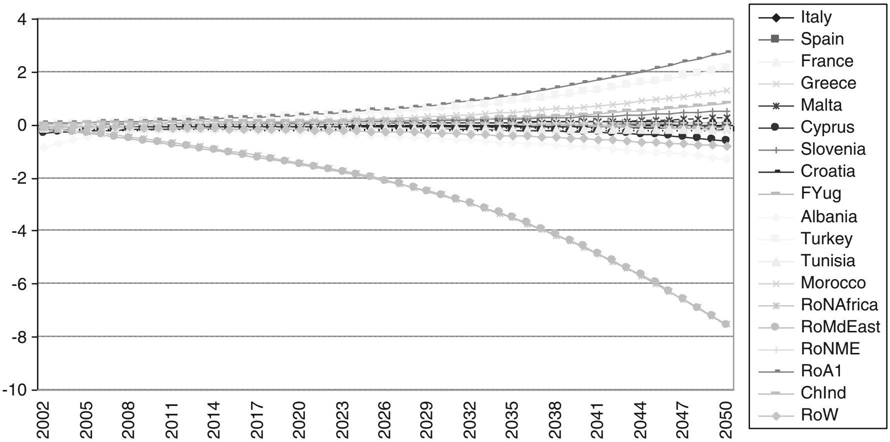

Fig. 10.6 Climate change impacts on terms of trade: % change wrt baseline (Source: Bosello et al. 2010)

10.6 Conclusions

The Mediterranean region is particularly exposed to climate change, however its final vulnerability depends on sensitivity and adaptive capacity which are quite differentiated across countries and particularly across the Northern and the Southern shore of the Mediterranean. A robust finding of the relevant economic impact assessment literature, part of wider integrated assessment exercises, points out a low vulnerability of Euro-Mediterranean countries (with losses ranging from the −0.25 to the −1.4% of GDP for extreme temperature scenarios or even slight gains), and a higher vulnerability of North African and Eastern-Mediterranean countries (of roughly the 2% of GDP by the mid of the century).

Major concerns for Euro-Mediterranean countries are impacts originated by sea-level rise and changes in tourism attractiveness with negligible effects which are expected from worsening in health conditions, or in crops productivity. These findings are particularly robust as they are common to both the direct costing literature and that more top-down oriented making use of large macroeconomic models coupled with climatic and climate change impact modules. This highlights the ability of Euro-Mediterranean regions to adapt economically and socially. Much less extended is the literature addressing climatic and economic pressures in North Africa and the Eastern Mediterranean. In the former region, impacts on agricultural productivity seem the more concerning building the 77% of total losses, while in the latter losses of tourism industry are the major source of GDP decrease.

The CIRCE project is the first conducting a fully fledged integrated assessment exercise on the Mediterranean region with a high spatial detail. The economic impact assessment part of CIRCE highlights Mediterranean countries' vulnerability to different climatic impacts considered in isolation and jointly. In particular it helps bridging the gap of knowledge affecting Southern and Eastern Mediterranean economies. The CIRCE economic impact assessments use the IPCC A1B SRES scenario as reference. Consistently with that scenario, a set of impact-specific studies have been performed estimating effects on tourism attractiveness, on energy demand, on sea-level rise, on agriculture, on ecosystem services, on migration flows and on water demand and supply. A subset of these studies, those related to energy demand, sea-level rise and tourism, provided results suitable to be used as input for a macroeconomic assessment conducted by a general equilibrium model.

In terms of aggregate impact the whole Mediterranean area losses the 1.2% of GDP with the Northern-Mediterranean countries clearly less vulnerable than the Southern-Mediterranean ones. Among the former the average loss in 2050 is the 0.5% of GDP, while among the latter this more than doubles. Particularly adversely affected are Cyprus, Albania and the Eastern Mediterranean region (−1.6, −2.4, −1.5% of GDP respectively in 2050). In terms of impact types, tourism and sea-level rise are clearly the most threatening, while GDP impacts induced by demand re-composition of energy use is less of an issue and often positive. Again, a difference emerges between the North and the South Mediterranean. In the former, impacts associated to sea-level rise and tourism are rather balanced, while in the latter, losses of the tourism industry dominate. Summarizing, CIRCE confirms the quite good adaptive capacity against climate change of Euro-Mediterranean countries and the higher vulnerability of North African and Middle East countries. This is driven not only by higher negative impacts on average, but by an economic structure where the tourism activity contributes with a higher share to the production of value added. It is also worth stressing that the impacts considered are just a small subset of those than climate change can originate. Thus total negative impact can be expected to be quite higher than those here estimated.

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Chapter 11
Water and People: Assessing Policy Priorities for Climate Change Adaptation in the Mediterranean

Ana Iglesias, Luis Garrote, Agustin Diz, Jeremy Schlickenrieder, and Marta Moneo

Abstract Water is scarce in Mediterranean countries: cities are crowded with increasing demand; food is produced with large amounts of water; ecosystems demand more water than is often available; drought affects all. As climate change impacts become more noticeable and costlier, some current water management strategies will not be useful. According to the findings of CIRCE, the areas with limited water resources will increase in the coming decades (Parts 1 and 2) with major consequences for the way we produce food and we protect ecosystems (Part 3). Based on these projections this chapter discusses water policy priorities for climate change adaptation in the Mediterranean. We first summarize the main challenges to water resources in Mediterranean countries and outline the risks and opportunities for water under climate change based on previous studies. Recognizing the difficulty to go from precipitation to water policy, we then present a framework to evaluate water availability in response to natural and management conditions, with an example of application in the Ebro basin that exemplifies other Mediterranean areas. Then we evaluate adaptive capacity to understand the ability of Mediterranean countries to face, respond and recover from climate change impacts on water resources. Social and economic factors are key drivers of inequality in the adaptive capacity across the region. Based on the assessment of impacts and

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adaptive capacity we suggest thresholds for water policy to respond to climate change and link water scarcity indicators to relevant potential adaptation strategies. Our results suggest the need to further prioritize socially and economically sensitive policies.

Keywords Adaptation policy • Water resources • Water policy • Climate change • Mediterranean

11.1 How Much Does Water Management Need to Adapt in View of Climate Change?

The geographical focus of this work is the Mediterranean countries; the aim is to provide some insight about the policy priorities for the adaptation of water resources to climate change. We think two questions are relevant: How much does water management needs to adapt in view of climate change? How able are societies to adapt to these changes? We address these questions by evaluating the impacts of climate change on water resources and their management, the adaptive capacity and the policy responses.

In this chapter we aim to answer the question of how much does water need to adapt in view of climate change. Our approach is comprised of the following steps: (1) review of climate change impacts on water resources in the Mediterranean, (2) description of a modeling tool to determine water availability under adaptive management, (3) mapping of the adaptive capacity for different countries, and (4) evaluation the policy options.

Our analysis bridges the gap between traditional impact assessment and policy formulation by directing policy attention to the causes of the water scarcity and adaptive capacity problems. Moreover we provide a platform for determining policy responses at the basin level. This evaluation helps define the sensitivity of a system to external shocks and to identify the most relevant aspects that can decrease the level of risk posed by climate change.

The assessment is based on indicators aiming to facilitate information transfer from water resource science to policy. The combined analysis of these indicators helps to diagnose the causes of water scarcity under different climatic conditions and to anticipate possible solutions. In a relatively large region composed of many systems. These indicators may also allow for comparisons between systems to establish action priorities and budget allocation policies.

11.2 Review of Impacts

11.2.1 The Challenges to Water Resources in Mediterranean Countries

Mediterranean countries are diverse from various points of view including their socio-economic development, climate, water availability, infrastructure levels, or social and ecological pressures natural resources. However, the region as a whole is undergoing rapid social and environmental changes which may harbor negative implications for current and future sustainability. This is particularly true for the Mediterranean water sector where pressures and impacts on water scarcity are projected to multiply under climate change. Water scarcity often results in conflicts among users which are compounded by complex institutional and legal structures that threaten the development of policies geared towards sustainable management (Iglesias et al. 2007a, b; Iglesias et al. 2011; Iglesias and Buono 2009).

A number of studies have shown that under climate change annual river flow is expected to decrease in Southern Europe and increase in Northern Europe; changes are also expected in the seasonality of river flows with considerable differences over the European region (Arnell 2004; Milly et al. 2005; Alcamo et al. 2007). Nevertheless many of these projections do not take into account the effects of policy. One alternative measure that has been used to include some policy aspects is the water exploitation index (WEI), which is calculated annually as the ratio of total freshwater abstraction to the total renewable resource (Raskin et al. 1997). But even though the WEI can provide additional information regarding runoff, such an analysis still struggles to fully reflect the level of available water resources.

In many countries throughout the region, water demand already exceeds water availability often imposing a strain on ecosystems (Iglesias et al. 2007a, b; Yang and Zehnder 2002; Hoff 2011) this indicates the need for a policy-sensitive approach. The average annual potential water availability per capita considering the total freshwater resources in southern Mediterranean countries is less than 1,000 m^3/capita and year (Table 11.1). In countries like Egypt, Israel, and Libya, demand is above the available resources, and water scarcity crises are common (Table 11.1). The difficulty in forecasting highly variable rainfall multiplies the challenges faced by water resource managers and increases the likelihood of water conflicts.

The region's overall socio-economic model places available water resources under considerable stress. In many cases, agriculture is responsible for water imbalances because it accounts for more than 50% of water use of most countries (FAOSTAT 2010). Thus, other economic uses of water – urban, energy and tourism – are imposing further challenges for meeting ecosystem services (Hoff 2011) and increasing conflicts among the affected parties. Some of the potential solutions to these problems – such as changes in infrastructure or limitations of irrigation – are not accepted by all social sectors. Water resource managers face the dilemma of ensuring future sustainability of water resources while maintaining strategic agricultural, social and environmental targets. Climate change imposes an additional challenge, and understanding its implications and policy requirements is a complex process, as we shall see.

11.3 A Survey of Previous Studies

The Mediterranean is considered to be a region that will experience large changes in climate mean and variability; that is a climate change "hot-spot" (Giorgi 2006). Scenarios of water resources availability are developed from climate projections but need to take into water management, infrastructure and demands. Our current

Table 11.1 Water resource indicators: total freshwater resources, available resources, use, and water availability in selected Mediterranean countries

Country	Total area ($\times 10^3$ km^2)	Population (million)	Rainfall (mm/year)	Internal usable water resources (km^3/year)[a]	Usable water resources (km^3/year)[b]	Internal ground-water (km^3/year)[c]	Total water use (km^3/year)	Total water use (% renewable)	Potential total usable water resources per capita (m^3/capita per year)
Algeria	2,382	32	89	13.90	14.32	1.70	5.74	40	473
Egypt	1,001	72	51	1.80	58.30	1.30	61.70	106	859
France	552	60	867	178.50	203.70	100.00	35.63	17	3,439
Greece	132	11	652	58.00	74.25	10.30	7.99	11	6,998
Israel	22	6.5	435	0.75	1.67	0.5	1.63	103	254
Italy	301	57	832	182.50	191.30	43.00	43.04	22	3,325
Libyan Arab J.	1,770	6	56	0.60	0.60	0.50	5.73	954	113
Morocco	447	31	346	29.00	29.00	10.00	12.23	42	971
Spain	506	41	636	111.20	111.50	29.90	35.90	32	2,794
Syrian Arab R.	180	18	252	7	26.26	4.2	20.6	100	1,403
Tunisia	164	10	313	4.15	4.56	1.45	2.58	57	482
Turkey	770	71	593	227	213	69	37	18	2,800

Source: Iglesias et al. (2007a, b)) and FAO (data of 2004)

[a] The values refer to both regulated and unregulated water. Real available water resources in all cases are a fraction of these values

[b] These values include transboundary water. See also Wolf et al. (2011)

[c] A proportion of these values is included in the total renewable water resources

understanding of Mediterranean climate leads to projected overall temperature increase from 2 to 4°C and precipitation changes of 10 to −50% by 2080s (RACCM Part1). The changes are not equally distributed across the regions or the seasons. The changes are likely to be more pronounced in North Africa, with temperature increase that reaches +5°C by the 2080s in some scenarios and an alarming increase of extreme temperature (hot and very hot days); drought periods may increase throughout the Mediterranean (Giorgi and Lionello 2008; Christensen and Christensen 2007). As result, evapotranspiration rates will increase, soil structure changes will result in increased rates of soil erosion. Climate change may also produce some positive changes in water resources in some areas, give an adequate adaptive management. The changes may results in risks and opportunities for the water system and the environmental and social systems that depend on water.

Scenarios of water resources availability rely first on climate projections. Our current understanding of Mediterranean climate leads to projected temperature increase from 2 to 4°C and precipitation changes of 10 to −50% by 2080s with large implications for water resources (RACCM Part 2, Alpert et al. 2011). These projections may result in reductions of average annual runoff up to 50% challenging the whole socioeconomic model which is based largely on water demanding activities: recreation, tourism, and food production. The solution to those problems will imply social changes, a progressive increase of water demand management and a consensus reallocation of water availability to essential users. The agreement on essential uses remains a controversial issue across the region. In this process, policies regulating water usage, water accessibility and hydraulic infrastructure, will play a critical role in making water available to users by overcoming the spatial and temporal irregularities of natural regimes.

Protecting the world's freshwater resources requires diagnosing threats over a broad range of scales (Vorosmarty et al. 2010) and sectors (Table 11.2). In the Mediterranean, climate change impacts on water will have a large impact on human water security and biodiversity (Vorosmarty et al. 2010). There are several hundred studies on the potential impacts of climate change on water resources in the Mediterranean which apply many different approaches (European Environment Agency 2009). According to Gleick and Palaniappan (2010), more and more watersheds appear to have passed the point of "peak water", a concept related to the sustainability of water management. These studies have different focus – from ecosystems to water pricing to recreational water–, a wide range of time-frames, different scenarios and spatial scales that vary from the local to the global analysis. Although the results are diverse and sometimes contradictory, a common element is that one of the primary impacts of climate change will be a reduction of water availability in the Mediterranean (European Environment 2007, 2009).

11.4 How Able Are People to Adapt to These Changes?

The ability of societies to anticipate and face an external shock is often called their adaptive capacity. When the external shock is climate change, this adaptive capacity is estimated by environmental, social and economic factors. At the same time these

Table 11.2 Climate change induced risks and opportunities and degree of expected impacts on different sectors

Description	Ecosystems	Urban areas	Agriculture	Health	Economic activities (excluding agriculture)
Risks					
Expansion of area with water deficit	High	Low	High	High	Medium
Increase in water demand (irrigation)	High	Low	High	High	Low
Increased drought and water scarcity	High	Medium	High	High	Medium
Increased floods	Medium	High	Medium	High	Medium
Water quality deterioration	High	Medium	Medium	High	Low
Increased soil erosion, salinity and desertification	High	Low	High	Medium	Low
Loss of snow and glaciers (natural reservoirs)	High	Low	High	Medium	Low
Sea level rise	High	High	Medium	High	Low
Opportunities					
Increased water availability	High	Medium	High	Low	Medium
Increased potential for hydroelectric power	n.a.	High	Medium	Low	High
Increased potential to produce food and bio-fuels	n.a.	n.a.	High	n.a.	High

Sources: Alcamo et al. (2007), Arnell (2004), Barnett et al. (2005), Blanco-Canqui et al. (2010), Copetti et al. (2011), EEA (2009), Iglesias et al. (2009), IPCC (2007), Milly et al. (2005), Parry et al. (2004), Plan Bleu (2010), Rosenzweig et al. (2004), Vorosmarty et al. (2010), Wolf et al. (2011)

factors are essential components of a country's development status and of the sustainability of its socio-economic model. In other words, adaptive capacity and development are closely linked processes that feed and rely on each other. In the case of water the synergies between the two are particularly noticeable.

The linkages between development and the water sector are widely recognized. According to the 2006 Human Development Report, over a billion people in developing countries have inadequate access to water primarily due to poor institutional and political choices (UNDP 2006). Access to water has often been considered a human right in itself (Gleick 1999), but water also has crucial implications for production and the environment (Rijsberman 2003). It therefore comes as no surprise that water is essential to achieving all of the Millennium Development Goals (UNDP 2006). The overarching importance of the water sector is best exemplified by its central role in two of the main development approaches – namely pro-poor growth and human capacity development.

The poor disproportionately bear the brunt of a weak water sector. Pro-poor growth policies seek to reduce overall poverty levels by enhancing the ability of poor people to participate in, contribute to, and benefit from growth (OECD 2006). Given the predominance of rural livelihoods in most low-income countries, problems in water availability, quality and management are likely to have a greater impact on poorer and more marginalized social sectors. For this reason water management has tangible pro-poor enhanced rights effects. Rights based policies are concerned with water accessibility. This involves the duties of providers and the rights of beneficiaries and their ability to supply and access water respectively. It also brings up issues of water quality and water conflicts all of which impinge upon a people's ability to access water.

Water is also an essential component of what Amartya Sen called "development as freedom" since water is essential as part of "a process of expanding the real freedoms that people enjoy" (Sen 1999). In that sense, poverty can best be understood as the deprivation of capabilities (Sen 1999). Water is a particularly important resource for creating such an enabling environment. While an ineffective water sector reinforces inequalities and has negative economic impacts, a strong water sector can foster equality while creating opportunities for the disadvantaged. For instance, securing water rights and availability helps disadvantaged people move away from conditions of poor sanitation, high mortality rates or environmental degradation while creating opportunities for furthering education and employment. This, in turn, promotes people's capacity to achieve higher levels of education, health, and employment.

Efficiently dealing with climate change impacts will imply choosing between conflicting water needs in a way that maximizes adaptive capacity. Choosing between the preservation of valuable ecosystems and the reduction poverty, for instance, is not an easy choice, but successfully managing both needs is of paramount importance. To navigate these difficulties it is necessary to understand how society and water are interconnected, including the synergistic ties that exist between adaptive capacity and development status. Thinking and acting strategically is the only way forward – this implies taking a holistic approach towards water in order to minimize the negative effects of variability and uncertainty. The objective of this chapter is to provide such a holistic approach in order to minimize the negative socio-economic effects that climate change's impacts on water may produce.

11.4.1 Determinants of Adaptive Capacity

Adaptive capacity is understood as the capacity of a system to cope with or recover from a potentially damaging change in climate conditions (Smit and Wandel 2005). In that sense, adaptive capacity is the combination of a number of social and economic components. (Yohe et al. 2006; Iglesias et al. 2010; IPCC 2007).In spite of the considerable associated uncertainties (Adger and Vincent 2005), a number of indices of adaptive capacity have been developed (Yohe and Tol 2002; Ionescu et al. 2009; Yohe et al. 2006; Iglesias et al. 2007a) to capture different elements of social and economic vulnerability to climate change. With this in mind the adaptive capacity index (ACI) presented in this section comprises five major components that characterize the social capacity, economic capacity, technological eco-efficiency, natural capital and climate capital of a country all of which determine a system's ability to adapt to climate change.

By establishing these five components the final objective of the adaptive capacity index is to evaluate how policy affects the magnitude of potential climate change impacts and to establish the differences in adaptive capacity between Mediterranean countries. The index presented in this section provides a measure of how able societies are to adapt to climate change impacts in the water sector; in doing so it provides insights for future policy developments.

The adaptive capacity index integrates determinants of policy in a country or region, based on the aggregate social, economic, technological, environmental, and climate components of adaptive capacity (described below). The value of the index for a system represents its potential adaptive capacity, understood as a modifier of climate impacts.

11.4.1.1 Social Capacity

As suggested by Brooks et al. (2005), in large part adaptive capacity is dependent on social and political characteristics. Social characteristics depend to a large extent on the type of policies implemented in the country or region and they determine the degree of social adaptive capacity to climate change. Social adaptive strategies can range from market-based, self-sufficiency strategies to protective policies for industrialized nations where agriculture plays a marginal role. The indicators selected for this component represent several aspect of social capacity that can support or limit a region's adaptation capacity.

Some indicators (i.e. human development, collective capacity, access to resources, institutional coordination, pressure on natural resource use, literacy rate, life expectancy or access to sanitized water) imply healthier and stronger societies that can develop and implement solutions to adapt to climate change in a more efficient manner. Other indicators, like agricultural employment, have a negative correlation to overall adaptive capacity because they imply a greater dependency on a highly variable sector.

11.4.1.2 Economic Capacity

The level of economic development is an indicator of the capacity of a country to invest in development technologies, food security and income stabilization. The indicators selected for this component are GDP and CO_2 emissions which represent a country's technological development. These two indicators exhibit a positive correlation to adaptive capacity, while the rate of agricultural GDP shows a higher dependence on agriculture and, again, a lower adaptive capacity.

11.4.1.3 Technological Eco-Efficiency

The efficiency in the use of resources for production and the adoption of new technologies significantly increases a system's adaptation potential (Godfray et al. 2010). The three aspects represented in this component are general eco-efficiency, technological development and the specific level of technology applied to agriculture. The indicators selected represent the technological advancements applied to agricultural production and include GDP per unit energy use, technology exports and CO_2 emissions per capita. The development of agriculture significantly decreases the sector's dependency on climatic variables and stabilizes production. Therefore these indicators have a positive correlation with the overall adaptive capacity index, as they indicate the level of independence from climatic variables.

11.4.1.4 Natural Capital

One of the most relevant threats imposed by climate change projections in the Mediterranean region is higher levels of water scarcity. Adequate climate change adaptation policies in the Mediterranean region depend on the reliability and vulnerability of water resource systems in future scenarios and the availability of adequate management policies. Water management depends on factors such as infrastructure for water storage or transport, excess of demands or their mutual incompatibility, and constraints for water management (determined by policies). Indicators of agricultural water use and irrigated area show a positive correlation with adaptive capacity because the more water is used for agriculture; the easier it is to stabilize agricultural production independently from annual precipitation or distribution.

11.4.1.5 Climate Capital

Climate capital represents the baseline state conditions that are not modified in the short term. Current temperature and precipitation are determinants of the potential climate policies developed in the region. This component incorporates information related to the variability of precipitation, which decreases a system's general adaptation capacity because it hampers the effectiveness of developed infrastructure. This component does not represent implemented policies but is essential as the representation of the external hazard that the regions are exposed to.

11.4.2 Computing an Adaptive Capacity Index

The methodology used to compute the ACI integrates both quantitative and qualitative characterizations of adaptive capacity. The index can be applied locally or spatially and with different aggregation levels of the input data. The intermediate

Table 11.3 Components of the adaptive capacity index, aspect of climate policy addressed and selected indicators

Components	Aspect relevant to climate policy	Indicators
Social capacity	Human development (individual level)	Adult literacy rate Life expectancy
	Collective capacity	Agricultural GDP Population without access to improved water Population below the poverty line
	Institutional coordination	Institutional relations Public participation
	Pressure on resources	Total population
Economic capacity	Economic welfare	GDP per capita Energy use
	Public intervention	Public expenditure
Technological eco-efficiency	Eco-efficiency	GDP per unit energy use High technology exports CO_2 emissions per capita
	Agricultural innovation	Agricultural machinery Fertilizer consumption
Natural capital	Water management	Total water use Agricultural water use Irrigated area
	Environmental damage	Area salinized by irrigation
Climate capital	Response to climate impacts	Precipitation Temperature

components can be evaluated independently, making for a comprehensive interpretation of the strengths and weaknesses of each system.

The sequential steps taken for the quantification of the adaptive capacity index are: (a) select indicators that are policy relevant; (b) normalize the indicators with respect to a common baseline; (c) combine the sub-component indicators within each policy category by weighted averages; and (d) quantify adaptive capacity index as the weighted average of the components. The scores of the adaptive capacity index range from 0 to 1, and are generated as the average of each component. The approach is flexible and can be applied to managed and natural ecosystems as well as to socio-economic systems. A similar approach has been taken in the context of drought.

11.4.2.1 Selection of the Indicators

Table 11.3 shows the components of the ACI that have already been defined and the indicator-relevant aspects of these components. The indicators included were selected according to the following eligibility criteria: (1) they are relevant to represent different aspects of the climate policy; (2) data were available and an example could be computed; and (3) the indicators are SRES scenario dependent and geographically explicit.

The described criteria for indicator selection allow for the computation of the index under current conditions or for each of the SRES storylines in the future.

11.4.2.2 Normalization to a Common Baseline

The indicators shown in Table 11.3 were normalized between the different countries in order to compare the results. The standardization has been made with respect to the maximum value of each indicator across the countries. This guarantees that the index can be expressed as a percentage rate. Sub-component indicators can be combined within each category by using either a geometric mean or a weighted mean with weights inversely proportional to the impact uncertainty level. This study considers the weights separately for each of the categories, as in Iglesias et al. (2007a, b), in order to evaluate them independently, underlining the strengths and weaknesses of each component in the total adaptive capacity index within each country. It should be noted that the climate policy components have an inverse interpretation compared to the indicators traditionally applied to vulnerability evaluations (Iglesias et al. 2009).

11.4.2.3 Quantification of the Adaptive Capacity Index

The adaptive capacity index here is calculated with a methodology similar to that of the Human Development Index (HDI). Each component of the index can be viewed as a dimension. Before calculating the overall adaptive capacity index, a value for each of the dimensions needs to be computed. To compute the dimension indices, minimum and maximum values are chosen for each underlying indicator. These minimum and maximum values are used to harmonize the index and refer to the minima and maxima of the nations which are in the scope of analysis. For all values, except literacy rate and life expectancy, the minima and maxima among the nations are used as a harmonization basis. For life expectancy and literacy rate, the goalposts from UNDP (2009) are applied.

Performance in each dimension is then calculated as the dimension index with (11.1) for proxies which exhibit a positive correlation to the overall adaptive capacity,

$$\frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{11.1}$$

and with (11.2) for proxies which exhibit a negative correlation to the overall adaptive capacity.

$$1-\left(\frac{x_i - x_{min}}{x_{max} - x_{min}}\right) \tag{11.2}$$

Where: x_i = proxy value for country in question, $x_{\min}$ = minimum value of the indicator, and $x_{\max}$ = maximum value of the indicator. The overall adaptive capacity index is then calculated as a weighted arithmetic mean of the dimension indices and gives the relative level of adaptive capacity for a country or region in relation to the countries included in the study.

11.4.2.4 Adaptive Capacity Index Distribution

We apply the GINI index methodology in order to determine the distribution of climate policies among the Mediterranean countries. The adaptive capacity index distribution measure can be expressed as:

$$ACI_D = \frac{1}{2n^2\mu}\sum_{i=1}^{n}\sum_{j=1}^{n}\left|ACI_i - ACI_j\right|$$

Which is, a half of the absolute differences average of every pair of ACI, normalized by the average value of ACI (μ). If the policies are equally distributed, the index value will be 0 (since the concentration area will be 0), and in a theoretical situation of one country concentrating all the efforts, the index value will be 1. This index has some interesting advantages, such as the independence of the ACI value. This is important since we have explained that the ACI is an ordinal index that allows for monotonic transformations.

The index can be calculated for different components and time periods, including climate change scenarios.

11.4.2.5 Evaluation of Adaptive Capacity

The total adaptive capacity index has been quantified as the weighted average of each of the five components previously described. Figure 11.1 shows the global values of the ACI for seven Mediterranean countries. The scores of the adaptive capacity index range on a scale of 0–1, 0 being the situation where adaptive capacity is least developed and 1 where adaptive capacity is most developed. The total index is generated as the average of all components. The final value of the index depends on the valuation of each component. Here we present the results of the index under a single scenario, where all components are valued equally. Alternatively we can weight the components differently. For example, a plausible scenario may give the social component an additional weight reflecting the assumption that a society with institutional coordination and strengths for public participation is less vulnerable to climate change.

Figure 11.1 shows how the global value of ACI is higher for countries located in the North of the Mediterranean basin, being the highest one for France, then Italy and then

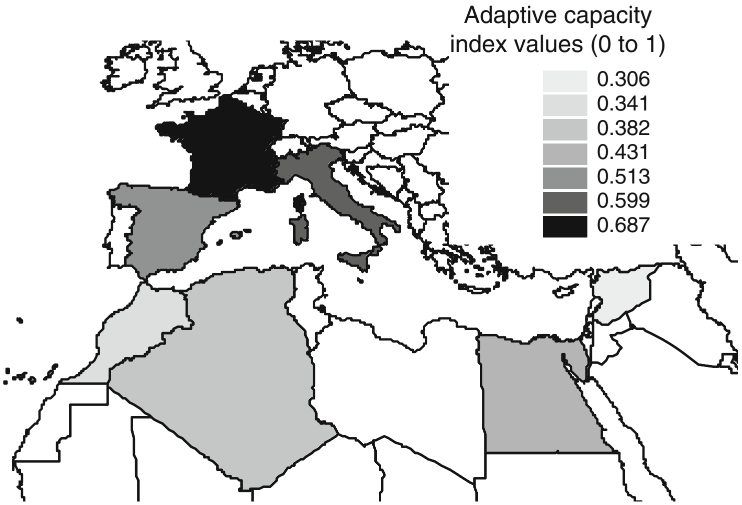

Fig. 11.1 Adaptive capacity index for selected Mediterranean countries

Spain. The lowest ACI value is for Syria, with a value lower than the half of the ACI for France. These values show the enormous difference existing in the Mediterranean basin in terms of adaptive capacity to climate change and the urgency of acting in certain areas to increase this capacity to face the future climate conditions.

The results of this evaluation lead to the identification of actions to minimize risk by increasing adaptive capacity. The results contribute to increase adaptive capacity and develop policy decisions to increase adaptation options. This assessment bridges the gap between impact assessment and policy formulation by directing policy attention to the underlying causes of adaptive capacity rather than to the potential impacts of triggering events such as climate change-driven water scarcity. This evaluation helps define a system's sensitivity to external shocks and identify the most relevant measures that decrease the level of risk under climate change.

Figure 11.2, on the other hand, shows the individual values for the components that integrate the global ACI. From this figure it is clear that for northern countries economic and social capacity are playing a major role in the maintenance of high ACI values, while the natural capital and the climate capital are quite similar or even lower than in southern countries. Technological eco-efficiency is also higher in France and Italy, but Spain shows levels quite similar to those of countries in the South.

This kind of information is useful for identifying priority aspects for the definition of adaptation strategies. According to the results from this study it would seem appropriate to develop strategies to improve the economic and social capacity of the countries in the south Mediterranean.

Figure 11.3 presents the distribution of the adaptive capacity index and each of its components, following the methodology used to calculate the GINI index

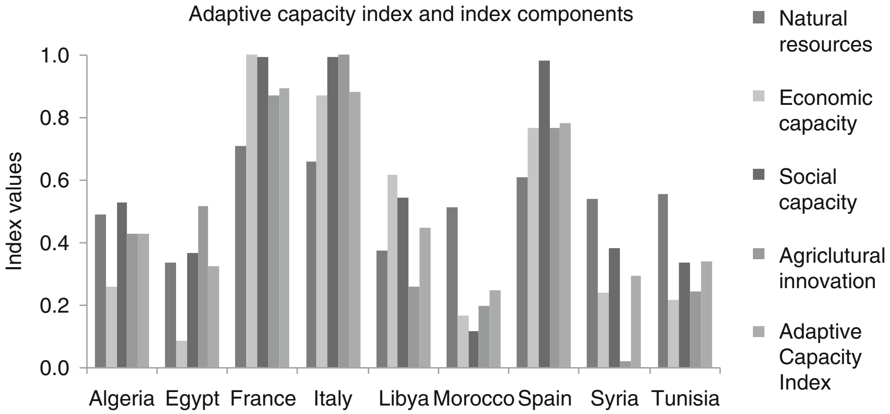

Fig. 11.2 Evaluation of the adaptive capacity index and components for selected Mediterranean countries

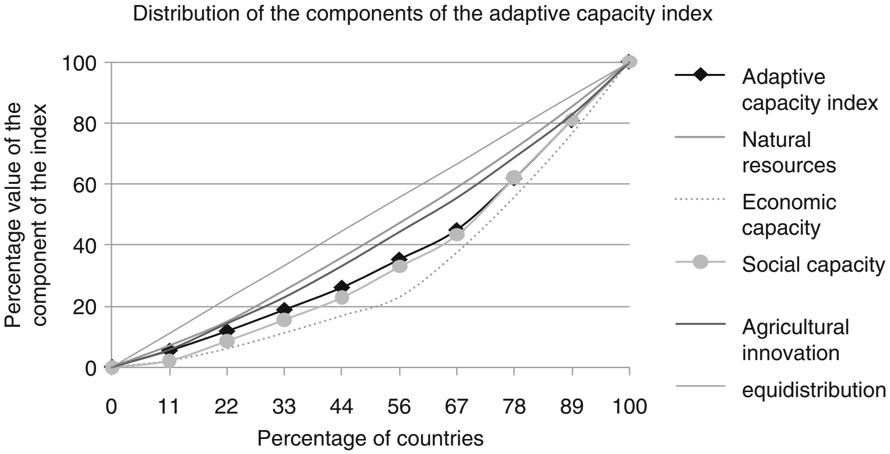

Fig. 11.3 Distribution of the components of the adaptive capacity Index

presented above. The Lorenz curve applied in the analysis helps identify the differential distribution and contribution of the different components to the global adaptation capacity level. The discontinuous line in Fig. 11.3 shows what would be a perfect distribution among the countries, where each country would contribute to the overall value in the same degree. However, all the components, including the adaptive capacity index itself, show distributions below that equity line indicating that countries have different levels of contribution. This difference is especially clear in the case of economic and social capacities. In the first case, nearly 60% of the countries contribute around 10% of the total economic capacity of the region, and in the case of social capacity, 40% of the countries contribute more than 65% to the total of the region. The distribution is quite even for the rest of the components, including the adaptive capacity index itself which underlines the importance of developing a partial analysis of the components.

Although, Mediterranean countries have similar adaptive capacity index distributions overall, countries differ greatly in their economic and social capacity. In contrast countries have similar technological and eco eco-efficiency capacity, natural capital and climate capital. As we shall see in the next section, this insight is extremely valuable for the development of policies that seek to redress low levels of adaptive capacity in order to cope with climate change impacts.

11.5 Estimating How People May Modify Water Availability

11.5.1 Water Supply and Demand Scenarios

All water-abstracting sectors require a reliable supply in order to provide sufficient water during periods of prolonged lack of rainfall. Over time, people have developed a number of ways to guarantee their water supply. As a result, the storage of surface water in reservoirs is commonplace and transfers of water between river basins also occur as is the artificial recharge of groundwater by river water. Recently, the production of freshwater via desalination or recycling is also playing an increasingly important role.

However, as we have seen, climate change jeopardizes the equilibrium of water resources systems and the impacts will vary as a result of local regulation capacity. Although there are many studies on the impacts of climate change in the natural hydrological regime, climate change impacts on regulated systems have not received as much attention. An analysis of climate change in regulated systems in the Mediterranean water basins would highlight the effects of adaptive regulation as management alternative.

Reservoir regulation has been one of the most important water resources management in Mediterranean countries and has generated significant impacts. A reservoir is a dynamic storage of water, which can be controlled, and is used to balance the irregularity of water resources. Existing reservoirs are being subjected to intense multi-objective demands on limited resources. Reservoir water uses include water supply, flood control, hydropower, navigation, fish and wild life conservation, and recreation. Water quality may also be considered a reservoir purpose when water is provided to assimilate waste effluents. It is not surprising then that defining optimal reservoir operation for reservoirs with multiple water uses is a challenge.

Reductions of water inflow and increased variability may result in significant decreases in the water availability. This clearly demands for adaptation measures with large impacts to society. In most Mediterranean basins the reductions in water availability will result in impositions of demand restrictions since regulatory capacity is already at a maximum.

This is particularly true in the case of irrigation water demand scenarios since it is reasonable to assume that, without changes in policy, land use or technology, projected irrigation demand in the basin will be higher than present irrigation demand even if farmers apply efficient management practices and adjust cropping systems to the new climate. Moreover, when policy and technology remain constant, it has been shown that agricultural water demand will increase in all scenarios in the region (Iglesias et al. 2007a, b; Iglesias 2009). The main drivers of this irrigation demand increase are the decrease in effective rainfall and increase in potential evapotranspiration (due to higher temperature and changes of other meteorological variables).

These scenarios demonstrate that in the Mediterranean, water availability is likely to be one of the great future challenges. Defining future water availability will therefore a basic step for water policy formulation

11.5.2 Defining Water Availability

The Water Availability and Policy Assessment model (Garrote et al. 2011; Fig. 11.4) links water supply, demand and management and is used to analyze policy options. The model computes water availability and reliability as result of implementing climate or policy scenarios. WAPA is used to compute water availability and demand-reliability curves, which provide a simple way to evaluate water availability under different policy and climate change scenarios. The model has been applied to evaluate economic decisions of drought policy and water policy in the Mediterranean (Iglesias et al. 2011).

11.5.2.1 Model Architecture

The WAPA model may be used to compute the water availability and demand-reliability curves, which provide a simple way to evaluate water availability under different policy and climate change scenarios. WAPA simulates the joint operation of all reservoirs in a basin to satisfy a unique set of demands. Basic inputs to the WAPA model are the river network topology, the reservoir characteristics (monthly maximum and minimum capacity, storage-area relationship and monthly evaporation rates), the naturalized stream flow series entering different points of the river network, the environmental flow conditions downstream of reservoirs and monthly values of urban and agricultural demands for the entire basin. The model is based on the mass conservation equation, and main assumptions refer to how reservoirs are managed in the system: to supply demands for any given month, water is preferentially taken from the most downstream reservoir available, since spills from upstream reservoirs can be stored in downstream ones.

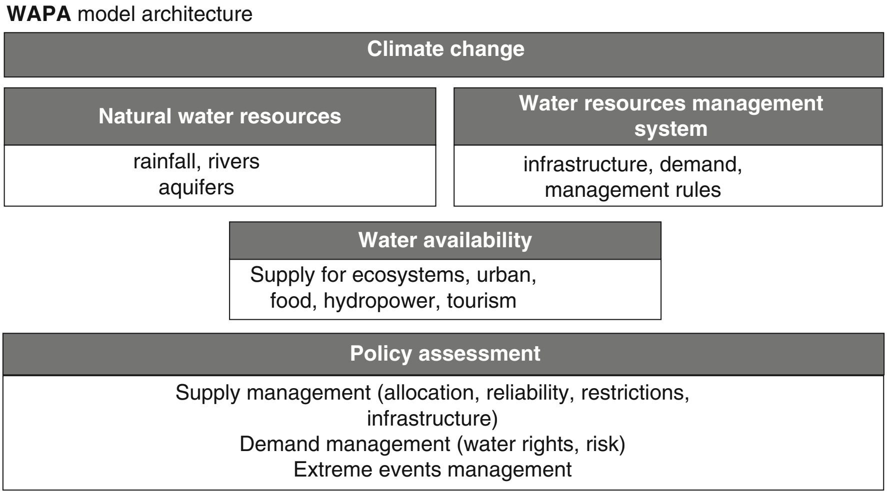

Fig. 11.4 Architecture of the Water Availability and Policy Assessment model (WAPA)

Model architecture is summarized in Fig. 11.4. The WAPA model is based on a basic reservoir operation model. The reservoir operation model takes as input the monthly inflows, the monthly required environmental flow, the monthly demand values sorted by priority with the corresponding return flow, the reservoir data (monthly maximum and minimum capacity, storage-area relationship and monthly evaporation rates) and the reservoir initial condition (initial storage). The result of the reservoir operation model is a set of time series of monthly volumes supplied to each demand, monthly storage values and monthly values of spills, environmental flows and evaporation losses. From this output, demand reliability can be computed applying any conventional procedure. Additionally WAPA can be operated as a joint reservoir operation model that combines all reservoirs in a basin to satisfy a unique set of demands. Reservoirs are ordered by priority (water is taken preferably from reservoirs with higher priority). In each time step, the model performs the following operations:

(a) Satisfaction of the environmental flow requirement in every reservoir with the available inflow. Environmental flows are passed to downstream reservoirs and added to their inflows.
(b) Computation of evaporation in every reservoir and reduction of available storage accordingly
(c) Increment of storage with the remaining inflow, if any. Computation of excess storage (storage above maximum capacity) in every reservoir.
(d) Satisfaction of demands ordered by priority, if possible. Use of excess storage first, then available storage starting from higher priority reservoirs.
(e) If excess storage remains in any reservoir, computation of uncontrolled spills.

11.5.2.2 Example of Model Results

WAPA model can be used to evaluate water availability for a set of specific demands under different conditions. As an example of model results, we present an analysis of water availability for irrigation demands, once urban demands are adequately satisfied. Runoff is estimated from the results of Regional Climate Models (RCMs). Monthly time series of runoff in every subbasin are generated from the results produced by RCMs for the "runoff" variable. Urban demands are estimated on the basis of population and per-capita water requirement. Subbasin population was obtained from the Global Rural-Urban Mapping Project (GRUMP), available at the Center for International Earth Science Information Network. An average value of 300 L/p.day was used as per capita water requirement.

WAPA computes water availability for irrigation demand with a loop that considers a fixed amount of urban demand and a variable amount of irrigation demand. For every value of irrigation demand, the model assigns available water in every month to urban demand first, and then to irrigation demand, computing demand reliability for both types of demands. Water availability for irrigation corresponds to the maximum irrigation demand that satisfies both urban reliability and irrigation reliability. Results are shown in Fig. 11.5, which corresponds to DMI to Regional Climate Model. The per-unit reduction in runoff in climate change scenario with respect to the control scenario is compared to reduction in water availability. In many European basins, the proportional reduction of water availability is larger than the reduction in mean annual runoff.

11.5.2.3 Trade-off Between Water Allocation and Supply Reliability

The regulatory effect is evaluated through water availability, i.e. the maximum demand that could be potentially attended in a certain point of the fluvial network for a pre-determined guarantee criteria. In order to facilitate the comparison, this variable is normalized using the average annual flow in a particular point of the system. Then it is possible to evaluate the effect of climate change scenarios.

Reliability is computed for every demand by comparing the actual supply values during the simulation with theoretical demand values. Figure 11.6 shows the supply reliability curve under current climate and climate change scenarios. In the current situation a defined volume of water is supplied to a sector with acceptable reliability. For example, reliability of urban supply is always 100% in European cities while reliability of agricultural supply may be as low as 50% in Mediterranean areas. Under climate change scenarios, the water allocation may remain the same (Management 1), but in this case reliability has to decrease significantly. This choice is not acceptable for urban supply. An alternative option (Management 2) is a reduction of the water allocation that is compatible with an acceptable reliability. For urban supply, a reduction of reliability is not an option. But for

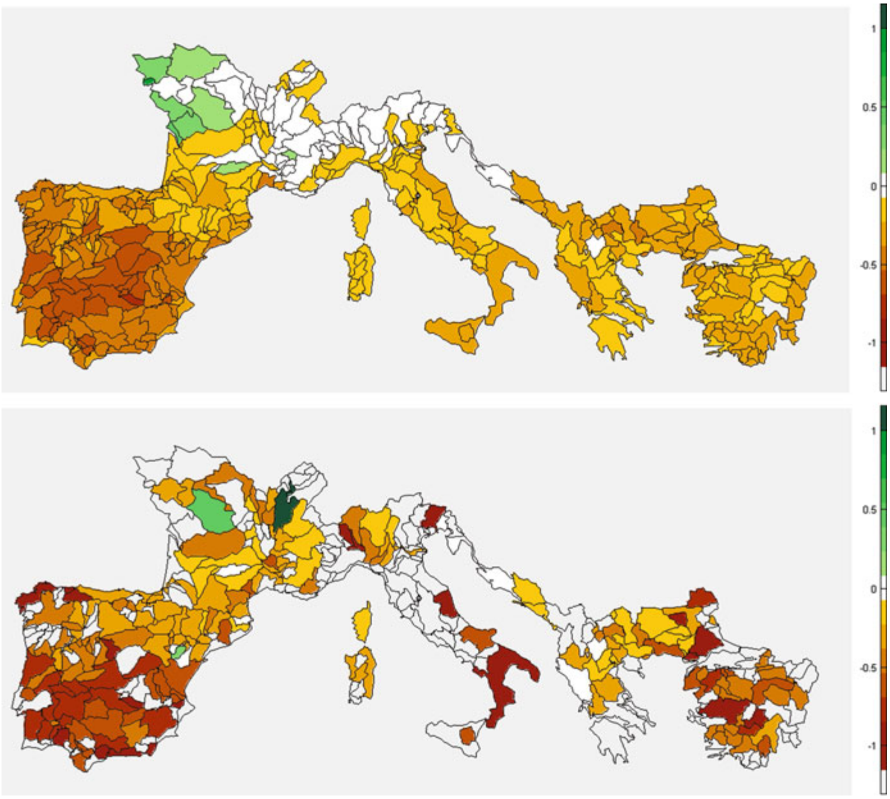

Fig. 11.5 Per unit reduction of runoff (*above*) and water availability for irrigation (*below*) in climate change scenario (2070–2100) with respect to control run (1960–1990) for DMI model in Mediterranean European basins

agricultural supply, a reduction of reliability may be acceptable if farmers have risk transfer mechanisms.

The choice between reduction of water allocation and reduction of reliability depend on the risk aversion that stakeholders (water managers and users) are willing to take (Quiroga et al. 2010). For example, reducing the water allocated for irrigation (Management 2 in Fig. 11.6) seems to be the optimal decision, independently of the risk aversion coefficient considered. On the other hand, when stakeholders accept a certain amount of risk, reducing water reliability (Management 1) is the optimal decision. Reducing water allocation has a lower associated risk level, and would therefore be preferred by managers that are more risk averse. Reducing water reliability has a higher associated risk level and would therefore be preferred by those less risk averse. The results show that there is no optimal policy response and that this is highly dependent on the scenario considered and the willingness to accept risk of the stakeholders.

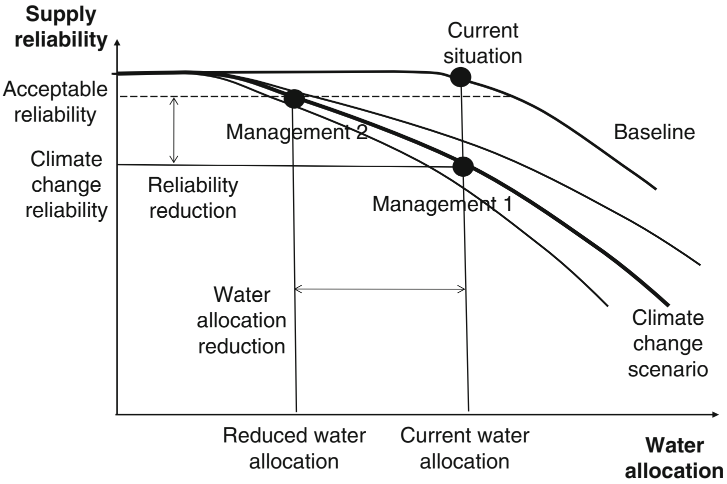

Fig. 11.6 Summary of the trade-off between water allocation and supply reliability under current climate and climate change scenarios

11.5.2.4 Management Policy Evaluation

Management policies may be evaluated in WAPA by modifying the different coefficients or parameters which affect system performance and create policy scenarios. Two broad management policy categories may be considered: supply management and demand management (Table 11.4).

11.5.3 Example of Application in the Ebro Basin

The Ebro basin is representative of a medium size water unit in the Mediterranean; the system is composed of 34 rivers, 27 major reservoirs totaling 7,13 km^3 of reservoir storage, an urban demand of 0,96 km^3/year and current irrigation demand of 6,35 km^3/year. Climate change scenarios were generated for every streamflow point in the Ebro basin by transforming the mean and coefficient of variation of the original series as suggested by the corresponding climate projection. Environmental flows were fixed at 10% of mean annual flow in every location.

Garrote et al. (2011) estimated change in water availability under climate change (Table 11.5). The study first estimated changes in runoff and runoff variation under a range of climate change scenarios, then applied the WAPA model to evaluate optimal management that represents the optimal policy options with the corresponding trade-off between supply and reliability as determined by the WAPA analysis. According to the results of the climate change simulations, runoff and water levels will change significantly during different seasons (Fig. 11.7). The results are in line with the results from previous studies in the Mediterranean regions (Iglesias et al.

Table 11.4 Types of polices and implementation in the WAPA model

Type of policy	Actions	Implementation in WAPA (example)
Supply management policies	Water allocation for environmental and consumptive uses	Selected quantile of the monthly marginal distribution to specify minimum environmental flow requirements
	Reuse of urban water	A coefficient for internal water reuse within cities that takes into account the population per-capita water requirement is and the return coefficient and a reuse coefficient
	Reduction of water allocation	Reduction of water allocation for a given use can be analyzed through its effect on demand reliability
	Increase water supply	Increase of the regulation volume available for water conservation or a densification of the water distribution networks
	Increase supply efficiency	Selected quantile of the monthly availability
Demand management policies	Reduction of per-capita or per-hectare water use	Reduction of per-capita water requirements in the model
	Water rights exchange programs	Changes in the required performance for urban demands
	Increase resource efficiency	Changes in the required performance for irrigation demands

Table 11.5 Simulation of water availability in the Ebro water unit under different management alternatives in the current climate

Type of management	Variable	Value
Current management	Annual streamflow mean (hm^3/year)	16,921.78
	Annual streamflow coefficient Var. (–)	0.27
	Storage volume (hm^3)	7,276.00
	Water availability (hm^3/year)	2,928.31
Simulated effect of management alternatives that imply no further expansion of infrastructure (effects of optimal reservoir management)	Water availability in the “Local management” alternative (hm^3/year)	9,401.56
	Water availability in the “Large distribution networks” management alternative (hm^3/year)	11,173.11
	Water availability in the “Global management” management alternative (hm^3/year)	11,464.45

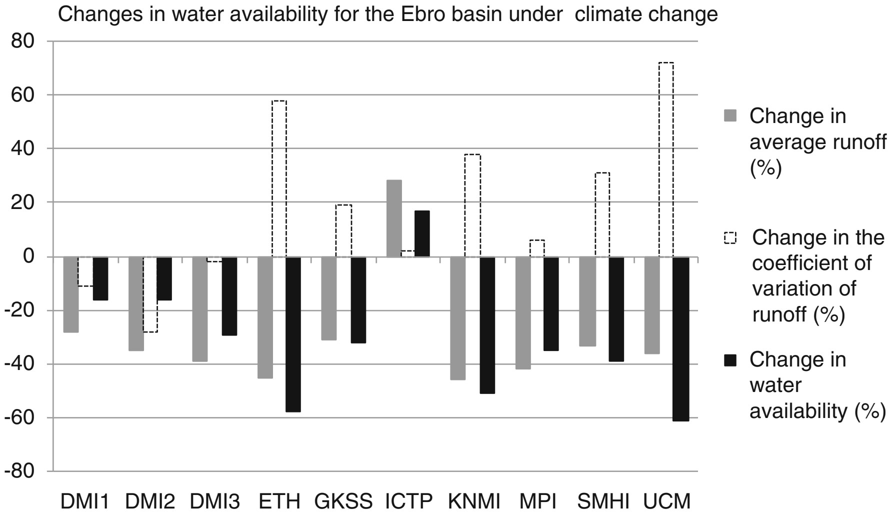

Fig. 11.7 Changes (difference between scenario climate change scenarios and baseline in percent values) of the average value and coefficient of variation of runoff and of water availability in natural regime for the Ebro basin

2007a, b; IPCC 2007; European Environment Agency 2008; Giorgi and Lionello 2008); climate change results in a moderate increase of flood risk throughout the year and a large increase in spring and summer drought. This implies the need to establish alternative options for water management for all sectors and highlight the importance of hydrological forecast to enhance the potential for improved regulation planning.

With the WAPA results for water availability under current climate and under climate change it is then possible to estimate the tradeoff between water allocation and supply reliability (Fig. 11.8). As we will see in the next section, understanding how supply reliability and water allocation are affected by climate change is a crucial part of determining water scarcity and hence establishing policy priorities.

11.6 Establishing Policy Priorities

Policy is deeply involved in the water sector. Usually, policy development is based on an historical analysis of water demand and supply. It is therefore a challenge to develop policies that respond to an uncertain future. Indeed, science-policy integration is one of the most complex challenges that the scientific and policy making communities face since it involves knowledge sharing and exchange among a wide range of disciplines and actors (Quevauviller et al. 2005). Despite these challenge, it is possible to achieve this goal and there are success stories throughout the world.

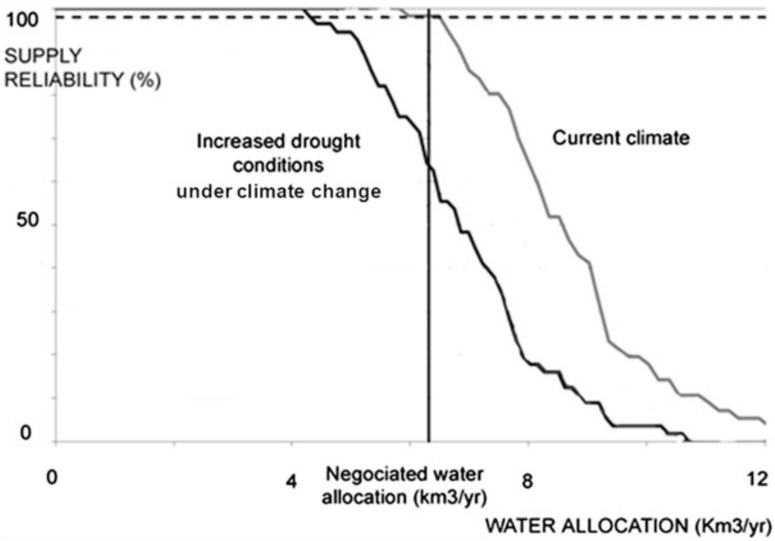

Fig. 11.8 Application of the WAPA model to estimate the trade-off between water allocation and supply reliability under current climate and climate change scenarios in the Ebro basin

In this chapter we have attempted to face part of this challenge by presenting an approach that assesses how people – society and policy – may influence water in the Mediterranean under climate change. We have also shown how an estimation of adaptive capacity evaluates the extent to which a system can respond to climate change. Together – the assessment of water risks and adaptive capacity – may be useful in singling out areas of potential water stress and conflict. This information may be used to implement and develop policy.

We recognize that the data needs for developing such a decision-making tool are complex and may be hard to satisfy; nevertheless, the conceptual steps that are presented remain valid and may be undertaken at a simplified level. Moreover, since the kinds of policy decisions being considered are at a national level it is likely that the availability of data will be greater. Building on the results of the WAPA model we characterize water scarcity to define policy thresholds, these are then combined with the results of the adaptive capacity index to establish policy priorities.

11.6.1 Policy Options and Thresholds

Here we summarize a diagnostic tool to identify and evaluate climate change adaptation policies in areas of water scarcity based on the indices of water scarcity developed by Martin-Carrasco et al. (2012). The methodological framework comprises a set of three indices, described below, that must be used jointly to

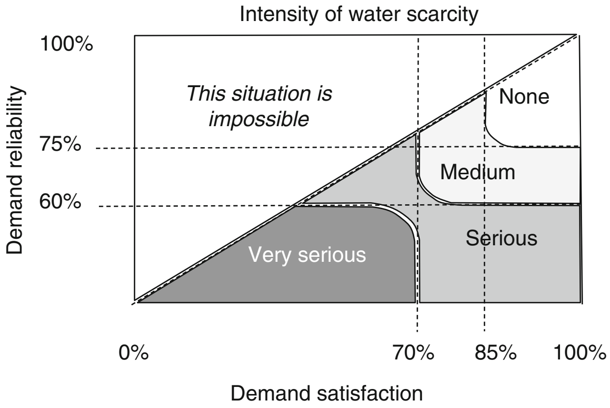

Fig. 11.9 Intensity of water scarcity problems and thresholds of demand reliability and satisfactions

quantify the severity of potential water scarcity problems in a system, its causes, and possible solutions. The indices are numerical index values that are classified in qualitative categories:

Water scarcity index (SI) evaluates the system's capacity to supply its demands.
Demand reliability index (RI) quantifies the system reliability to satisfy demands.
Potential for more infrastructure index (II) evaluates the natural resources available for development in the system.

Figure 11.9 shows a characterization of the intensity of water scarcity through a combination of the demand reliability index and the demand satisfaction index. This characterization is used to define thresholds of water scarcity based on their intensity – this is the first step in formulating water policy.

Next a combined analysis of the indices is used to diagnose water management problems and the reliability and vulnerability of systems under climate change scenarios this also helps identify public policies to recover equilibrium between water supply and demand. In general, systems with high water scarcity require actions that increase available resources while systems with low demand reliability generally require structural actions to consolidate water supply to demands or non-structural actions to mitigate drought impacts. When these problems coincide with low values of potential infrastructure development, actions should focus on the demand side, trying to improve water conservation by reducing losses, increasing water efficiency, encouraging water recycling, and making different demands compatible. Table 11.6 shows how the characterization of water scarcity problems can be combined with broad categories of policy solutions. Each category of policy solution proposes the utilization of different tools that target different user groups in order to tackle the problem of water scarcity flexibly.

Table 11.6 System characterization as a function of index values

		No water scarcity		Low water scarcity		High water scarcity	
		Problem	Solution	Problem	Solution	Problem	Solution
Reliable demand	Potential more infrastructure	n.a	n.a	1	B	1	B, C
	No new infrastructure	n.a	n.a	1	A, B	1, 3	A, B, C
Some unreliable demand	Potential more infrastructure	2	D	1, 2	B	1, 2	B, C
	No new infrastructure	2	A, D	1, 2	A, B	1, 2, 3	A, B, C
High unreliable demand	Potential more infrastructure	2	B, D	1, 2	B, C	1, 2	B, C
	No new infrastructure	2, 3	A, B, D	1, 2, 3	A, B, C	1, 2, 3	A, B, C

Problems

1: Vulnerable: water scarcity may produce important damages

2: Unreliable: low intensity droughts may lead to water scarcity

3: Excess of demand with respect to natural resources

Solutions

A: Demand management

B: Supply management: regulation

C: Supply management: water transfers or additional resources (i.e., water re-use)

D: Efficiency management: Communication and education

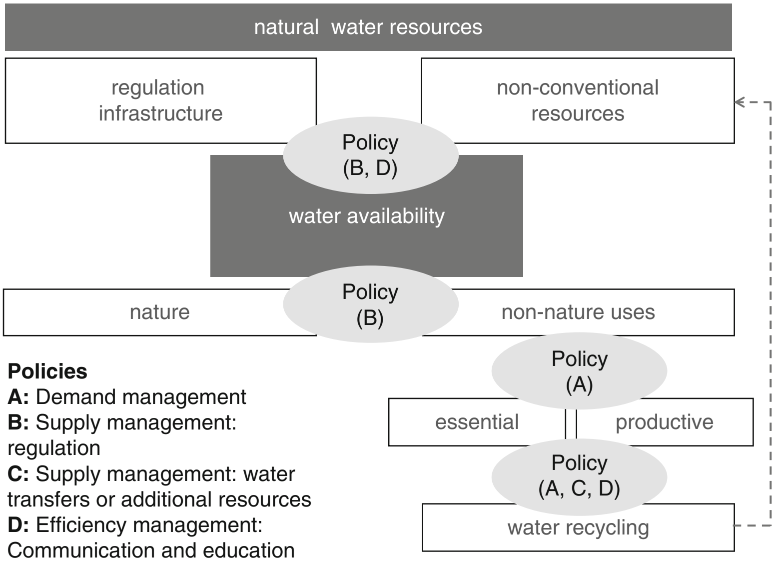

Fig. 11.10 Role of policy interventions on the water sector

11.6.2 From Index Thresholds to Policy Recommendations

The effect of water policy decisions may be evaluated by considering the resulting water availability for nature and non-nature use. Figure 11.10 outlines how policy interventions may modify water for nature and for non-nature uses. Water allocation for environmental and consumptive uses is an essential policy (type B in Fig. 11.10). Policy makers establish the criteria to authorize water abstractions from rivers based on the environmental conditions that should be respected for natural ecosystems. In the past, little attention was paid to environmental status of water bodies, and abstractions were usually approved even if there was no minimum environmental flow specified. Recently, the Water Framework Directive has placed emphasis on environmental status, and therefore strict control is placed on environmental flows before water abstractions are authorized.

The reuse of urban water may be included in a group of policies (type A, C and D in Fig. 11.10) that will need to become increasingly important since future scenarios project higher population and per-capita water requirement. Other demand side policies could make use of appropriate water pricing mechanisms, investments in technology to improve efficiency, upgraded distribution networks and making sure that agricultural subsidies are linked to efficient use (European Environment Agency 2009). Efficiency policies may play a major role for improving management (type D in Fig. 11.10). For example reduction of per-capita or per-hectare water use that always results in an increase of water availability and reliability.

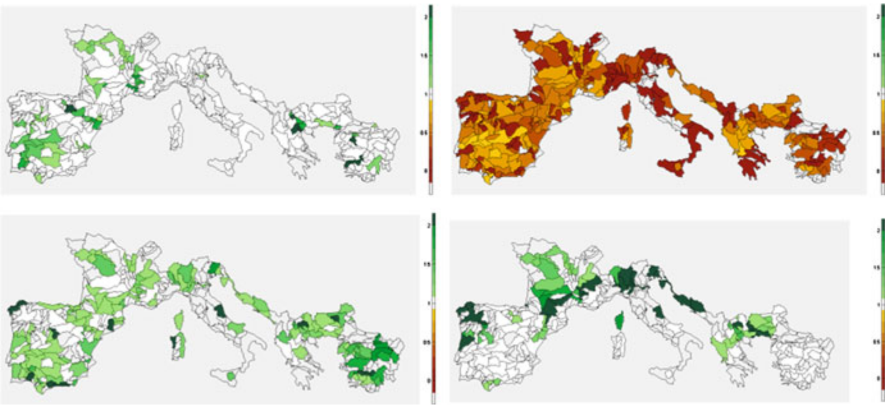

Fig. 11.11 Effect of policy options on water availability for irrigation: per unit change in water availability for irrigation in climate change scenario (2070–2100) with respect to control run (1960–1990) for DMI model in Mediterranean European basins under four policy options: (**a**) Improved water resources management (*top left*) (**b**) Water allocation for environmental uses (*top right*) (**c**) Improved water efficiency in urban use (*bottom left*) and (**d**) use of hydropower reservoirs for water conservation (*bottom right*)

A number of polices may be implemented to overcome temporary water deficits. Water rights exchange programs (type A in Fig. 11.10) may be implemented to overcome temporary deficits and to increase system performance. Proactive drought management measures to increase drought resilience may include improved performance for irrigation demands (type A and D in Fig. 11.10). Policies that foster communication and education are also since it has been shown that joint participative knowledge is an important factor in facilitating efficient water management (Huntjens et al. 2010).

Finally, polices may seek to increase water supply (type B and C in Fig. 11.10) by effectively increase of the regulation volume available for water conservation or a densification of the water distribution networks. Among other measures this may include water recycling and desalination (European Environment Agency 2009).

The quantitative assessment of the effect of policy options may be carried out with the help of WAPA model. Alternative policy options may be implemented in several ways. For instance, the effect of four policy alternatives for water availability analysis performed on European Mediterranean basins is presented on Fig. 11.11.

Adding the adaptive capacity evaluation to previous policy assessment we can formulate specific recommendations that respond to a range of water scarcity levels and address the weakest component of the adaptive capacity. The policy recommendations formulated in Table 11.7 vary according to the water scarcity level as described below and have a double aim: (1) to prioritize management strategies; (2) to evaluate synergies between environmental and development policies.

Table 11.7 Proposal of potential policy interventions based on water scarcity and adaptive capacity

Water scarcity levels	Weakest component of the adaptive capacity	Policy Recommendations
Low to medium	Social and economic factors	Promote pro-poor management Promote health and education Improve access to water for production and sanitation
	Technological eco-efficiency and natural capital	Focus on environmental mitigation Promote more efficient technologies Reduce water use
	Climate	Promote flexible water storage options Invest in physical infrastructure Develop safety net programs
Serious to very serious	Social and economic factors	Develop micro-irrigation technologies Integrate ground and surface water management
	Technological eco-efficiency and natural capital	Reform conflict prevention institutions. Promote information sharing and cooperative management
	Climate	Promote policies that help create a paradigm shift Design adaptation policies Develop new alternative sectors

11.6.2.1 Low to Medium Water Scarcity

In conditions of low to medium water scarcity where social and economic drivers of inequality prevail, policies should foment social and economic development policies that will improve policy formulation and implementation in the future, thus minimizing the risks of climate change impacts. In this case, basic needs such as education and health need to be taken care of. At the same time, in contexts of climate change, a longer term strategy that seeks to diversify a country's economy could also help mitigate the effects of climate change impacts.

Where water scarcity remains at low to medium levels and inequality is driven by technological eco-efficiency and natural capital, then environmental mitigation policies are recommended. Some policy options might include the development of more efficient technologies that would reduce water use in key economic activities.

When water scarcity is low or medium and climate drives inequality then current policies should be adjusted for adaptation. Policy options might include fostering greater flexibility in water storage options in order to choose those that will maximize sustainability and effectiveness. Other options could be building or improving physical infrastructure to prevent the risk of extreme events or developing safety net programs to strengthen livelihood asset availability for vulnerable populations.

11.6.2.2 High Water Scarcity

If water scarcity levels are serious or very serious and social and economic drivers of inequality prevail, then pro-poor water management policies are recommended. Effective policies might include the development of micro-irrigation technologies, or the promotion of mechanisms that allow an integrated management of groundwater and surface water.

If water scarcity is serious or very serious and technological eco-efficiency or natural capital drive inequality then the most appropriate policies would be those that reform institutions for the resolution of water conflicts. These reforms would imply developing a more holistic approach for the management of shared water resources that ensure that different user needs are taken care of. Increased cooperation and information-sharing at sub-national, national and even regional levels will be required in order to prevent water conflicts from aggravating.

Finally in conditions of serious to very serious water scarcity where climate drives inequalities than climate-driven policies that allow adaptation and a greater paradigm shift should be put in place. In this case, profound reforms aimed at transforming a country's economic activity should be emphasized. Particularly in agriculture-dependent countries the strengthening of other economic sectors such as industry or tourism would be in order.

The policies outlined above show that, for the water sector, planned interventions must consider both supply side and demand side solutions. On the supply side, adaptation options involve increases in storage capacity or abstraction from water courses; demand-side options, like increasing the allocative efficiency of water to ensure that economic and social benefit is maximized through use in higher-value sectors, aim to increase value per volume used and to ensure that quality is maintained. All in it becomes clear that the water sector's importance for numerous other productive and social arenas requires policies and management strategies to be well aware of water's widespread impacts.

11.7 Conclusions

This chapter shows that policies need to be successfully balanced to achieve a true integrated water resources management, which will require striking a balance between human resource use and ecosystem protection. This is no surprise (Vorosmarty et al. 2010) but has special relevance in the Mediterranean where water policies are often centuries old and socially embedded. The reality of climate changes renders it impossible to use the past as an indicator for the future. In this assessment we find reasons to be optimistic given the important role that science and technology will play in increasing adaptive capacity and improving water accessibility. There are however also reasons to be pessimistic. It remains to be seen whether the current inequalities that exist in the Mediterranean will be successfully redressed given the high costs associated with technology transfer for less advantaged regions and countries.

The recent past has demonstrated a high sensitivity of water resources to changes in climate and the resulting effects on the social system. Adaptation planning is inherently challenging and often, restricted by a number of factors, including limitations in the participatory processes with the stakeholders that will have to adapt in the future; the exhaustive data requirements for evaluating adaptive capacity; the problems related to selecting adequate evaluation methods and criteria; difficulties in forecasting water supply and demand; and challenges in predicting the future adaptive capacity of the water system. Uncertainties in climate change science and long planning horizons add to the complexity of adaptation decision-making. A further important complication is presented by the difficulties in identifying and linking adaptation and development policies in many areas in the Mediterranean where a large proportion of the population does not have access to clean water and sanitation. The uncertainty of the cost and benefits of the various policies suggested is not addressed here; this is a shortcoming of this assessment.

Knowledge transfer to water managers and users and to sectors linked to water use (technology, energy, health, agriculture, and tourism sectors) is essential to enable adaptive action. The indirect impacts of water resources change in these other areas will have additional cumulative affects. Knowledge transfer between scientists, political decision-makers and the people directly affected by climate change is currently weak, and existing information is poorly used. One of the difficulties is the number and range of stakeholders involved. Another challenge is the inherent uncertainty in climate science and impacts projections: uncertainty can lead to confused messages and inertia, if it is not communicated in the right way.

While there is a continuing need to strengthen the climate change knowledge base (through research), improved understanding of climate change science will be insufficient on its own for adaptation policy development and to drive adaptation action. There is a complementary need to engage stakeholders, by developing suitable methodologies for assessment of impacts, vulnerabilities and planning as a pre-requisite for cost-effective adaptation.

Wider influences on water users' behavior, such as changes in demand and tariffs, must be considered alongside climate change. It is important to consider whether adaptations are sustainable, or rendered irrelevant by other sectoral drivers. This holistic approach should also ensure that adaptation decisions and investments are both cost-effective and proportionate to the risks or benefits that may be incurred.

The development of adaptation measures must take into account future socio-economic scenarios as well as future climate change scenarios. Practitioners need to understand the relevance of a future climate to a future society, rather than to society today. Credible socio-economic scenarios are required to provide a framework for adaptation decision-making for practitioners.

With so many competing pressures and drivers, and so many contributing factors to consider, not only in understanding the impacts of climate change, but also in developing adaptation options, it is likely that the role of training and advice facilities for the users and suppliers of water could become more important. While there may be many simple adaptation measures that could theoretically be introduced to address a particular risk or opportunity, these may only be practically possible under certain circumstances. For example, improving efficiency of irrigation or introducing water metering may only be options for societies that already have an understanding of alternative technologies, and who know how to encourage implementation.

A final challenge for consideration is that of finance. Many potential adaptation options are low-cost and technically manageable by individual water managers. However there are also adaptations that require large scale and long-term effort, either water district management or in infrastructure development. In order for policy to be able to consider and take up such options, it may be necessary for financial support mechanisms to be made available.

The approach to impacts and adaptation developed in this study has provided options for wide-ranging problem. However adaptations often involve combined effort across many sectors. Water resources are sensitive to the responses in many sectors; particularly agriculture, tourism and biodiversity conservation, and so adaptation measures for water will be strongly influenced by policies in other sectors.

Adaptation is unlikely to be facilitated through the introduction of new and separate policies, but rather by the revision of existing policies that currently undermine adaptation and the strengthening of policies that currently promote it. If adaptation is to become "mainstreamed", it will be necessary for relevant polices, such as the CAP and the Water Framework Directive to address the issue more directly.

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Chapter 12
Adaptation Strategies for the Mediterranean

Raphaël Billé, Tom Downing, Benjamin Garnaud, Alexandre Magnan, Ben Smith, and Richard Taylor

Abstract Mediterranean countries have started implementing adaptation to climate change for a decade. This chapter aims to draw a panorama of this current adaptation effort in contrasted contexts of action – typically developed and developing countries. It identifies and discusses early developments of this endeavor, demonstrating its fragmentation and relative lack of ambition. It highlights current disconnections between practice and theory, and insists on the current minimal use of climate information in designing adaptation measures. It finally builds on the analysis of Mediterranean adaptation practices to provide guiding principles for the future elaboration of adaptation strategies in the region, focusing on timing, integration, and contextualization.

Keywords Adaptation strategies • Implementation • Climate information • Uncertainties • Drivers of change

12.1 Introduction

Climate change is underway and its effects within the coming half-century are partially inevitable (IPCC 2007). In less than two decades, the question of climate change and its consequences has become the focus of international concern through two main approaches – namely the reduction of greenhouse gas (GHG) emissions (or mitigation) and adaptation. Lately, adaptation has become increasingly important

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as the international community became aware of the difficulties of defining and obtaining mitigation objectives that would at the same time be mutual, realistic and sufficiently ambitious. Already addressed in 1992 UNFCCC, it was during COP13 (Bali, December 2007) that the issue of adaptation was put firmly into the spotlight, a position that was reaffirmed during COP14 (Poznan, 2008), COP15 (Copenhagen, 2009) and COP 16 (Cancun, 2010). While COP debates on adaptation mainly deal with funding (who pays? How much? To whom? According to which mechanism?), scientists as well as many stakeholders are more concerned with the numerous implementation challenges. Many of the latter relate to the fact that the fight against climate change (mitigation and adaptation) should not be separated from other policies, such as sectoral, development, planning and environmental policies. Such "traditional" policies are no less important for the future of any society than the consequences of climate evolutions: it is at the crossroads of climatic, socioeconomic and environmental issues that the fight against climate change must be considered for the short, medium and long term.

This is particularly true in the Mediterranean. The region's rapid growth in recent decades, while delivering significant positive impacts for the living conditions of the population, has however largely occurred at the expense of the environmental balance and has often contributed to an increase in social and economic disparity, which today are well-known characteristics of the Mediterranean basin. Major pressures and threats already place a heavy demand on Mediterranean resources and activities. As evidence from previous sections shows, climate change will accentuate these pressures, but will not necessarily change their nature.

This chapter aims to build a framework for the implementation of adaptation in the Mediterranean, from conceptual clarifications to operational recommendations. Section 12.2 will provide a panorama of current adaptation practices in the Mediterranean, in contrasted contexts of action – typically developed and developing countries. It will identify and discuss early developments of this first decade of adaptation to climate change in the Mediterranean. Section 12.3 will focus on what appears to be one of the main challenges for implementing adaptation: the use of climate information, and the necessary dealing with derived uncertainties. Finally, Sect. 12.4 will build on the analysis of Mediterranean adaptation practices to provide guiding principles for the future elaboration of adaptation strategies in the region, focusing on timing, integration, and contextualization.

12.2 Adaptation Implementation in the Mediterranean

This section is devoted to analyzing the first decade of implementation of adaptation around the Mediterranean basin. We distinguish developing and developed countries to account for different implementation processes, logics and characteristics, and concentrate on initiatives originating from public authorities. The part also seeks to discuss early developments and trends, and highlights the need for integration.

12.2.1 Adaptation in Developing Countries: The Key Role of Development Cooperation

In recent years, adaptation to climate change has gained serious momentum in development practices, with many development agencies and NGOs launching adaptation projects and programs in developing countries. While most of these organizations decided to start "doing" adaptation 4–5 years ago, the available knowledge on what to do and how to do it was not particularly satisfactory. With a "trial and error" mindset, it was thus argued that starting at that time would allow such organizations to "learn by doing", which seems fairly sensible in a context of great pressure for action from civil society and poor countries themselves.

We are actually entering an uncertain phase where on the one hand there is a need for critical review of what has been done so far in terms of adaptation projects and programs, and on the other hand a very strong push is felt to rapidly scale up the current initiatives in response to both much more pressure and much more financing. This push is related to the international context of climate change, and most obviously to the talks under the UNFCCC: the momentum around adaptation has been growing since COP11 in Montreal (2005) and has sped up since COP13 in Bali (2007) and COP14 in Poznan (2008) (Garnaud 2009a, b).[1] Yet the two terms of the adaptation equation – a need to pause for reflection; the push to go faster and to scale up – are more contradictory than compatible. In practice, it seems that the need to review what has been done so far in order to draw lessons from this "learning by doing" phase is something that often falls off the agenda.

The implementation of adaptation is thus still in a relative infancy with a low number of adaptation projects being currently financed in the Mediterranean. Countries show some disparities in the attention they receive from cooperation agencies. Albania, Algeria or Egypt, for instance, are home to fewer adaptation projects than Tunisia and Morocco, countries that can be considered as relatively advanced, at least for the region. But once again, adaptation implementation is still in its early years and it seems reasonable to believe the other countries will catch up soon. Similarly, all vulnerability types have not yet been covered, with a quasi-exclusivity of a few sectors (agriculture, water and coastal zones/sea-level rise); it seems however likely that sectors such as health or energy will not remain disregarded for much longer. These sectors are indeed subject to well-known threats such as droughts, desertification and sea-level rise. Addressing these threats is often a response to immediate existing pressures: Tunisia and Morocco's recent consideration of the impacts of climate change has been caused by long-lasting droughts that have triggered a national debate. Indeed, when the rains returned to Morocco in 2008 in an exceptional way, adaptation practitioners feared that the momentum would be lost.

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[1] It is interesting to note that the issue of adaptation was already addressed extensively in the text of the Convention in 1992; it is thus not an emerging issue.

The message here is that translation into action is more a result of political rationale than true scientific work of identifying priorities with sound criteria or decision-making tools, and must take advantage of a political window of opportunity. The same logic is found in public risk management, where a major part of action taken is reactive management to a crisis. This is far from an ideal vision of adaptation to climate change, that of an anticipatory and proactive process able to identify possible future impacts and vulnerabilities, rather than a reaction to current threats. Yet it is difficult to encourage authorities, in the Mediterranean as elsewhere, to allocate time, money and human resources to adaptation to climate change, as there is little political incentive to consider such long term and uncertain concerns, and there are often much more pressing and concrete issues to deal with. This highlights the need for adaptation strategies to start by addressing immediate and short term needs in line with national development priorities while laying the groundwork to adapt to future changes. Thus a more positive analysis should try to focus on how to piggyback onto reactive, sectoral behaviors and slowly build a long-term partnership with governments and ministries, with a view to incorporating more sectors. This approach is currently being taken by the GIZ in Tunisia.

Another reason why agriculture, water and sea-level rise are often considered as priorities for adaptation in the eastern and southern shores of the Mediterranean is that there is an international bias that drives adaptation efforts towards the poorest. The underlying assumption is that the poorer an individual or a group, the more vulnerable he is and the less adaptive capacity he has. We will not dwell on this assumption here (see e.g. Magnan 2010), but it has greatly shaped the implementation of adaptation in the developing world. Indeed, adaptation finance and cooperation is generally aimed at the poorest developing countries, and the poorest people in these countries, to such an extent that Least Developed Countries (LDCs) are currently the main recipients of adaptation funding, and that pro-poor adaptation projects are by far the most frequent form of implementation. The picture is slightly different around the Mediterranean because none of the riparian countries are LDCs and as such they have some difficulties in accessing international adaptation finance. Small-scale, pro-poor adaptation projects are thus slightly less numerous than elsewhere, but still represent an important proportion of all adaptation projects. There are also relatively more national planning projects in North Africa than in other regions, but here the number of countries and the number of such projects within the countries do not provide a sufficient basis for the elaboration of sound “statistics”. Still, the relative overrepresentation of agriculture, water and to a lesser extent sea-level rise is in part due to the fact that these sectors are seen as impacting primarily upon the poor. The intention here is not to contend that consideration of the poor is a bad thing, but that experience from more advanced countries in terms of implementing adaptation to climate change has shown that there is a risk of small-scale, pro-poor adaptation projects becoming the main form of adaptation in the field, leading to major limitations. A first constraint is the creation of a situation where adaptation in a country becomes fractionated, described in the Sect. 12.2.1.1; a second limitation pertains to the fact that excessively focusing on the poorest can lead to inefficient adaptation (see Sect. 12.2.1.2).

12.2.1.1 Fragmentation of Adaptation Implementation

One of the major limitations associated with small-scale, stand-alone projects in terms of their contribution to adapting a country to climate change is that they are often detached from the larger context that drives local vulnerabilities (e.g. national, political and economic choices). Morocco, for example, is an area of harsh competition for water, mainly between agriculture, domestic usage and tourism. National policies for tourism in the Marrakech region or in coastal areas, as well as national infrastructure plans to bring water from one river basin to another, have a great impact on the availability of water for agriculture, but such a large scale issue is hardly ever taken into account in small-scale projects. While an adaptation project might progress smoothly and meet its targets, it could yet have no impact or value (or even viability) in terms of adaptation to climate change if the rest of the country takes steps in the opposite direction (Billé 2007). There is however a real need for small-scale adaptation projects as part of sequenced national adaptation implementation. At an early stage of the process, such projects can help raise awareness by showing what can be achieved and demonstrating that no-regret strategies can be implemented. But they should not constitute the bulk of a country's adaptation strategy, nor represent the sole implementation channel. Instead, after this first phase of awareness raising and publicity, a more comprehensive, national approach encompassing all sectors and stakeholders should be promoted. In a third phase, once the planning of adaptation is agreed upon by a wide panel of stakeholders, it might be necessary to begin supporting the implementation of the plan through adaptation projects that bring in technical assistance (Billé and Rochette 2010).

What we observe at the moment in developing countries of the Mediterranean basin is more of an incomplete patchwork of small-scale projects, with very little connection between them. The level of disconnection is clearly increased by the fact that projects are designed and managed by different agencies, and furthermore that small-scale and more wide-ranging projects are promoted by different types of agencies. Such accumulation of chiefly independent projects cannot, and should not, constitute an adaptation strategy. Not only does this lead to unnecessary additional costs (e.g. repetition of the same scientific studies, failure to capitalize on existing good practices), it also neglects the overarching adaptation target of changing development paths and can lead to unsustainable adaptation. This is clear when considering major challenges facing the Mediterranean which will require not only coordinated national responses but also strong regional cooperation (for example over water resources). It can however be argued that fragmentation could favor diversity and innovation, two features that are of utmost importance in a context of novelty and uncertainty about climate change impacts and adaptation measures. Nevertheless, projects are often quite similar from one to another and it seems reasonable to assume that the potential for innovation is still significant.

The same fragmentation tends to occur regarding sectors and climate impacts. In North Africa, the picture is in some way enlightened by the presence of a few very innovative projects that make, or intend to make, a considerable effort to integrate all sectors and climate impacts. This is not, however, generally the case and adaptation projects are usually focused on a very limited number of impacts (e.g. more scarce water resources, or sea-level rise) and only a few sectors at most (typically agriculture). Yet, the same climate impact will interfere with many sectors, and each one will face numerous impacts. In the case of water for instance, water shortages will not only affect agriculture, but also tourism, electricity generation, industry and domestic use. Focusing on agriculture and disregarding other usages, or dealing with them in another arena, is likely to lead to an inefficient and segmented treatment of the issue. There is thus a need for a comprehensive vision of adaptation that would encompass all stakeholders (including development cooperation agencies), scales, sectors and impacts under a single umbrella. In that vein, the emergence of projects such as UNDP's Territorial Approach to Climate Change in Algeria is a promising step towards greater integration.

12.2.1.2 Adaptation for the Poor

We stated earlier that too much focus on the poor can lead to inefficient adaptation. Even in developing Mediterranean countries, where economic structures are relatively developed, the poorest people are the overwhelming focus of adaptation projects. Although it is irrefutable that they are among those vulnerable to climate change, this situation poses at least two problems.

First, pro-poor adaptation projects have a strong inclination to replicate "traditional" development projects – i.e. projects that have nothing to do with climate change, thus lacking innovation and unaware of the true nature of climate change impacts. The practice of development and development cooperation in particular has always been draped with trends or fashions, such as Integrated Conservation and Development Projects (ICDP), pro-poor environmental conservation and integrated management. The question is whether adaptation to climate change will turn out to be the latest tag for business-as-usual development and environment projects, or a real introduction of new issues and new ways of "doing" development. The former would definitely not be satisfactory in terms of actual "climate-proof" development. Moreover, it is difficult to defend the view that adapting to climate change can be limited to "climate proof" development. In reality, adaptation – and fighting climate change in general – requires development to follow a radically different pathway, which is difficult to achieve with small-scale, "climate proof" but essentially "business as usual" development projects. A review of pro-poor small-scale projects in North Africa reveals two main biases of such projects. First, they adopt a very short-term conception of adaptation to climate change, often not looking beyond a few years after the expected end of the project (in essence these projects are addressing climate variability rather than climate change). "Official" justification for this lies in the fact that such projects place an emphasis on community participation in adaptation strategies, and that as these communities are poor, have little rationality to consider horizons beyond a year. This line of reasoning is questionable because, on the one hand, the reasons behind a short-term vision are more complex – and are sometimes related to the rationale of cooperation projects – and on the other hand because the adoption of this short-term vision being assumed to be the favorable option, it thus hampers the inclusion of long-term project dimensions. Similarly, a second bias lies in project sustainability, i.e. what happens once a project has been completed, something that is hardly ever considered in the project objectives. The classic answer to the issue of project sustainability is that the project in itself is intended to reduce vulnerability to climate change. Thus once the project is completed, the vulnerability will be sustainably reduced. This is not always true however, mainly because vulnerability is a dynamic process affected by many external factors. Another answer is that such projects have a pilot value and are hence intended for replication and continuation. Sustainability is supposed to result from this replicability, but nothing is generally done to guarantee it (Billé 2009). Theoretically, pro-poor adaptation by no means has to remain confined to a "climate proofing development projects" approach. On the contrary, it should be an important part of a larger, planned and integrated adaptation action plan targeting *inter alia* the poorest as one of the most vulnerable groups.

This leads to the second problem with the observation that adaptation implementation takes the form of pro-poor adaptation projects: other groups are disregarded in the current implementation of adaptation in the Mediterranean, although they might also be vulnerable and of utmost importance to the national economy, and thus to the vulnerability of all groups. For instance, Mediterranean cities are rarely the focus of adaptation studies or cooperation in the field.[2] However, a large proportion of the populations and assets of North African countries are located in cities. Due to unchecked development trends, these urban areas have been rendered ill-equipped to deal with potential climate impacts such as sea-level rise, flash floods or an increase in heat waves or water shortages. The inference here is not that the poor do not require attention from cooperation agencies, particularly regarding climate change. It is rather that the current filter through which adaptation is viewed – and understood – obscures other groups and sectors that might also be highly vulnerable to climate change, with low adaptive capacities and potentially high socioeconomic importance. What applies for sectors is thus also true for socioeconomic categories: they will all experience the impacts of climate change and they will all impact upon the success or failure of adaptation by other groups. The focus of adaptation implementation on "pro-poor adaptation" and the way in which "pro-poor adaptation" is conducted therefore raises questions on the true efficiency of current adaptation. Both fragmented and in fact unconscious of the full scale of the problem, it presents a real avenue for improvement if the implementation of adaptation is to be successfully scaled up in the near future.

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[2] To the noteworthy exception of a current World Bank study on the vulnerability of North African cities to climate change (www.cmimarseille.org/FR/Cities-and-climate-change.php).

12.2.1.3 A Need for Enhanced Integration

The issues raised in the previous section call for a much more integrated approach to adaptation. International cooperation has a major role to play in this regard as a catalyst for integration. Key aspects that will feature in the dialogue on adaptation include: transboundary issues, multi-objective development programs and cross-scale linkages. Ideally, we believe that adaptation should be multiform with programs, policies, strategies, action plans and projects of all types, sizes and scales that cover all sectors, regions, communities and climate change impacts. The existing barriers to adaptation should be acknowledged, the symptoms of which are often revealed by current environmental stresses; and the many other changes and impacts that affect decisions and results (including mitigation policies) should be taken into account. Adaptation should identify opportunities as well as risks and there must be an acknowledgement that a large part of adaptation – and thus maladaptation – happens within a context of "business as usual" policies. The intention to adapt a country to climate change should be included within the larger context of moving development pathways towards sustainable development.

12.2.2 Adaptation in Developed Countries: A Proliferation of Scattered, Top-Down Initiatives

The implementation of adaptation in the industrialized countries of the Mediterranean basin is relatively less advanced, or at least less visible, than in developing countries. Industrialized countries as a whole have had fewer incentives to start adapting to climate change, because of a strong initial international bias toward those that are considered the most vulnerable to climate change, i.e. the developing countries and the poorest among them. This has sometimes had the effect of making industrialized countries believe they were immune to climate change, although finding evidences of the contrary is an unchallenging task (e.g. the 2003 European heat wave, Hurricane Katrina in 2005). Although adaptation is now on some countries of the Mediterranean north coast's agendas, initiatives still lack ambition. These initiatives are mainly elaborations of national adaptation strategies or plans, the quality of which leaves much to be desired.

To date, two Northern Mediterranean countries have adopted national adaptation strategies: France (2006) and Spain (2006) (Swart et al. 2009); besides, the European Commission presented its White Paper for adaptation to climate change in 2009.[3] Spain's National Plan for Adaptation to Climate Change[4] provides a reference framework for the coordination of government activities on impact assessment,

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[3] http://ec.europa.eu/environment/climat/adaptation/index_en.htm

[4] http://www.mma.es/secciones/cambio_climatico/areas_tematicas/impactos_cc/pdf/pna_v3.pdf

vulnerability and adaptation in Spain. As a result of public consultation, the plan was approved in 2006. It determines the overall structure of sectoral, systemic or regional assessments and is based on the learning principle to identify relevant adaptation options, whether sectoral, multi-sectoral, regional or cross-sectional. It identifies in particular information, communication and training actions as essential for its own coherence. The plan puts forward a vision of participatory adaptation even though the development of the strategic framework for some assessments of leading sectors can be regarded as top-down processes. However the definition of adaptation options at the level of Spanish sectors, systems and regions must be fulfilled by a decentralized and bottom-up approach. The adaptation plan also stresses the importance of synergies with other environmental issues, and with many of the standard planning instruments as well. The integration of polices for the fight against climate change into public policies as a whole, is therefore considered as essential. The Oficina Española de Cambio Climático (OECC) coordinates the implementation of the Adaptation Plan. It supports in particular the generation of data, tools and information relevant to the development of impact assessments and facilitates the participatory process.

France's National Strategy for Adaptation to Climate Change[5] (2006) expresses the view of the administration on how to address the issue of adaptation to climate change. This national adaptation strategy was developed through wide consultation, conducted by the National Observatory on the effects of global warming (Observatoire National sur les Effets du Réchauffement Climatique, ONERC). The strategy was validated by the Inter-ministerial Committee for Sustainable Development, organized on the 13th November 2006 by the Prime Minister. Four major areas are identified in this strategy for climate change: security and public health; social aspects: unequal exposure to risk; cost minimization, making the most of advantages; and to preserve natural heritage. Some courses of action are proposed as prerequisites for the future development of a national plan for adaptation, which aims to identify a group of specific measures to be decided at different levels. The validation of this strategy is followed by the current elaboration of a National Adaptation Plan to be published at the beginning of 2011 and bound to be more in-depth and prescriptive than the Strategy.

The White Paper of the European Commission for adaptation to climate change (2009) provides a framework for action and adaptation policies in order to reduce the vulnerabilities of the European Union to the impacts of climate change. The report positions itself as a preparatory work for the development of an adaptation strategy at the European level. Respecting the principle of subsidiarity and recognizing that much of the adaptation measures will be made at Member State level, it lays the foundations for the European Union as a facilitator of national efforts, especially for cross-border issues and European policy. The White Paper proposes the establishment of a Clearing House Mechanism by 2011 to serve as a platform for

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[5] http://www.ecologie.gouv.fr/Adaptation-au-changement.html

discussion on the impacts of climate change and best practices. It also announces that adaptation to climate change will be integrated into all EU policies, and clearly reflected in its foreign policy. The EU has also started integrating climate change considerations in some of its policies and measures, including the Water Framework Directive and the Flood Directive, which is arguably its most promising initiative in terms of adapting to climate change.

Beside these overarching national frameworks for adaptation – that are generally seen as "first steps" towards more ambitious national actions –, local authorities of industrialized Mediterranean countries have also started engaging in adaptation. However, the sample that has been studied here – mostly cities and other local authorities of France – shows little ambition and the few actions that are distinguishable stem from the guidance and/or pressure of the national administration. North shore countries are finally involved in supporting adaptation in developing countries. Two main types of financing are used (Ayers et al. 2010): classical Official Development Aid (ODA) channels (bilateral donor agencies and contribution to multilateral agencies) and dedicated UNFCCC funds. The bulk of adaptation finance still comes through ODA channels (Atteridge et al. 2009). By doing so, they contribute to an international effort of defining what adaptation means in practice. It is thus somehow paradoxical to note that this work of definition still hardly percolated from their action in developing countries into their domestic involvement in adaptation.

12.3 The Relative Importance of Precise Climate Information

The implementation of adaptation to climate change has thus started less than a decade ago around the Mediterranean basin. A common concern of all these strategies, plans and projects is the central question of information about the future climate. This section focuses on the crucial challenge of using climate information and dealing with uncertainties in adaptation; it will present the theory on uncertainties and adaptation, and will question how this challenge is met in the Mediterranean.

12.3.1 The Need for Information on Future Climate, and the Difficulties of Using It

Proactive adaptation is often necessary to optimize the management of future impacts of climate change. However, the necessary information on the future climate is constrained by many uncertainties, which hamper current adaptation efforts. Scientific progress is often put forward as a means to reduce uncertainties, and strategies are proposed to start adapting despite a high level of uncertainties.

12.3.1.1 A Plea for Early Action on Adaptation: Three Reasons

Climate change is not the only source of change decision-makers have to face, and its impacts are remote and uncertain. What then makes it necessary to adapt to climate change now, in addition to managing the current and numerous other stresses (including, but not limited to, present climate variability)? Why should a Mediterranean country's energy sector consider adapting to higher temperatures in 2050 if it already has to face growing demand, rising prices and short term stringent emissions reduction policies? Why should poor North African farmers think about their vulnerabilities to climate change if they are already vulnerable to recurring droughts, volatile market prices and competition for water with the tourism sector?

Conceptual research on adaptation to climate change tends to distinguish anticipatory and reactive adaptation. Reactive adaptation is defined as adaptation that is done after climate changes; on the contrary, anticipatory adaptation is done before climate changes – and impacts are felt – in order to minimize (resp. maximize) its negative (resp. positive) impacts (Smit et al. 1999; Smith 1997). This distinction has strong limitations because climate change is not an instant with a previous and a subsequent state, but rather a continuous change to which it is impossible to assign a beginning and an end. Nevertheless, it helps clarifying two different types of adaptation that can be confused. The main difference between anticipatory and reactive adaptation is actually not the timing, but rather the logic behind adaptation. Adapting as a reaction means that one waits for the impact, and the potential damage, to be felt a first time before responding to it. Adapting as anticipation requires an understanding of what might happen, and taking decisions before it happens in order to make the best out of it. According to a "precautionary principle", it would always be wiser to adapt proactively. However, in practice it might not be rational because of opportunity costs, and because of "imperfections" of the real world. Uncertainties about future climate change impacts are among them. These imperfections, and a strong belief in the capacity of human beings to adapt "as they always have", have made many believe that human societies would adapt naturally to climate change, without having to resort to centralized planning (Mendelsohn and Neumann 1999; Nordhaus and Boyer 2000).

This belief is however challenged by the observation that reactive adaptation might not be as straightforward and automatic as expected. Repetto (2008) observes that the capacity of a society to adapt does not necessarily prejudge whether it will actually adapt, and highlights barriers that hamper adaptation action: uncertainties in the future evolution of climates and its impacts, moral hazards issues, organizational behaviors that lead to slow and painful changes, and the fact that individuals have a tendency to strongly discount remote events such as climate change. The rate of change is also an issue for reactive adaptation, as climate changes might prove too rapid to let individuals adapt *a posteriori* and independently. Besides, some specific situations call for early actions: long-lived investments and decisions, potential lock-in situations of maladaptation, and potential irreversible yet unacceptable changes.

- Long timeframes. Some investments made today will be impacted by future climates. Within the design lifespan of infrastructure, climate change will exceed the noise of current climate. It may be cheaper to design these investments to support climate change than replace them prematurely because of unexpected conditions.
- Lock-in situations. Investments and decisions made today might have a negative influence on future capacities to adapt, i.e. situations in which it will be more difficult to take corrective adaptation decisions later. A typical example of such decisions that create lock-in situations for adaptation is that of authorizing the urbanization of coastal zones that might later be prone to sea-level rise.
- Irreversible changes. Some characteristics of the world that we want to preserve might disappear irreversibly because of climate change: acting reactively will be too late. This situation is mainly that of extinctions of species or disappearance of whole ecosystems such as coral reefs. Tipping points into new states for socio-ecosystems may produce undesired conditions that are difficult if not impossible to correct (Biggs et al. 2009).

These reasons explain why an important part of the overall adaptation effort should not be left to circumstantial and ad-hoc/reactive responses but should be guided by professional practices and start sooner rather than later.

12.3.1.2 The Need for Climate Projections and the Problem of Uncertainty

Adaptation is defined as “an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2007). Optimal proactive adaptation would thus require information on these stimuli, i.e. on future climate changes and their impacts on ecosystems, societies and economies. Climate science has developed rapidly to be in a position to provide projections about the future climate. Future climate change will depend on two factors: greenhouse gas emissions (which are directly linked to development patterns) and the response of the climate system to these emissions. To determine climate projections, scientists work out future emission scenarios and design climate models. The former are mainly derived from economic, social and technological sciences, and the latter from physics and biology. These projections are thus based on numerous assumptions, and derived uncertainties are significant.

We can distinguish three main sources of uncertainty related to the data obtained by climate modeling (Dessai et al. 2009; Terray and Braconnot 2008):

- Future greenhouse gas emissions, driven by socioeconomic evolutions;
- Our limited understanding of the climate system (e.g. clouds, tipping points, feedbacks), as well as the functioning of climate models, inherent in the model’s structure (the type of equations). The last point includes downscaling to local climate evolutions from elements taken from global models;
- Natural climate variability, due to chaotic components of the climate system.

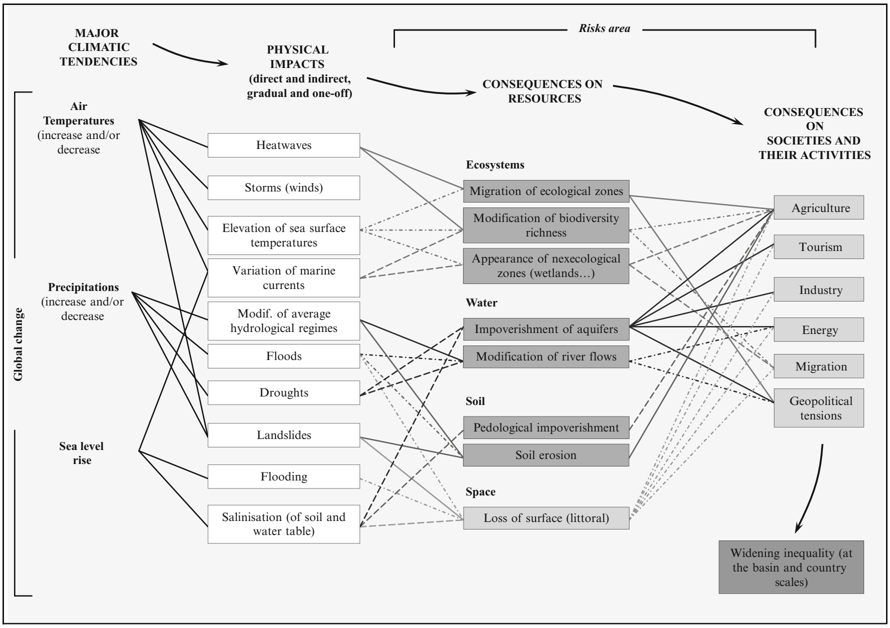

Fig. 12.1 Some examples of "chains of impacts" that explain the effects of major climatic changes on future human activities (Source: Magnan et al. 2009)

Beside climate data, the information required to adapt to future climate change is subject to more uncertainties, linked to the assessment of these changes' impacts on ecosystems and societies. Indeed, changes in temperature, precipitation and sea level over the decades and centuries to come will result in various physical impacts, of gradual occurrence for some, or as extreme events for others. These disturbances are not necessarily new; many Mediterranean areas are already plagued by some of these hazards. The "novelty" of climate change lies mainly in the intensification of these disturbances and their occurrence. It is the existence of "chains of impacts" that should be emphasized, i.e. sequences of repercussions from climate impacts to human activities, through natural resources. Figure 12.1 illustrates the kind of chain of impacts that links major climate variables used in climate models and the consequences of their change on natural and human systems. A similar map of the complexity of causal links between climate impacts, vulnerability and adaptation underpins the economics of climate adaptation (Downing 2011; Watkiss et al. 2010).

The uncertainties of climate models translate into uncertainties on regional and sub-regional trends, affecting predictions of the tangible impacts of climate change on the environment and societies. Furthermore, the complex workings of natural and/or human systems add another level of uncertainty as their reaction to the impacts are themselves difficult to predict – especially as they will potentially be highly contrasted from one place to another. There is therefore a real difficulty in developing prospective climate and socioeconomic studies that, at regional or local scales, provide the necessary scientific knowledge to make informed decisions for the future.

The response of socio-ecological systems to climate stress, including extreme events and gradual changes, must also be integrated as a source of uncertainty. It should be remembered that the greatest source of concern remains the vulnerability/lack of resilience of socio-ecological systems in the face of the relative rapidity of climate and environmental changes to come. The adaptation capacities of ecosystems and societies encompass the uncertainties and risks of biodiversity loss and the threat to the future of human communities. The richness of the Mediterranean basin, in terms of biological, socio-cultural and political diversity, provides a further degree of complexity: species and societies will not react the same way.

With specific regard to human societies, capacity to respond to the climatic threat raises the question: will humans be able to reduce their GHG emissions in the necessary proportions and within the required time scale? And what anticipation/adaptation capacity do they have to respond to the aspect of climate change that is already inevitable? If they do have adaptive capacity, will they use it to adapt?

12.3.1.3 A Theoretical Way Forward

Uncertainties linked to estimating future impacts of climate change are described as a great barrier to adaptation efforts, in the Mediterranean and elsewhere (e.g. Barnett 2001; Lorenzoni et al. 2007). Scientific progress is often seen as a solution to reduce these uncertainties, and thus to set the bases for future adaptation efforts. Even if it seems sensible to push for better science in order to reduce uncertainties, it appears that some of these uncertainties are irreducible, and that the other uncertainties will not be reduced in the near future, and might even – at least temporarily – increase with progress in science (e.g. Dessai et al. 2009; Hansen 2007). In particular, uncertainties about the chaotic nature of the climate system and future emissions of GHG, the latter being based on decisions that have not yet been taken, will not be reduced by advancing climate science. It is therefore naive to assume that the uncertainties concerning the impacts will inevitably be reduced and that waiting to make decisions is a wise and effective strategy.

Thus, we cannot turn to climate scientists for detailed and precise information about the climate in the long term future, as we would do today with meteorologists for the weather forecast for the coming days (Hallegatte 2008). The implementation of adaptation strategies requires improvement in the way that the climate, and therefore the uncertainties, is taken into account when considering decisions regarding investment and planning. The aim is essentially to choose solutions that integrate the uncertainty rather than solutions that are designed around a single figure (like the average of projections).[6]

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[6] The majority of work is based on the A1B scenario because it is considered an average scenario, but the IPCC is clear: this scenario is not more likely than the others. Findings from an international conference on climate held in March 2009 in Copenhagen (“Climate congress: global risks, challenges and decisions”) actually states that the current trajectory of GHG emissions is beyond that of the most pessimistic scenarios, to which A1B does not belong.

Decision making under uncertainty is nothing new (Morgan and Henrion 1990), and suggestions have been made to adapt in an uncertain context (Barnett 2001; Hallegatte 2009; Lempert et al. 2003; Schneider 1989; Smith 1997):

- Institutionalization of long term planning (e.g. for the management of coastal zones or water at the regional level), in addition to a process of regular review according to new information. Adaptation is a continuous learning process;
- Promotion of "no regrets" strategies, i.e. strategies that are beneficial even without considering the impacts of climate change. For example: restoration of coastal dunes (which are buffer zones facing risks linked to the sea), implementation of plans to prevent natural hazards, etc;
- Introduction of robust solutions, i.e. those that are relevant to a broad range of future climates. For example: including the consideration of the most "pessimistic" outcomes in the design phase of infrastructure, rather than having to intervene after it has been put in place;
- Promotion of reversible strategies rather than irreversible ones, to minimize the cost of an inaccurate estimate of climatic changes. For example: it may be better to reject urbanization plans for an area of coastline, based on the fact that if climate information one day becomes more precise, it will be possible to reverse the decision at a low cost; and from the opposite perspective, choosing to urbanize despite uncertainties will bring immediate benefits, but can lead to a future situation where the choice is between heavy protection and taking a step backwards, two options that are often cost-prohibitive and not always feasible;
- Avoidance of a focus on technical solutions to adaptation; in some cases, institutional or financial instruments may be more appropriate. One example is easy access to insurance systems (agriculture) or the establishment of early warning systems, rather than heavy coastal protection. The main interest of these "soft" options of adaptation is that they have much less inertia and irreversibility.
- Promotion of diversity in the implementation of adaptation. While a great global effort has been put on thinking about and implementing adaptation solutions, little is still known about what to do and how to it; thus, in a context where both the object of adaptation (the impacts to which the society adapts) and the solution are uncertain, the eggs shall not be put in the same baskets. There is a need for innovating and testing a wide variety of adaptation solutions.

In summary, the fundamental uncertainty relating to climate change will not disappear in the coming years, thus policy makers should not rely on climate scientists, economists and other modelers to avoid having to make difficult decisions in an uncertain context. What is needed is a concerted effort to improve communication between climate scientists and decision-makers, with a focus on using the information available to help decision-makers make informed decisions under uncertainty.

12.3.2 The Minimal Use of Climate Science for Mediterranean Adaptation

Theoretical research on adapting to climate change has acknowledged for decades that uncertainties on future climate were large, that their reduction would – at best – take time, and has put forward several strategies to adapt despite this blurred vision of the future climate (Schneider 1989). As Sect. 12.2 revealed, it is fair to say that adaptation has now started in the Mediterranean. The study of this blossoming implementation demonstrates that the use of climate information in adaptation is somehow disconnected from this theory: adaptation projects are far from using the best available science, be it on future climate change and its impacts, or on adaptation strategies.

Section 12.2 showed that the practice of adaptation in the Mediterranean happens at different levels and through different modalities: national strategies or plans, research projects, localized, stand-alone projects, etc. The distribution between these categories varies from a country to another, and the number of initiatives is bigger in developing Mediterranean countries, where development cooperation drives the practice towards stand-alone, self-proclaimed innovative projects. These seemingly diverse initiatives can be grouped into two broad categories: those that contribute to enhancing the enabling environment for adaptation, and the no-regret projects. Enabling environment measures aim at providing stakeholders with knowledge, information and tools to facilitate their adaptation to climate change. These measures comprise for instance the production and distribution of satellite imagery and vulnerability mapping in Algeria (UNDP project), or the promotion of interdisciplinary climate research and broader-based collection of climate and water resource data to improve the quality of forecasting in Tunisia (GIZ project), as well as the development of climate change data platforms in France (DRIAS).

No-regret measures regroup a wide array of projects, policies and measures. The IPCC defines a no-regret policy as “a policy that would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs” (IPCC 2007). The vast majority, not to say the entirety, of adaptation projects that do not seek to enhance the enabling environment are no-regret. Said differently, Mediterranean projects that are actually meant to adapt something (e.g. a country, a sector, a community, an infrastructure) to climate change are essentially adapting it to the current climate, or to current stresses (e.g. water scarcity or coastal erosion). Doing so, they are also seen as a means to reduce the vulnerability to future threats. For instance, integrated coastal zones management is implemented in Egypt and Tunisia under the adaptation label (GEF and UNDP projects). In the same vein, the GIZ is promoting a better enforcement of existing water and agricultural ordinances as well as the introduction of insurance services for climate-related damage in Tunisia. In Morocco, UNDP implements more efficient, community-managed irrigation schemes. In France, the city of Paris reinforces its heatwave management plan. All these initiatives are labeled as adaptation to climate change, and are clearly no-regret in the sense that they are beneficial in the current context, irrespective of the future climate.

The quantity and quality of information used to design and implement such no-regret projects is minimal. Some use synthesized, large-scale scientific projections (e.g. IPCC reports) to substantiate the initiative's *raison d'être*. This is especially true for stand-alone projects, but it is also valid for public strategies (e.g. from a national or local authority) which usually start by reminding the main future climate threats, occasionally with dedicated climate studies, but then leave them aside and focus on no-regret actions, postponing sometimes the "true" adaptation measures, i.e. which are not no-regret, to later. However, a large proportion of no-regret projects do not even use information about the future climate and assume – explicitly or not – that reducing the vulnerability or adapting to current climate-related stresses automatically contributes to adapting to future threats. In all cases, there is no real use of climate change data in designing and tuning Mediterranean adaptation policies, measures and projects. The question is: why? One reason is clearly the fact that there are no precise climate change forecasts, and that uncertainties hinder the design of adaptations to the future climate. However, the observation that current Mediterranean projects do not even use the best available science suggests that there might be other explanations.

12.3.3 A Rationale Behind the Underutilization of Precise Climate Information

Why do Mediterranean adaptation initiatives use only minimal, not to say no, climate change data? The possibility of a threshold effect in using uncertain science to design actions adapted to future conditions cannot be completely set aside. It might be that there is such a theoretical line in scientific progress before which transactions costs are too high: using and optimizing the best available science, thus designing more-than-no-regret adaptation policies or projects, is too complex compared with the very little and uncertain extra-benefits it brings in place of no-regret actions. However, the analysis of Mediterranean adaptation initiatives reveals two other possible leads.

12.3.3.1 Differential Needs for Precision in Climate Information

The first lead is that all adaptation measures might not need the same levels of precision in the climate information they use. The current level of implementation, inevitably biased by its infancy, tends to show that the number of measures requiring precise, or even tailored, climate data is far lower than those for which large trends are enough. On the whole, it seems that the number of adaptation initiatives decreases with the quality and quantity of information they need, so that the relation between the number of projects and the precision of the required information follows a pyramid shape (see Fig. 12.2).

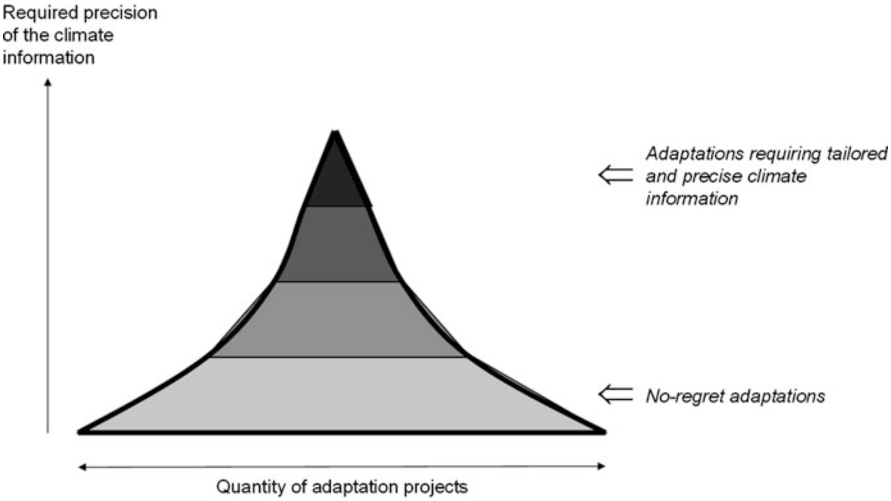

Fig. 12.2 Apparent distribution of adaptation projects according to the level of precision of the climate information they use

Furthermore, time appears to be a third dimension in the equation: the early adaptation implementation sequence seems to be devoted to low-information measures, and more information-intensive adaptations tend to appear later in the process. This might be due to a “low-hanging fruit” or “progressive learning” approach to the implementation of adaptation, with the simplest (no-regret) actions being conducted before those demanding true innovation. It also reflects the fact that adaptation to climate change does not make sense if Mediterranean societies are not adapted to the current climate and climate-related stresses. For instance, adapting to a future decrease in water availability due to climate change is of limited interest if there is no endeavor to tackle the numerous current water stress challenges. Adapting to these stresses is precisely the aim of no-regret measures which, as we have seen, require minimal climate information. There is therefore a rationale for implementing non-information-intensive measures first.

All in all, the number of adaptation measures that require precise or even tailored climate information is seemingly low compared to the bulk of necessary implementation of no-regret projects and policies. A few points support this hypothesis. First, experiments in providing tailored and precise climate change data to stakeholders reveal it is both costly and time-consuming. The cost-benefit ratio is thus high, limiting the number of issues for which we could afford it. Besides, adaptation decisions are often made in complex contexts, involving current stresses and challenges, as well as other factors of future changes and their share of uncertainties. The need for precise information on future climate change impacts is thus reduced by the complexity of the context in which the decision has to be made.

12.3.3.2 Non-climatic Drivers of Change and Related Uncertainties

Climate change is not the only driver of change in the Mediterranean, and not even the main one in many cases. Rapid and profound socioeconomic changes, independent of climate issues, have indeed been important in recent decades and should still be observable in the twenty-first century. These major trends can be quickly presented through significant economic changes, which reflect, as much as they influence, the demographic and urban dynamics. Examples of such non-climatic drivers of change are sectoral dynamics, development and urbanization, and water resources depletion.

- Sectoral dynamics: conditions have been shaped by the boom of the service sector and strong economic growth, although economic disparities remain large between Mediterranean countries. Within the tertiary sector, tourism distinguishes itself (Bethemont et al. 1998), placing the Mediterranean at the forefront of the world's tourist regions, as much in terms of tourist flows as of income linked to tourism.
- Demographics: the population of Mediterranean countries is estimated at nearly 450 million, against nearly 285 million about 40 years ago. The expected population growth rates for the period of 2000–2025 are respectively 14 and 13 times as high in Southern and Eastern Mediterranean countries as the average of northern countries. This concentration is correlated to the phenomenon of urbanization that is particularly relevant in coastal areas.
- Development: the rapid development the region has known for the past few decades, despite its positive effects on living standards, was largely achieved to the detriment of environmental equilibriums vital to human well-being. Resources and activities in the Mediterranean are under strong pressures and threats, which climate change will essentially reinforce rather than change their nature. For instance, many Mediterranean countries have water extraction levels which are higher than what is needed for minimum recharge of groundwater. This is largely the result of a rapidly increasing population, technological change, and economic growth leading to an increase in per capita demand and inefficient use of water resources (Wingqvist 2010).

These major trends also percolate in adaptation decision-making: impacts of climate change are never the only future changes that have to be taken into account to design a project or an investment. Other factors of change have comparable or greater levels of uncertainties (e.g. local demographics, future political choices, international trends, evolution of tourists' preferences) so that sources of uncertainty in real-life decision-making go far beyond emissions scenarios and climate science. Decisions regarding mitigation of climate change can also be very important factors of change, the anticipation of which is still a challenge. In this context, it is likely that the need for decision-makers to have climate change uncertainties reduced is not obvious, if other uncertainties remain at higher levels. This observation tends to diminish the value of the attempts at reducing uncertainties of climate change impacts: is it that essential if uncertainties regarding other factors of change are kept at a high level?

These two alternative justifications to the relative underutilization of precise climate information – namely the differential needs in precision and the presence of other uncertain factors of change – challenge the hegemony of the explanation along which the lack of precise information hinders their use. The need for precise information might not be that pressing for climate change adaptation.

12.3.3.3 A Need to Communicate the Best Available Science

Although the need for more precise climate change data in all situations is challenged by the practice of adaptation in the Mediterranean, the same practice still reveals a certain underutilization of the best available science. To put it differently, some Mediterranean adaptation measures could have been better designed at little cost, if the best available science had been made available to the practitioners. There is clearly a need to do so. We have seen that enabling environment measures, including the provision of information about future impacts and tools to assist in making adaptation decisions, are already part of the overall nascent adaptation effort in the Mediterranean. However, these measures are often provided by public actors, not necessarily well-informed about the best available science. There is a frequent missing link between the climate and impact science on one side and the practice, including its enabling environment, on the other.

This calls for the development of climate services, emphasized at the third World Climate Conference in Geneva in September 2009. Climate services can be defined as the provision of information and expertise, adjusted to the needs of the end-user. They can range from general information on climate change and its potential impacts, to the publication of raw climate data, to the delivery of tailored data to a particular actor on a specific need. Most importantly, they aim at providing the right level of climate information to the right stakeholder. Still in an early development phase at a global level, they could foster optimal adaptation in the Mediterranean. Already, scattered initiatives bloom that could be of use to the Mediterranean basin,[7] but suffer from their isolation and a general lack of consideration of their usability and adequacy with the true needs of the targeted stakeholders. This observation raises the question of the opportunity of having a regional climate services platform for the Mediterranean basin.

12.4 Principles for the Elaboration of Adaptation Strategies

Adaptation to climate change is happening in the Mediterranean basin, though still in its infancy. The two previous sections of this chapter elaborate on early trends that can be identified and lessons that can be drawn from the first decade of practice.

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[7] See for instance weADAPT (www.weadapt.org) and the Climate Change Explorer Tool (www.weadapt.org/knowledge-base/wikiadapt/the-climate-change-explorer-tool).

This section builds upon this analysis and develops some principles to guide the elaboration of future adaptation strategies, policies or projects in the Mediterranean.

12.4.1 The Need for Integration

12.4.1.1 Climate Change and Other Drivers

Although we have seen there is a rationale for starting adaptation now, it should be understood that climate change adaptation is not a stand-alone matter. Again, climate change is not the only – and arguably often not the main – factor of change likely to impact Mediterranean environment and societies. While this observation might seem obvious, it still raises the difficulty of not conceiving adaptation to climate change in isolation: any long term strategy should consider future climate impacts on tomorrow's world, rather than on today's world as is often the case. Coming back to the example of energy sector, clearly climate change is not the only change that should be taken into account, and a stand-alone "adaptation to climate change strategy" would seem rather peculiar. Issues such as the impact of mitigation policies and measures on the energy sector, oil and gas depletion, or transformation of energy production modes due to individualization of the production are changes whose impacts might certainly prove more tangible and immediate than those of climate change, and to which adaptation is undoubtedly needed. There is thus a crucial need of integration in the design of adaptation strategies.

12.4.1.2 A Two-Way Integrated Approach

While climate change will have indirect effects on the development of future societies, we now know that current modes of development affect climate evolutions and will continue to do so. Therefore, feedbacks between development and climate change must be taken into account in the actions and policies that must be promoted. Insofar as adaptation strategies can have negative impacts for the environment or in terms of GHG emissions (e.g. air conditioning), it is important to develop adaptation approaches in an integrated manner with mitigation activities. Furthermore, it is equally important that policy interventions that do not directly aim to combat climate change, take into account issues of adaptation, and do not lead, even unintentionally, to a progressive reduction of the range of adaptation possibilities. Faced with uncertainty it is important to avoid decisions which narrow the range of possible solutions which can be implemented. This requirement, which also applies to the logic of reducing GHG emissions, is important for example in the forefront of major infrastructure implementation (highways, dams…), referring indirectly to the issues of robust solutions.

12.4.1.3 A Wide Range of Possibilities

Adaptation can be applied at many levels, not only technical but also behavioral, economic, financial, political, institutional… Adaptive capacity is often reduced to economic and technological attributes, but the modes of social organization or the political-administrative structure, for example, are also important elements of a region's capacity (i) to respond to a crisis or a succession of crises and (ii) to anticipate potential future crises.

Thus, conceivable practical solutions do not only concern transfers of technology or instruments of wealth creation, even if they obviously have a role to play. For example, we can consider actions in favor of maintaining social links as an indirect way to strengthen the capacities of a society to show cohesion during a crisis (social support, insurance…) and to implement collective anticipation policies (developing irrigation networks, strengthening structures and relief organizations…).

Finally, while considering a wide range of intervention fields in terms of adaptation, we should also underline that actions can be implemented at multiple scales, from small measures in a single urban district or on a few agricultural fields, to national and international policies (agricultural, commercial…), and including development planning of local and regional areas (economic reorientations, peri-urban dynamics, preservation of ecological areas, use of renewable energies, trans-boundary water management…). This echoes the two-way relationship between the fight against climate change and sustainable development. It implies that all stakeholders are involved in adaptation. Adopting an optimistic outlook, we can see in this complexity a proliferation of opportunities for the implementation of adaptation (which means a multiplicity of actions and stakeholders).

12.4.1.4 Contrasted Stakeholders' Interests

Single adaptation needs and efforts are often relevant to a number of stakeholders. In situations where different agents may affect the process of adaptation, this can constitute an opportunity for implementation. However it also calls for recognition of the existence of divergent interests between stakeholders, and thus potential conflicts around the adaptation strategies to be implemented. A classic example is the sharing of water between agriculture and energy sectors. It is essential that the issue is not ignored, but that we recognize and address it with the whole range of available instruments: participation, negotiation, mediation, communication, consensus building… and eventually taking painful decisions in favor of certain interests to the detriment of others. Adaptation as well as emissions reduction, while they have strong technological and scientific bases, are still fundamentally political processes around which power relations will exert.

12.4.2 Choosing Adaptation Options

There are many different factors which influence the choice of adaptation decision, and many different methods on offer help choose between different adaptation actions.[8] None of these decision-support tools will provide the “ultimate” answer as to which adaptation action is best, as each method prioritizes a different set of factors in ranking the options. For example a cost-benefit analysis is commonly used but prioritizes economic return over other aspects of the decision. Different stakeholder groups have different priorities and objectives, and this will be reflected in the decision-support method they choose. This makes it vital to include as many stakeholder groups as possible in the decision-making process, and not to rely on any one decision-support tool to provide the “best” answer.

As part of the Circe project SEI has worked on an approach to decision-support for adaptation in which multiple methods can easily be included and compared. This work resulted in a beta version of the “Adaptation Decision Explorer” in which users can compare the results of multi-criteria analysis and voting-by-ranking exercises (weADAPT 2008). Further research in the EU Mediation project is seeking to characterize the different types of policy decision-context for adaptation, and the information needs and types of support tools which are needed in each context in order to make a sound adaptation decision.

In the face of uncertainty over future conditions, one promising approach for choosing adaptation options is based on Robust Decision-Making (RDM). Robust decision-making looks for strategies which perform well under a range of plausible socio-economic and climatic scenarios, rather than looking for the optimal strategy for a given climate future (Lempert et al. 2004, 2006). This involves developing a set of plausible scenarios of future climate change and narratives of socio-economic change, covering the range of uncertainty between different projections. A set of adaptation options which are acceptable to different stakeholders are then developed, and their expected performance is then assessed against the different scenarios of the future. The important point is that this approach looks for strategies which are robust and expected to perform well across the range of possible future conditions, rather than looking for a strategy which is optimal for one scenario but is sensitive to changes and may perform badly under a different (but equally probable) scenario (Wilby and Dessai 2010). It does not assume that it is possible to accurately predict the future.

12.4.3 Contextualizing Best Practices and Adaptation Initiatives

In its implementation phase (preparation of a strategy, identifying concrete measures…), adaptation is a process of decision and intervention that is specific to a given territory, therefore indirectly specific to one or more stakeholder(s) who

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[8] A summary of different options can be found here: http://wikiadapt.org/index.php?title=Climate_Adaptation_Decision_explorer.

act in a particular context characterized by specific threats and opportunities. There is no unique process of adaptation, nor any generic solutions that can be applied regardless of context. This invites careful consideration of "good practices" which, although attractive a priori, often obscure combinations of factors specific to a particular case that are crucial to succeed. Thus, a common mistake is to consider these experiences as "recipes" that can be transferred without modification, rather than as simple examples of the implementation of general principles.

To the extent that science can support this practice, improvements need to be made both in the generation of explanations (theories) of the relationship between climate impacts and adaptation decision making options and processes, and in the use of evidence (observation and measurement). In particular in social science (where the techniques of data collection are relatively poorly developed), this task is made more difficult by the changing nature of the phenomena; societies tend to undergo frequent structural changes leading to a reorganization of priorities and relationships, and their relationships to the natural environment.

However, on several counts, much attention is currently being focused on these problems. This may allow shifting out the boundaries of good science for adaptation.

12.4.4 Using What Already Exists

In the same way, it should be reminded that we are far from being deprived of possible courses of action. Indeed in many cases, legal, institutional and technical instruments, for example, already exist and can be mobilized for the implementation of robust adaptation strategies. This is typically the case in the field of risk management through prevention plans. Just as some countries also have social policies that have potential benefits. It is therefore important to fully utilize existing levers, before seeking innovation in response to "new" climate change problems – because if we consider the consequences of this problem, we realize that it is only partially new, in the sense that the impacts of climate change refer more broadly to an area of management and prevention of natural hazards. This refers to the state of mind previously mentioned "start doing well what we do badly", and therefore the idea that there currently exists diverse ways of circumventing (at least partially) uncertainty.

For example, the Mediterranean has developed under the framework of the Barcelona Convention (signed in 1976, revised in 1995) a strong international agreement that aims at protecting biodiversity, reducing pollution, sustainably managing coastal zones… In its various components, including the new Protocol on integrated coastal zone management (Billé and Rochette 2008), the Convention has a key role to play in adapting to climate change.

12.5 Conclusion

12.5.1 Adaptation for a Long Period of Time

The multitude of possible impacts of climate change makes this problem one of the greatest concerns for the future of the Mediterranean in the medium and long terms. The challenge is both to reduce GHG emissions, and to adapt to changes that are already ongoing and those to come in future, in order to reduce the vulnerability of societies that may be dramatically changed over the coming decades. Generally, this issue is seen as a matter of balance – and therefore, among others, as an issue of allocation of costs – between emissions reduction and adaptation. In the Mediterranean, the problem cannot really be viewed in these terms because while the region is substantially involved in international efforts to reduce GHG emissions, it remains in itself a relatively marginal emitter at the global scale,[9] and the impacts that it will endure are mostly related to emissions from all industrialized countries. This justifies that in terms of adaptation, Mediterranean countries must mobilize now and for a long period of time, because there are few uncertainties about the irreversibility of the changes already underway. The phenomenon of latency in climate processes plays an important role in the explanation of the fact that the GHGs that have been released into the atmosphere by human activities since the beginning of the industrial era will continue to have consequences on the functioning of the global system for the long term. A recent study very clearly shows, for example, that even if we stopped all GHG emissions by 2100, its concentration in the atmosphere would remain high at least until the year 3000 (Solomon et al. 2009). The irreversibility of the trend is also shown at shorter time scales (from decades to the whole of the current century) (IPCC 2007; Parry et al. 2008; Rahmstorf 2007).

We will therefore have to manage what is already unavoidable, while taking care not to consider climate change as the only driver of change. It is important to consider the impacts of the future climate on the future society, and not on today's society, even if this adds to the complexity. On the other hand, current society and current problems provide the context for adaptation, and these, along with the socio-economic histories, will inform the starting point for considering adaptation on a long time-frame. Long term cross-projections are necessary.

12.5.2 An Emerging Framework of Action

While the issue of adaptation may appear to be new, policy makers, planners and stakeholders are not deprived of solutions. Instruments exist, and experiments are

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[9] Although it is clear that even within the basin, all countries do not have equivalent emission levels.

ongoing which, although not always specifically targeted to the fight against climate change, can provide a serious contribution. Five points are listed here:

1. Adaptation requires success in areas where we have largely failed so far: control of urbanization, environmental protection, reduction of inequalities… In many cases, the current or short-term foreseeable situation is not sustainable, even without taking climate impacts into account. Climate change may also provide opportunities to solve existing problems. While few examples of these opportunities are currently available, the fact remains that any progress towards more sustainable paths of development will be an important initial step in adaptation. In other cases, however, particularly in agriculture, it seems impossible to manage the climate impacts without a radical change of the dominant agricultural development model – which implies that the leeway in this area is already significantly reduced;
2. Stakeholders, both public and private, must now improve their use of climate information, i.e. greater integration of such data in their policies, development plans, business plans… In many cases, information and knowledge, even imperfect, seems to provide a sufficient basis for action, but it is slow to permeate into the decision-making sphere;
3. Attention should logically focus initially on the orientations and measures that are "without cost or regret". Many of these can have positive impacts in terms of mitigation and adaptation while allowing a return on investment in the short term. However, synergies are limited and in some cases will be confronted with necessary decisions that require prioritization of the choice between emission reduction and adaptation;
4. The policies and adaptation measures should be considered at the intersection of climate scenarios and socioeconomic projections. They should not only be derived from climate and impact scenarios, but be based on the intersection between climate and non-climate conditions.

A real consideration of climate change constitutes an opportunity for the Mediterranean states to revisit their development strategies for the medium and long terms and to adopt sustainable paths of development.

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Chapter 13
Health

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Abstract This chapter presents a review and new scientific evidence on climate change health risks in the Mediterranean. It summarizes the results of the work of the research line on health in CIRCE, which focused on two examples of health risks related to climate change: 1. heat and air pollution and 2. infectious diseases. Responsible authors differ for the specific thematic sections: Sect. 13.2: Tanja Wolf, Bettina Menne; Sect. 13.3: Klea Katsouyanni, Antonis Analitis, Paola Michelozzi, Daniela D'Ippoliti; Sect. 13.4: Miguel Angel Rodriguez-Arias, Tanja Wolf, Xavier Rodo, Afif Ben Salah; Sadok Chlif; Sect. 13.5: Tanja Wolf, Elsa Casimiro, Bettina Menne.

Keywords Climate change • Health • Temperature • Heat • Air pollution

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13.1 Introduction

Human health in Mediterranean countries is at risk from climate change. The observations and scenarios compiled within the CIRCE project (RACCM, Parts I–IV) highlight that the climate in the Mediterranean is getting warmer, dryer and more extreme. This affects the environment, society, health determinants and well-being of Mediterranean people. This chapter documents for the first time the combined results of the effects of heat and air pollution in urban areas on mortality and the growing risks from climate sensitive infectious diseases. It further provides examples of capacity development in assessing the health impacts of climate change, research and adaptation. The key findings are:

13.1.1 Heat, Heat-Waves and Air Pollution

The percentage increase of mortality associated with 1° increase of apparent temperature ranged from 0.1 to 8.0% in seven Mediterranean cities with a high level of heterogeneity among cities. Temperate European cities showed higher increases of mortality compared to the warmest cities where the increase starts at higher temperatures. The effects of heat-wave days on mortality are very pronounced: the total natural daily number of deaths increased by 14%, cardiovascular deaths by 22% and respiratory deaths by 32% on heat wave days. The percentage increase of deaths with a 1°C increase of apparent temperature was 3% higher during days with high levels of PM10 pollution and 4% higher on days with high levels of ozone pollution.

13.1.2 Infectious Diseases

Thirty-three infectious diseases were identified as being climate sensitive and relevant in the Mediterranean. Besides already ongoing changing patterns in water- food- and air-borne (meningococcal) infections, the distribution of vector borne diseases is likely to change under changing temperature and precipitation regimes, ecosystem and socio-economic changes. Some areas might become too dry for further disease transmission. At the same time, there is an increasing risk of outbreaks of Chikungunya and Crimean-Congo Hemorrhagic Fever (CCHF), meanwhile Leishmaniasis, Lyme disease, Mediterranean spotted fever, Rift Valley Fever (RVF), Tick-borne encephalitis and West Nile Virus are further expected to change their range of distribution.

13.1.3 Capacity Building in Assessing Health Risks

A training package to assist the development of climate change and health assessments has been developed by WHO Regional Office for Europe.. The training package is targeted to national public health experts and scientists, either as standalone technical expertise or as a tool to develop health targeted adaptation action. The training methods have been applied to two countries within this project: Turkey and Malta. Future work could be targeted at estimating the national health damage and adaptation costs.

13.1.4 Health Adaptation Needs

The range of already observed health effects and future health risks is potentially wide. Sustainable adaptation as well as healthy mitigation measures are needed to protect health from climate change. To foster efficient and sustainable adaptation, some general development is required now, namely:

- Strengthen monitoring and disease surveillance;
- Strengthen public health systems in responding to climate change;
- Promote the development of a green economy and health co-benefits of mitigation and adaptation.

13.1.5 Research on Climate Change and Health

While research and evidence on climate change and health is increasing overall, in the Mediterranean and in particular in the countries on the southern shore of the Mediterranean Sea a lack of evidence still prevails. Additional research is required to model future developments and disease distribution, adaptation effectiveness, health economic damage, and specific threats such as water scarcity and its geopolitical security dimension for health. Health risks related to water availability and quality (see Part II), droughts, food and nutrition can trigger migration and conflict. The full scale of the health security risks need to be further understood. Additional efforts need to be put into data collection, surveillance, homogenized definitions and partnerships across disease networks.

13.2 Research on Climate Change and Health

> “Every century has its own public health challenges; climate change is our century’s challenge”, Dr Margaret Chan, Director-General, World Health Organization.

Climate change is affecting human health both directly and indirectly (Portier et al. 2010). Direct effects are a consequence of extreme weather events such as heat waves, cold spells, drought, fires, flooding and storms. Such events directly impact on health through injury, drowning, post disaster mental stress and excess mortality and morbidity. Indirect health effects occur via ecosystem changes (desertification, air pollution)

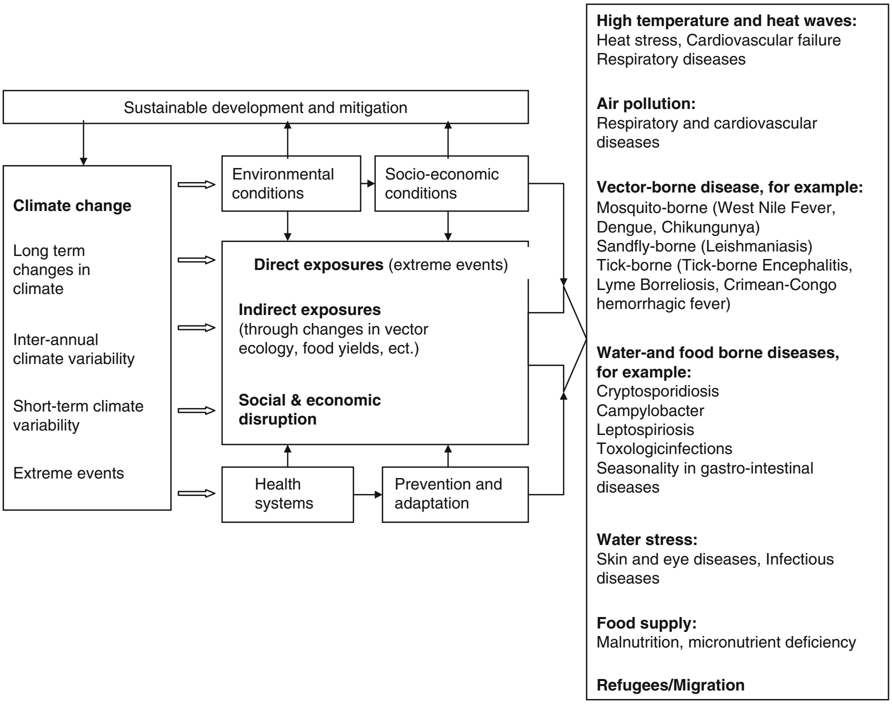

Fig. 13.1 Health effects of climate change

and include changes in seasonal and spatial patterns of infectious diseases. In particular food-borne diseases that increase in summer and diseases transmitted by ticks, mosquitoes or other vectors are projected to increase in a warmer climate, but this also applies to allergies and respiratory diseases (Confalonieri et al. 2007). Longer-term consequences of climate change may include adverse effects on food production and micronutrients in food, the availability of safe water and secure dwelling. In combination with other recent emerging processes of global environmental change (such as urbanization, stratospheric ozone depletion, biodiversity loss, land degradation, depletion of freshwater supplies) the stress on humans and the potential health effects of climate change are even worse (Confalonieri et al. 2007; McMichael et al. 2003). Figure 13.1 summarizes the possible health impacts of climate change as outlined in the health chapter of the IPCC Fourth Assessment Report.

Attributing the health effects observed in recent decades to anthropogenic climate change remains a challenge (Rosenzweig et al. 2008). The main goals of empirical studies on climate change and health are to determine the baseline climate-health relationship, detect emerging impacts and estimate current and future climate change related burden (Kovats et al. 2005). The research includes:

- the analysis of the health impacts of individual extreme events; spatial studies, where climate is an explanatory variable in the distribution of the disease or the disease vector;

- temporal studies, which assess the health effects of inter-annual climate variability, of short-term (daily, weekly) changes in temperature or rainfall, and of longer-term (decadal) changes in the context of detecting early effects of climate change and
- experimental laboratory and field studies of vector, pathogen, or plant (allergen) biology.

Based on such research, modeling studies can then use climate scenarios to project future health risks in a changing climate (Ebi and Gamble 2005).

Estimates of future climate-induced health effects over coming decades draw a concerning picture (Confalonieri et al. 2007). Heat-related mortality and morbidity are projected to increase. Even if milder winters have the potential to decrease cold-related mortality and morbidity locally (Donaldson et al. 2001), the direct and indirect effects of climate change are expected to have negative impacts on human health and well-being at the global scale in the future, in particular in the Mediterranean (Campbell-Lendrum et al. 2007; Paz et al. 2010; Schiermeier 2011). Quantitative estimates of the burden of disease caused by climate change have shown that many thousands of lives have already been lost. The modest change in climate that has occurred since the mid-1970s is estimated to have resulted in the loss of over 150,000 lives and 5,500,000 disability adjusted life years (DALYs) by the year 2000 and these numbers are projected to approximately double by 2020 (Campbell-Lendrum et al. 2003; Ezzati et al. 2002).

Generally, scientific literature on climate change and health has grown over the last decade. Searches with Endnote in PubMed with "climate change" and "health" as search terms ("any field") for specific years show that the literature on the health effects of climate change is increasing. Part of this can be explained by a general increase in publications thanks to digital media, easy access through online libraries and so on. Also the number of papers on "climate" per se has increased from 1,100 in 1980 to 6,600 in 2009. For comparison, the number of papers with the keyword "health" in any field increased steadily from 14,872 to 85,113 in 2009. In both cases, the increase during the past 30 years is sixfold. For the combination "climate change" and "health" however, the increase from 5 to 370 papers is much stronger and is especially pronounced since 2006 when the threshold of more than 100 papers on this subject was exceeded. In addition, a lot of scientific material on the association between climate factors and specific health outcomes can be found in more specific searches.

A fraction of this literature on climate change and health is specific to the Mediterranean region. In summer 2010 a literature search on health effects and health risks of climate change relevant to the Mediterranean region lead to merely 31 papers, most of these focusing on health risks from heat. Very recently, Habib et al. (2010) published a review on climate change and health research in the Eastern Mediterranean Region of WHO (EMR)[1] between 1990 and 2010. Sixty-four

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[1] The Eastern Mediterranean Region (EMR) of WHO comprises 22 countries: Afghanistan, Bahrain, Djibouti, Egypt, the Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Morocco, Oman, Pakistan, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, the Syrian Arab Republic, Tunisia, the United Arab Emirates (UAE) and Yemen.

publications were identified as qualifying for review, covering the categories extreme weather events, air quality, infectious diseases and malnutrition. The main findings for these countries are (Habib et al. 2010):

- Air quality related: pulmonary diseases in North Africa: dust storms are becoming more frequent due to climate change and desertification and pose a risk to human health.
- Air quality related: respiratory allergies in Lebanon (cross-sectional study of 1,613 students): students reported weather changes as a common trigger of allergies.
- Air quality related: respiratory allergies in Egypt (modeling, GIS): changes to environmental factors, such as water availability, changed malaria vector regions.
- Air quality related: respiratory allergies in Egypt (Retrospective study on anopholine vectors): hot temperatures positively influenced the population of anopholine vectors while wind speed and humidity had no effect.
- Infectious diseases, Schistosomiasis, Egypt (Modeling of snail population, GIS): modeling/GIS is an effective tool for predicting environmental risk for schistosomiasis in Egypt.
- Infectious diseases, Schistosomiasis, Egypt (Laboratory analysis): hot weather leads to increased release of shistosoma mansoni cercarie from infected snails.
- Infectious diseases, Leishmaniasis, EMR: some outbreaks of leishmaniasis in the EMR have been linked to heavy rains, while droughts have lead to population migrations that have changed the disease epidemiology.
- Infectious diseases, Cholera, Morocco (laboratory analysis): low temperatures promote survival of cholera virus in water.
- Blastocystosis, Libya (clinical study): prevalence of blastocystosis on patients may be related to hot and dry weather conditions (Habib et al. 2010).

The lack in scientific literature on the variety of health risks from climate change in the highly vulnerable Mediterranean region underlines the need to undertake work in this area. This applies especially to the countries that did not participate in research projects on climate change and public health like cCASHh, PHEWE, MICRODIS, EuroHEAT, EDEN, INTARESE, CEHAPIS, EUROMOMO.

13.3 Health Impact of Extreme Temperature and Air Pollution in Ten Mediterranean Cities

Every summer, high temperatures and heat waves are associated with large increases in mortality, especially among the most susceptible individuals living in urban areas. Large multi-city studies from Europe and the United States have documented a geographical heterogeneity in both the temperature threshold and the effect of high temperatures (Baccini et al. 2008; Hajat and Kosatky 2010; Zanobetti and Schwartz

2008). Thresholds at higher temperatures were found in the warmest cities, suggesting that these populations are probably better acclimatized to high temperatures (Baccini et al. 2008; Hajat and Kosatky 2010; Zanobetti and Schwartz 2008). The extent of heat-related effects depends on the size of the susceptible population, the intensity and duration of heat stress conditions and the adaptation measures in place at both individual and population level. The public health significance of heat-related effects on human health is expected to increase and some areas in the world, such as the Mediterranean, will be particularly at risk (IPCC 2007).

To date, the Mediterranean area has received little attention, and the effect of heat and heat-waves has been studied only in northern Mediterranean cities, such as Rome, Athens, Barcelona, Valencia, Seville, in one-city and multi-city studies (Baccini et al. 2008; Ballester et al. 1997; D'Ippoliti et al. 2010; Diaz et al. 2002; Kassomenos et al. 2007; Saez et al. 1995). These studies suggest a stronger effect of high temperatures on the elderly, in both cardiovascular and respiratory causes (+4.66 and +8.10%, respectively), while no overall significant effect was found in younger age groups, in those Mediterranean cities included (Athens, Rome, Barcelona, Valencia, Turin, Milan, and Ljubljana) (Baccini et al. 2011). Evidence from North Africa and the Middle-East is scarce, with only one time-series study in Greater Beirut, Lebanon (El-Zein et al. 2004). These areas are the most vulnerable due to the typically exceptionally hot conditions during summer (see below), but the unstable local political system and low economic development hamper the availability of routine data on health and meteorology.

Work package 9.2 of the CIRCE project was aimed at investigating the effect of high temperatures on mortality for all-causes, respiratory and cardiovascular causes, in nine cities in the Mediterranean region, including European cities (Rome, Palermo, Bari, Barcelona, Athens), and North-African and Middle-East cities (Istanbul, Tunis, Tel-Aviv), and one city outside the Mediterranean basin (Lisbon). The geographical location of the cities influences their climate. Also, cities differ in terms of their socio-demographic characteristics such as age structure and level of education, health care organization, level of economic development. A specific aim was to investigate the effect of high temperature for specific age groups (0–64 and 65+ years) and gender. Furthermore, this WP was aimed at assessing the possible confounding by air pollution and investigating the interaction between high temperatures/heat waves and air pollutants.

With respect to the previous multi-city PHEWE study (Michelozzi et al. 2007) that investigated the heat effect in European cities (Athens, Barcelona, Budapest, Dublin, Helsinki, Ljubljana, London, Milan, Paris, Prague, Rome, Stockholm, Turin, Valencia, and Zurich), the added value of the CIRCE project was to also include cities from North Africa and the Middle-East some of which had never been studied before and could be more vulnerable to high temperature and heat wave effects, because of more extreme weather conditions and lower availability of adaptation resources. Moreover the differing demographic and socio-economic of European cities may influence the impact of high temperature.

13.3.1 Data

The CIRCE database includes daily data on mortality, meteorological conditions and air pollution from 10 cities (Athens, Barcelona, Bari, Istanbul, Lisbon, Palermo, Rome, Tel Aviv, Tunis and Valencia). The series covered study periods within the years 1991–2007 and always included at least three consecutive years. For Athens, Barcelona, Rome, and Valencia the EuroHEAT database was used, Rome was updated, while for the new cities (Bari, Istanbul, Lisbon, Palermo, Tel-Aviv, and Tunis), data were obtained from public institutions by the researcher responsible for each city, following a standardized protocol. The Tel-Aviv and Istanbul data used for the analysis were those collected in the APHEA2 project. The Tel-Aviv data were obtained from public institution by the collaborating researcher (Chava Peretz, School of Public Health, Faculty of Medicine, Tel Aviv University, Israel). The Istanbul mortality data were collected by the collaborating researcher's team (Zeynep Dörtbudak, Assistant Professor, Epidemiology and Public Health, School of Health Sciences, Koç University, Istanbul, Turkey) from copies of death certificates kept in the five biggest burial grounds centers in Istanbul. For this reason and to avoid misclassification we only analyzed all causes mortality for all ages. Overall, the total population studied was about 18 million. The number of study years ranged from four in Istanbul to 15 in Rome. Mortality was computed as the daily number of deaths occurring in each city and was obtained from local mortality registries (except Istanbul, see above). In each city, daily deaths among the resident population from all natural causes (ICD-9: 1–799), cardiovascular diseases (ICD-9: 390–459) and respiratory causes (ICD-9: 460–519) were considered by gender and age groups: 0–64, 65+ years, and all ages.

Meteorological data (air temperature, dew point temperature, barometric pressure, wind speed and direction), were obtained from the airport weather station located closest to the city and 6-h values were considered to calculate daily mean max and min values. A great heterogeneity was observed in the quality of data among the different cities. The exposure variable was composed of the apparent temperature, a combination of air temperature (temp) and dew point (dew) according the formula: $AT = -2.653 + 0.994 * temp + 0.0153 * (dew)2$ hochgestellt/superscript/ in apice, considered as a measure of relative discomfort due to combined heat and high humidity. For all cities, the maximum diurnal value was considered as daily exposure (Tappmax), while for Istanbul, due to the lack of data, the mean of apparent temperature was calculated.

The air pollution dataset was obtained from the urban monitoring network of each city. Gaseous and particulate pollution indicators were included, and specifically: PM10 (mean 24-h), total suspended particles (TSP) or Black Smoke (mean 24-h), O_3 (maximum 1 h, maximum 8-h moving average), NO_2 (maximum 1 h, mean 24-h), SO_2 (mean 24-h) and CO (maximum 8-h moving average). In Tel-Aviv only 1-h maximum NO_2 and ozone values were available. In Istanbul only black smoke measurements were available and in Valencia the particulate pollution indicator was TSP.

It has to be noted that the available datasets were very heterogeneous in terms of study period, information available and data quality. For Tel-Aviv, Bari and Istanbul information on gender was not available. For Bari and Istanbul data for ages 0–14 years were not available. For Istanbul only a short and old study period was available (1992–1995). Despite the lack of registry-based recent data for Istanbul, the city was included in the analysis because of the large population size exposed during summer to high temperatures and the expected strong impact on population.

13.3.2 Methods

The impact of high temperature on mortality was investigated through a time series approach and a heat wave-episode analysis. In each model potential confounders of temperature were introduced as covariates: barometric pressure, wind speed, calendar month, day of the week, holiday, time trend and NO_2 at lag (0–1), as an indicator of the overall daily air pollution level for all the cities (Analitis et al. 2008; Baccini et al. 2008; Schwartz and Dockery 1992). For the investigation of interaction between temperature/heat-wave and pollutant effects, an interaction term between temperature/heat-wave and each available pollutant was introduced separately into the model and the effect of heat-wave days was estimated during "high" (75th percentile) and "low" (25th percentile) pollution days.

For the time series analyses, the study period was confined to the warm season (April–September). A GEE approach was applied to analyze longitudinal data on the basis of the PHEWE project methodology (Baccini et al. 2008). The relationship between maximum apparent temperature and mortality was graphically represented using generalized additive models (GAM) to describe the shape; while city-specific thresholds values (the value of Tappmax at which the mortality achieved its minimum), were identified using the segmented regression approach (Muggeo 2003). The effect of high temperatures was estimated as percentage change in mortality for a temperature change of 1°C in Tappmax above the city-specific threshold value. Distributed lag models were used to study the delayed effect of exposure and the harvesting effect. A Poisson distribution was assumed for the outcome variable (mortality). Observations from different years were assumed to be independent, while observations during a single year were correlated. A similar approach has already been suggested in other studies (Analitis et al. 2008; Baccini et al. 2008; Schwartz and Dockery 1992). Since the number of clusters (summers) was small, and equal to the number of years in the study period, we used the model-based estimator for the coefficients' standard errors, as recommended in the presence of few large clusters (Diggle et al. 1994). To account for serial correlation, a first order autoregressive structure within each year was added into the model based on similar analysis (Chiogna and Gaetan 2003, 2005).

To evaluate the impact of heat waves on mortality the EuroHEAT project definition for heat-waves was considered (Daniela D'Ippoliti et al. 2010). For heat wave analysis only the period June to August was considered. Specifically, a heat-wave is defined as periods of at least 2 days with Tappmax exceeding the 90th percentile of the monthly distribution or periods of at least 2 days in which Tmin exceeds the 90th percentile and Tappmax exceeds the median monthly value. The percent increase in mortality during heat-wave days versus non heat-wave days was estimated for each city. A dummy variable indicating a heat-wave day was the main exposure variable when heat-episodes were studied. Potential confounders introduced as covariates in the model, were the same as described above.

To assess the "joint" effects of meteorological and air pollution variables we investigated (1) potential synergistic effect between the various air pollutants for which data were available and high temperatures, either as continuous apparent temperature levels or as the presence/absence of heat-wave and (2) the confounding effects by the various air pollutants on the estimated temperature/heat-wave effects on health. For this purpose, the core models described before were used. A second-stage analysis was performed to provide a quantitative summary of all individual-city results using random effects meta-analysis (Berkey et al. 1995). For the investigation of interaction between temperature/heat-wave and pollutant effects, an interaction term between temperature/heat-wave and each pollutant separately was introduced in the model and the effect of heat-wave days was estimated during "high" (75th percentile) and "low" (25th percentile) pollution days. Other confounders entered in the model were the same with those described before respectively.

13.3.3 Results and Discussion

13.3.3.1 High Temperature and Mortality

Table 13.1 shows for each city the study period, the city characteristics, the daily number of deaths for age groups, and the meteorological conditions. Cities differ by population size from the largest Istanbul (around seven millions inhabitants) to the smallest Bari (around 300,000 inhabitants).

Temperature is very variable among cities. Mean summer temperatures range from 18°C in Tunis to 23.9°C in Athens, while maximum and minimum temperatures are highest in Athens and lowest in Palermo and Valencia. The exposure variable, Tappmax, has the highest mean value in Athens, Palermo and Tel Aviv, with maximum values over 46°C in Valencia, Tel-Aviv, Athens and Tunis. Important to note that Istanbul only reported on mean temperature and humidity values, so the exposure variable is mean apparent temperature, justifying the lower values reported. In addition, Istanbul and Tel-Aviv use time series of data which do not include summer 2003, which was a very hot summer for most cities.

Variability was also evident in the air pollutants concentrations. Table 13.2 shows the descriptive characteristics of the outcome variables by age group, maximum apparent temperature and NO_2 concentrations during heat-wave and non-heat-wave days. NO_2 daily mean levels ranged from 22.8 $\mu g/m^3$ in Tunis to 74.7 $\mu g/m^3$ in Rome.

Table 13.1 City characteristics, study period, meteorological and air pollution conditions and mortality data in the ten cities

			Meteorological and air pollution data					Mortality data (daily mean number of deaths)		
			Temperature (°C)			Tapp max (°C)[a]	NO2 conc. (µg/m³)	All causes by age-group		
City	Study period	Population	Mean	Min	Max	Mean	Mean	All ages	0–64	65+
Rome	1992–2006	2,547,677	20.7	16.0	25.4	26.2	74.7	53.1	9.4	43.3
Barcelona	1991–2004	1,512,971	19.5	16.9	22.8	23.5	39.2	36.5	5.4	31.1
Bari	1996–2004	316,532	21.0	16.7	24.9	26.1	–	6.5	1.1	5.4
Istanbul	1992–1995	7,195,773	18.9	–	–	25.6	–	68.4	10.7	35.2
Valencia	1994–2003	739,004	18.1	14.3	22.2	31.4	65.4	14.9	1.5	12.0
Lisbon	2000–2004	564,657	20.0	16.5	23.8	23.5	33.5	53.4	12.5	40.8
Palermo	2001–2005	670,820	19.7	12.3	25.9	27.0	48.4	13.9	2.4	11.4
Athens	1997–2004	3,188,305	23.9	20.0	28.4	28.6	61.5	74.2	12.9	61.3
Tunis	2005–2007	728,453	18.0	16.6	24.7	30.7	22.8	20.3	9.7	10.6
Tel-Aviv	1991–1996	378,900	24.3	16.4	24.3	31.7	94.2	24.7	4.2	20.4

[a] In Istanbul mean apparent temperature was used

Table 13.2 Average daily number of deaths by cause and age group, pollution concentrations and apparent temperature in days with and without heat waves

		Total mortality			CVD mortality			Respiratory mortality				
City	Heat wave days (y/n)	All ages	0–64 years	65+ years	All ages	0–64 year	65+ years	All ages	0-64 year	65+ years	N O$_2$ 24 h (μg/m^3)	Max App temp (°C)
Athens	53	95.1	15.2	79.9	48.6	5.0	43.5	7.5	0.9	6.7	71.1	40.1
	683	73.7	12.7	61.1	35.5	4.1	31.5	5.8	0.6	5.2	58.0	33.8
Barcelona	89	45.9	5.9	39.9	15.0	1.2	13.8	5.3	0.2	5.1	48.6	35.0
	1,107	35.7	6.0	29.6	12.2	1.1	11.2	3.0	0.2	2.8	35.1	27.2
Bari	60	7.5	1.4	6.1	–	–	–	–	–	–	–	36.3
	757	6.4	1.1	5.3	–	–	–	–	–	–	–	30.1
Istanbul	16	71.1	–	–	37.7	–	–	4.8	–	–	–	34.8
	343	59.6	–	–	32.0	–	–	4.1	–	–	–	29.6
Lisbon	38	66.1	12.4	53.7	28.1	2.6	25.5	4.8	0.2	4.6	47.8	32.7
	411	51.5	12.4	39.0	20.5	2.5	18.0	3.7	0.4	3.3	25.9	25.8
Palermo	35	16.8	2.7	14.2	2.3	0.2	2.1	0.5	0.0	0.5	51.3	36.9
	425	13.8	2.3	11.4	2.8	0.3	2.5	0.5	0.0	0.5	45.0	31.0
Rome	91	68.6	10.5	59.1	28.9	2.1	27.7	4.4	0.2	4.2	78.2	36.2
	1,195	51.3	9.4	42.0	20.0	1.9	18.1	2.6	0.2	2.4	74.0	30.1
Tel Aviv	21	24.5	4.6	19.9	10.0	0.9	9.1	0.8	0.0	0.8	83.0[a]	38.5
	347	24.2	4.1	20.1	9.6	0.9	8.8	1.1	0.1	1.0	74.8[a]	34.9
Tunis	21	23.3	10.3	12.9	–	–	–	–	–	–	22.1	42.7
	255	19.9	9.4	10.2	–	–	–	–	–	–	21.2	33.9
Valencia	56	16.1	2.6	13.4	5.9	0.6	5.3	1.9	0.1	1.8	56.5	40.6
	864	14.6	2.9	11.7	5.0	0.6	4.4	1.4	0.1	1.2	61.2	35.5

[a] 1-h max values available

The highest ozone concentrations (maximum 8-h moving average) were 87.4 μg/m^3 in Palermo with Rome and Athens being very close (85.9 and 83.5 μg/m^3 respectively) while lowest were 45.2 μg/m^3 in Tel-Aviv. Daily PM10 concentrations were highest in Tunis (82.6 μg/m^3) and lowest in Palermo (35.0 μg/m^3).

Differences among cities in daily mean number of deaths reflect the differences in population size and in the age structure, ranging from 6.5 daily deaths in Bari (316,532 inhabitants) to 74.2 daily deaths in Athens (3,188,305 inhabitants).

Figure 13.2 shows the city specific exposure-response curves of the relationship between Tappmax and daily mortality. The curves showed a J-shaped relationship in most cities, with a significant impact of high temperatures on mortality above the city-specific thresholds. The highest increase above the threshold was observed in the more temperate European cities (Athens, Barcelona, Bari, Lisbon, and Rome) whereas in the warmest cities (Tel-Aviv, Tunis and Valencia) the relationship was weaker. The lower effect observed in the very hot cities was also observed in a study conducted on Italian cities for the identification of threshold levels for heat warning systems. In a selection of southern Italian cities, in particular Sicily the local populations showed a lower susceptible due probably to a higher adaptation to extreme conditions during heat waves (Michelozzi et al. 2010). In Istanbul, no effect of high Tappmax on mortality was observed and this might be partially explained by the short time series data and referred to part of the population and some time ago, when several conditions (weather, demography) were different.

Figure 13.3 shows the effect above the city specific threshold on mortality in all ages and by age groups (0–64 and 65+ years). The Tappmax threshold values ranged from 26.0°C in Barcelona to 33.6°C in Tunis. The greatest thresholds were in the warmest cities, reflecting the adaptation of local populations that are usually exposed to more stressful weather conditions. In all of the age groups considered there was a significant Tappmax effect in most cities, except Palermo and Valencia where no effect was observed in the 0–64 age group. As expected, results showed the greatest impact in the 65+ age group in most cities, whereas in Bari and Tel-Aviv a higher effect was observed among younger age groups (respectively, +8.7% and +4.2%). These results have no straightforward explanation. Some population characteristics, such as socio-demographic factors and the health care system, might partially explain these results and will be taken into account in a further analysis. In Istanbul no effect was found in any of the age groups considered.

Figure 13.4 shows the Tappmax effect by age groups and gender. Mortality data for gender were not available for Bari, Istanbul and Tel-Aviv so they were not included in the analysis. In all cities a greater effect was found among females than in males both in the all ages and 65+ age groups, except in Tunis in the elderly. This differences between genders could be at least in part explained by the different age structure in males and females in the elderly, since this analysis was not adjusted for age. In the 0–64 age group, a difference between gender was found only in Lisbon where the effect was greater in males than females (+2.87%, 95% IC 0.03–5.79 versus +1.94%, 95% IC −1.88–5.91), while in Athens and Tunis the impact was present only in females.

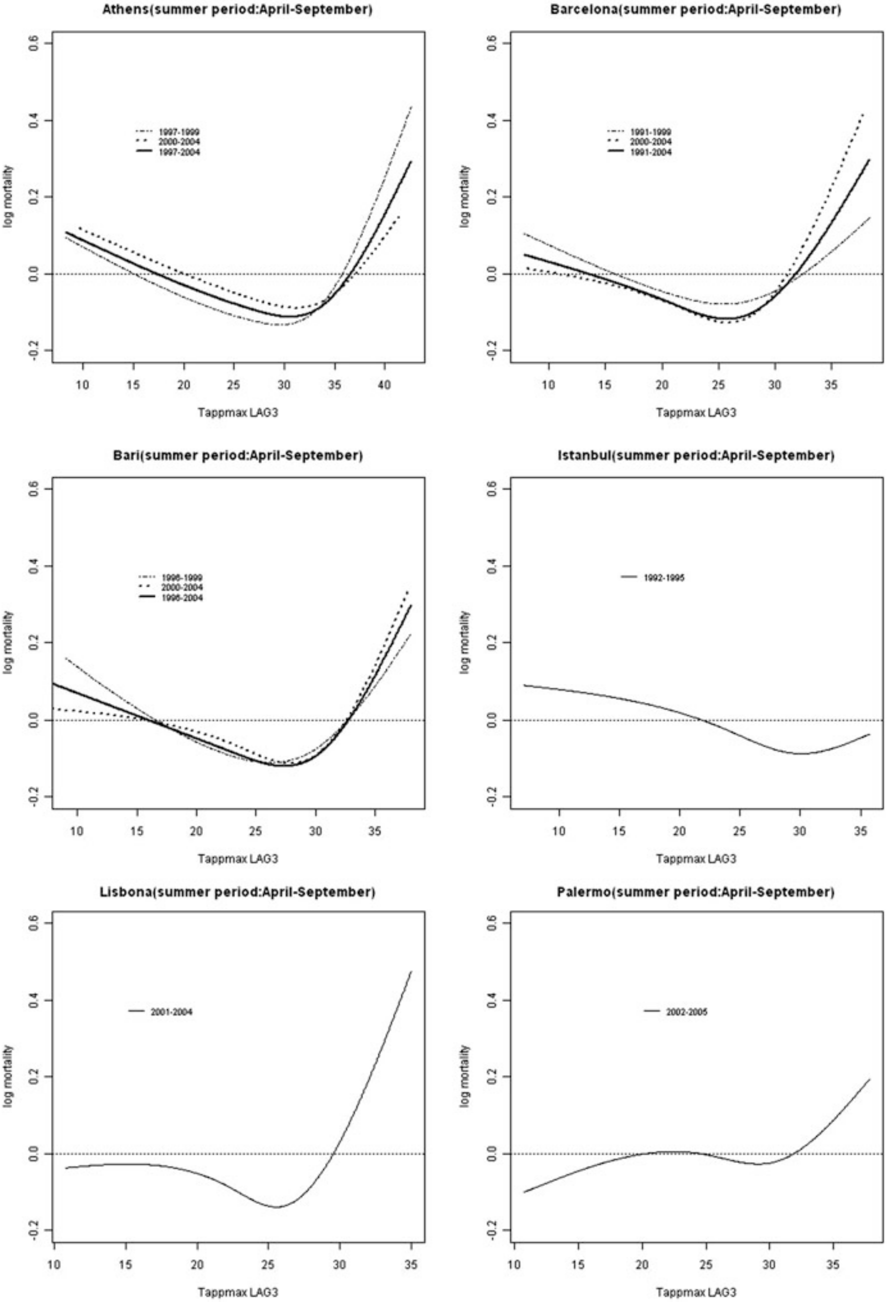

Fig. 13.2 Relationship between daily maximum apparent temperature (lag 0–3) and mortality in ten Mediterranean cities: Athens, Barcelona, Bari, Istanbul, Lisbon, Palermo, Rome, Tel Aviv, Tunis and Valencia

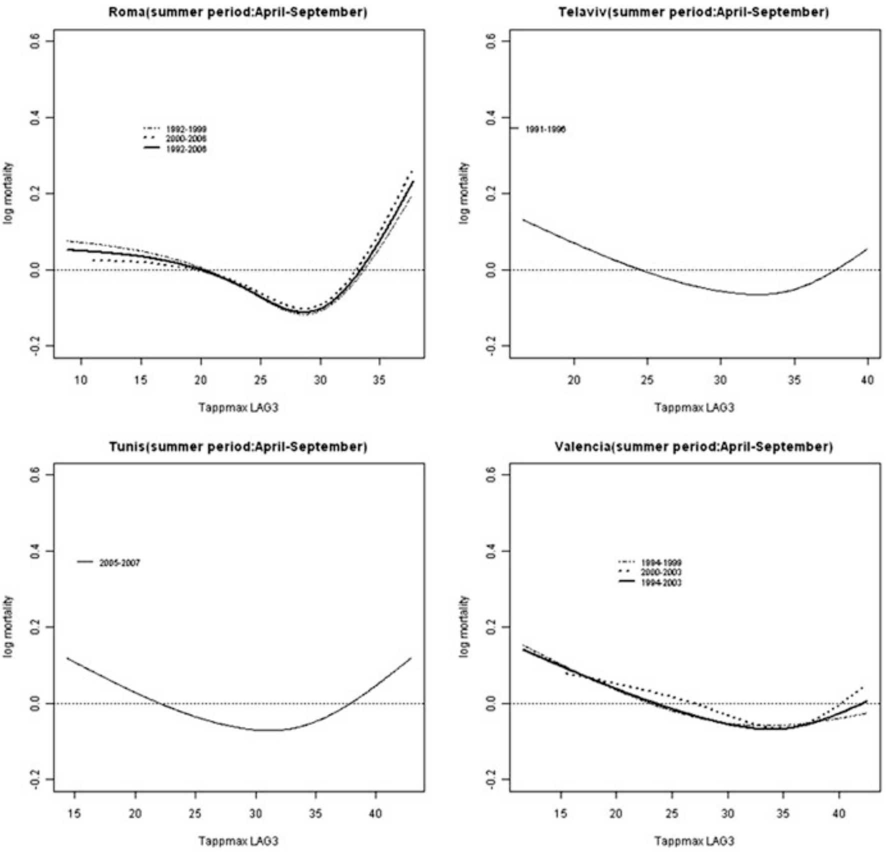

Fig. 13.2 (continued)

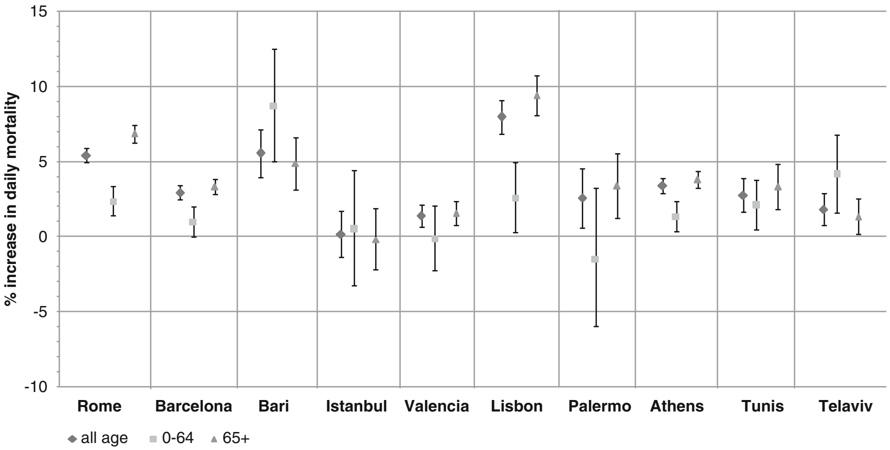

Fig. 13.3 Effect of maximum apparent temperature (Tappmax) on daily mortality during April–September in the ten cities

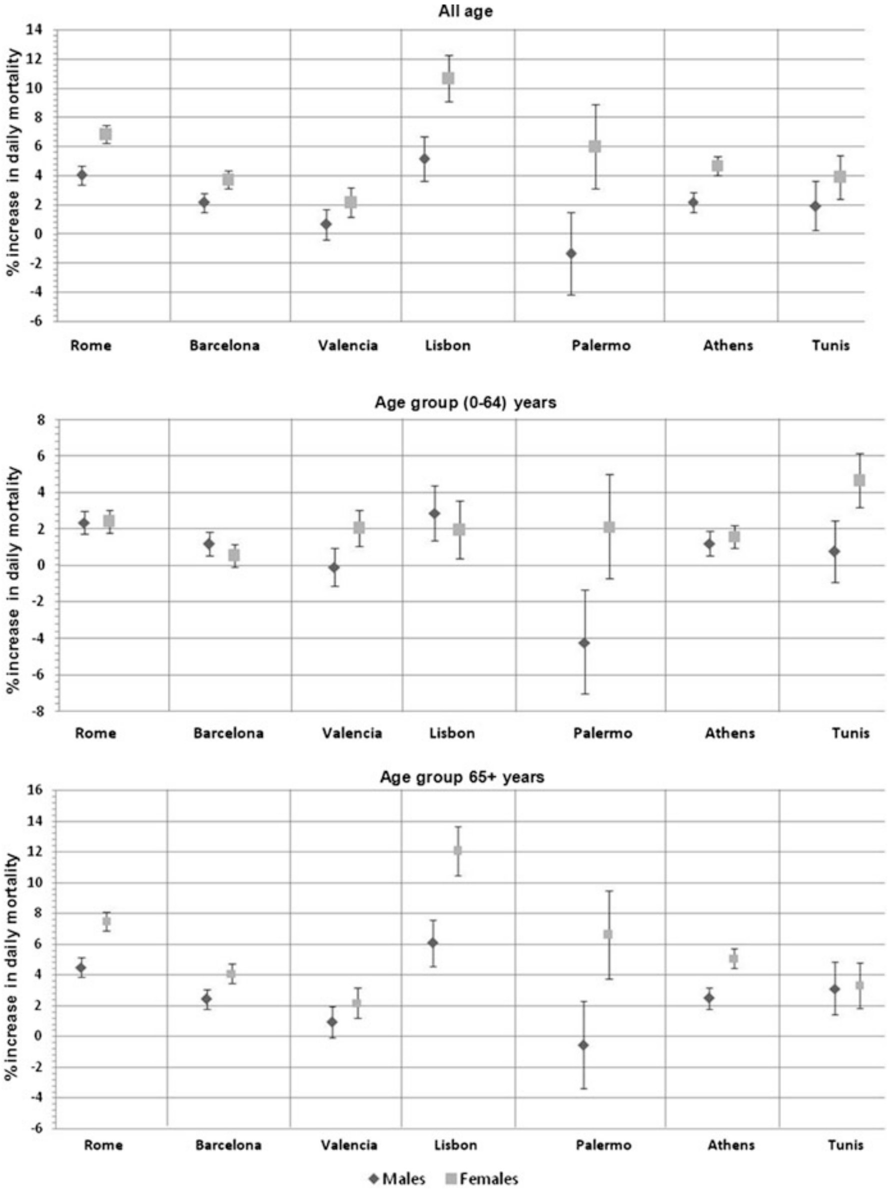

Fig. 13.4 Effect of maximum apparent temperature (Tappmax) on daily mortality by gender during April–September in seven cities. For Bari, Istanbul and Tel-Aviv data for gender were not available

13.3.3.2 Heat Wave Episodes and Mortality

The overall effects of heat-waves for all cities combined are presented as percentage increase in the daily number of deaths during days with heat-waves versus non-

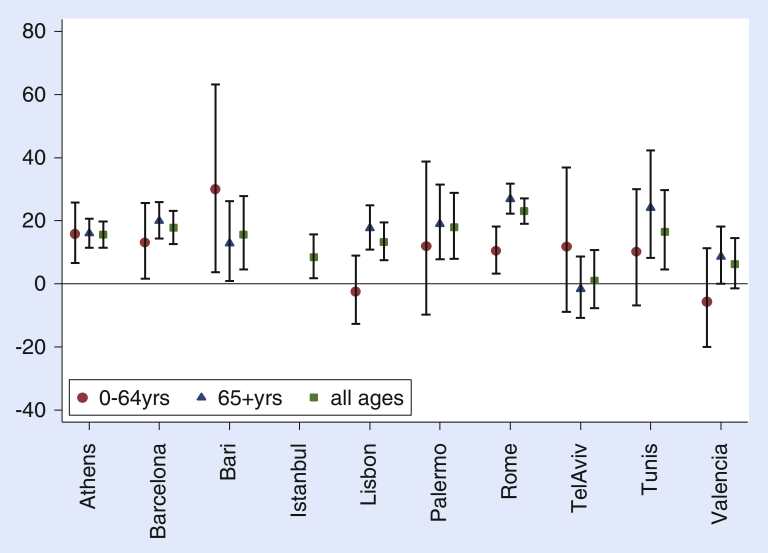

Fig. 13.5 Percent increase in the daily number of total natural deaths by age group in days with heat-waves in each participating city

heat-wave days. Mortality was greatly increased during heat-wave days by 14% (95%CI: 10–18%), 22% (95%CI: 15–29%), and 32% (95%CI: 15–50%) for total, cardiovascular and respiratory causes, respectively. The increase was more pronounced in the elderly especially for respiratory causes. This pattern is evident in almost all cities, as shown in Fig. 13.5. Thus for total mortality in the elderly (65+ years old) the increased effect was statistically significant in all cities except Tel Aviv, in which no effect was observed. For the 0–64 age group the effect was significant in Athens, Barcelona, Bari, Rome. A greater heat-wave effect on the elderly and on respiratory mortality confirms previous results. Some of the differences between cities could be explained by different meteorological conditions, air pollution levels and socio-demographic conditions.

13.3.3.3 Joint Effects of High Temperatures and Air Pollution

In this section (1) the synergistic effect between maximum apparent temperature and air pollution and (2) the confounding effects by the various pollutants are presented. Results are displayed as percentage change in the daily number of deaths per 1°C increase in apparent temperature above the turning point in “low” (at 25th percentile of each pollutants concentration distribution) and “high” (at 75th percentile of each pollutants concentration distribution) pollution days.

The increase in the total number of deaths associated with an increase of 1°C in maximum apparent temperature during days with “low” PM_{10} is 2.3%, whilst it is 2.9% (Table 13.3) during days with “high” PM10 levels. The difference is statistically

Table 13.3 Percent increase in the total daily number of deaths associated with a 1°C increase above the turning point in max apparent temperature and a "low" or "high" level of PM_{10} (random effects pooled estimates)

Age group	Low[a] PM_{10} % increase (95% CI)	High[b] PM_{10} % increase (95% CI)	p-value[c]
All ages	2.26 (1.17, 3.37)	2.86 (1.81, 3.93)	0.053
0–64 years	1.14 (0.23, 2.05)	1.74 (0.97, 2.51)	0.176
65+ years	2.37 (1.15, 3.60)	3.02 (1.71, 4.35)	0.049

[a] At the 25th percentile of the distribution of PM10
[b] At the 75th percentile of the distribution of PM10
[c] p-value for the interaction term

Table 13.4 Percent increase in the total daily number of deaths associated with a 1°C increase above the turning point in max apparent temperature and a "low" or "high" level of ozone (random effects pooled estimates)

Age group	Low[a] O_3 % increase (95% CI)	High[b] O_3 % increase (95% CI)	p-value [c]
All ages	3.19 (2.20, 4.18)	3.53 (2.38, 4.69)	0.077
0–64 years	1.54 (0.87, 2.23)	1.51 (0.87, 2.15)	0.612
65+ years	3.56 (2.36, 4.78)	4.03 (2.65, 5.43)	0.041

[a] At the 25th percentile of the distribution of O_3
[b] At the 75th percentile of the distribution of O_3
[c] p-value for the interaction term

significant (pooled interaction term p-value = 0.05) and can be seen in both age groups (although for the younger age group it is not statistically significant possibly due to the smaller counts). The same pattern is observed for the cardiovascular number of deaths (data not shown) and here the differences in effects between "low" (1.8% increase) and "high" (2.8% increase) pollution days are more statistically significant (pooled interaction term p-value < 0.01). The effects of higher apparent temperature on respiratory mortality (data not shown) are also larger during "high" PM_{10} days but the differences from "low" PM_{10} days do not reach the statistical significance (4.7% vs. 4.1% increase respectively). The synergistic effects were not entirely consistent between cities. In five cities the effects on mortality are higher during high PM_{10} days but in four of the cities (Athens, Tel Aviv, Tunis and Valencia) the difference is either null or slightly in the opposite direction (data not shown).

On "high" ozone days a 1°C increase in maximum apparent temperature is associated with a 4.0% increase in the total daily number of deaths among the elderly, whilst on "low" ozone days a 3.6% increase is estimated (pooled interaction term p-value = 0.04) (Table 13.4). No synergistic effects exist between high ozone concentrations and higher apparent temperature on either CVD or respiratory deaths (data not shown). The pattern is not entirely consistent and there is no difference in the effects of apparent temperature between high and low pollution days in Barcelona, Tel Aviv and Tunis. Although the temperature effect is larger during "high" NO_2 days the difference of the effect between "high" and "low" NO_2 days does not reach the nominal level of statistical significance. In every city the effect of apparent temperature is higher during high NO_2 days except in Athens.

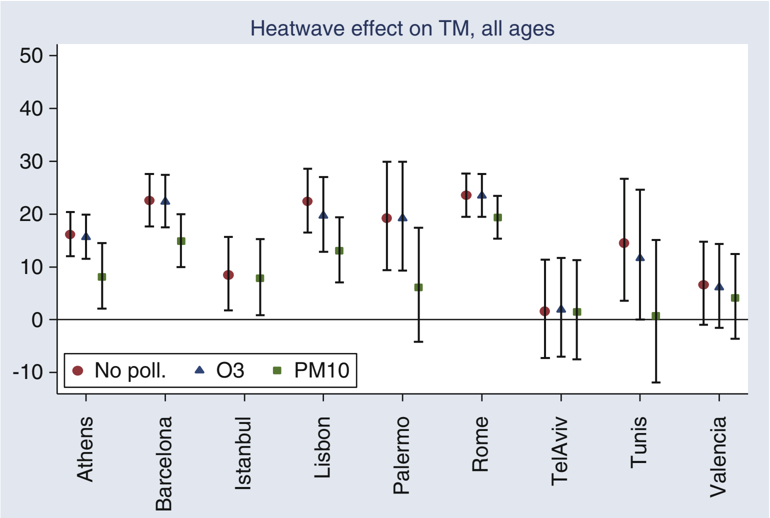

Fig. 13.6 Percent increase in the total daily number of deaths in days with heat-waves, without adjusting and with adjustment for various pollutants in each participating city

In contrast to the above results on the synergy between apparent temperature and PM_{10}, there are no observed synergistic effects between heat-wave days and PM_{10} on the total daily number of deaths. Larger effects of heat-wave on days with "high" PM_{10} especially in the elderly, are observed for CVD deaths but this difference does not reach statistical significance. A similar pattern is observed with respiratory mortality. The effect of heat-waves is larger by about 9% on high PM_{10} days in the elderly but this difference of the heat-wave effect between "high" and "low" PM_{10} days is not statistically significant.

Concerning confounding, there is substantial confounding by PM_{10} levels resulting to a 5.7% and 6.2% lower effect of heat-waves on total mortality, all ages and the elderly respectively, when we adjust for PM_{10}. No confounding is evident by ozone and NO_2 levels. We observe similar findings in CVD (reduction of 7.3% in all ages and 7.6% in the elderly when we adjust for PM_{10} levels) and respiratory mortality (reduction of 7.9% in all ages and 9.6% in the elderly when we adjust for PM_{10} levels). In Fig. 13.6 city-specific results for total mortality are presented. The pattern described is evident in all cities except Istanbul, in which adjusting PM makes no difference, and Tel Aviv in which no heat-wave effect was observed. Thus if PM_{10} is not adjusted for, the apparent temperature and especially the heat-wave effect on mortality is overestimated.

These findings are in accordance with those reported by the EuroHEAT project. Although both projects shared data from some cities (Athens, Barcelona, Rome and Valencia), in the EuroHEAT project, the rest of the cities were located in the north and central Europe so characteristics related both with outcome and exposure patterns differ. There are also several studies reporting synergistic effects of high temperature and air pollution, mostly particles and ozone, in the literature

(Katsouyanni et al. 1993; Ren and Tong 2006; Ren et al. 2006; Roberts 2004). Concerning confounding, in the literature there is some evidence that confounding does indeed occur, and the effect sizes of heat are shown to become smaller when adjusted for pollutants (Pattenden 2003). In most cases though, there is a significant independent effect of both heat and air pollution which remains after mutual adjustment for confounding (Le Tertre et al. 2006; Rainham and Smoyer-Tomic 2003). In summary, the following points can be concluded from the research:

- A synergistic effect of higher PM_{10} concentrations and higher temperatures was found, which was more pronounced for the elderly and for cardiovascular causes. This finding is not entirely consistent in all cities but further exploration of heterogeneity was not possible.
- For ozone levels, a synergistic effect with temperature was evident only for total mortality, among the elderly.
- No synergistic effect was observed between NO_2 and temperature.
- Although the heat-wave effects were larger during days with higher PM_{10} concentrations, this interaction did not reach the nominal level of statistical significance.
- It is shown that if PM_{10} is not adjusted for, the apparent temperature and especially the heat-wave effect on mortality is overestimated.

13.4 Climate Sensitive Infectious Diseases

Infectious diseases are still one of the heaviest burdens for public health, both in terms of lives lost and in loss of health and quality of life (Lopez et al. 2006). Climate, as one of the main modulators of the environment, influences several aspects of epidemiological dynamics and the interaction between bacteria, viruses, parasites, vectors and humans. Therefore there is concern about the emergence or re-emergence of some infectious diseases as a consequence of a changing environment. This section gives a general overview on the linkages between climate and infectious diseases, provides a list of climate sensitive infectious diseases and summarizes the current research on climate sensitive infectious diseases.

Climate can influence infectious diseases by three principal pathways: though human behavior, the disease pathogen and the disease vector. At different temporal scales (seasonal, inter-annual, longer-term climate trends) factors like temperature, rainfall, parasitic life cycle and vector activity, population movement, water availability after storms and floods can drive outbreaks of different climate sensitive infectious diseases (Confalonieri et al. 2007). According to the type of transmission, infectious diseases can be divided into water- and food-borne, vector-borne diseases and those transmitted from humans to humans.

Occurrence of water-borne diseases is related to the quality of drinking water and recreational water. Water quality is sensitive to changes in runoff, seasonality and frequency of extreme events (heavy rains, floods, droughts) (Confalonieri et al. 2007).

Food-borne diseases are sensitive to temperature as food-borne pathogens growth and survive more in higher temperatures. In the case of mistakes in food handling, prolonged warm seasons may increase cases of food poisoning (D'Souza et al. 2004; Fleury et al. 2006; Kovats et al. 2004; Semenza and Menne 2009). Bacterial enteric infections, however, have recently decreased throughout Europe through health-behavior interventions and food-safety regulations (Tirado et al. 2010). On the other hand, shellfish poisoning may increase as a result of more frequent harmful algal blooms in warmer seas due to global warming (Hunter 2003; Korenberg 2004; McLaughlin et al. 2005).

Vector-borne diseases are infections transmitted by the bite of infected arthropod species, such as mosquitoes, ticks and sandflies. Most vector-borne diseases have several species of birds or mammals acting as an intermediate hosts (Confalonieri et al. 2007). Arthropod vectors are cold-blooded and thus especially sensitive to environmental factors. Climate influences the survival and reproductive rates, the habitat suitability, the distribution and the abundance of each vector species; as well as the intensity and temporal pattern of activity (e.g. biting rates) (Rogers et al. 2006).

The challenge for scientific work on climate sensitive infectious disease is the general lack of reporting of these diseases and availability of data. Numbers of cases and incidences are crucial for researching the links with climate change as the evidences are based on empirical studies of:

- the anomalous incidence of infectious diseases as a consequence of individual extreme climate events (floods, severe storms, droughts),
- the temporal variability of a disease using climate time-series from the short-term disease variations (daily-weekly) to the decadal trends resulting from climate drifts, and including the influence of climatology on the seasonal dynamics of diseases and the development of incidence peaks and epidemics outburst as a response to inter-annual climate forcing such as the ENSO (El Niño – Southern Oscillation),
- laboratory experiments or field studies to understand vector and pathogen controlling factors, and
- the characterization of the spatial distribution and spatial variability of the disease or the disease vector using climate variables as explanatory factor. Spatial modeling approaches can help to overcome the lack of numbers of cases of climate sensitive diseases to some extent and the majority of studies use this approach.

Within CIRCE, climate sensitive infectious diseases of specific relevance for the Mediterranean Region were identified through an extensive and objective literature review (review of reviews and database mining) in 2007 (Rodríguez-Arias et al. 2008). Out of several climate-sensitive infectious diseases those most relevant to the Mediterranean region in terms of incidence, severity and – in case not yet being present in the area – risk of arrival were identified (Table 13.5). Most of these diseases relevant for the Mediterranean were also considered in a review of climate sensitive infectious diseases in Europe (Semenza and Menne 2009). In addition, in autumn 2010 a literature search on the diseases identified as climate-sensitive

Table 13.5 Climate-sensitive infectious diseases in the Mediterranean

Disease	Already present in Mediterranean?	Number of papers published 2007–2010
Food-and water borne		
Amebiasis	Yes	4
Campylobacter enteritis	Yes	12
Cholera	No, potential risk	9
Cryptosporidiosis	Yes	22
Diphyllobothriasis	Yes	2
Escheria coli infectious	Yes	10
Foodborne Vibrio paraphaemolyticus	?, Potential risk	25
Giardiasis	Yes	17
Legionnaires disease	Yes	17
Leptospirosis	Yes	21
Rotaviral enteritis	Yes	7
Salmonella infections	Yes	24
Schistosomiasis	Yes	3
Shigellosis	Yes	6
Strongyloidiasis	Yes	1
Typhoid and paratyphoid fevers	Yes	7
Air/human to human transmission		
Meningococcal infection	Yes	24
Vector borne		
Typhus fever (lice)	Yes	12
Chikungunya virus disease (mosquitoes)	Yes	25
Dengue and dengue hemorrhagic fever (mosquitoes)	?, Potential risk	14
Malaria (mosquitoes)	Yes	13
Rift Valley fever (mosquitoes)	Yes	6
West Nile virus infection (mosquitoes)	Yes	40
Plague (rodents/fleas)	?, Potential risk	4
Leishmaniasis (sand flies)	Yes	31
Sandfly fever (sand flies)	Yes	15
Crimean Congo hemorrhagic fever (ticks)	Yes	24
Lyme disease (ticks)	Yes	34
Spotted fever (tick-borne rickettsiosis) (ticks)	Yes	21
Tick borne relapsing fever (ticks)	Yes	2
Tick-borne viral encephalitis (ticks)	Yes	13
Tularemia (ticks and deer flies)	Yes	4
Filariasis (flies, mosquitoes or crustaceans)	Yes	4

Source: Rodríguez-Arias et al. (2008)

limited to the years 2007–2010 and the countries of the Mediterranean Region provided an update on the knowledge on these diseases. The following focuses on these recent papers.

The number of papers on climate sensitive infectious diseases in the Mediterranean countries from 2007 to November 2010 amounts to 474 papers, 43 of these are specific to "Climate and Disease, Disease Emergence or Re-Emergence and Other Factors Affecting Disease Dynamics Relevant to Assess Future Risks". All studies except one in Tunisia (Ben-Ahmed et al. 2010) and two in Israel (Orshan et al. 2010; Paz and Albersheim 2008) have been performed in the Northern Mediterranean Basin, especially in France, Italy, Spain and Turkey.

All studies except one focus on vector-borne diseases and most studies are climate-environmental correlation-studies with disease incidence or vector abundance that are just valid on a local/regional scale. Some others are investigations of vector population dynamics on a regional scale and have the potential to be extended to the rest of the Mediterranean. With regard to spatial distribution studies, the use of Geographical Information Systems to monitor and forecast the distribution of infectious diseases and to detect environmental niches has advanced in the past years. Using geographical information systems and remote sensing, land cover and vegetation indexes can be mapped over large areas at high resolution.

In several countries however, climate is no longer considered to be the main driver of disease spread. Instead, factors such as habitat fragmentation and other environmental or social factors are associated with the disease spread and incidence rate (Allan et al. 2003; Estrada-Pena et al. 2010). In fact, several authors recommended caution in the interpretation of such modeling results, despite some of these methods combining geographical information, remote sensing data and spatially-explicit population dynamics, have a strong potential to be used for risk assessment in future climate scenarios (Altobelli et al. 2008). Of special interest is the multi-agent disease transmission model developed by Linard et al. (2009a, b) that takes into account ecological factors, spatial heterogeneity, and managerial aspects. The model has been used to analyze the risk of malaria re-emergence in the French Camargue (Linard et al. 2009a, b), but it could have the potential to be used in other regions, for other diseases, and under climate-change scenarios.

A substantial part of the scientific literature on climate sensitive infectious diseases is result of an Integrated Project of the European Commission. EDEN (Emerging Diseases in a changing European eNvironment) evaluated how climate change is affecting Europe's ecosystems, particularly with regard to the spread of vector-borne diseases. EDEN concluded that climate change alone cannot be held entirely responsible for the rise in or emergence of vector-borne diseases in Europe. In the Baltics for example, socioeconomic factors such as poverty and human behavior (going to the forest to pick mushrooms, blueberries, wild berries) had a far greater impact on the risk of diseases such as tick-borne encephalitis (Sumilo et al. 2007). At the same time, studies in the EDEN project revealed that some mosquitoes (Culex spp.) can allow overwintering of the West Nile virus (WNV), which has been established in a number of European countries like Spain and Romania. This means that the virus does not have to be introduced from Africa by migratory birds in order for WNV outbreaks to emerge. This calls for better surveillance of WNV strains in both Europe and Africa, for preventing extensive WNV epidemics (Durand et al. 2010). Table 13.6 summarizes the major findings of the papers on climate sensitive infectious diseases in the Mediterranean. These findings urge for further research.

Table 13.6 Summary of findings of literature on climate-sensitive vector borne diseases in the Mediterranean (2007–2010)

Disease	Geographical area	Relevant publications for climate risk assessment	Type of study	Scalability of results
Chikungunya	Countries with stable A. Albopictus populations	Arboviruses potential agents of outbreaks in temperate countries (Charrel et al. 2008)	Meta-analysis/opinion	Mediterranean basin (and other temperate zones)
	Northern Italy	Seasonal emergence and end of adult vector activity influenced by minimum temperature, abundance of vectors affected by temperatures of the previous 3–4 weeks and vector activity by mean weekly temperatures (Roiz et al. 2010)	Vector population dynamics	Regional but potentially larger
Crimean-Congo Haemorrhagic Fever (CCHF)	Turkey	Use of vegetation indexes as an early-warning system (Estrada-Pena et al. 2007a). Higher risk in zones of high climate suitability for ticks and a high rate of landscape fragmentation (Estrada-Pena et al. 2007a). The connection between landscape patches correlates with CCHF incidence (Estrada-Pena et al. 2010)	Landscape and ecological analysis	Regional but potentially larger
		Turkey is the origin of the recent emergence of CCHFV in the Balkans (Mild et al. 2010)	Genetic analysis	Mediterranean basin
Leishmaniasis	Tunisia	Larger incidence in zones with high temperature, low rainfall and high vegetation index (Ben-Ahmed et al. 2010)	Climate-environmental analysis	Regional but potentially larger
	Israel	Sand fly seasonality affected by night time temperatures and not affected by high summer temperatures (Orshan et al. 2010)	Vector population dynamics	Local
Lyme disease	North-eastern Italy	Good method for climate risk assessment under future climate scenarios (Altobelli et al. 2008)	Modeling, remote sensing and GIS	Regional results but global method
	Slovenia	Risk of infection correlated with type of ecosystem type and season (Cinco et al. 2008)	Landscape and ecological analysis	Regional
	Serbia	Seasonal patterns and climate drive interannual variations in tick abundance (Milutinovic et al. 2008)	Vector population dynamics	Regional

Malaria	Southern France	Low risk of malaria reemergence (Linard et al. 2009a). Multi-agent disease transmission model that takes also into account ecological factors and spatial heterogeneity and can be adapted to different vector-borne diseases nd regions (Linard et al. 2009b)	Spatial modeling of disease dynamics	Local result but global method
		Mosquito population dynamics of different species varies with respect to biological and climatic factors as well as local water management, mosquito control and landscape use (Poncon et al. 2007)	Vector population dynamics and modeling	Regional but potentially larger
Mediterranean spotted fever	France	The increase of temperature will lead to a larger period of vector activity and more proclivity to bite humans (Parola et al. 2008)	Vector population dynamics	Regional but potentially larger
	Sardinia (Italy)	Temperature from previous summer leads a larger MSF incidence (Vescio et al. 2008)	Climate analysis	Regional
Rift Valley Fever (RVF)	Mediterranean Basin	Presence of potential vectors of RVF in all the Mediterranean basin (Moutailler et al. 2008)	Vector distribution	Mediterranean basin
Tick-borne diseases	Central France	Ticks and bacteria interactions are affected by the ecological setting (Halos et al. 2010)	Environmental analysis	Regional
	Slovenia	Decrease of questing ticks in summer as a result of air temperatures and humidity (Knap et al. 2009)	Climate analysis	Regional
	Northern Italy	Incidence of TBE in human cases correlated with tick infestation on deer and with autumnal cooling rate (Carpi et al. 2008)	Climate-environmental analysis	Regional
	Italy	TBE incidence unrelated to climate, but highly dependent on habitat suitability for reservoir hosts (small mammals), as well as on land and wildlife management practices (Rizzoli et al. 2009)	Climate-environmental analysis	Regional
	Eastern Europe	Upsurge of TBE in central and eastern Europe related to abrupt temperature changes but also to poverty indicators. Sudden spikes in incidence appear to be due to exceptional weather conditions affecting people's behavior, which have a differential impact depending on socio-economic factors (Randolph 2010)	Climate-environmental and societal analysis	Regional but potentially larger

(continued)

Table 13.6 (continued)

Disease	Geographical area	Relevant publications for climate risk assessment	Type of study	Scalability of results
West Nile Virus	Western Africa, Southern Europe and the Mediterranean Basin	Overwintering is not needed to explain the presence of WNV during the activity period as a result of continuous reintroductions by migratory wild birds (Durand et al. 2010)	Vector distribution and behavior	Mediterranean basin (and other temperate zones)
	Israel	Positive temperature anomalies related to the mosquito abundance. Additionally, extreme heat in the early spring leads to an increase on the vector population and on the disease incidence some weeks later (Paz and Albersheim 2008)	Climate analysis	Regional
	France (Camargue)	Mosquito population dynamics of different species varies with respect to biological and climatic factors as well as local water management, mosquito control and landscape use (Poncon et al. 2007)	Vector population dynamicsand modeling	Regional but potentially larger

13.5 Capacity Building in Assessing Health Risks of Climate Change

Assessments of climate change and health risks help to set priorities for adaptation and financing. Although several Mediterranean countries highlighted the importance of health impacts in their national communications to the UNFCCC (Table 13.7), only few have already undertaken comprehensive health impact assessments or have developed national health adaptation strategies. To address the lack of health impact assessments and to build capacity, WHO Regional Office for Europe and CIRCE partners developed a training package on climate change and health related mitigation and adaptation strategies. The package provides training for assessing health risks of climate change and enables national public health experts to co-ordinate the development of a climate change and health strategy, emphasizing the health sector role in adaptation and mitigation. A pilot training was carried out in Athens in June 2008. Among others, 12 participants from Ministries of Health of Mediterranean countries participated to the pilot training, which consequently triggered action and publications in Portugal (Almeida et al. 2011, in preparation; Casimiro et al. 2010), Malta (Environmental Health Directorate and WHO Regional Office for Europe 2010) and Turkey (forthcoming). Extracts of the two national assessments in Malta and Turkey, which were elaborated together with WHO are given as examples in Boxes 13.1 and 13.2. These assessments are a strategy to foster research, to raise awareness and to improve the evidence for improved decision making.

Table 13.7 Mediterranean countries with UNFCCC communications

Country	UNFCCC communication (link)	Specific health concerns outlined
Albania	http://unfccc.int/resource/docs/natc/turnc1.pdf	Only general health concerns mentioned, not specified
Croatia	http://unfccc.int/resource/docs/natc/hrv_nc5.pdf	Heatwaves, foodborne disease, respiratory allergies, malaria, tick borne meningoencephalitis
France	http://unfccc.int/resource/docs/natc/fra_nc5rev.pdf	Mainly heat, separate assessment published
Greece	http://unfccc.int/resource/docs/natc/grc_nc5.pdf	Forest fires and floods, as well as air pollution aggravated in cases of extreme heat waves
Italy	http://unfccc.int/resource/docs/natc/ita_nc5.pdf	All possible risks are listed
Malta	http://unfccc.int/resource/docs/natc/mlt_nc02.pdf	All possible risks are listed and in part assessed
Montenegro	http://unfccc.int/resource/docs/natc/mnenc1.pdf	All possible risks are listed and partly assessed
Spain	http://unfccc.int/resource/docs/natc/esp_nc5.pdf	Only general health concerns mentioned, not specified
Algeria	http://unfccc.int/resource/docs/natc/algnc1.pdf	Only general health concerns mentioned, not specified

(continued)

Table 13.7 (continued)

Country	UNFCCC communication (link)	Specific health concerns outlined
Egypt	http://unfccc.int/resource/docs/natc/egync2.pdf	Schistosomiasis, Malaria, Lymphatic Filariasis, Rift Valley Fever, emerging: Tuberculosis, Avian Influenza, water-borne and food-borne diseases
Israel	http://unfccc.int/resource/docs/natc/lbnnc01.pdf	Only general health concerns mentioned, not specified
Lebanon	http://unfccc.int/resource/docs/natc/lbnnc01.pdf	Only general health concerns mentioned, not specified
Morocco	http://unfccc.int/resource/docs/natc/mornc1e.pdf	Only general health concerns mentioned, not specified
Tunisia	http://unfccc.int/resource/docs/natc/tunnc1esum.pdf	Health not mentioned
Turkey	http://unfccc.int/resource/docs/natc/turnc1.pdf	Only very general health concerns mentioned, not specified

Box 13.1 Health Effects of Climate Change in Malta

Since 1970 an increase in air temperatures of 1.5°C, especially in summer, has been observed. There is no clear trend in rainfall, but an increase in days with thunderstorm and a decrease in wind speed overall. Projections indicate an annual temperature increase of 2°C by 2050 and 2.8°C by 2100, with the largest increase between June and August (3.1 and 3.5°C by 2050 and 2100, respectively) and a shift of precipitation events to a shorter time window.

An increase in summer temperatures is a concern for human health because at mean apparent temperatures above 27°C the daily mortality rate increases by 3% per degree rise, especially in the elderly.

Meteorological conditions in Malta give rise to high levels of particulate matter and ozone, in particular in rural areas and during summer. These air pollutants have a considerable health impact and will be affected by a changing climate.

The increased number of days with thunderstorms and flash floods can lead to injury and death and can also have indirect effects on health by causing damage to hospitals, pharmacies and other health-providing infrastructure.

Climate change affects infectious diseases; increases in food-borne diseases. For Salmonella an increase of 0.54 cases per month for every additional degree Celsius in minimum temperature has been observed.

To detect changes in the transmission and incidence of vector-borne diseases such as Leishmania, Mediterranean Spotted fever, West Nile Fever and sandfly fevers, improved vector surveillance and monitoring of social and other factors should be established and laboratory capacity needs to be extended.

(continued)

Box 13.1 (continued)

The most vulnerable are the elderly, disabled, children, ethnic minorities, and people on low income.

Eighty-four percent of the Maltese population is aware of climate change and the Maltese public perceives climate change “only somewhat” as a threat to human health. However, the public has difficulty in making a clear distinction between climate change and air pollution, and between climate change and ozone depletion.

Source: Environmental Health Directorate Malta and WHO Regional Office for Europe (2010)

Box 13.2 Health Impact Assessment of Climate Change in Turkey

In Turkey, less winter precipitation, a 0.75°C warming and more drying and desertification in the south-west regions are the main climate trends observed during the twentieth century.

In a changing climate, mortality and morbidity could increase due to more frequent and intense heat waves, higher concentrations of ground-level ozone and transboundary air pollution and altered distribution of allergens and infectious disease vectors. Human migration may increase as a result of climate change related disasters. As a consequence of floods or droughts, massive displacement of populations and over-crowding in refugee camps may facilitate epidemics. The assessment of health risks of climate change in Turkey puts an emphasis on infectious suspected. Risks of vector-borne, water- and food borne diseases are growing. Crimean-Congo Hemorrhagic Fever, Hantaviruses and phlebovirus infections were recently detected in Turkey, and all were suspected to be associated to climate changes (Table 13.8).

Table 13.8 Current and potential vector borne diseases associated with climate change in Turkey

Agent/disease	Vector	Climate factor	Current situation	Risk
Endemic in Turkey				
Malaria	Mosquitoes	Temperature, precipitation	Decreasing trend (Ergonul 2007)	The geographic distribution may change
Leishmania	Sandfly	Temperature, precipitation	5,000 CL cases in last 3 years	There is an increasing trend (Dujardin et al. 2008)

(continued)

Box 13.2 (continued)

Table 13.8 (continued)

Agent/disease	Vector	Climate factor	Current situation	Risk
Tularemia	Rat	Temperature, precipitation	Increasing trend (Akalin et al. 2009)	An emerging infection at new epicenters
Crimean-Congo haemorrhagic fever (CCHF)	Tick	Temperature, dry weather	>5,000 cases with 250 deaths	The infection could expand geographically (Estrada-Pena et al. 2007b)
Hemorrhagic fever with renal syndrome (HFRS)	Rat	Temperature, precipitation	Emerging infection	There is an increasing trend (Celebi and Sozen 2009)
Phleboviruses	Sandfly	Temperature	Newly detected epicenters	The infection could be detected in new geographical areas (Demiroglu et al. 2010)
Sporadic in Turkey				
Lyme	Tick	Temperature, precipitation, humidity	–	These infections could be notified by case reports or case series
Mediterranean Spotted Fever (Rickettsiosis) (Mouffok et al. 2009)	Tick	Temperature	–	
Bartonellosis	Fly	Temperature	–	
Ehrlichiosis	Tick	Temperature	–	
No detected human cases yet				
Chikungunya	Mosquito	Temperature, precipitation	–	These infections could be defined by sero-surveys and detection of the new cases
Tick-borne encephalitis	Tick	Temperature, precipitation, humidity	–	
Rift valley fever	Mosquito	Drought	–	
Dengue	Mosquitoes	Temperature, precipitation	–	
Tahyna	Mosquito	Temperature	–	
Sindbis	Mosquito	Temperature	–	
Inkoo	Mosquito	Temperature	–	
Alkhumra	Tick		–	
Usutu	Mosquito		–	

Source: Ergönül et al. (forthcoming)

In addition to adaptation as a response to climate change to protect human health, climate change mitigation can also have co-benefits for health. There are considerable health co-benefits for health in climate change mitigation action in the housing, transport, household energy and health sector, which only now are analyzed systematically. Preliminary findings of an initial review have been published in WHO policy briefings in a series on health in the green economy (WHO 2011). For developing countries the potential to "leapfrog" fossil intensive and environmentally damaging economies and to instead apply green principles at an early developmental stage would benefit health at the same time, for example in the transport sector. To maximize health benefits, transport mitigation strategies should focus on land use planning that makes cities more accessible by walking, cycling and improved public transport. Such healthy transport increases levels of physical activity with substantial and immediate benefits for cardiovascular health, but also reduces air pollution, noise and traffic injuries. Healthy transport strategies also increases equity through better access to goods and services (WHO 2011).

13.6 Conclusions

> "Climate change is the price being paid for policies that favored the growth of economic wealth over the protection of ecological health." Dr Margaret Chan, Director-General of the World Health Organization, Address to the Regional Committee for Europe, sixtieth session, Moscow, Russian Federation , 14 September 2010

The findings of research and national assessments indicate that climate change-related exposures of importance to human health in the next decades in the Mediterranean are likely to increase health effects from high temperatures, heat waves and air quality and change the distribution and patterns of climate sensitive infectious diseases (including vector, rodent, food and waterborne disease).

The direct effects of increased temperatures on human health in the Mediterranean region are important and pronounced in temperatures often observed today. These effects become more adverse as the concentrations of some important pollutants increase (mainly PM and ozone). They are expected to worsen with climate change.

The indirect health effects of climate sensitive infectious diseases are a risk for public health in the Mediterranean. Some of these are endemic in parts of the Mediterranean or at risk of (re-)emergence. It is still debatable if modeling approaches can allow better forecast and early warning in the occurrence of these risks. Close monitoring and surveillance is recommended.

Important adaptation actions in the area of public health include to:

- strengthen health, social and environmental systems and services to improve their capacity to prevent, prepare for, and cope with climate change
- ensure that all current and future mitigation and adaptation climate change measures, policies and strategies integrate health issues at all levels;
- raise awareness to encourage health promoting mitigation and sustainable adaptation policies in all sectors;

- increase the health and environment sectors' contribution to reducing greenhouse gas emissions;
- share best practices, research, data, information, technology and tools at all levels on climate change, environment and health and to identify research gaps (WHO Regional Office for Europe 2010).

At the same time, sustainable development and moving towards a green economy in many sectors can help to mitigate climate change and provide co-benefits for health.

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Chapter 14
Energy Demand and GHG Mitigation Options

Leonidas Paroussos, Pantelis Capros, Panagiotis Karkatsoulis, Nikoalos Kouvaritakis and Zoi Vrontisi

Abstract This chapter presents an analysis of the conditions under which energy can be a lever of sustainable development for the N. Africa (The countries considered are: Algeria, Libya, Egypt, Morocco and Tunisia.) countries in the context of intensification of greenhouse gas abatement policies. The analysis begins with the identification of the distribution, uses and potential uses of the energy resources in the N. African countries. Then growth opportunities for N. African economies are examined in the context of an increasing intensity of climate policy and of a widening of its geographical scope providing opportunities for cross border integration of energy markets, for extension of emission permit markets and the use of JI and CDM development mechanisms (JI (Joint Implementation) and CDM (Clean Development Mechanism) are market instruments introduced in the Kyoto Protocol). In particular, alternative scenario simulations are used to analyze how the N. African countries may gain from incorporation into Europe's greenhouse gas abatement effort. From a methodological point of view the analysis is performed by means of a computable general equilibrium model, named GEM-E3-Med, specifically constructed for the CIRCE project (CIRCE Integrated Project – Climate Change and Impact Research: the Mediterranean Environment. Supported by the European Commission's Sixth Framework Programme, Sustainable Development, Global Change and Ecosystems). The analysis is quantitative and focuses on the effect of alternative scenarios on competitiveness, welfare, employment and economic growth of the Mediterranean economies and in particular the N. African countries.

Keywords Climate change mitigation policy • Computable general equilibrium • Concentrated solar thermal power • North Africa • Carbon permits

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14.1 Introduction

Economic growth of N. African countries is characterized by a strong dependence on fossil fuels. Although these countries have significant potential to generate electricity through CSP (Concentrated Solar Thermal) power plants (plethora of sites and highly potent solar radiation input) it is likely that in the short term these developing countries will continue to fuel their growth using gas, oil and coal.

N. African countries, although not committed to reduce their GHG emissions, can take advantage of their high CSP potential in order to contribute to the GHG mitigation effort by providing clean energy (potentially through CDM projects) to countries that undertake GHG mitigation policies. Within this context three alternative scenarios were designed and simulated in order to explore quantitatively the welfare and employment implications of policies that aim to promote clean energy production in N. Africa.

The alternative scenarios considered are: (i) EU – Alone: EU27 unilaterally reduces its greenhouse gas emissions, (ii) Concerted action: countries reduce their greenhouse gas emissions based on their pledges at COP-15, (iii) EU27 promotes CSP power generation in N. Africa within the context of an international concerted action to mitigate GHG.

A comparison of the above mentioned scenarios is made in order to evaluate each policy in terms of the growth and employment opportunities they provide both in N. Africa countries and in EU27 member states.

From a methodological point of view the analysis is performed by means of a computable general equilibrium model, named GEM-E3-Med (General Equilibrium Model for the Economy, Energy and the Environment), specifically constructed for the CIRCE project. The GEM-E3-Med is a recursive dynamic computable general equilibrium model covering the period from 2010 to 2030 with a 5 year time step. The model covers the whole world disaggregated into 14 countries/regions, namely S. European Member States, N. African countries, New Member States, the rest of EU-15 and the Rest of the World (RoW), in order to analyze the sustainable development potentials of N. Africa in a global context. The model links all countries through endogenous bilateral trade and disaggregates their economies in 28 branches.

This chapter is structured in four parts: in the first part an overview of the energy sector of the N. African countries is given highlighting the distribution and use of their energy sources and the potential they have to host investments on clean energy production, the second part presents the reference case of the GEM-E3-Med model, in the third part the main assumptions of the alternative scenarios are presented and their results are analyzed, the fourth part provides conclusions while in the appendix a brief overview of the GEM-E3-Med model is given.

14.2 Overview of the Energy Sector and GHG Emissions

Hydrocarbons are the backbone of the Algerian and the Libyan economy, while Morocco, Egypt and Tunisia largely rely on hydrocarbon consumption for their development and economic growth.

According to the BP Statistical Review (2008) Libya holds the largest proven oil reserves in the African continent (41.5 billion barrels) and the ninth largest proven oil reserves in the world, while Algeria holds the third position in Africa with 12.3 billion barrels. Both Algeria and Libya are OPEC members and therefore their supply is subject to assigned quotas. Tunisia has a lower oil production with proven reserves of 0.6 billion barrels, while Morocco has a minor production. Egypt is also a net oil exporter but this position could change in the near future into a net importer of crude due to rising domestic consumption.

Egypt has experienced a rapid increase in natural gas production, rising from 21.2 billion m^3 in 2000 to 58.4 billion m^3 in 2008 and at the same time estimations regarding the proven gas reserves have been revised upwards (Enerdata 2010b). Algeria holds the second largest natural gas proven reserves in Africa (159 trillion cubic feet) above Egypt (58.5 trillion cubic feet) and Libya (54.4 trillion cubic feet). Finally gas-producing N. African countries are big exporters of LNG, with Algeria being one of the largest LNG exporters in the world.

The energy sector and particularly the hydrocarbons sector will continue to hold the largest share in the Algerian and Libyan export revenues. Tunisia is also an oil exporting country but to a much smaller extent and does not export natural gas. In particular, in 2007 energy exports represented 98% of total exports of Algeria, 52% of total exports of Egypt, 3.8% of total exports of Morocco and 16% of total exports of Tunisia while for Libya this share has been constantly above 95% of total export revenues (Enerdata 2010a).

The hydrocarbons sector has attracted a big amount of foreign investment mainly in Algeria. However, the imposition of a windfall tax on profits from oil which was implemented in 2006 has toughened the terms for foreign oil companies. As regards the oil sector, which was conceived as closed and risky, Libya has structured a more investor-friendly framework (Cordesman and Burke 2004). In general, N. African countries foreign investment is gradually being accepted but National Oil Companies still play a major role. Moreover, foreign investors are increasing their presence in joint projects for the development of power plants.

14.2.1 Northern Africa Countries Energy Demand

According to the (IEA 2005) World Energy Outlook, primary energy demand will grow at an average rate of 2.8% per year in the N. African countries. Oil will continue to dominate the energy fuel mix but gas is expected to increase its share strongly and overtake oil around 2020. This fuel switching is mainly driven by the cost-effectiveness of gas compared to oil when calculations are based on export netbacks. Moreover, the gradual substitution of oil by gas holds for the electricity sector due to the much lower generation costs that characterize gas technologies when compared to oil boilers costs. Lastly, domestic energy policies that promote the use of gas instead of oil by keeping prices for household use low have been introduced.

Energy demand is expected to grow strongly not only due to the robust economic growth projected for the N. African countries but also due to the growth of

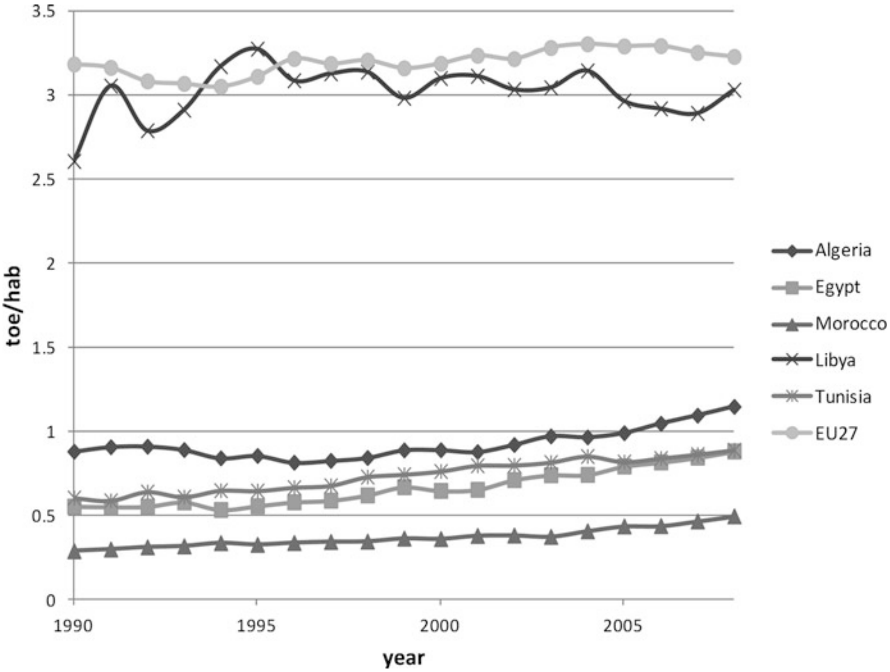

Fig. 14.1 Total energy consumption per capita 1990–2008 (Source: Based on ENERDATA data 2010)

energy-intensive industries attracted in the region due to low energy prices. The industrial sector will dominate energy demand for most N. African countries and natural gas will be the leading industrial fuel. Energy intensive industries in the region include desalination, petrochemical and iron and steel industries; the first aiming at domestic use and the rest mainly aiming at exports. In light of this increase in foreign energy intensive industrial investments, the Industrial Development Authority of Egypt refused to issue new licenses for aluminum or fertilizer projects, citing efforts to restrain excessive growth in national energy consumption (Global Investment House 2009).

Regarding trends in different industries, water desalination energy needs are a major driver of the energy demand growth especially for Algeria and Libya, accounting for more than 30% of the increase of total fuel use in the power and water sectors (WEO 2005). The fertilizers and petrochemicals industry are of great importance for domestic agricultural use, especially in countries like Egypt, while the cement industry is also growing in all N. African countries. Lastly, as the share of services and tourism in GDP grows, energy demand of the sector increases and this is especially the case for Tunisia and Morocco.

Figure 14.1 shows that the levels of energy per capita consumption of N. African countries are much lower than that of the South European and overall European ones. There are big potentials for an increase of per capita electricity consumption both due to

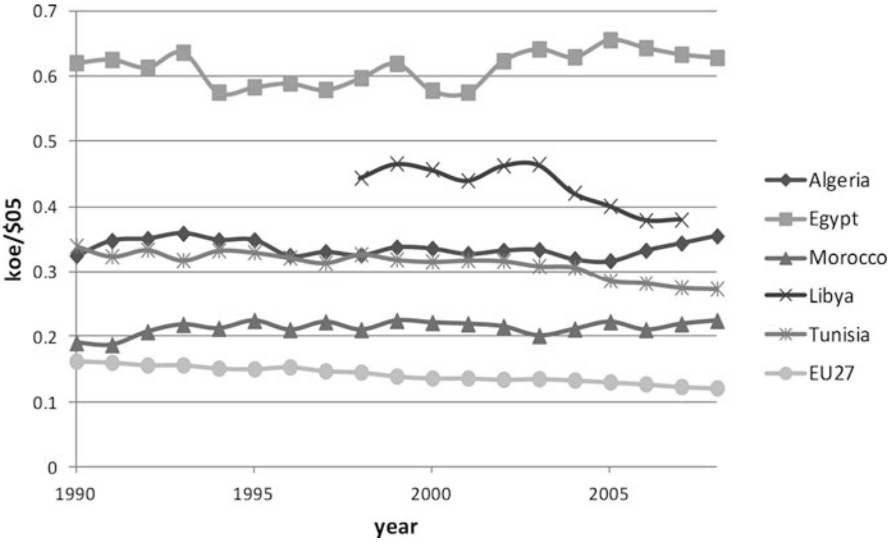

Fig. 14.2 Primary energy intensity 1990–2008 (Source: Based on ENERDATA data 2010)

the increase in the appliances ownership and due to air-conditioning needs (i.e. the electrification rates are much lower than in most developed countries). Regarding transportation, strong growth is expected especially from a rapid increase in private mobility. Development needs mean that commercial transport will also experience rapid growth. Overall, the energy sector of N. Africa is by itself also a major user of energy.

Energy distribution network extensions are required in N. African countries in order to enable economic growth and achieve the inclusion of RES (Renewable Energy Sources) in the energy mix. Regarding the electricity transmission system, new interconnections at the 400 kV level between N. African countries but also between N. Africa and EU-MS are projected to come in full operation by 2010, thus enabling the realization of the MEDRING vision (OME 2006).

Historical trends in primary energy intensity with respect to GDP of the countries examined are shown Fig. 14.2. N. African countries are characterized by high energy intensities compared to the EU. This suggests that a large potential for energy intensity reductions may exist. Figure 14.3 represents a comparison of the sectoral energy intensities between South and North Mediterranean countries.

According to IEA 2005, N. African energy intensity will remain virtually constant to 2020 and will then gradually decrease.

14.2.2 Northern Africa Countries: GHG Mitigation Potentials

In major N. African energy producing countries, lower energy prices mean that there is limited incentive for improving energy intensity by substituting energy for

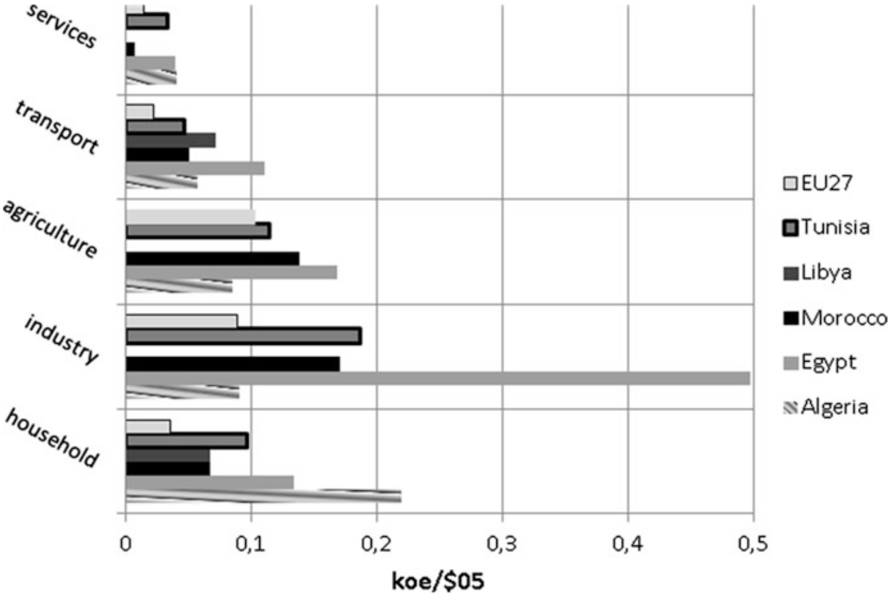

Fig. 14.3 Sectoral primary energy intensities; 2008 (Source: Based on ENERDATA data 2010)

capital. Moreover, government incentives for energy efficiency are minimal since there is an abundance of energy resources. There is scope for technology efficiency improvements (in end-use and production activities) but also for a gradual energy market liberalization which will enable a better reflection of the production costs and hence lead to more rational use of energy resources.

In order to reduce the vulnerability of their economies to fluctuations of oil and gas prices and also to facilitate electrification of rural areas, N. African countries are expanding their energy portfolio to incorporate renewable energy technologies. All countries have a high RES potential mainly in solar and wind energy but also in geothermal energy. Yet they are currently characterized by a very low development of renewable energy technologies with the exception of large hydro plants and traditional biomass. In 2008, hydro generation represented 6% of total energy consumption in Egypt while Egypt and Morocco have an installed capacity of 2,842 and 1,265 MW respectively (Enerdata database). Traditional biomass for domestic and agricultural use in Egypt, Tunisia and other N. African countries is important but is expected to decrease as a consequence of economic development resulting in increased access to commercial energy.

With the intention of significantly altering the current status of renewable deployment, some N. African countries have recently developed institutional frameworks to promote RES both in large and small scale applications for wind parks, solar heating, PV plants and CSP (Berdai 2007). In 2009, for example, Tunisia established a Tunisian Solar Plan for the period 2010–2016 while Egypt has developed a "National Sustainable Development Strategy" with energy playing a major role

Table 14.1 GEM-E3-MED active population in reference case (annual % rate)

	2010–2015 (%)	2015–2020 (%)	2020–2025 (%)	2025–2030 (%)
Egypt	2.5	2.0	1.7	1.6
Tunisia	2.6	1.9	1.3	1.2
Morocco	2.2	1.8	1.6	1.5
Libya and Algeria	3.2	2.2	1.5	1.4

Source: ILO 2009

(Georgy and Soliman 2007; Amous 2007). Nevertheless, there are still many barriers to remove both nationally, regionally and internationally in order to provide the right incentives for RES development.

N. African countries have all ratified the Kyoto protocol and have already hosted certain Clean Development Mechanism (CDM) projects with the aim of promoting the GHG mitigation actions, attracting foreign investments and saving hydrocarbons for exports.

14.2.3 The Reference Case

The analysis with the GEM-E3-Med model starts by constructing a reference projection of economic growth for the 14 regions represented in the model. The reference projection, serves as a basis of comparison for the policy scenarios. For the development of the reference scenario assumptions were made on total factor productivity, active population growth and anticipated growth rates of sectors. In the GEM-E3-MED model the EU is aggregated into eight regions, namely France, Germany, Italy, Greece, Portugal, Spain, Rest EU15 and New Member States while N. Africa consists of Egypt, Morocco, Tunisia and Algeria and Libya.

The assumptions of future growth of population and active population were based on the Long-Term forecasts of the ILO (International Labour Organization). These are presented in Table 14.1. The rate of growth of the population of N. African countries is 2% on average, amongst the highest in the world. The population of these countries has increased in the last two decades and it is projected to increase by 40% in 2030 as compared to 2005.

Historically the high increase in population and active population in N. Africa was not supported by an equivalent creation of jobs. In the 1990s these countries had an average of 12% unemployment rate that increased to 15% in 2000. Employment creation in these countries requires a restructuring of these economies. The public sector of these economies accounts for 20% of total employment and 30% of non agricultural employment. The GEM-E3-MED reference case assumes a reduction of the share of public sector jobs with a simultaneous increase in the private sector (an assumption that is consistent with the policy reforms planned within these countries). The ratio of employment growth to GDP growth in these countries is historically around 0.7 and it is assumed to stay at these levels within the projection

Table 14.2 GEM-E3-MEd reference case unemployment rates

	1990[a]	2000[a]	2010	2020	2030
Egypt	8.6	7.9	8.4	6.6	5.7
Tunisia	16.2	15.9	11.9	9	7.5
Morocco	12.1	13.7	16.6	13.7	11.6
Libya and Algeria	19.8	29.9	12.5	10.1	8.8

Source: GEM-E3-Med
[a]Historical data

period of GEM-E3-Med. Table 14.2 presents the reference case unemployment rates that are consistent with GDP growth rates projected for these countries.

N. Africa historically exhibits low productivity growth rates. The countries with the lowest productivity rates (Egypt, Algeria) are the ones with the largest shares of government employment (IMF 2003). Tunisia and Morocco present relatively higher rates of productivity growth reflecting efficiency gains from the gradual liberalization and opening of their economies to competition.

The world economy is projected to grow at an annual average rate of 3.1% over the reference case (2010–2030). N. Africa countries are projected to accelerate growth compared to the past. The projection shows however a slight slowdown of the rates of growth after a period of high development. The stimulus behind the assumed economic growth of the developing countries lies on the idea that in most developing economies the majority of the population works in the low productivity sectors (Goujon and Lutz 2001).

The rapid growth of the labor supply combined with a changing composition of the labor force (from low skilled or informal sectors to high skilled sectors) represents an important determinant of growth. Another source of economic growth for the developing countries comes from international trade and the terms of trade improvements because of trade liberalization and lowering of tariffs and quotas. This liberalization is expected to improve the export position of the developing countries and especially the sectors of consumer goods and intermediate products (Table 14.3).

It should be mentioned that the reference annual GDP growth assumed for our modeling exercise is lower than that of the IPCC-A1b scenario (see Table 14.4) due to the consideration of the effects from the recent financial crisis, as those were described in the 2009 Ageing Report (European Commission 2009).

14.2.4 Energy Demand and Power Generation

World primary energy demand in the reference scenario is projected to increase by 2% annually between 2010 and 2030. In N. African countries energy demand is projected to increase by 3% annually for the same period. Fossil fuel reserves are considered to be adequate to support the economic growth of N. Africa and thus will continue to be dominant in their energy system (Table 14.5).

Table 14.3 Annual % GDP growth

	05–10	10–20	20–30
Spain	0.87	3.07	2.44
Italy	−0.37	1.81	1.64
Greece	2.11	2.85	1.92
France	0.38	2.00	1.75
Germany	0.28	1.80	1.01
Portugal	−0.25	2.03	2.12
Rest of EU15	0.60	2.22	1.86
New EU member states	2.70	3.23	2.17
Algeria and Libya	3.47	4.87	4.03
Egypt	4.79	6.05	5.24
Morocco	4.93	5.50	4.65
Tunisia	4.67	5.21	4.51
Rest of the world	3.33	3.55	3.79

Source: GEM-E3-MED

Table 14.4 Comparison of annual % GDP growth for A1b IPCC scenario and GEM-E3-Med

	A1b			GEM-E3-Med		
	05–10 (%)	10–20 (%)	20–30 (%)	05–10 (%)	10–20 (%)	20–30 (%)
N. Africa	7.27	6.91	6.58	4.55	5.34	5.11
EU27	2.20	2.22	2.29	0.47	1.79	2.28
RoW	4.19	4.58	5.15	3.33	3.55	3.79
World	3.64	4.00	4.56	2.53	3.13	3.47

Source: IPCC (Nakicenovic et al. 2001), GEM-E3-MED

Table 14.5 N. Africa annual growth of energy demand

	05–10	10–20	20–30
Coal	1.81	2.74	2.91
Oil	1.51	4.10	3.66
Gas	0.35	1.36	2.50
Electricity supply	1.97	3.35	3.11

Source: GEM-E3-Med

In the reference scenario, Egypt's energy demand is projected to grow by 3% per annum in the period 2010–2030. Energy-demand growth will be lower relative to the past as the economy is becoming more energy efficient. Natural gas will remain dominant in the energy mix and even increase its share mainly at the expense of oil. Electricity generation is projected to increase 3.9% annually in 2010–2030. The share of energy from renewable sources will increase from 10 to 13%. Within the renewable group wind and solar energy are projected to increase their share at the expense of hydro.

Energy demand in Algeria and Libya is projected to grow at an annual rate of 1.53% over the reference case (2010–2030). Natural gas and oil represents 99% of total power generation. The persistence of cheap and available natural gas means

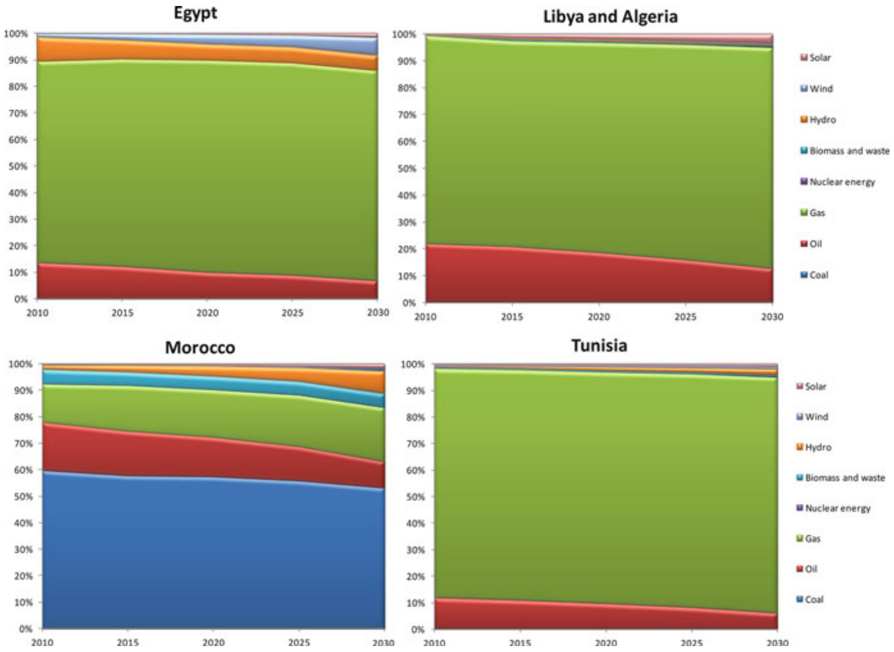

Fig. 14.4 Electricity fuel mix in N. Africa countries (Source: GEM-E3-Med)

that there is little scope for development of RES under reference assumptions.[1] Their share remains virtual stable throughout the projection period. Gas, which Algeria holds in abundance, will remain the leading fuel in power generation (Fig. 14.4).

Energy demand in Morocco is projected to grow by 2.55% over the 2010–2030 period, driven largely by rapid economic growth. Coal will remain the dominant fuel in power generation, but the share of gas will increase at the expense of oil. Tunisian energy demand is projected to grow by 2% per annum in the period 2010–2030. Natural gas is projected to remain the dominant fuel in power generation.

14.3 GHG Mitigation and Adaptation of the Energy Sector

This section provides the main assumptions and results of the alternative scenarios simulated with the GEM-E3-Med model. Three scenarios are simulated, namely the EU27-Alone, the International concerted action and the CSP. The EU27-Alone scenario refers to the case where the European Union takes unilateral action in mitigating its greenhouse gasses (there are no mitigation policies in the RoW), the International concerted action refers to a GHG mitigation policy where the pledges

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[1] Continuation of basic trends and no additional policy initiatives.

Table 14.6 EU Alone scenario emission reductions compared to 2005

	2020[a]	2020[b]	2030[a]	2030[b]
ETS	−21	−27	−32	−42
Non-ETS	−10	−14	−11	−21
Total GHG	−14	−18	−18	−29

[a] % change compared to 2005 emissions

[b] % change compared to baseline emissions

made by the different nations at COP 15 are implemented. The CSP scenario refers to the case where North African countries collaborate closely in the energy sector with Europe in order to mitigate climate change. This is done by the deployment of CSP power plants in North African countries, which are constructed with the financial assistance of the EU and produce electricity in order to primarily export it to the EU27, but also by the inclusion of N. Africa in the GHG abatement effort. The overall GHG mitigation policy is the same as in the concerted scenario with the exception that N. Africa also participates in the effort in collaboration with the EU27. This collaboration is assumed to take the form of participation in a common emission permit market with an allocation of permits to N. African countries equal to their reference case CO_2 emissions.

14.3.1 EU Alone Scenario

The EU27 is committed to reduce its GHG by 20% compared to 1990 levels (or 14% compared to 2005 levels) by 2020 in order to mitigate climate change (European Commission 2009b). This target is decomposed to a 21% reduction compared to 2005 levels for the Emissions Trading System (ETS) sectors (power industry and energy intensive industries which currently account for 40% of total GHG emissions) and a 10% reduction compared to 2005 levels for the emissions originating from the non ETS sectors (transport – except aviation which will join the ETS in 2012 –, farming, waste and households). Table 14.6 gives the emission reduction targets imposed on the European economy. The emission targets and hence our analysis exclude emissions produced from Land Use Change and Forestry. The ETS sectors participate in a European wide market, while non-ETS sectors are assumed to face a uniform carbon tax, which is calculated endogenously.

In the EU Alone scenario it was assumed that the EU27 continues its mitigation policy up to the end of the simulation period, namely till 2030. The EU27 emission reduction constraint imposed in 2030 is an 18% reduction compared to 2005 levels which is decomposed to a 32 and 10% reduction for the ETS and non-ETS sectors respectively. Additionally, a Renewable Energy target is imposed stipulating a 32% penetration in electricity production by 2020 and 37% in 2030. The EU-Alone scenario incorporates current EU legislation. The analysis of the EU Alone scenario is based on its differences from the reference scenario (where no climate policies are assumed) as developed within the CIRCE project The GEM-E3-Med model provides

Table 14.7 Allowances allocation rules

	2015	2020	2025	2030
Power sector, refineries	Full auctioning	Full auctioning	Full auctioning	Full auctioning
Energy intensive ETS sectors	95% free	85% free	75% free	65% free
Non-ETS sectors	Endogenous carbon tax[a]	Endogenous carbon tax	Endogenous carbon tax	Endogenous carbon tax

[a] A tax (calculated endogenously within the model) that is sufficient to ensure respect of the emission reduction constraint

a number of alternative recycling options regarding the use of income generated from permit sales or permit auctioning. The options usually considered are: (i) inclusion in capital income of the sector, (ii) decrease in the firms' unit cost of production (iii) reduce the employers social security contributions and (iv) lump-sum transfer to support household income. In the current simulation the emission permits are auctioned (Table 14.7 provides the allocation rules of allowances) to the ETS sectors and the revenues are recycled to household income as a lump-sum transfer. For the energy intensive ETS sectors that face international competition, like ferrous, non-ferrous metals and chemical products, a gradual transition from grandfathering of the allowances to auctioning is assumed in order to reduce potential carbon leakage (i.e. a shift towards imports from regions that do not apply climate policies).

The GEM-E3-Med model is an open economy model; the current account of each region can change from one scenario to another without necessarily considering effects on monetary variables. However, when policy scenarios are quantified with the model it is necessary to impose a certain overall monetary condition so that a policy scenario is comparable with the reference case. For example, if the policy scenario, such as the climate change scenario leads the EU economy to get additional (from the reference case) external financing intended to finance part of the activity related to GHG mitigation, then the EU economy will enjoy a clear benefit, since it may invest in GHG mitigation options without having to equally reduce financing of other economic activities. This would imply higher deficit in its current account with the rest of the world. Then the results of this policy scenario would not be comparable with those of the Reference because part of the impacts would be explained by the additional resources from abroad. To make the scenario comparable it is necessary to impose a global EU monetary constraint which determines a variable (in our modeling exercise the basic interest rate) which otherwise would be left exogenous and unchanged from the reference case. In the present simulation, the EU basic interest rate adjusts so as to render the current account of the EU region as a percentage GDP unchanged from the reference case.

In the scenario as well as in the reference case capital is assumed to be fully mobile across sectors but not across regions. This implies a uniform return on capital for all the sectors within the regions identified in the GEM-E3-Med model.

Table 14.8 Permit/Tax price evolution EU-Alone scenario (€ 2005/tnCO_2eq)

	2015	2020	2025	2030
EU-ETS	8	16	25	43
Non-ETS average	24	56	82	99

Source: GEM-E3-Med

Table 14.9 Macroeconomic aggregates, change of EU-Alone scenario from reference

	GDP		Investment		Consumption		Net import as % of GDP	
	2020	2030	2020	2030	2020	2030	2020	2030
EU-27	−0.46	−0.68	−0.19	−0.29	−0.42	−0.63	0.3	0.4
N. Africa	0.10	0.04	−0.17	−0.38	−0.11	−0.19	−0.1	−0.2

Source: GEM-E3-Med

14.3.1.1 Results

The emissions reduction constraint generates a shadow value (carbon permit price) that increases the costs of GHG emitting activities through the internalization of this cost in the production structure and in final consumption decision-making. Table 14.8 illustrates the evolution of the permit price for the ETS and non-ETS sectors. The implicit European marginal abatement cost curve of the GEME3 model is steeper for the non-ETS sectors, thus resulting in higher prices than the ETS sectors even though their reduction target is weaker (ETS sectors achieve 41% emissions reduction from reference in 2030 while the respective reduction for the non-ETS sectors is 21%).

Table 14.9 illustrates the change of macroeconomic aggregate indicators with respect to the reference scenario for both N. Africa and EU regions. Overall EU-27 activity levels decrease by 0.46% in 2020 as compared to the reference case. This decrease is mainly driven by a deterioration of the balance of trade by –0.4% of GDP in 2030 and by a decrease in private consumption by 0.42%. As indicated in Table 14.9, the unilateral climate mitigation effort results in a loss of competitiveness leading to increased imports and reduced exports.

The activity level of N. Africa countries virtually remains the same (increase of 0.1% in 2020) relative to the reference. N. African balance of trade is improved due to the competitive gains realized by the region in the absence of an internalized carbon price especially as regards the markets of agricultural, transport and chemical products. However, terms of trade deteriorate by 1.17% due to a global fall in fossil fuel prices stemming from the fall in global fossil fuel demand, which in turn causes a decrease in N. African private consumption. In contrast, European terms of trade improve by 0.67% since imported fossil fuel is cheaper.

At a world level GDP decreases slightly by 0.04% in 2020 with a subsequent decrease of 2.81% in GHG emissions when compared to the reference case, while the economy becomes more energy efficient under the GHG constraint with a fall of energy intensity of –0.81% in 2020.

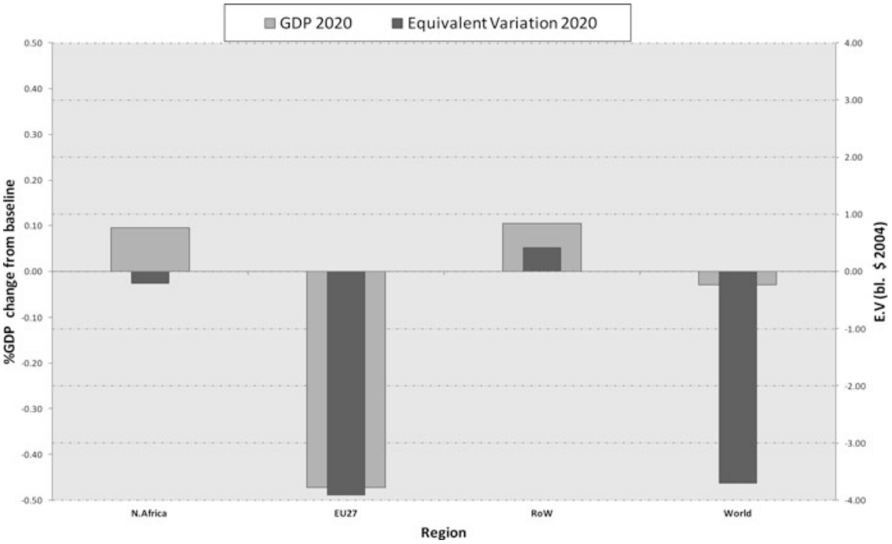

Fig. 14.5 Change from reference of regional welfare (Hicksian Equivalent Variation) and GDP in EU Alone scenario; year 2020 (Source: GEM-E3-Med)

14.3.1.2 Economic Welfare

In order to assess the effects of Europe's mitigation policy on N. Africa, it is worth looking at the changes of the economic welfare and the money metric measure of utility, the Hicksian equivalent variation of the regions. The Equivalent Variation takes the old equilibrium incomes and prices and computes the change needed to achieve new equilibrium utilities. Figures 14.5 and 14.6 show the welfare effects resulting from the unilateral European climate policy by region and country respectively.

Overall, European countries present a negative welfare effect. Product demand falls hence labor demand falls resulting in lower real wages when compared to the reference scenario. Household consumption at the EU level is reduced in all consumption categories and mainly in the operation of personal transport equipment (–2.79%) and heating and cooking appliances (–2.24%) whose prices increase sharply.

Each of the N. Africa countries shows a small increase of around 0.1% in economic welfare with the exception of the export-led economies of Algeria and Libya (see Fig. 14.6), who register a decrease of welfare despite the projected increase in their economic activity compared to reference. This is attributed to the result that Algeria's and Libya's terms of trade deteriorate by 3% due to the fall of the price of their exporting products (mainly fossil fuels) and the parallel increase of the import price of European products resulting in reduced Algerian and Libyan purchasing power. On the other hand, Egypt registers the greatest welfare gains by increasing domestic consumption through higher real wages and increase of employment,

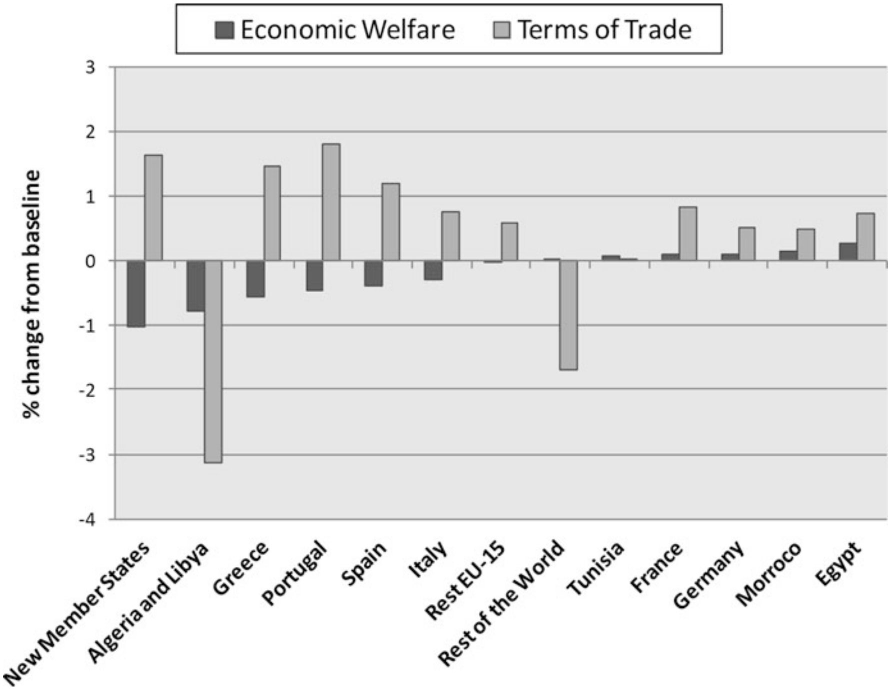

Fig. 14.6 Change from reference of economic welfare and terms of trade in EU Alone scenario; year 2020 (Source: GEM-E3-Med)

especially in the exporting sectors of agriculture and transport, and by keeping at the same time the balance of trade unchanged from reference.

14.3.1.3 Sectoral Results and International Trade

The biggest percentage decrease in EU domestic production relative to reference scenario is presented in the fossil fuel sector (−10%), while the agriculture and transport sectors are also greatly affected registering a reduction of 3.08 and 1.91% respectively as compared to reference in 2020. The agriculture and transport sectors are affected due to the high endogenous carbon tax imposed on the non-ETS sectors. EU domestic production is also reduced in the energy intensive industries and especially in chemical industries (by 0.75 and 1.22% respectively, as compared to reference). This is attributed both to the heavy dependence of chemical industry on energy inputs and to its non-CO_2 emissions which constitute part of the overall constraints.

The fossil fuel sector presents the greatest decrease in imports with oil imports falling by 7.39% in 2020 as compared to reference, thus giving a positive boost to the current account of the European economy by reducing imports. This reduction

Table 14.10 GHG emissions sectoral impact in EU-Alone scenario from reference; 2020

	% Share of total EU-27 GHG emissions	EU27 (%)	% Share of total N. African GHG emissions	N. Africa (%)
Agriculture	7.9	−24.8	37.6	0.3
Coal	0.8	−28.9	0.0	0.0
Oil	0.6	−53.7	11.2	0.2
Gas	1.0	−29.5	3.8	−1.8
Electricity supply	21.9	−22.5	4.5	0.1
Ferrous and non ferrous metals	2.9	−11.6	0.6	0.0
Chemical products	7.9	−44.4	12.6	0.7
Other energy intensive	6.5	−9.8	0.6	0.0
Electric goods	0.1	−55.3	0.0	0.0
Transport equipment	0.2	−13.9	0.0	0.0
Other equipment goods	0.5	−12.9	0.2	0.0
Consumer goods industries	1.6	−15.7	0.4	0.0
Construction	0.8	−11.5	0.4	0.0
Transport	34.9	−12.5	8.1	1.5
Market services	3.1	−12.4	0.2	0.0
Non market services	9.3	−21.7	19.7	0.1

Source: GEM-E3-Med

however is overtaken by the increase in energy intensive imports and agricultural products. The European balance of trade further deteriorates with a decrease of exports in energy intensive products and consumer goods.

The only sector registering an increase in European domestic demand for this scenario is the electric goods sector. This can be attributed to the fact that their products are used as intermediates for the production of abatement technologies and the construction of renewable energy plants. For the same reason, the domestic demand of the sector of other equipment goods is only slightly affected by the overall activity fall.

The least cost allocation of sectoral abatement for the EU27 and N. African regions is presented in Table 14.10. The biggest EU emitter according to the reference is the transport sector which reduces its total GHG emissions by 12.46% in 2020 as compared to reference. Chemical products also have a big share in EU27 GHG emissions and show the biggest reduction (44.36%) in 2020 as compared to reference. It should be noted that abatement is primarily taking place in non-CO_2 emissions rather than on emissions from energy consumption in all energy intensive sectors: methane emissions are reduced by around 55% in all energy intensive sectors, while nitrous oxide emissions are also cut by 60% in chemical industries and other energy intensive sectors. In the same manner, electric goods achieve a great part of their GHG emissions reductions by reducing by 80% in 2020 PFC emissions and respectively ferrous and non-ferrous by reducing by 60% SF6 emissions in 2020.

Overall, an increase of around 0.27% in GHG emissions, as compared to reference, is simulated in N. African countries attributed to the geographical shift of energy intensive industries. The carbon leakage incurred by the EU-Alone policy is estimated to be 0.10% of reference emissions in RoW in 2020 and 0.27% of reference emissions in N. Africa. The sectors that present the highest emissions increase in N. Africa are the transport sector, chemical and agriculture. This is attributed to the increase in their exports. The case of rising exports in the transport services sector has been registered during the 1990s in several eastern European transition economies and mainly concerned land transportation, while in our case shipping would primarily explain the case of rising transport exports from N. African countries. Algeria and Libya followed by Egypt register the greatest GHG emission increase, by 0.40 and 0.23% respectively as compared to the reference case.

N. Africa countries register an increase in domestic production in all sectors apart from the fossil fuel sector which registers a reduction of −2.20% as a consequence of diminishing European fossil fuel demand. In particular, Italy which is the major gas importer from the N. Africa region reduces by 14% gas-fired electricity production and increases renewable energy production in order to comply with the renewable target. N. African countries are affected by the decrease in the EU's fossil fuel consumption hence their fuel exports are reduced, however all N. Africa countries apart from Tunisia improve their balance of trade due to moderate geographical shift of production from the EU. Exports of agricultural products are increased in all N. Africa countries, representing an important increase in the value added of the Moroccan and Egyptian economies. The agricultural sector shows the highest percentage decrease in European exports due to a loss of competitiveness caused by increased costs of energy inputs and due to the tax imposed on CH_4 and N_2O emissions of the sector. In absolute numbers, the sharpest European export reductions occur in the energy intensive sectors.

Regarding the electricity sector, the share of EU-27 renewable energy generation is increased in the EU Alone scenario by 12% reaching 32% of electricity production in 2020. This is driven by the RES target imposed. In particular, wind and biomass generation are driven up at the expense of fossil fuel fired plants (by 8 and 3% respectively).

N. African countries increase their energy intensity by +0.28% in 2020. This can be attributed to the carbon leakage that leads to a more energy intensive structure of the N. African economy but also to the reduction of fossil fuel prices. Algeria, Libya and Egypt, where energy-intensive relocation is registered, present the highest increase of energy intensity. The European energy intensity decreases by −4.3% in 2020 compared to reference.

14.3.1.4 Labor Market Effects

The EU27 labor market is only slightly affected by the GHG mitigation policy; the unemployment rate is increased by +0.06 with a subsequent fall of the real wage by 1.55%. Employment falls only by 0.6% in the market services sector but since this

Table 14.11 Employment sectoral impact in EU-Alone scenario from reference; year 2020

	% Share of total EU-27 employment	EU27 (%)	% Share of total N. African employment	N. Africa (%)
Agriculture	0.8	−2.3	5.3	0.2
Coal	0.0	−20.8	0.0	10.5
Oil	0.2	−9.6	9.6	0.1
Gas	0.2	−11.5	5.5	−1.9
Electricity supply	0.5	−0.7	0.6	−0.2
Ferrous and non ferrous metals	1.4	−0.6	1.5	−0.2
Chemical products	2.2	−1.3	1.4	0.4
Other energy intensive	2.1	−0.5	3.6	−0.1
Electric goods	0.7	0.7	0.6	−0.1
Transport equipment	1.4	−0.1	0.7	0.2
Other equipment goods	2.9	−0.2	0.6	−0.3
Consumer goods industries	4.3	−0.7	10.4	−0.1
Construction	4.5	−0.2	5.8	−0.2
Transport	4.2	−0.6	7.3	1.6
Market services	50.6	−0.6	28.1	−0.1
Non market services	24.0	0.00	19.0	−0.1
Total employment		−0.5		−0.1

Source: GEM-E3-Med

is the most labor intensive sector of the European economy the absolute reductions are the highest, namely 0.6 million persons. This reduction is attributed to the fall in activity of other more energy intensive sectors that use market services as an input. The agriculture and chemical products sectors also reduce their labor demand. Table 14.11 illustrates the regional effects on employment.

Total employment in the N. African region virtually remains the same while sectoral employment clearly follows the changes in production structure that are induced by the European carbon policy. In particular, results illustrate that the gas sector which represents 5% of total N. African employment is significantly affected by Europe's mitigation efforts, falling by 2% from the reference case. The negative effect on the demand of the gas sector is particularly marked in Algeria and Libya where the sector employs 10% of the active labor force. This reduction in labor demand is compensated by the increase in employment of the transport sector. Egypt registers a 1.7% increase compared to reference case in the employment of transport sector which represents 10% of Egyptian total employment. All N. Africa countries show an increase in the employment of the agricultural sector due to increased agricultural exports. In particular Morocco, which registers negative employment impacts on other sectors, displays a small increase (0.5%) in the agricultural and transport sector, each of which represent 9% of total Moroccan employment.

Table 14.12 Emission reduction plan (% changes from 2005)

Annex-I (%)		Non-Annex I (%)	
Australia	−10	Brazil	6
Belarus	58	China	54
Canada	−17	India	81
Croatia	9	Indonesia	−21
EU 27	−24	Mexico	7
Iceland	−22	South Africa	24
Japan	−30	South Korea	−4
New Zealand	−28	Singapore	38
Norway	−35	Turkey	52
Russian Federation	25		
Switzerland	−21		
Ukraine	77		
United States	−17		

Source: UNFCCC; author's calculations based on UNFCCC (2010)

14.3.2 International Concerted Action Scenario

In its climate action package *"..EU matched its 20% unilateral commitment with a commitment to move to 30%, as part of a genuine global effort."* (EC 2010). During COP-15 several countries made pledges to reduce their GHG emissions; Table 14.12 summarizes these pledges based on the quantified emission reduction limitations submitted to the UNFCCC and re-calculated in order to express the targets with respect to base year of the model (2005). It should be noted that for the present analysis the high pledges submitted have been retained. The reduction target for the Rest of the World (RoW) is calculated according to the pledges presented in the table below. N. Africa countries have not made any official quantified emission pledges, although Algeria and Tunisia have expressed their willingness to be associated with the Copenhagen Accord. Therefore N. Africa is the only region in this modeling exercise with no emissions constraint imposed.

The RoW is assumed to follow a uniform carbon tax policy; therefore the scenario is formulated so that an endogenous tax is imposed in all sectors and household activities in order to meet the targets. Emissions from the agricultural sector are excluded from the common RoW carbon constraint. The EU27 is assumed to have one common carbon tax imposed on the entire economy, thus omitting the segregation between ETS and non-ETS sectors. A uniform carbon tax normally results in lower welfare losses as it implies a more efficient distribution of effort. In this simulation, the basic interest rate of each N. African country adjusts so as to render the current account of the country as percentage GDP unchanged from the reference case. As in the previous scenario, the government tax revenues of the RoW and EU are recycled to household income (Table 14.13).

Table 14.13 Concerted scenario emission reductions

	2020[a]	2020[b]	2030[a]	2030[b]
EU-Total GHG	−24	−28	−36	−44
RoW GHG (ex. Agriculture)	3	−27	−11	−49
RoW-Total GHG	14	−21	13	−38

[a] % change compared to 2005 emissions
[b] % change compared to baseline emissions

Table 14.14 Carbon tax price evolution Concerted scenario

	2015	2020	2025	2030
EU27	13	65	120	227
ROW	14	30	76	129

Source: GEM-E3-Med

14.3.2.1 Results

Global GHG emissions fall in the concerted scenario by −22% compared to the reference in the year 2020 and by −39% in 2030, substantially more than the EU-Alone scenario since an emissions constraint is now imposed on more than 80% of global GHG emitters. This emissions reduction can be expressed as a 3.8% increase of emissions in 2030 compared to 2005 levels. Global economic activity is reduced by 2.33% in 2030.

EU27 reduces total GHG emissions from reference by 27% in 2020 and by 44% in 2030 in order to achieve the target, and subsequently economic activity falls by 1% in 2030 as compared to the reference case. N. African countries increase their emissions from reference by around 0.8% in 2030 as compared to the reference (Algeria, Libya and Egypt show the highest increase among N. Africa) while their overall activity remains virtually unchanged in 2020 and increases by 0.45% in 2030 as compared to the reference case. N. Africa GHG emissions increase only marginally despite the increase in energy intensive exports due to the fall of domestic demand stemming from the deterioration of terms of trade and a decrease in the real wage, as will be analyzed below.

Table 14.14 shows the evolution of the endogenous carbon tax levels for the period 2015–2030 for the different permit markets of the scenario. When compared to the EU Alone scenario, the EU permit price increases as would be expected due to the imposition of a stricter emissions reduction target.

The impacts of a higher emissions reduction target on European economic activity are blunted since a constraint is imposed globally and thereby Europe does not decrease its competitiveness unilaterally. In particular, the RoW register a reduction from reference in GDP (−2.7% in 2030) which is stronger than the respective reduction of the EU27 (−1%), even though the emission reduction effort of the EU27 is greater. A key driver of domestic market effects is the reference energy and carbon intensities of the economies analyzed that determine the ease by which a move to less carbon intensive production methods is possible (Böhringer and Rutherford

Table 14.15 Macroeconomic aggregates change of Concerted scenario from reference

	GDP		Investment		Consumption		Net import as % of GDP	
	2020	2030	2020	2030	2020	2030	2020	2030
EU-27	−0.80	−1.08	−0.46	−0.80	−1.04	−1.74	0.2	0.0
N. Africa	−0.01	0.45	−0.25	−0.64	−0.54	−0.86	0.3	1.1
RoW	−1.02	−2.68	−0.91	−1.72	−1.39	−3.67	−0.1	0.0

Source: GEM-E3-Med

2002). RoW is characterized by higher energy intensity for the overall economy than the EU27, a marked feature of both North America and rapidly growing developing regions.

GDP in N. African countries remains unaffected in 2020 and is even favored by 0.4% in 2030 due to the international mitigation action regardless of the importance of energy exports for their economies. This is attributed to a gradual improvement in their balance of trade.

Table 14.15 illustrates the aggregate indicators of macroeconomic impacts initiated by the international climate policy. The macroeconomic and sectoral effects of the Concerted scenario for N. Africa exhibit the same qualitative pattern as in the EU-Alone scenario but at a greater intensity due to stronger global commitments. As mentioned previously, N. African countries are favored in this scenario with increasing exports since they are a non-constrained economy.

While in the EU Alone scenario the RoW increases its exports to the carbon constrained European economy, in this scenario exports are reduced but at the same time imports are also reduced thus improving the balance of trade for RoW compared to the reference. Sectors that show an increase in exports are the electric goods and the consumer goods industries (by 1.9 and 2.6% respectively). Globally, electric goods and transport equipment are the only sectors to show an increase in demand since their products are used for the production of abatement technologies and the construction of renewable energy plants.

14.3.2.2 Economic Welfare

Overall, the Concerted Scenario presents deeper impacts for N. African countries than the EU Alone one since the N. Africa region is now the only one without a carbon constraint. The welfare effects are given in Figs. 14.7 and 14.8 where, as expected, the equivalent variation is much greater than that of the EU-Alone scenario since the emissions reductions achieved globally are ten times those of the EU-Alone scenario. N. Africa also shows welfare losses despite its non-inclusion to the mitigation efforts. This is mainly due to the effects of imported inflation form the rest of the world directly and indirectly linked to additional costs resulting from the mitigation effort. Such inflation exceeds the rise in the export prices of N. Africa implying a deterioration of the terms of trade. These effects are particularly marked in Algeria and Libya that suffer a substantial welfare loss due to their high

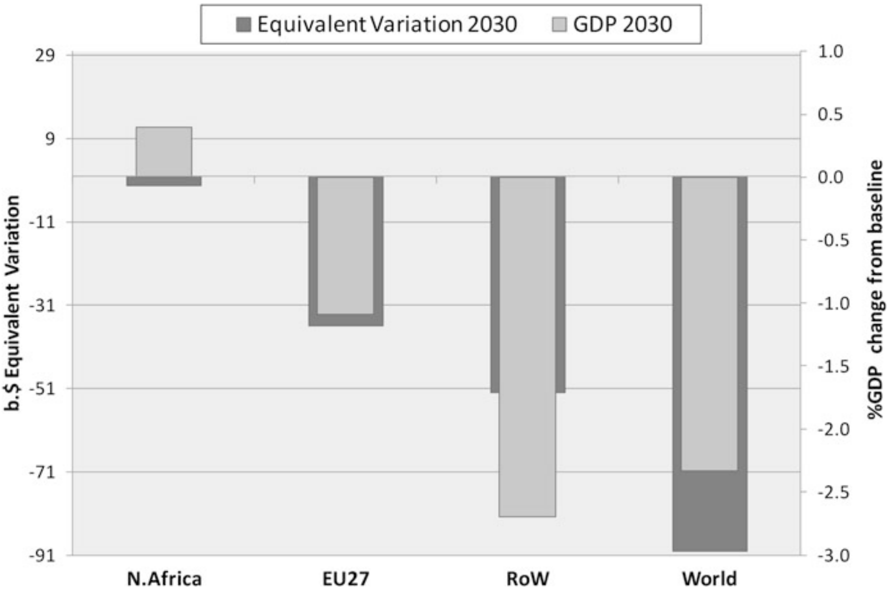

Fig. 14.7 Regional welfare (Hicksian Equivalent Variation) and change from reference of GDP in Concerted scenario; year 2030 (Source: GEM-E3-Med)

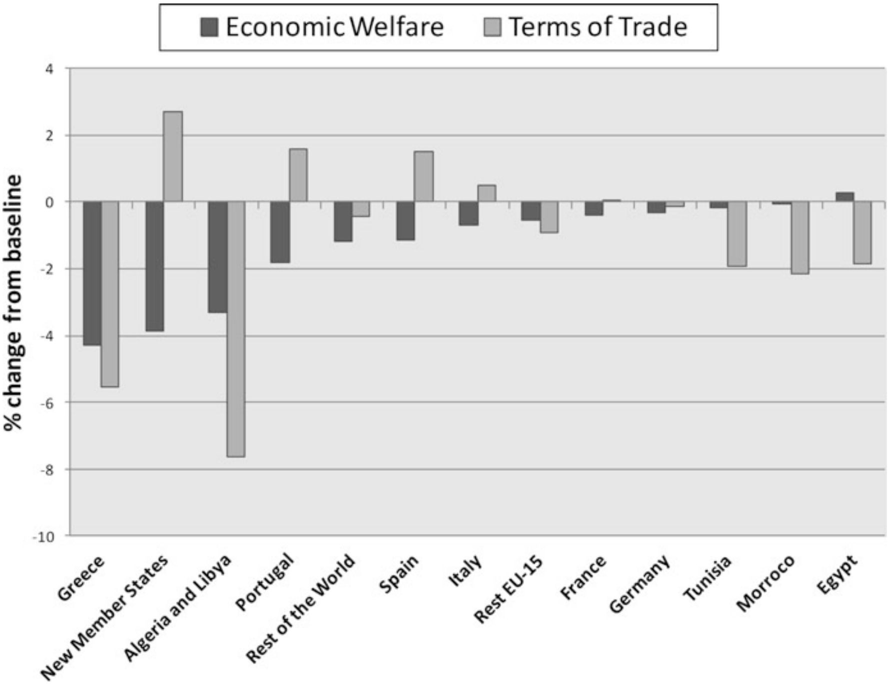

Fig. 14.8 Change from reference of economic welfare and terms of trade in Concerted scenario; year 2030 (Source: GEM-E3-Med)

economic dependence on fuel exports (see Fig. 14.8). Welfare in Algeria and Libya is greatly affected by the decrease of global fossil fuel demand and the ensuing fall of terms of trade. Terms of trade in this scenario deteriorate for all N. African countries, while in the EU-Alone scenario this was true only for Algeria and Libya. While in the EU-Alone scenario the deterioration of terms of trade for Algeria and Libya (but not the rest of N. Africa) stemmed from the fall in global fossil fuel demand, in the Concerted scenario the overall deterioration in terms of trade is attributed to higher European and RoW export prices.

14.3.2.3 Sectoral Results and International Trade

Despite the fact that global fuel demand falls by −14% in 2020 as compared to the reference case, N. Africa maintains its overall fossil fuel production levels. This is primarily due to the very low production costs that characterize the region providing competitive advantages in world markets. For example even though the gas main trading partner, Italy, greatly reduces demand, N. Africa is more competitive than RoW and hence increases its exports share.

Domestic production in N. African countries presents a higher increase from reference than that of the EU Alone scenario when it comes to energy intensive products. Despite the fall in domestic demand for energy intensive products, the production increases due to import substitution and increasing exports. On the other hand domestic production of most other sectors is reduced compared to the EU-Alone scenario due to the sharper fall in domestic demand. The key driver in the reduction of agricultural, consumer goods and service domestic production is domestic demand. The only sectors registering an increase in domestic demand in N. Africa is the energy sectors (fuels and electricity) due to the rise of energy intensive production. All N. African countries increase their exports, while the greatest increase remains in the transport, agricultural and chemical sectors as in the EU-Alone scenario. Algeria and Libya gain the largest share in the increase of N. African exports.

EU27 presents a sharp decrease in fossil fuel domestic demand and a subsequent increase in renewable energy deployment, reaching 47% of electricity production from RES in 2030 10% more than the penetration of renewable in the electricity production for the EU-Alone scenario. This is due to the additional Renewable energy penetration constraint imposed on the economy, which is assumed to be greater than that of the EU-Alone scenario. A strict but lower Renewable energy target for RoW is also assumed. On the other hand, N. African countries show an increase in fuel and electricity demand due to their shift to more energy intensive production. These are the only sectors showing an increase in demand compared to the reference, resulting from increased demand for energy-intensive exports.

14.3.2.4 Labor Market Effects

Regarding the labor market, unemployment globally increases by 0.3% in 2030 due to reduced global activity levels (−2.33% of GDP). The N. Africa unemployment rate remains roughly the same while real wage falls by 0.6%. Employment is

Table 14.16 Employment sectoral impact in Concerted scenario from reference; year 2030

	% Share of total EU27 employment	EU27 (%)	% Share of total N. African employment	N. Africa (%)	% Share of total RoW employment	RoW (%)
Agriculture	0.7	−5.2	5.3	−0.3	5.3	−0.5
Coal	0.0	−51.3	0.0	34.8	0.2	−54.3
Oil	0.1	−24.3	9.4	2.6	3.7	−23.5
Gas	0.1	−26.0	4.6	−4.4	1.2	−14.6
Electricity supply	0.5	−2.1	0.6	0.1	0.5	0.7
Ferrous, non ferrous metals	1.1	−1.6	1.4	1.2	4.2	−0.3
Chemical products	1.9	−1.1	1.4	5.7	4.3	−1.5
Other energy intensive	1.7	−1.7	3.6	1.5	3.7	−0.4
Electric goods	0.7	5.1	0.6	0.2	2.7	6.7
Transport equipment	1.3	1.1	0.7	0.0	2.4	3.7
Other equipment goods	2.6	0.1	0.6	−0.3	5.9	1.6
Consumer goods industries	3.9	−0.9	10.9	−0.1	9.4	0.3
Construction	4.2	−0.5	5.8	−0.6	5.7	−0.6
Transport	4.2	−2.0	7.5	1.5	4.6	−2.2
Market services	53.0	−1.8	27.8	−0.6	31.3	−2.6
Non market services	23.9	−0.2	19.8	−0.4	15.0	−1.4
Total employment		−1.3		−0.03		−2.43

Source: GEM-E3-Med

projected to decrease in the gas sector of Algeria and Libya, where a reduction in employment of 7.5% is registered in 2030 but at the same time this is compensated by an increase in energy intensive industries. Employment in the region is increased for the sectors that register an increase in exports, namely transport, agriculture and chemical products. Table 14.16 presents the regional changes in employment (in million persons) when compared to reference. The sectoral results regarding the effects of the climate mitigation policy on the labor market for N. Africa highlight the improved competitiveness of N. Africa in this scenario compared to the EU-Alone case.

14.3.3 CSP Scenario

The GEM-E3-Med model has been extended so as to incorporate CSP as a discrete power technology. The technical specifications of the technology were extracted from the TECHPOL database SAPIENTIA (2005), Table 14.17.

Table 14.17 Technical specification of CSP with storage

		2007	2011	2050
Nominal capacity	MW	100–150 MW		
Overnight Inv. cost	€/kW	5,350	4,865	3,650
Interest during construction	€/kW	272	247	186
Technical lifetime	Years	30	30	30
Construction time	Years	3	3	3
Interest rate	%	5	5	5
Discount rate	%	8	8	8
Economic lifetime		25	25	25
Total investment cost	€/kW	5,622	5,112	3,836
Annuity payment for WACC 8%	€/kWy	482	439	329
Annual O&M costs		67	61	46
Load. factor	%	50	50	50
Generation (annual)	MWh	4.38	4.38	4.38
Production cost	€/MWh	126	114	86
Total required land	km^2	11.4	11.4	11.4

Source: Authors calculations based on TECHPOL database (2004–2006)

Table 14.18 Investment cost for 20GW CSP plant in Egypt

		2020
Capacity	GW	20
Investment cost – CSP	billion €	81.30
Investment cost-lines	billion €	16.00
Total Investment cost	billion €	97.30

Source: Salazar (2008)

In order to take into account the additional costs per kW installed, incurred by the transmission of electricity from N. Africa to the EU27 the information provided in Salazar (2008) was exploited (Table 14.18).

The production costs per MWh for each power producing technology identified in the GEM-E3-MED are presented in Fig. 14.9 below.

The CSP scenario is defined as an international concerted action to reduce GHG emissions and the deployment of 36GW CSP power plants in Northern African countries (in order to produce carbon free electricity for the EU27, the exact deployment for each country is depicted in Table 14.19). The overall GHG mitigation policy is the same as in the concerted scenario with the exception that N. Africa also participates in the effort in collaboration with the EU27. This collaboration is assumed to take the form of participation in a common emission permit market with an allocation of permits to N. African countries equal to their reference case CO_2 emissions.

CSP deployment in the N. African countries implies a transfer of funds from the EU-27 in exchange for carbon free electricity, this transfer corresponds overall to 175b€ by 2030. The CSP investment is funded by the EU27, and can be interpreted as a CDM project. The share of CSP financing of each member state is analogous to its CSP electricity imports.

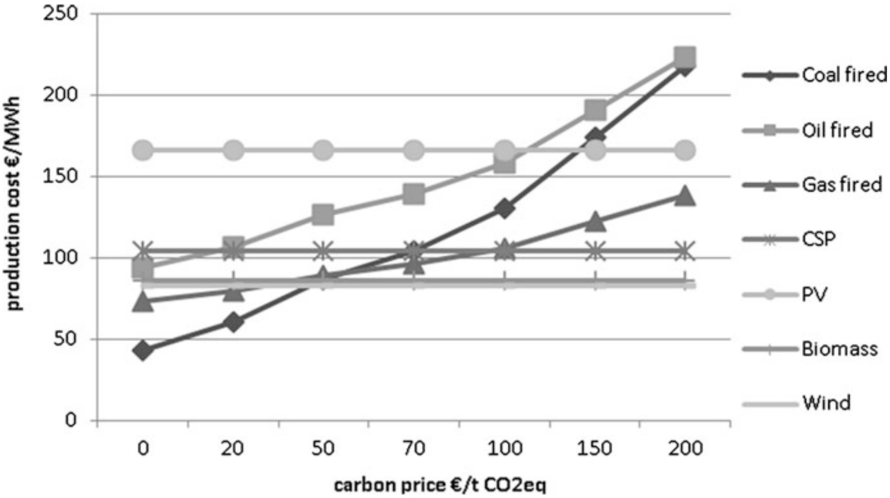

Fig. 14.9 Power technologies production cost per MWh for different carbon prices in 2025 (Source: Authors calculations using reference fossil fuel prices)

Table 14.19 CSP capacity in GW

	2020	2025	2030
Egypt	2.2	4.9	7.5
Morocco	1.6	3.6	5.6
Tunisia	0.1	0.2	0.4
Algeria and Libya	6.6	14.6	22.6
Total	10.5	23.3	36.1

Source: TRANS-MED (DLR)

The initial shock that triggers changes throughout the N. Africa economies relate to the: (i) revenues resulting from electricity sales to the EU-27 (ii) foreign direct investment from EU in order to build the CSP power plants and (iii) the effect from their inclusion in a common permit trading club with the EU27. In the N. Africa region it is assumed that revenues from permit sales are recycled back to the production sectors of the economy.

The inclusion of N. African countries in a common trade club with the European Union offers EU27 member states wider opportunities to seek cost effective abatement options. Thus in 2030 the enlarged permit market offers more options for arbitrage hence a lower carbon price (210€ t. CO_2), compared to the concerted scenario (234€ t. CO_2), is required in order to meet the same overall GHG emission reduction.

14.3.3.1 Economic Welfare

In terms of welfare (measured through Hicksian equivalent variation) the CSP scenario provides the best prospects, amongst all the scenarios examined, for the

Table 14.20 Welfare and labor market effects in N. African countries in 2030

	Welfare[a] in billion $	Employment[b]	Wages[b]	Unemployment rate
Egypt	4.2	0.84	11.10	0.06
Morocco	1.8	−0.45	6.50	0.11
Tunisia	0.2	0.21	1.39	0.07
Algeria and Libya	1.0	0.36	3.14	0.09
N. Africa	7.1	0.46	4.06	0.08

Source: GEM-E3-MED

[a] Hicksian equivalent variation (billion $2005)

[b] % changes from reference case

N. Africa region, with a 7 b.$ gain in 2030. The effect on welfare is driven mainly through the adjustments in the labor market. The net effect on employment for the region is positive (unemployment rate is reduced by 0.2% as compared to the reference case in 2030) due to the increase in labor intensive industries (agriculture, services, consumer goods industry) that compensates for the job losses in the energy, the ferrous and non ferrous metals and the equipment manufacturing sector (see Table 14.23). The effect on employment is driven by: (i) the additional demand for labor induced by the deployment of CSP power plants and (ii) the positive effect from recycling the permit revenues sales, which is larger in the labor intensive industries. The increased demand for labor, mainly in the construction and services sectors, increases wages for the region by an average of 4% in 2030 as compared to the reference case.

Table 14.20 provides the welfare effects at both regional and country level together with the impact on wages and overall employment. At a country level Egypt and Algeria and Libya are those that benefit most, in terms of welfare, from the CSP deployment. These countries account for 60% of the total CSP installations.

14.3.3.2 Labor Market Effects

In the GEM-E3-Med model welfare is a function of employment and wages. The effect on wages as presented in Table 14.20 mainly depends on: (i) the unutilized labor stock (as this is indicated by the unemployment rate), (ii) labor productivity (iii) substitution effect between fossil fuels and primary factors of production and (iv) the sectoral distribution of employment (see Table 14.23). In 2030 Egypt is projected to have the highest labor productivity growth amongst all other regions and its wages are lower by a factor of two (2) on average, while its unemployment rate is projected to be the lowest amongst the region. This implies that the additional labor demand (implied by the substitution effect) exerts an upward pressure on wages which is proportionally higher than any other region due to Egypt's lower unemployment rate and wage levels projected in the reference case. In addition the sectoral structure of employment, different in each N. African country, plays a key role in determining the final effect on wages. Employment in the energy sector in Algeria and Libya (Table 14.21) accounts for one third of the total. As will be discussed

Table 14.21 Structure of employment in Northern Africa, CSP scenario (shares in total in 2030)

	Egypt	Morocco	Tunisia	Algeria and Libya
Agriculture (%)	5	10	6	4
Energy (%)	8	2	2	28
Energy Intensive (%)	7	8	5	5
Rest of Industry (%)	24	20	16	10
Services (%)	55	60	72	53

Source: GEM-E3-MED

Table 14.22 Macroeconomic aggregates (% change from reference case in 2030)

	GDP	Investment	Consumption	Net import as % of GDP[a]
Egypt	4.0	1.7	8.6	2.3
Morocco	1.3	1.3	7.3	3.3
Tunisia	0.6	0.0	0.8	−0.3
Algeria and Libya	2.7	0.6	2.0	−1.2
N. Africa	2.7	0.9	5.5	0.9

Source: GEM-E3-MED

[a]Absolute difference from reference case

below the energy sectors throughout the N. Africa countries register a production decrease as compared to the reference case. This entails a release of labor that increases the total available labor supply (the model assumes full labor mobility within the sectors of a country/region). Hence wages increase less in Algeria and Libya as compared to Egypt despite the fact that the CSP deployment in the country is three times bigger.

In 2030 GDP increases in N. Africa countries by 2.7% as compared to the reference case. Table 14.22 presents the decomposition of this increase by GDP component. Higher wages and employment lead to an increase of household consumption by 5.5%, as compared to the reference case. Capital inflows from the EU27, used for the CSP deployment, drives investment that increases by 0.89% as compared to the reference case.

Wage increases result in a deterioration of the relative competitiveness of the region leading to falling exports while at the same time increased demand for equipment required to build the CSP plants produces a deterioration of the region's trade balance (in 2030 the net imports as a share to GDP increase by 0.9% as compared to the reference case).

14.3.3.3 Sectoral Results

From a sectoral point of view, in 2030, it is the energy and energy intensive sectors that register the sharpest decreases in production as compared to the reference case (−8.74 and −1.9% respectively). The electrical goods, construction and service are sectors that contribute to the deployment of the CSP power plants and hence in 2030 production increases as compared to the reference case (Table 14.23). The sectoral

Table 14.23 CSP scenario effects on sectoral employment and production (% changes from reference case in 2030)

	Employment	Production	% of total employment	% of total production
Agriculture	4.1	4.2	5.6	9.2
Coal	−8.0	−22.7	0.0	0.0
Oil	−10.3	−6.0	8.2	9.1
Gas	−15.2	−11.9	4.2	2.2
Electricity supply	−9.1	−18.5	0.5	1.6
Ferrous and non ferrous metals	−3.4	−5.3	1.4	2.0
Chemical products	−1.0	−2.6	1.3	3.0
Other energy intensive	1.5	0.9	3.6	3.5
Electric goods	1.8	0.8	0.6	1.0
Transport equipment	–3.6	−3.2	0.7	1.2
Other equipment goods	−3.4	−2.8	0.6	1.6
Consumer goods industries	1.6	1.4	11.1	18.6
Construction	1.2	1.0	6.0	9.8
Transport	–2.3	−3.6	7.2	4.7
Market services	1.6	3.0	28.6	17.5
Non market services	2.1	1.8	20.4	14.9

Source: GEM-E3-MED

Table 14.24 CSP and Concerted scenario aggregate results (% change from reference in 2030)

	CSP				Concerted			
	GDP	Welfare	Emissions	Carbon price	GDP	Welfare	Emissions	Carbon price
N. Africa	2.7	7.1	−13.0	210.8	0.4	−2.1	0.4	234.1
EU27	−0.9	−31.0	−42.6		−1.1	−36.0	−44.2	
World	−2.2	−75.2	−38.2	127.1	−2.3	−90.0	−38.2	127.2

Source: GEM-E3-MED

impact on employment to a large extent follows the pattern of the sectoral production results.

The effects of the CSP deployment scenario at an international level are presented in Table 14.24 next to the respective results of the Concerted scenario. The overall outcome is a win-win situation for all countries involved (both the Northern Africa countries and the EU27 member states) both in terms of welfare and GDP. EU27 is affected positively both by the enlargement of the permit market (at a low rate however since total CO_2 emissions from northern Africa countries represent roughly 4% of EU27 emissions in 2030) and by the imports of low cost carbon free electricity from northern Africa. Such imports help the EU to meet the RES target without having recourse to more expensive options (i.e. wind) which otherwise encounter serious supply limitations.

Table 14.25 Carbon price (2005 €/t of CO_2)

	EU-Alone	Concerted	CSP
N. Africa	0.0	0.0	211
EU27	105	234	211
World	0.0	127	127

Source: GEM-E3-MED

Table 14.26 GDP, Welfare and Employment results for all scenarios examined (2030, % change from reference case unless otherwise indicated)

	GDP			Welfare[a]			Employment		
	EU-Alone	Concerted	CSP	EU-Alone	Concerted	CSP	EU-Alone	Concerted	CSP
Algeria and Libya	0.05	0.08	2.67	−1.20	−3.30	1.55	−0.12	0.03	0.36
Egypt	0.12	0.59	4.04	0.32	0.26	6.79	0.01	−0.02	0.84
Morocco	0.11	0.51	1.25	0.17	−0.06	3.95	−0.01	−0.15	−0.45
Tunisia	0.12	0.68	0.63	0.08	−0.17	0.52	0.00	−0.05	0.21
N. Africa	0.02	0.40	2.67	−0.50	−2.15	7.12	−0.03	−0.03	0.46
EU27	−0.69	−1.09	−0.85	−9.33	−35.98	−30.99	-0.55	−1.24	−1.13
World	−0.02	−2.33	−2.25	−8.70	−90.05	−75.22	−0.03	−2.37	−2.35

Source: GEM-E3-MED

[a] Hicksian equivalent variation for regional results (billion $2005), and changes in economic utility for country specific results

14.4 Conclusions

The computable general equilibrium model GEM-E3-MED is used to examine the growth opportunities for N. African economies in the context of an increasing intensity of climate policy and of a widening of its geographical scope providing opportunities for cross border integration of energy markets, for extension of emission permit markets and the use of CDM development mechanisms.

The analysis is quantitative and focuses on the effect of the alternative scenarios on competitiveness, welfare, employment and economic growth of the Mediterranean economies and in particular the N. African countries.

The carbon price produced in all scenarios is presented in Table 14.25. The inclusion of N. Africa countries in a common trade club with the European Union offers EU27 member states wider opportunities to seek cost effective abatement options. Thus in 2030 the enlarged permit market offers more options for arbitrage hence a lower carbon price (211€ t. CO_2), compared to the concerted scenario (234€ t. CO_2), is required in order to meet the same overall GHG emission reduction.

Table 14.26 presents the results on GDP, employment and welfare obtained from all alternative scenarios examined. In all scenarios world activity is reduced as a result of the GHG mitigation policy within a range of −0.02 to −2.33% as compared to the reference case in 2030. In the EU-Alone and the concerted scenario N. Africa is virtually unaffected by the decrease in world activity whereas towards the end of the simulation period (2030) positive gains in terms of GDP (0.4% as compared to the reference case) are registered. This effect is mainly attributed to a shift of production towards energy intensive activities as a result of import substitution.

Fuel demand falls at the global level, especially in the Concerted scenario and as a result N. African economies that depend highly on revenues from fuel exports, like Algeria and Libya, register a deterioration in their terms of trade. In the EU-alone and concerted scenario the impacts of the GHG mitigation policy are stronger in Algeria and Libya due to the importance of fuel exports in their trade balance.

The overall outcome of the CSP scenario is a win-win situation for all countries involved (both the Northern Africa countries and the EU27 member states) both in terms of welfare and GDP. EU27 is affected positively both by the enlargement of the permit market and by the imports of low cost carbon free electricity from northern Africa.

In the CSP scenario employment effects largely depend on the unutilized labor stock, labor productivity of each N. Africa country, the substitution effect between fossil fuels and primary factors of production and the sectoral distribution of employment. The net effect on employment for the N. Africa region is positive (0.4% in 2030 as compared to the reference case) due to the increase in labor intensive industries such as agriculture, services and consumer goods industry that compensates for the job losses in the energy, the ferrous and non ferrous metals and the equipment manufacturing sectors.

14.5 Annex

Table 14.27 GEM-E3-MED sectors/products

No	Activity	No	Activity
1	Agriculture	15	Coal
2	Ferrous and non ferrous metals	16	Oil
3	Chemical products	17	Gas
4	Other energy intensive	18	Electricity supply
5	Electric goods	19	Coal fired
7	Other equipment goods	20	Gas fired
8	Consumer goods industries	21	Oil fired
9	Construction	22	Nuclear
10	Telecommunication services	23	Biomass
11	Transport	24	Hydro electric
12	Services of credit and insurances	25	Wind
13	Other market services	26	CSP
14	Non market services	27	Photovoltaics

Table 14.28 GEM-E3-MED countries/regions

No	Country/Region	No	Country/Region
	EU-MED		Northern Africa
1	Spain	8	Alegria and Libya
3	Greece	9	Egypt
4	France	10	Morocco
5	Germany	11	Tunisia
6	Portugal	12	New EU member states
7	Rest of EU15	13	Rest of the world

Table 14.29 GEM-E3-MED consumption by purpose categories

No	COICOP	No	COICOP
1	Food beverages and tobacco	8	Purchase of vehicles
2	Clothing and footwear	9	Operation of personal transport equipment
3	Housing and water charges	10	Transport services
4	Fuels and power	11	Communication
5	Household equipment and operation excl heating and cooking appliances	12	Recreational services
6	Heating and cooking appliances	13	Miscellaneous goods and services
7	Medical care and health	14	Education

14.6 Appendix

14.6.1 Overview of the GEM-E3-MED Model

The GEM-E3-World model[2] (GEM-E3 2008) is a multi regional, multi-sectoral, recursive dynamic Computable General Equilibrium (CGE) model that incorporates all economic agents, an environmental module that includes permit trading markets for all GHG emissions, endogenous bilateral trade flows, discrete representation of power producing technologies and an imperfect labor market based on the efficiency wages approach (Shapiro and Stiglitz 1984). The regional and product coverage of the GEM-E3-MED model are presented in Annex (Tables 14.27, 14.28, and 14.29). The input output tables of the model are computed based on the GTAP v.7 dataset.[3] A more analytic description of the model can be found in the E3MLab website.[4]

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[2] The model has been developed as a multinational collaboration project, partly funded by the Commission of the European Communities, DG Research, 5th Framework programme and by national authorities.

[3] https://www.gtap.agecon.purdue.edu/databases/v7/

[4] http://www.e3mlab.ntua.gr/e3mlab/GEM%20-%20E3%20Manual/Manual%20of%20GEM-E3.pdf

14.6.2 Firms' Behavior

Domestic production is defined by branch and it is assumed that each branch produces a single product which is different from any other product in the economy. Production functions in the *GEM-E3-MED* are of the Constant Elasticity of Substitution (CES) type and exhibit a nested separability scheme, involving capital (K), labor (L), energy (E) and materials (M). The top level of the CES nest defines capital and Labor-Energy-Materials bundle input substitutability. Firms operate in a perfect competition environment and maximize their profits subject to their production function. The solution of the firms' optimization problem consists of the optimal demands for each production factor. The derived demand and the unit cost functions determine the firms demand for production factors and its product supply.

14.6.3 Household

In the GEM-E3-MED model there is one representative household by region. Household behavior is derived through a two stage utility optimization problem. The consumer utility function is a LES (Linear Expenditure System – Stone (1954)) extended according to Lluch (1973) and has as arguments the consumption of goods, subsistence minima of consumption, leisure, and subsistence minima of leisure. In the first stage households decide on the allocation of their income M between consumption of goods and leisure. In the second stage the consumer should allocate its consumption over the different consumption goods. In GEM-E3-MED the consumption purposes (*fn*) are distinguished in durable goods (*dg*) and non durable goods (*nd*) where (fn:{dg,nd}) and the approach of Conrad and Schroder (1991) is followed.

14.6.4 Labor Market

General equilibrium models usually assume that no involuntary unemployment can exist and if wages were flexible enough the supply and demand for labor would balance at what is essentially considered to be full employment. Unemployment can be interpreted only as a voluntary choice of households for leisure. This situation clearly does not pertain to the North African countries and some modifications to the model had to be introduced in order to enhance its realism in this respect as well as a fuller analysis of the consequences of different policies. In the GEM-E3-Med model the efficiency wage approach is incorporated in order to represent involuntary (equilibrium) unemployment. Our approach is consistent with the efficiency wages theory of Shapiro and Stiglitz (1984) which states that productivity/quality of labor has a positive correlation with wages. The model has been calibrated to ILO statistics.

14.6.5 Investment

The demand for capital for the next year, which fixes the investment demand of firms, is determined through their optimal decision on factor inputs for the next year within the framework described above. The optimal long-run cost of derived capital is according to Ando- Modigliani formula (Ando et al. 1974). The comparison of the available stock of capital in the current year with the desired one determines the volume of investment decided by the firms. Since capital is fixed within each period, the investment decision of the firms affects their production frontier only in the next period. The investment demand of each branch is transformed into a demand by product, through fixed technical coefficients, derived from an investment matrix by product and ownership branch. This together with the government investments which are exogenous in GEM-E3-Med, constitute the total demand for investment goods.

14.6.6 Discrete Representation of Power Producing Technologies

The Input-Output tables represent the electricity sector as an aggregate of two activities: the power generation and the transmission and distribution of electricity. In the GEM-E3-Med model the electricity sector is split into different activities according to data from energy balances and company-related economic data about generation and transmission and distribution activities by country. It is assumed that power technologies produce electricity using a constant elasticity of substitution (CES) production function. The data are extracted from Eurostat, IEA and USA DOE statistics. Figure 14.10 shows the nesting scheme of the GEM-E3-Med model.

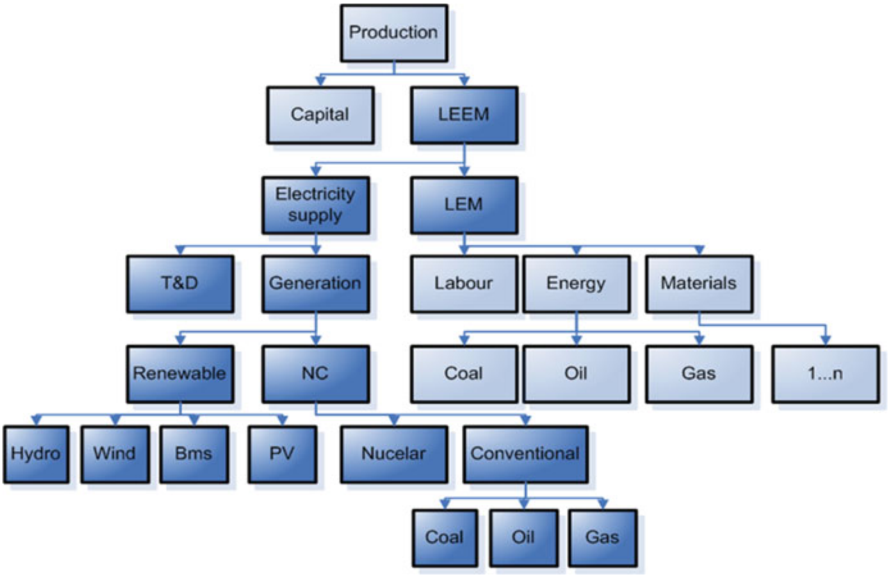

Fig. 14.10 GEM-E3-Med nested production function

Table 14.30 Shares to total electricity generation (2005)

	Egypt	Tunisia	Morocco	Libya and Algeria
Coal fired (%)	0.0	0.0	58.1	0.0
Oil fired (%)	16.1	14.2	21.4	25.3
Gas fired (%)	72.1	84.9	12.8	74.4
Nuclear (%)	0.0	0.0	0.0	0.0
Biomass and waste (%)	0.0	0.0	0.0	0.0
Hydro (%)	11.2	0.7	6.9	0.4
Wind (%)	0.5	0.3	0.8	0.0
Solar (%)	0.0	0.0	0.0	0.0

Source: IEA

Table 14.30 provides the statistics used for the calibration of the power generation technologies in 2005 for the N. African countries.

14.6.7 Trade

The Armington assumption is followed in GEM-E3-Med according to which demand for products (final or intermediate) is allocated between domestic products and imported products. In this specification, branches and sectors use a composite

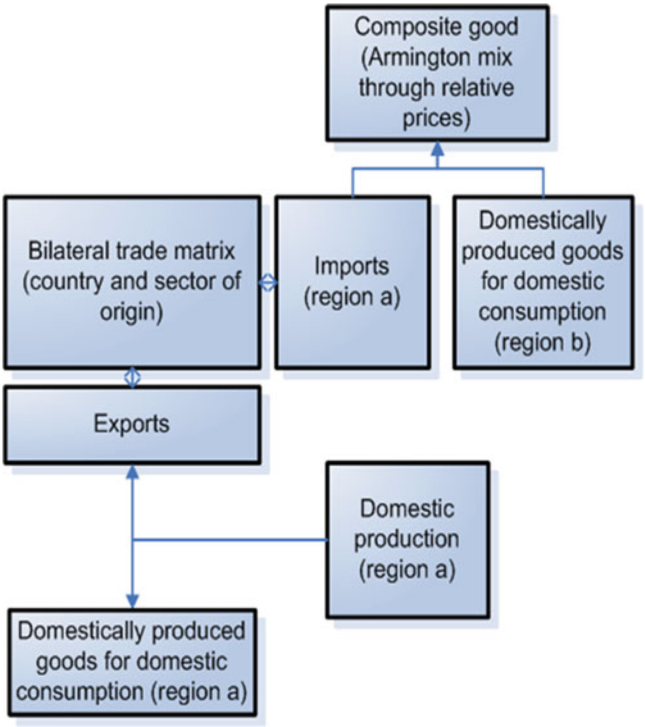

Fig. 14.11 Trade flows in the GEM-E3-Med model

commodity which combines domestically produced and imported goods, which are considered as imperfect substitutes. Demand for imports is allocated across imported goods by country of origin. Bilateral trade flows are thus treated endogenously in GEM-E3-Med. The optimal demand for domestic and imported goods is obtained by employing the Shephard's lemma. Import demand is allocated across region of origin using a CES functional form. The model ensures that the balance of trade matrix in value and the global Walras law are verified in all cases.

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Chapter 15
Mediterranean Tourism and Climate Change: Identifying Future Demand and Assessing Destinations' Vulnerability

Alexandre Magnan, Jacqueline Hamilton, Jaume Rosselló, Raphaël Billé, and Angel Bujosa

Abstract This chapter estimates the trends, impacts and responses of Mediterranean tourism, with special emphasis on coastal areas. It presents some part of the work done by two research lines (Economic impacts, Induced policies), namely scenarios for future tourism flows (regional and national scales) and a method for assessing vulnerability of local destinations.

Keywords International tourism • Tourism flows modeling • Coastal zones • Vulnerability assessment • Djerba Tunisia

15.1 Introduction

International tourism is today one of the most important tradable sectors, with an estimated contribution of the Travel and Tourism Industry to World GDP of 9.2 and a 8.1% of jobs of the total employment (WTTC 2009). These figures are more important when countries around the Mediterranean Sea[1] are considered with a GDP contribution of 11.1% and a share in the total employment of 11.5%.

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[1] Including: Albania, Algeria, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia and Turkey.

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Tourism constitutes a dynamic force in the economy of the Mediterranean region (Bethemont et al. 1998), as much through its direct effects as by those it induces. Because of its proximity to rich and populous source markets and the length of time that tourism has been active there, the Mediterranean is the largest tourism region in the world in terms of tourist arrivals and in terms of revenue. The average annual growth rate of international tourists' arrivals between 2000 and 2005 was 3.3% at world level and 2.2% in Europe (UNWTO 2006). In 2000 the countries surrounding the Mediterranean received 220 million international tourists, which are 32% of the world total of 684 million[2] (UNWTO 2005; authors' own calculations). One hundred and fifty nine million arrivals of domestic tourists at accommodation are reported by thirteen Mediterranean countries (UNWTO 2005; authors' own calculations).[3] Nevertheless, these figures should be taken with care considering the fact that not all the Mediterranean Countries concentrate the tourism industry near the coastal areas.[4] Coastal tourism, however, is the dominant form of tourism in many regions and destinations across the Mediterranean.[5] Furthermore, coastal areas are at the terrestrial and marine interface: they constitute very sensitive environments. Consequently, this chapter will look specifically at the coast, in terms of the physical impacts of climate change, and at coastal tourism, in terms of the impact of climate change on tourism demand and on the vulnerability of coastal destinations to climate change.

In spite of the important contribution of the tourism sector to the economy, it is remarkable that the academic literature has paid comparatively little attention to analyze the interactions between climate change and tourism. There are indeed a few studies (for example: Maddison 2001; Eugenio-Martín and Campos Soria 2010) that build statistical models of the behavior of certain groups of tourists as a function of weather and climate, and there are similar studies on recreational behavior. Although, it seems the situation is now slowly changing and during the last years,

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[2] For comparison: the Americas had 109 million international arrivals (16%), Western Europe had 139.7 million international arrivals (20%) and Asia and the Pacific had 110 million international arrivals (16%) in 2000 (UNWTO 2005).

[3] Not reporting: Algeria, Egypt, Lebanon, Libya, Malta, Tunisia and Turkey.

[4] The sub-national breakdown of tourist arrivals will be discussed later in the chapter.

[5] This explains why fieldwork developed in the CIRCE project had been focused on seaside tourism and had considered tourism in its global dimension. The whole set of direct and indirect activities that determine the tourism potential and/or that benefit from tourism development (e.g. airport services, taxis, farming and fisheries activities, small groceries, etc.) had thus not been taken into account separately, although all of them will be impacted by a decrease of tourism in case of too constraining climatic conditions. We judged in this research that having an understanding of the general processes at work (considering the tourism territory as a coherent system rather than focusing on the multiple forms of tourism) was a preliminary work. Conclusions should thus have to be completed by in-depth local case studies in order to explain the chain of impacts that lead from a general decrease/reorganisation in tourism flows to an economic catastrophe affecting the whole territory. Considering coastal tourism as the driver of tourism in the Mediterranean also led us to not study the potential consequences of climate change on winter and urban tourism, e.g., although these impacts could be of major importance for mountain territories and cities, respectively. Here again, specific studies should be conducted.

different branches of literature have started to grow. Firstly, a handful of studies (e.g., Berritella et al. 2006) analyze the economic implications on interactions between climate change and tourism. Secondly, there are some studies (e.g., Hamilton et al. 2005a, b; Hamilton and Tol 2007) that use simulation models of the tourism sector. And thirdly, other studies (e.g., Mieczkowski 1985; Matzarakis 2002; Lise and Tol 2003; Amelung and Viner 2006) try to define indicators of the attractiveness of certain weather conditions to tourists. These studies predict that as climate change occurs, there will be both losers and winners in terms of destination attractiveness. Therefore, a reorganization of tourism flows can be expected at the scale of the Mediterranean in addition to the world scale. The need for instruments that can measure changes in tourism demand has led to the development of different quantitative methods to evaluate the effects of climate change on tourism demand in terms of arrivals or departures (Hamilton et al. 2005a, b; Bigano et al. 2006a, b; Hamilton and Tol 2007). However, various gaps exist due to the use of aggregate data – both at a spatial level and at a temporal level. Thus, the CIRCE project in the Economic Impacts research line has tried to fill some of these gaps by estimating empirical relationships between tourist flows and indicators of weather, climate, and the environment using sub-national data and monthly and quarterly time series. In addition, these relationships can be used to analyze scenarios of a variety of changes, so as to gain insight into the relative strength of threats and opportunities to the tourism industry in the Mediterranean.

In parallel, the research line dedicated to Induced Responses and Policies has included a local scale approach in order to also understand what implications climate change and potential associated reorganization of tourism flows could have on local destinations. In this view, an assessment of local coastal destinations' vulnerability to natural hazards and climate change was undertaken. The methodology that had been developed during this work is presented, emphasizing both the associated framework and the criteria and indicators used for the assessment. A case study is also presented (Djerba island, Tunisia) and the general assets and limitations of the work are discussed.

By linking both different scales of analysis (national and regional on the one hand, local on the other hand) and theoretical and field approaches, this chapter aims clearly at providing some general basis to examine the challenging relationship between tourism and climate change and help developing realistic strategies to cope with the climate threat.

The text is organized in six main parts. After the present introduction Sect. 15.2 provides an overview of the relationship between tourism, climate and climate change. It emphasizes the fact that this relation is extremely complex and that climate features are not the sole influential factors of tourists' choices. Section 15.3 gives an overview of the expected physical impacts of climate change on coastal destinations. The Sect. 15.4 reminds the main features and challenges of coastal tourism in the Mediterranean, on the one hand by presenting the results of the integration of climate change scenarios into the future perspectives for tourism, on the other hand by presenting the uncertainties which must be considered and which justify the elaboration of adaptation strategies. Section 15.5 presents the concept of vulnerability and a framework for assessing it. Indeed, because vulnerability assessment allows making a territorial diagnosis, it is considered here as an interesting basis for starting working on the adaptation issue. The final section (Sect. 15.6) concludes.

15.2 Tourism, Climate and Climate Change

15.2.1 Tourism in the Mediterranean

When looking at the national totals for countries of the Mediterranean (Table 15.1) for the year 2000, it appears that tourism at the Mediterranean contributes to almost a third of the world tourism total. Seventy-five percent of this comes from France, Italy and Spain. France and Spain, however, have a significant amount of tourism in non-Mediterranean regions. This can be seen in Table 15.2 where the arrivals of international and domestic tourists at accommodation in 2005 at the Mediterranean NUTS 2[6] regions are shown. For France the Mediterranean's share of total arrivals is only 16%. For Greece and Croatia, tourism at the Mediterranean coast is dominant: the Mediterranean regions have shares of 100 and 91% respectively. It should be noted, however, that only one of Greece's NUTS 2 regions is not directly on the coast. For Slovenia, Italy and Spain Mediterranean tourism is significant with shares of 74, 72 and 68% of total national tourism respectively. The most popular regions for international tourists are Catalonia, Veneto and the Balearic islands. The NUTS 2 regions are in many cases quite big and a significant amount of tourism will not be directly at the coast.

15.2.2 The Relative Importance of Climate for Tourism

15.2.2.1 The Role of Climatic Conditions for Tourism

The relationship between tourism and climate has been studied for several decades (Besançenot 1990). The general viewpoint is that the climate conditions dictate the organization of tourism flows. Therefore since the beginning of the tourist era, the Mediterranean has represented the pleasure periphery[7] for northern Europeans, between the end of the eighteenth century and the mid-twentieth for its winter warmth, and until now for its summer charms. This evolution shows that what makes a place attractive can change with time, and therefore that the period perceived as

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[6] NUTS is a classification system of regions used by countries in the European Union. NUTS 2 is the second level of this system and the best informed in terms of data.

[7] The expression is borrowed from J. Turner and L. Ash (The golden hordes: international tourism and the pleasure periphery, 1976, St. Martin's Press).

Table 15.1 Arrivals of international and domestic tourists in 2000

Country	International tourist arrivals at borders in thousands	Domestic tourist arrivals at all collective accommodation in thousands	Country	International tourist arrivals at borders in thousands	Domestic tourist arrivals at all collective accommodation in thousands
Albania	32	133	Libya	174	
Algeria[a]	866		Malta	1,216	
Croatia	5,831	911	Morocco	4,240	1,080
Cyprus	2,686	279	Serbia and Montenegro	239	1,529
Egypt	5,116		Slovenia	1,090	512
France	77,190	64,913	Spain	47,898	32,133
Greece	13,096	5,567	Syria	1,416	685
Israel	2,417	4,132	Tunisia	5,058	
Italy	41,181	37,963	Turkey	9,586	8,825
Lebanon	742		Total	220,074	158,662

Source: UNWTO (2005)

[a] Arrivals of international visitors is used as international tourists arrivals is not available

Table 15.2 Regional international and domestic tourist arrivals at accommodation in 2005

NUTS 2 region	International tourist arrivals	Domestic tourist arrivals
Croatia		
Jadranska Hrvatska	6,027,793	962,108
Croatia total	6,027,793	962,108
Share of Mediterranean regions in country total	91%	71%
Cyprus	1,762,658	456,128
France		
Languedoc-Roussillon	1,652,147	5,124,941
Provence-Alpes-Côte d'Azur	4,608,171	7,710,649
Corse	643,382	1,154,425
France total	6,903,700	13,990,015
Share of Mediterranean regions in country total	16%	17%
Greece		
Anatoliki Makedonia, Thraki	103,648	486,016
Kentriki Makedonia	594,341	965,925
Thessalia	227,066	561,135
Ipeiros	57,043	285,306
Ionia Nisia	731,493	271,250
Dytiki Ellada	255,670	391,728
Sterea Ellada	222,046	346,523
Peloponnisos	364,850	617,267
Attiki	1,758,546	1,107,049
Voreio Aigaio	132,727	155,151
Notio Aigaio	1,465,992	383,133
Kriti	1,414,626	318,053
Greece total	7,328,048	5,888,536
Share of Mediterranean regions in country total	100%	97%
Italy		
Liguria	1,108,175	2,338,840
Veneto	7,571,713	4,916,151
Friuli-Venezia Giulia	694,219	1,043,382
Emilia-Romagna	1,850,100	6,113,484
Toscana	5,212,222	5,162,873
Marche	325,320	1,740,931
Lazio	5,885,889	3,931,076
Abruzzo	175,197	1,293,393
Molise	14,770	182,822
Campania	1,721,715	2,724,802
Puglia	368,667	2,116,740
Basilicata	57,779	409,012
Calabria	188,321	1,240,051
Sicilia	1,540,745	2,762,903

(continued)

Table 15.2 (continued)

NUTS 2 region	International tourist arrivals	Domestic tourist arrivals
Sardegna	574,717	1,324,202
Italy total	27,289,549	37,300,662
Share of Mediterranean regions in country total	72%	74%
Malta	1,030,540	105,231
Slovenia		
Zahodna Slovenija	1,120,121	394,619
Slovenia total	1,120,121	394,619
Share of Mediterranean regions in country total	74%	49%
Spain		
Galicia	704,763	3,262,659
Principado de Asturias	178,960	1,498,018
Cantabria	254,629	1,282,788
País Vasco	643,618	1,484,954
Cataluña	7,991,512	7,546,061
Comunidad Valenciana	2,622,443	5,288,587
Illes Balears	6,998,883	1,549,757
Andalucía	5,952,765	9,648,294
Región de Murcia	227,228	1,024,294
Spain total	25,574,801	32,585,412
Share of Mediterranean regions in country total	68%	65%
Total all European Mediterranean regions	77,037,213	91,682,714

Source: Eurostat (2009) and authors' own calculations

the most suited for travelling is not fixed. Furthermore, a reversal of the situation (sunshine changing from a repellent to an attraction) raises speculation about the evolution of the situation in the context of climate change.

Tourism exploits geographic areas (Gómez Martín 2005), which are characterized by diverse attributes such as topography, landscapes and resources. A potential for tourism therefore appears according to intrinsic conditions of a place, which partly characterized its attractiveness. The first successes of coastal Mediterranean resorts resulted specifically from the contrasts with the climate conditions of northern European areas (Lozato-Giotart 1990; Miossec 1998). Some authors (Giles and Perry 1998; Smith 1990) showed that an exceptionally pleasant summer in northern Europe can immediately lead to a reduction in the number of tourists heading for the Mediterranean, with effects extending over the following years. However, the Mediterranean obtains its most favorable weather conditions for northern Europeans in October–November, since it is in this period that the origin/destination contrast is the strongest (Perry 2000). Then, other cultural or institutional parameters (e.g. school calendar) are also involved, making the summer period the most prized, followed by spring and, only then, by autumn.

Schematically, there are five climate variables recognized to have a definite influence on tourism (Lise and Tol 2002; Gómez Martín 2005; Amelung and Scott 2007): temperatures, sunshine, rainfall, wind and humidity. One generally considers these variables at the destination, because they are assumed to dictate its tourism attractiveness. But the real determining factor, on a strictly climatic point of view, is the contrast between the routine living conditions of tourists and those of the place they go for a limited time. The question then is to know to what extent this contrast has a determining role.

15.2.2.2 Other Drivers Exist Besides Climatic Conditions

Other factors interfere in a tourist's choice of destination, and sometimes with more force than the previous ones. Although climate issues are important, they contribute to the destination's attractiveness as underlying factors. Economic aspects, for example the prices of plane tickets and of accommodation, have a considerable impact (Song et al. 2009). In this case marketing rationale is at least as important as the attractiveness of the climate. Security aspects also contribute to the choice of one destination over another, which can depend on political or public health stability for example. Geopolitical crises and the outbreak of diseases have well known consequences on tourist flows. On a secondary level, questions of accessibility can come into action. In this sense, and regarding the distance-time factor, the Mediterranean offers undeniable comparative advantages to the European population. Finally, other physical characteristics could play a function: if the presence of sun, warm air and sea temperature is desired, would these factors be as important if the destination was not packaged with a beach ("Sea, Sand and Sun")?

Another factor refers to the social changes within the countries where tourists originate, which explain for example the emergence of 'popular' or 'mass' tourism following the introduction of paid holiday in Europe (Miossec 1998). Similarly, fashions had changed within leisure societies, from the attraction of mild winters and then of hot summers, a change which has occurred in less than two centuries as living conditions have evolved; or on a shorter timescale, the enthusiasm for a few over-advertised destinations that have acquired certain reputations. This is the case for Mykonos in Greece or Ibiza in Spain, which promote themselves as unrivalled party destinations. The image of Djerba is more that of a cheap family holiday location, whereas the French Riviera has imposed itself as a chic destination. On a more secondary level, the cultural, historical and natural characteristics of a location can explain its attractiveness (Santorini in Greece, Alexandria in Egypt or Malta).

Therefore, if climatic factors can be considered as determinate on a wide geographic scale (the Mediterranean) they become more relative on a local scale as other elements influence the development of tourism at any given place: the presence of an airport and/or road, the proximity to an economic centre, the exposure to wind (constraining in certain places, useful in others in order to reduce hot temperatures), etc.

Tourism does not respond to any type of natural and climatic determinism, or to a simple economic, social or cultural determinism. Tourist choice actually results from a subtle combination of highly diverse factors, the respective importance of which vary from one individual to another, and from one moment of the year to another (Lise and Tol 2003; Céron and Dubois 2004).

15.2.3 Tourism and Climate Change: A Two-Way Relationship

Climate conditions impact on the availability, current and future, of quality resources as well as on landscapes. Modern transport infrastructure, and therefore systems of goods importation, however tend to reduce this dependence situation, which is particularly evident in terms of the food supply to hotels (international rather than local food). In the same way, hotels are places with relatively high vegetation density, often contrasting with the surrounding areas, which are less green because they are less maintained or more exposed to unfavorable hydrological regimes. Tourism operators obtain modern and expensive technologies which enable them to "redesign nature" (lush landscapes, sand on beaches, water in swimming pools…). One could then be tempted to say that technologic developments will be able to compensate climatic changes. But this schema is too simplistic (Simpson et al. 2008; UNWTO 2008) in the sense that on one hand many tourist operators do not have the necessary financial means to acquire water treatment plants and seawater desalination facilities, or implement the artificial renovation of beaches with sand. On the other hand, technical solutions will not allow solving all problems: if increased temperatures at tourist destinations can indeed be compensated by the development of controlled temperature swimming pools and air conditioning systems, such solutions constitute sources of greenhouse gas (GHG) emissions, which therefore reinforce the long term consequences of climate change. A short-term perspective can therefore be more damaging in the long term, and then the complexity of the relationship must be acknowledged (Besancenot 1990; Smith 1990; Lise and Tol 2002, 2003; Perry 2003; Billé et al. 2009).

Tourism indeed contributes to the exacerbation of climate change through energy consumption and GHG emissions. The transport sector is particularly responsible: in France for example, leisure and business travel contribute to 24% of emissions from the transport sector and to 8% of emissions from all sectors, while air transport is responsible for 62% of the emissions (D4E 2008). The cleaning of linen (sheets, towels etc) is also energy intensive. These examples demonstrate that tourism has a potential effect on climate change. But tourism tends also to suffer from climate change because of the relationships between beach tourism practices and the natural and climatic characteristics of destinations. It is therefore certain that the expected modification of climate conditions within the coming half-century will result in the modification of practices, of locations (new locations to the detriment of old ones?) and of the temporalities (new seasonalities?) of tourism. The Mediterranean will be all the more vulnerable because the elevation of sea level will tend to accelerate, and with it associated phenomena (coastal erosion, submersion of littoral plains, salinization of ground waters…) (Nicholls and Hoozemans 1996).

Although these two aspects of the problem (impacts of tourism on climate change, and vice versa) are partially linked and inter-dependent (Billé et al. 2009), this text will focus on the vulnerability side.

15.3 How Would Climate Change Threaten Coastal Tourism?

To only consider the impacts on human societies, climate change will have the direct effect of modifying the availability of fundamental resources, such as water, raw materials for energy production, or land itself (e.g. following sea level elevation). This ‘reshuffling of cards’ will necessarily imply a redeployment of human activities, whether they will be transferred into other areas that become, or have remained, suitable; or because of abandonment in preference for others areas. Indeed, a modification of the conditions of water and sea temperatures, more frequent and more intense storms, more active forces of coastal erosion, and a reduction of water resources could lead to a loss of attractiveness for many beach resorts that are currently well reputed. The very future of the legendary town of Venice, a hotspot for world tourism, is jeopardized. What will happen to windsurfing hotspots, such as Alacati in Turkey, for example, if in the near future the winds get weaker? At the opposite extreme, opportunities for tourism development will probably arise in places with beach resort characteristics that today appear relatively unattractive. This is without taking into consideration that summer beach tourism may progressively disappear, just as winter tourism by the sea declined at the end of the nineteenth century.

15.3.1 The Non Climate Pressures in the Mediterranean

Before considering the expected consequences of climate change for tourism, it is necessary to consider the other natural and man-made factors that strongly influence the evolution of coastal regions. The Mediterranean is indeed an area of multiple natural risks (Villevieille 1997) which not all are directly linked to climate processes. Numerous earthquakes e.g. are due to an intense tectonic activity that constitutes one of the major natural threats for the Mediterranean coast. Similarly, the region is subject to strong volcanic activity (e.g. Vesuvius and Etna in Italy) and to the risk of tsunamis.

In parallel, tourism is a part of a much wider process that is leading to growing settlement of the coastal areas and to land-use changes (Benoit and Comeau 2005). In some countries such as Greece, Israel or Lebanon, more than 80% of people are already concentrated near to the sea, and in Tunisia and Italy this proportion varies between 60 and 70%. In total, the Blue Plan[8] estimated that one third of the inhabitants of countries close to the Mediterranean were effectively concentrated in coastal regions. These demographic concentrations cause as much as they are induced by coastal urbanization – more than 40% of the coastline according to the Blue Plan. Yet, the notable consequences of urbanization include the development of infrastructure: road networks, airports (112 along the Mediterranean coast), commercial and leisure ports (more than 1,000 altogether), and elements dedicated to the production of energy or the desalination of seawater and treatment of wastewater.

15.3.2 The Expected Consequences of Climate Change

Climate change will have direct and indirect consequences on tourism and they will be both physical and induced by greenhouse gases mitigation policies. All together, they permit the consideration of both one-off incidents, isolated in time, and gradual perturbations.

15.3.2.1 The Physical Impacts on Coastal Areas

Six principal types of natural hazards can be identified[9] that will directly impact on tourism activity (IPCC 2007): three related to the expected elevation of sea level (coastal erosion, submersion of littoral plains, salinization of ground water); one related to the increase of air temperatures (heat waves); and two related to the change of rainfall patterns (drought, floods). All these risks are not necessarily new, as numerous coastal territories already experience them, but the effect of climate change will probably reinforce them.

15.3.2.2 Some Consequences for the Tourism Activity

Two major threats seem to guide the identification of climate change adaptation strategies for tourist coasts: the probable modification of biodiversity richness and exploitable resources, and the possible loss of land. And yet, local and regional

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[8] http://www.planbleu.org/indexUK.html

[9] For detailed and Mediterranean targeted climate projections, please refer to Part I of the RACCM.

development strategies are constructed and articulated around the availability of resources and land. For example, conflicts are likely to increase/arise between local communities and the tourism sector because the pressure exerted by climate change on attractive but resource limited ecosystems represents a major threat to the related activities (e.g. diving *vs.* fishing, golf *vs.* agriculture).

Scott et al. (2007) also emphasize that two other kind of consequences must be considered. Firstly, GHG emissions reduction policies will also have indirect impacts on tourism, for example through transportation costs. These impacts could prove to be as decisive for tourism as those of climate change itself. Secondly, climate change is expected to have very indirect consequences on society, in particular on lifestyles, economic growth, political stability, etc.

When combined, these impacts (direct and indirect, physical and anthropogenic) will have effects on the vulnerability of specific destinations and tourism sectors, and more generally on the competitiveness of destinations. They will very likely lead to the seasonal and spatial redistributions of tourism flows. For example in summer, the mass movement from northern Europe towards the Mediterranean could break down as northern Europeans find that tourist destinations closer to home are increasingly satisfying; while Mediterranean populations may be more likely to seek milder climes in the north. Conversely, in autumn and winter the north-south flow could intensify.

Regarding on one hand the degradation of coastal and marine ecosystems, and on the other the exacerbation of differences between coastal development from one area to another, one worrying question is to know what role tourism can play towards the more consistent and therefore balanced development of the Mediterranean basin as a whole. Furthermore, it is crucial to place this into a climatic perspective.

15.4 What Trends Are Expected for Mediterranean Coastal Tourism?

The projections we usually use for the Mediterranean region take the total volume of tourists in the basin to more than 637 million in 2025. Unfortunately, these Blue Plan projections do not go beyond 2025 and, more important here, do not consider the potential effects of climate change. This was one of the objectives of the CIRCE's research line called 'Economic impacts' to start filling this gap.

Although there has been recent controversy over the weaknesses of the current models in predicting tourist flows under scenarios of climate change (Gössling and Hall 2006; Bigano et al. 2006a), quantitative methods to evaluate the possible effects of climate change on tourism demand in terms of arrivals or departures have been developed. Within the CIRCE project three perspectives have been evaluated: the national and regional demand models, time series models and microeconomic choice models.

15.4.1 National and Regional Demand Models

One perspective can be found in the global models developed and applied by Hamilton et al. (2005a, b), Bigano et al. (2006b) and Hamilton and Tol (2007) where a simulation model of world international flows is estimated and climate change scenarios of tourist departures and arrivals are evaluated. The Hamburg Tourism Model has been used to examine the changes in international and domestic tourism up to 2100 (Bigano et al. 2008).

The Hamburg Tourism Model (HTM) simulates global tourism demand. Both in terms of how many tourists a country generates as well as how many tourists a country receives. Total tourism demand is estimated using population and per capita income. Then using data on land area, length of coast, temperature and per capita income the number of domestic and international tourists a country produces is estimated. Following this the arrivals for each country are estimated using, among other things, temperature. In order to examine the situation with and without climate change scenarios of population growth, economic growth and climate change are used. For the scenario with climate change all three are used. For the scenario without climate change only population and economic growth are used. The SRES scenario A1B was used for the results shown in Table 15.3. The model simulates in 5 year time steps throughout the twenty-first century for 207 countries and territories.

The model predicts that climate change will reduce the numbers of tourists in the countries to the south of the Mediterranean and for the islands nations of the Mediterranean (see Table 15.3). This is because on the one hand the main source markets in the north of Europe become more attractive for domestic tourism and international tourism and on the other hand the destination countries become less attractive for international tourism. Thirteen countries have a difference of more than 20% between the scenario with and without climate change. For Algeria arrivals would be almost half in the scenario with climate change compared to without climate change. The impact on domestic tourism is not quite as dramatic. Several countries would experience no change in the amount of domestic tourists. The impact ranges from a positive impact on domestic arrivals of 31.5% to a negative impact of −17.4%. In terms of expenditure, there are small gains for the countries in Northern Mediterranean (for example, 23% for Slovenia) and larger losses for the countries of the Southern Mediterranean (up to −30% in the case of Cyprus). It must be noted that these results are for the impact over the century. Compared to the annual growth rates of tourism caused by population and economic growth the annual growth rates from climate change are relatively small.

It is not just the direct effects of the change in climate that are likely to affect tourism demand.[10] The Hamburg Tourism Model (HTM) uses coastal length per

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[10] It should be noted here that the consequences of both changes in tourism arrivals levels and the spatial reorganisation of the flows on national economies have been more in-depth analyzed in Chap. 1 (Bosello et al.), notably using the HTM model. Please, refer to this chapter.

Table 15.3 Percentage difference between the scenario with climate change and the scenario of population and economic growth only by 2100 in international and domestic arrivals as well as expenditure

	Percentage difference[a] by 2100				Percentage difference[a] by 2100		
Country	(1)	(2)	(3)	Country	(1)	(2)	(3)
Albania	−5.2	20.3	4.7	Lebanon	−25.5	1.6	−3.3
Algeria	−52.1	−17.4	−16.7	Libya	−45.5	−5.2	−4.3
Bosnia and Herzegovina	2.4	27.9	13.7	Malta	−34.5	−5.9	−29.3
Croatia	−4.3	22.6	8.3	Morocco	−32.2	−1.3	−5.7
Cyprus	−32.2	−4.6	−30.3	Serbia and Montenegro	−45.9	0.0	0.7
Egypt	−45.5	0.0	−2.0	Slovenia	6.9	31.5	23.3
France	−3.6	8.5	6.0	Spain	−15.2	5.6	−1.0
Greece	−22.1	0.0	−7.0	Syria	−31.7	−3.3	−10.7
Israel	−35.9	−7.5	−12.5	Tunisia	−37.9	−6.9	−26.7
Italy	−14.8	10.5	5.3	Turkey	−1.4	0.0	2.0

Source: Bigano et al. (2008)

(1) In international arrivals *(2)* In domestic arrivals *(3)* In expenditure

[a] The difference relative to the situation without climate change in 2100 using SRES scenario A1B

country to model tourism demand. The length of coast is of course an important factor, but looking at the characteristics of the coast would be even more useful. It is, however, difficult to find information on coastal characteristics or coastal type for all countries of the world. One study within the CIRCE project (Hamilton and Tol 2010) uses, among other variables, data on the area of beaches, dunes and sands from the CORINE landscape cover database to estimate tourism demand. Sub-national data on tourist arrivals at accommodation in 201 NUTS 2 regions of the European Union was used to examine tourism demand in terms of temperature, number of heritage sites, water quality as well as economic characteristics. Ordinary Least Squares was used to estimate demand and Theil indices were used to examine the variation between and within countries. A positive relationship between beach area and tourism demand is found. Furthermore, the optimal temperature was found to be 18 °C. The Theil indices show that there is greater variation within countries than between countries (Hamilton and Tol 2010). This shows the limitations of the studies using national data.

15.4.2 Time Series Framework

Being one of the important areas in tourism research, tourism demand modeling has attracted much attention from both academics and practitioners. Literature review (Song and Li 2008) agreed in presenting time-series models as one of the most popular methodologies when analyzing aggregated data, as it is possible to work only with historical observations of the tourist variable (univariate models) or the use of determining variables (multivariate models). Particular attention is paid to exploring the historic trends and patterns (such as seasonality) of the time series in order to determine and/or predict the future of this series.

However, in the framework of tourism demand modeling, the use of weather conditions as a predictor of domestic and international tourism had been neglected. Two exceptions can be found in Subak et al. (2000) and Agnew and Palutikof (2006). Thus, Subak et al. (2000) investigated three time series that relate to UK domestic tourism. Although the time series were short, all the series were found to be responsive to weather fluctuations. However, the relationship between the time series in some cases was not easy to understand, concluding that further investigations of the relationship between weather and tourism was needed. Agnew and Palutikof (2006) investigated the sensitivity of UK tourism to weather conditions using monthly data for domestic tourism and annual data for trips abroad, showing that outbound flows of tourists are responsive to weather variability of the preceding year, whereas domestic tourism is responsive to variability within the year of travel. However, the use of the annual scale in the analysis of tourism flows could underestimate tourism short term decisions.

Thus, two main case studies have been developed using transfer function model methodology. The first one (Rosselló et al. 2010) evaluates the significance of the short-term weather conditions in the determination of outbound British flows and simulate the effects of different climate change scenarios. Results show how mean temperature, heat waves, air frost and sunshine days are the weather variables that can be significantly related to the dynamics of the outbound British flows time series. Simulation show how higher temperatures will imply a change in the optimal holidaying weather conditions and, consequently, negatively affect British outbound flows. Meanwhile, because of the non linear relationship introduced in the model by the heat wave variable, it was shown that the effect of temperature warming on tourist flows will not be homogeneous throughout the year, showing the highest impact during summer months and the lowest one during springtime. This result will be of special interest for those tourist destinations located in the Mediterranean as a high percentage of summer British tourist flows chose this destination for their summer holidays.

The second application (Rosselló 2011) analyses variability patterns between quarterly Revenue Passenger Kilometres (RPK), as tourism indicator, and the North Atlantic Oscillation (NAO) index, as climate variability indicator. Using a traditional international air travel demand model, it has been found that the dissociation of the NAO index into positive and negative fluctuations can be related to changes in different geographical RPK time series, once seasonal effects are removed. The results are consistent with the perception that climate and meteorological conditions can play a role as both pull and push factors. Thus, it is suggested that Northern Europeans could be discouraged from travelling to short-haul warm destinations in Southern Europe when weather conditions are favorable in the tourists' main countries of origin, whereas tourists from Southern European countries might travel to the Caribbean when colder winters persist in the Mediterranean.

15.4.3 Discrete Choice Models

Interest in how individuals decide on purchase alternatives (products, brands, etc.) makes the analysis of choice and preference one of the most studied areas of economics in recent years. In the context of climate conditions and tourism choice, the pioneering study of Maddison (2001) was followed by Lise and Tol (2002). However, different gaps persist within the tourism choice analysis, related to the consideration of domestic tourism, the inclusion of intra-annual temperature variations for a particular destination and the exclusive consideration of the sun and sand tourism market segment within a context of climate change. Bujosa and Rosselló (2009) have analyzed the role of monthly temperature in summer domestic travel by Spanish residents to coastal provinces using data from the Spanish Domestic and Outbound Tourism Survey (Familitur). Using a random utility model where a set of destination-specific attributes, including monthly temperatures, explains a particular choice of destination was undertaken and two climate change projections (A1F1 and B1) were evaluated. Results show how while climate change and the consequent increase in daytime temperatures will impact negatively on coastal provinces located in the south of Spain, coastal provinces in the north will experience a big increase in their expected choice probabilities. At the same time, the impact of climate change on provinces in eastern Spain shows a lower magnitude and higher variability from province to province. Overall, the results of this study predict a redistribution of domestic tourism travel within Spain's coastal provinces, with a shift from southern and eastern Spain to northern Spain. It is important to note that these results are only based on temperature variations and hence the effects of changes under other climate-sensitive conditions (e.g. land cover, sea level rise, biodiversity, etc.) that might be jointly altered in the presence of higher temperatures were not considered.

15.5 A Methodological Framework for Assessing Coastal Tourism Vulnerability

The vulnerability approach can bring useful elements for understanding the impacts of climate change at local scales as it allows a diagnosis to be made on the weaknesses and the strengths of a territory (Downing and Patwardhan 2003; Brooks et al. 2005; Füssel and Klein 2006; Smit and Wandel 2006; Magnan 2009b, 2010). However, despite its growing popularity among scientific circles, one problem here refers to the widespread belief that scientists are able to forecast the level of vulnerability of a specific tourism territory over a long timeframe. This text[11] argues that

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[11] The work we developed in the CIRCE project had not consisted in an in-depth analysis of past events and of societies' reaction to these events, mainly because of a lack of time and access to reliable and exhaustive sources of data. We rather paid attention to the current situation in order to examine what is currently at stake in a context of gradual environmental changes.

because of broad uncertainties both on impacts at local scales and on future tourists' desires and practices (Magnan 2009a), it remains very speculative to make such long range forecasts. It also makes the case for monitoring the evolution of a destination's current level of vulnerability as a better option than attempting to quantify the vulnerability of a territory in 2050 or 2100. From this viewpoint, the challenge consists in developing tools that can be used by local decision-makers and stakeholders. Consequently, this section aims at presenting one possible methodological approach for assessing the vulnerability to current natural hazards, namely those coming from the sea. However, studying the vulnerability to current natural hazards cannot be dissociated from the climate change challenges which must be considered as defining the underlying context.

15.5.1 Elements for Assessing Vulnerability at a Local Scale

15.5.1.1 One Possible Methodological Framework

A particular methodology can only be relevant with regards to the specific objectives and scale of the study. It is then important to note here that a lot of methods exist for assessing the vulnerability of coastal areas (Patt et al. 2009; Romieu and Vinchon 2009). In the CIRCE context, various underlying scientific positions were considered: to focus at a local scale, to put tourism stakeholders (decision-makers and practitioners) at the centre of the work, and to promote a "simple" tool that allows an appropriation by these local stakeholders and then a potential monitoring of the levels of vulnerability.

In this view, four main steps could be considered (Fig. 15.1) in trying to strengthen decision-making capacities at a local scale for promoting wise planning and management practices (Duvat and Magnan 2009). This present tool does not replace technology-based methodologies, but as it can easily be appropriated by decision-makers and practitioners, it aims to support the launch of action plans in contexts where knowledge is inadequate for the promotion of overly complex approaches (lack of technical, institutional and human capacities). Despite low capacities, such coastal areas and countries face coastal hazards that are as serious as those in other territories and similarly they strive to achieve human development and environmental preservation. Climate change enhances these challenges as it is partly irreversible and also because, over the next decades, uncertainties related to its impacts at the local scale will remain high. In such a context, waiting for advancements in order to define action plans is a bad strategy in terms of adaptation to climate change (Hallegatte 2009; Magnan et al. 2009). Simple tools can be useful for drawing up a first diagnosis of the situation that can be completed by additional data once work is underway.

In this methodological perspective, vulnerability is defined by three main components: coastal environment sensitivity (S), anthropogenic features (infrastructures, buildings and populations) and the level of exposure (E) of those elements to

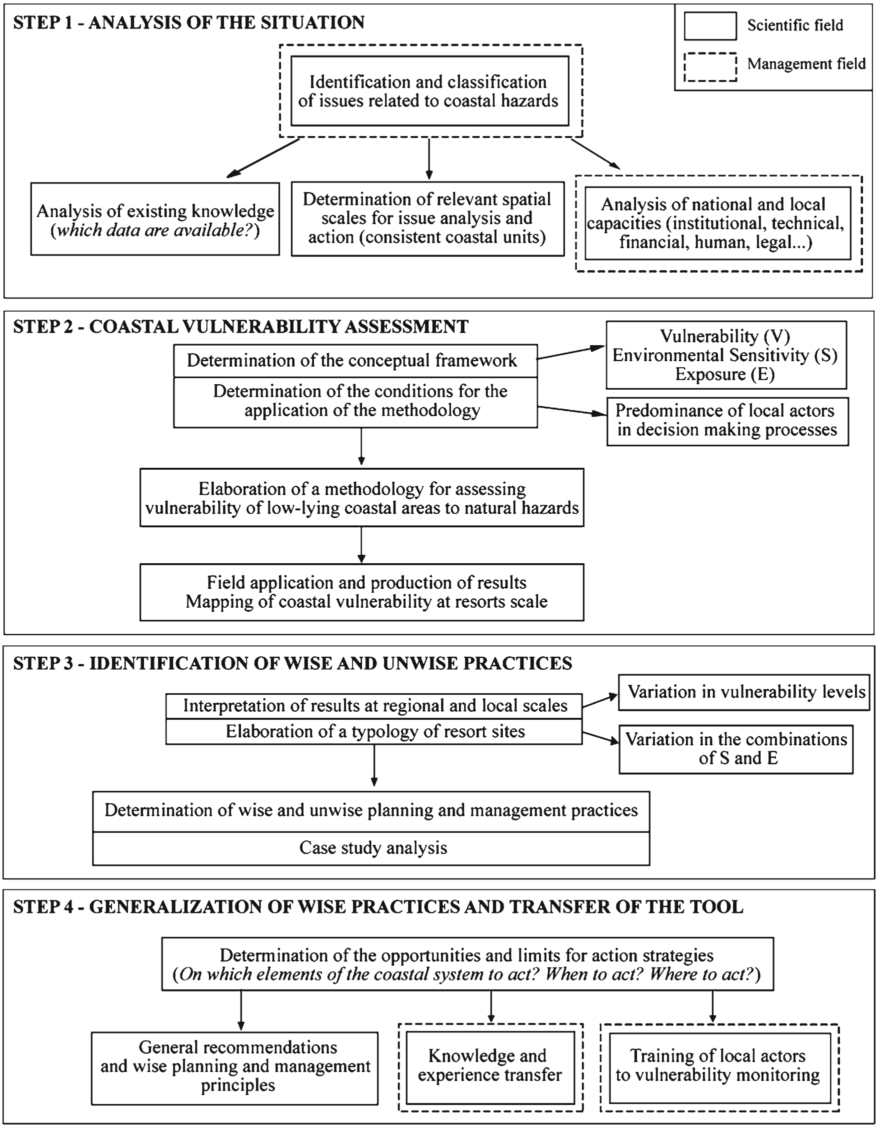

Fig. 15.1 General scientific framework

coastal erosion and flooding. We defend the theory that local scale approaches of tourism territories are relevant for vulnerability analysis, firstly because tourism is one of the major economic sectors in coastal zones. Secondly, we argue that as interactions between S and E can easily be observed at this scale, it is the most adequate for analyzing coastal planning and management practices. Finally, territories with limited capacities often have incomplete legislative apparatus and show a low level of implementation of regulations. In such conditions, local stakeholders and particularly tourism operators are generally the main drivers of decision-making processes, and that is why they are at the centre of the present vulnerability analysis.

The analysis of the situation (step 1) aims at organizing coastal hazards faced by local actors into a hierarchy. The objective is to define precisely their needs and perception of issues in order to propose suitable solutions. Moreover, the level of knowledge of coastal environments, the processes at work and the causes of the present issues must be clearly established so as to determine the current data that is to be integrated into the assessment and the research fields to be developed to improve the understanding of the situation. This step also comprises the determination of relevant spatial scales, both for making a diagnosis of the issues – *Are they localized or general and over what time scale do they occur?* – and for supporting action. Consistent coastal units must be identified on the basis of a good understanding of management processes. The following questions must be answered: *Is the scale of tourism establishments relevant in terms of action? Or should management strategies be based on administrative divisions?* Finally, step 1 includes the analysis of national and local capacities (institutional, legal, financial, technical) as needed in order to draw up recommendations and plans of action.

Coastal vulnerability assessment (step 2) firstly requires the choice of a suitable conceptual framework. The three main concepts that underlie the present work are Vulnerability (V), Environmental Sensitivity (S) and Infrastructures, Buildings and Population Exposure (E). S depends on the physical assets and dynamics of the coastal system and refers to its responses to stresses, which relate back to its resilience (Dutrieux et al. 2000). E is proportional to the number, technical characteristics and location of infrastructures, buildings and human settlements. The present work applies to contexts where decision-making processes are highly influenced by local stakeholders, either economic such as resort managers or institutional. On this basis, the methodology for assessing vulnerability can be developed and applied (see below). The main output at this stage is the mapping of vulnerability.

Step 3 consists in assessing planning and management practices on the basis of local variations of V, S and E. A typology of resort sites is elaborated and wise/unwise practices are brought to light from significant case studies.

Step 4 encompasses the scheme of action. Based upon the definition of conditions for action, general recommendations are formulated and experience sharing encouraged. Local stakeholders' participation is supported through training in vulnerability monitoring.

15.5.1.2 Associated Methodological Bases for Assessment

An experimental application of this methodological approach was done in Djerba (Duvat and Magnan 2009), one of the hot spots of tourism in Tunisia and in the Mediterranean (41,100 beds in 2008, 18% of the national capacity). Since the 1950s, about 110 tourism establishments were built on the north-eastern coast, which consists

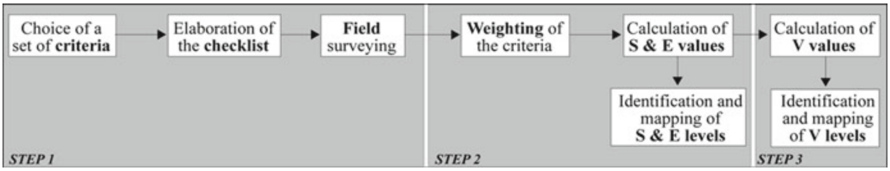

Fig. 15.2 Methodological procedure

of 25 km of sandy beaches, bordered by low dunes and sebkhas.[12] The rapid evolution of this coast exacerbates both environmental sensitivity and current coastal hazards (Miossec and Paskoff 1979; Oueslati 2004; Bourgou 2005). Djerba is also interesting because it exhibits various models of resort management as international companies exploiting buildings belonging to national investor, since international companies, that utilize buildings owned by national investors, coexist with small establishments run by Djerbians. Available data from previous studies and contextual physical and anthropogenic factors make this destination relevant for studying vulnerability to coastal hazards.

The methodological procedure for assessing vulnerability is briefly presented in Fig. 15.2 and its main features are described below.[13]

For each criterion (step 1), a set of situations was listed to which values were attributed in an ascending order according to their influence on the global vulnerability of the system. S and E are characterized respectively by 4 and 14 criteria (Table 15.4). The checklist used for field surveys is built on the same basis and applied at the scale of each resort.

In a second step, all criteria are weighted according to their influence on the global level of vulnerability. The numerical values of S and E are determined by the aggregation of the weighted values of their respective criteria. These weights must be established regarding the specific features of the destination: role and influence of the authorities, of private stakeholders, of domestic tourism flows, etc. And finally, the numerical values of S and E are aggregated (step 3), which allows different levels of E, S and V to be emphasized.

15.5.2 Example Results: The Case of Djerba, Tunisia

15.5.2.1 The Local Context

This study was carried out on the north-eastern coast of Djerba (25 km of coastline, about 110 tourism establishments). In the central part of this area, rocky shores form two capes called Pointe Torbkhana and Pointe Ras Taguermes. At its northern and

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[12] Sebkhas are coastal lagoons in desert areas that have been separated from the sea by sand barriers.

[13] For a more detailed presentation of the procedure, see Duvat and Magnan (2009).

Table 15.4 Set of criteria for vulnerability assessment

Vulnerability criteria	Values
(1) Sensitivity (S)	
A. General physical assets (dune, swamp…)	6 values from 1 to 6
B. Terrestrial buffer zone (dune, berm…)	5 values from 1 to 5
C. Marine buffer zone (sea grass beds, headland…)	6 values from 1 to 6
D. Recent evolution of the coastline	4 values from 1 to 4
(2) Exposure	
E. Location of the site regarding the direction of storm swells	3 values from 1 to 3
F. Location of the site regarding the direction of predominant seasonal swells	3 values from 1 to 3
G. Line of the coast (rectilinear, convex, concave…)	5 values from 1 to 5
H. Presence of emerged lands intercepting swells	4 values from 1 to 4
I. Model of development (distribution and general characteristics of infrastructure, buildings and human settlements)	7 values from 0* to 6
	5 elements are considered: *(i)* their number, *(ii)* their surface, *(iii)* their location, *(iv)* their elevation, *(v)* their distance from the sea
J. Exposure of main roads	6 values from 0* to 5
	4 characteristics are included: *(i)* strategic importance, *(ii)* elevation, *(iii)* distance from the sea, *(iv)* protection by hard defense works
	A road is *strategic* when it plays a major role at the scale of the country and of the region
K. Exposure of main harbors (commercial, industrial, ferries and cruise ships)	Identical to criteria J
L. Exposure of yachting harbors and marinas	Identical to criteria J
M. Exposure of local fishing harbors	Identical to criteria J
N. Exposure of the main airport	Identical to criteria J

(continued)

Table 15.4 (continued)

Vulnerability criteria	Values
O. Main facilities (desalination plants, pumping stations, power station, fossil fuel storage zones)	5 values from 0* to 4 Values are determined by three elements: *(i)* elevation, *(ii)* distance from the sea, *(iii)* protection by hard defense works
P. Key public buildings (administrations, hospitals and clinics, police and fireman stations)	Identical to criteria O
Q. Exposure of tourism buildings and infrastructures	7 values from 0 to 6 Levels are determined by the combination of four elements: *(i)* number, *(ii)* elevation, *(iii)* distance from the sea, *(iv)* actions made for raising the height (e.g. pile, mound)
R. Exposure of urban systems/human settlements	5 values from 0 to 4

*The value 0 is attributed when the component (road, airport…) is absent southern ends, two sand spits have recently formed (Ras Rmel in the north and Lella el Hadhria in the south) which are bordered by sebkhas. The low elevation of dunes (max. 4 m) and the narrowness of these spits in some coastal sections explain why flooding events occur in certain areas. Morphodynamism is dominated by the influence of winds and swells from northern to south-eastern directions. Predominant north-eastern swells up to 4 m high generate erosion peaks, particularly in winter. The direction of the longshore current and associated sand drifting changes direction at Pointe Ras Taguermes. This coast is affected by sediment shortage as terrestrial and marine sediment sources have diminished in recent times (Paskoff 2003; Oueslati 2004).

Tourism started in the 1950s and rapidly developed from the 1970s (Bourgou 2005). Mass tourism emerged, characterized by massive concrete buildings with considerable room capacities. Most hotels were built a short distance from the sea (20–60 m), on foredunes and dunes that were planed down. The sand used for construction has been extracted from coastal dunes in 55 quarries (Bourgou 2005). Other tourism establishments were built next or within reclaimed sebkhas. In parallel, sea grass beds were damaged by inadequate fishing techniques, which certainly reduced wave refraction and then exacerbated coastal erosion.

15.5.2.2 Results of Vulnerability Assessment (Levels of V, S and E)

Apart from main urban areas, the tourism coast of Djerba is one of the most vulnerable areas of Tunisia. As stated by A. Oueslati (2004: 500), "an advance of the sea will oblige [local stakeholders], if they want to keep a beach, to make heavy rehabilitation works". The results of the assessment give medium to very high levels of V for different sections of coast (e.g. Fig. 15.3, in the central part of the tourism area). The highest levels of V are due to unwise development strategies (building at a short distance from the sea, planning down of dunes, and reclamation of sebkhas) in very sensitive environments (sebkhas, low areas, beaches affected by rapid erosion or active sand transport). The worst situation is that of the northern resorts that are affected by rapid sand loss due to major sediment transport towards the prograding end of the Ras Rmel sand spit. Hotels should never have been built on this section of coast. Hard-engineering techniques have been used since the 1970s to protect against wave attack and as it frequently occurs in such circumstances, these structures have accelerated coastal erosion and therefore aggravated environmental sensitivity, which has increased the exposure of buildings. The worst situations mostly involve establishments built in the 1960s and 1970s, while resorts of the 1990s are less vulnerable, mainly due to their better position in sediments cells and/or to their construction at a greater distance from the sea. Some of these hotels are protected from waves by natural (dunes) or artificial (vertical structures made of palm or wood) buffer zones. Beach erosion mitigation measures (hard and soft) have an important influence both on S (substantial in the case where beach destabilization and dune degradation occurs) and on E (exacerbation of S in the case where engineering works and buildings have adverse impacts on coastal morphology and natural processes). The importance of the influence of S on E and vice-versa explains why S and E levels are often correlated.

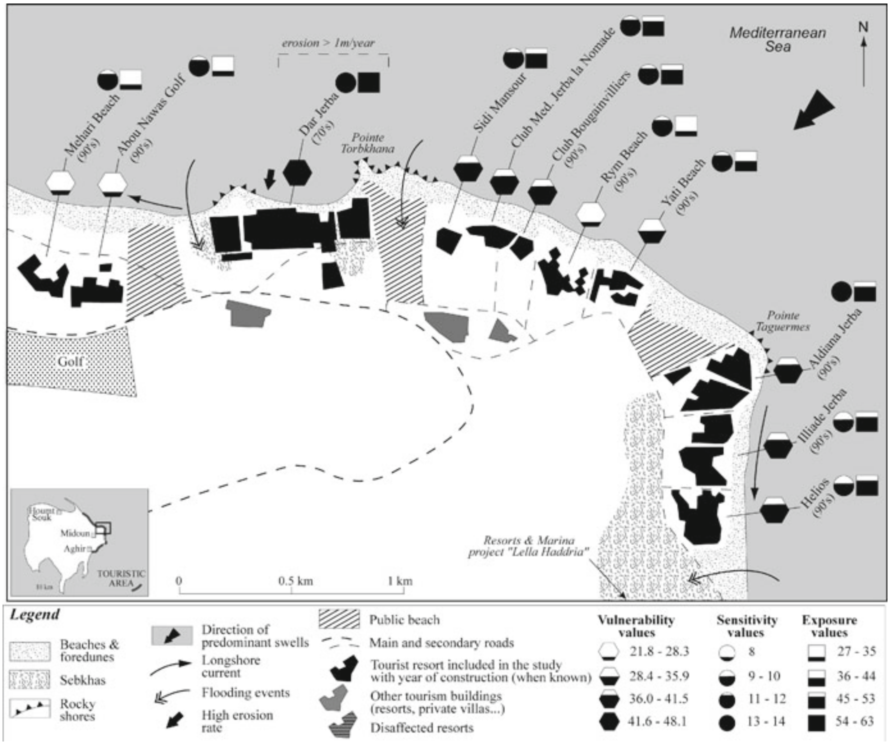

Fig. 15.3 The central part of the tourism area

15.6 Conclusions

Some general conclusions from the CIRCE's work on tourism can be highlighted here.

15.6.1 Concerning the Future of Tourism Flows

Since numerous factors (economic, sociological, environmental, political etc.) are involved in both tourism and climate change, it is hugely complicated to analyze their interrelations. A review of key studies that have explored the impacts of climate change on tourism highlights the pioneering development and application of different methodologies. In the field of the spatial distribution of tourism flows, tourism demand models have been taken into consideration, both from a micro and macroeconomic perspective, with the sole objective of simulating the effects of climate change on the Mediterranean.

Results have reinforced the idea that from an international perspective, it seems that a higher temperature in northern European countries could discourage international flows from North to South and, at the same time, reinforce flows within Northern Europe. Although these results involve bad expectations for the Mediterranean international tourism market it should be highlighted how developed models have been based on aggregated average data precluding an in-depth understanding of the regional differences within the Mediterranean and other important changes that are currently characterizing tourism trends such as the increase in short breaks during the off peak season.

From a regional perspective, models have identified temperature as a positive factor determining the probability of visiting a specific coastal destination. However, the non-linear effect of temperature on choice probabilities and on tourism demand shows the existence of a threshold level where rising temperatures turn coastal destinations into less desirable places for tourism. Thus, it is expected that the increase in temperatures will have a negative impact on coastal provinces located in the Mediterranean during the peak season. Furthermore, sandy beaches in a region are associated with a higher tourism demand. The loss of beaches through erosion would result in reduced demand for some regions unless adaptation measures such as beach nourishment are carried out. Of course, inland destinations may benefit from the reduced attractiveness of the coast.

Based on these results, multiple implications for public and private institutions can be identified. At destination level, efforts toward the diversification of the Mediterranean tourism product, based mainly on good climate conditions, should be emphasized in view of the increasing competition that other northern countries could impose in this specific tourism segment. On the other hand, Spring and Autumn seasons should be tested as tourism attractor alternatives for the Mediterranean regions since their comparative advantage will tend to decrease during summer time. The interest shown by different international bodies should encourage the incorporation of tourism as a whole and not just its subsectors in forthcoming studies by the Intergovernmental Panel on Climate Change. Then, this is a first great challenge for science to continue the efforts undertaken in order to understand the potential reactions of the tourism industry in the face of climate change impacts.

15.6.2 Concerning the Vulnerability of Local Destinations to Climate Change

A second great challenge is to understand the potential reactions of the local destinations. In that sense, the vulnerability analysis presented here has highlighted three main conclusions. *(i)* Firstly, vulnerability is definitely a relevant manner to start understanding how climate change will precisely threat the functioning of local coastal destinations. Vulnerability is indeed a result of the ratio between the weaknesses and the strengths of a territory. Its analysis allows making a scientific diagnosis of the situation. *(ii)* Secondly, as climate change is characterized by uncertainty regarding its impacts at a local scale, it appears to be impossible to say if one specific destination is definitely vulnerable to climate change or not. The only one thing which can be assessed today is its vulnerability to current natural hazards; in this study the ones coming from the sea. This is what the methodology we presented aimed at arguing that the most relevant approach consists in monitoring this level of (current) vulnerability in order to follow the development of the destination's weaknesses/strengths ratio. *(iii)* Finally, the approach has highlighted the necessity to develop easy-use tools for assessing vulnerability. Indeed, if scientists can help to build an adequate method to assess the vulnerability of a particular destination, the monitoring approach must mainly be under the responsibility of local stakeholders and decision-makers. Then, easy-use methods for monitoring vulnerability are necessary for getting their support. Case studies developed under the CIRCE project (here the one of Djerba had been presented) have also proved that such a tool can demonstrate the reversibility of some situations: management practices can change a very vulnerable situation into a more sustainable one (e.g. when building resorts far from the sea in places threatened by coastal erosion) and then encourage private stakeholders to participate to sustainable coastal development.

The potential evolution of tourism flows one the one hand, and the fact that many Mediterranean coasts are already threatened by climate-related hazards on the other, emphasize the need for tourism territories to develop strategies for adapting to climate change.

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Chapter 16
International Retirement Migration from Northern Europe to the Mediterranean: New Results on the Role of Climate with a Possible Application to Climate Change

David Maddison, Tom Murray, and Onyebuchi Chigbo

Abstract A great deal of climate change research focuses on forced migration as a response to sea level rise and the loss of livelihoods. By contrast much less research considers altered patterns of amenity led international retirement migration as a response to climate change. An increase in the number of individuals reaching retirement age and improvements in life expectancy combined with changes serving to reduce the cost of international migration have increased sharply the number of individuals choosing to retire abroad. This phenomenon has a range of socioeconomic and political implications not least in terms of the provision of public goods and services. Despite difficulties in defining 'international retirement migration' surveys suggest that climate is the main push and pull factor. As such, the pattern of international retirement migration is potentially impacted by climate change. Using regression analysis this chapter analyses cross country data for 2005 on the stock of individuals living abroad entitled to a UK state pension in each of 210 different countries. The analysis reveals that international retirement migration is higher in countries with warmer winters and cooler summers, and with less precipitation and more sunshine. Climate however seems less important that whether a country has former colonial links with the UK and whether English is widely spoken.

Keywords Climate change • Retirement • Migration • United Kingdom • Statistical analysis

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16.1 Introduction

International retirement migration (IRM) is a growing area of research across a variety of academic disciplines. The phenomenon of large scale IRM has attracted the attention of population geographers, social gerontologists, anthropologists, sociologists, actuaries, demographers, economists and town planners. There is moreover an emergent market of firms offering advisory services to individuals contemplating retirement abroad. Government departments such as the United Kingdom Foreign Office offer advice to would-be migrants.

IRM is generating awareness because of the diverse experiences of the individuals involved and the potential impact on target countries. And insofar as IRM is driven by differences in climate amenities, IRM is potentially affected by climate change.

Economists have traditionally viewed unemployment and wage rates as the principal determinants of migration. Sjaasted (1962) argues that an individual has an incentive to migrate if present value future earnings in the current location are less than the present value of earnings in another location region after allowing for the costs of relocation; costs that are likely to increase with distance.

In theory retirement markedly alters the incentives to migrate (Sjaasted 1962). More specifically, with approaching retirement the propensity to migrate declines along with any geographical differences in the present value future earnings. However, despite this theoretical prediction it transpires that a ‘retirement peak’ of migration is observed within many different countries (King et al. 2000; Warnes and Williams 2006) clearly indicating that the returns to migration are not solely dependent on monetary factors but also non-pecuniary ones whose value is difficult to measure (e.g. Greenwood 1975). We will go on to review a variety of evidence suggesting that climate is chief amongst these non-pecuniary factors. Pointing to other non-economic factors, Wiseman and Roseman (1979) argue retirement migration can be caused by family considerations and a desire to return to one’s place of origin.

Clearly however, IRM is a more complex phenomenon than mere domestic retirement migration. An individual must first decide when to retire and then consider whether or not to retire abroad. If the decision is to retire abroad the individual must decide which country. The retiree must then select either to purchase a property abroad or to enter into some other kind of rental agreement. Lastly the retiree must divide his or her time between different countries mindful of the impact that this might have on his or her welfare entitlements.

This chapter serves two purposes. First, it very briefly summarizes the IRM literature. Second, it provides an overview of new research funded by the European Union undertaken under the auspices of the CIRCE project analyzing the influence of climate on IRM emanating from the United Kingdom. The purpose of the research is empirically to explain the number of United Kingdom pensioners living in different countries of the world. Only with a quantitative model can one generate quantitative predictions regarding the impact of climate change on the pattern of IRM. Although the focus of the research is on retirement to the Mediterranean all countries of the world are included to identify more precisely the role of climate and the political integration of the European Union. The ultimate goal is to use the model to predict the impact of the climate change on IRM from Northern Europe to the Mediterranean.

Although our particular interest is in retirees who move from Northern Europe to the Mediterranean equivalent population flows can be observed in other parts of the world e.g. in the United States where retired couples move from the populous North Eastern States to Florida, California and Arizona (King et al. 2000). Tucker et al. (1988) surveys Canadian ‘snowbirds’ in Florida whilst Warnes (1996) looks at retirement migration to the southern coast of England and the Midi region of France.

The remainder of the chapter is organized as follows. Section 16.2 describes the factors underlying the sustained growth of IRM. Section 16.3 explains the complexities of identifying who is an ‘international retired migrant’ and reviews data sources. Section 16.4 discusses various methodological approaches to studying the phenomenon of IRM and their merits. Section 16.5 summarizes the socioeconomic and environmental impacts of IRM. Section 16.6 presents new results arising from the European Union funded CIRCE project relating to the IRM behavior of United Kingdom nationals. This section provides a case study of the extent to which climate is already the principal motivating factor for international retirement from Northern Europe to the Mediterranean. Section 13.7 discusses the results of the exercise whilst the final section concludes.

16.2 The Rise of International Retirement Migration

Although for reasons that we will go on to explain IRM is a concept which is difficult to measure available evidence points to a continuing increase in IRM emanating from the United Kingdom between the years 2000–2007. Information from Germany points to a similarly large increase. This growth in IRM from Northern Europe to the Mediterranean has no single cause but instead many causes. Although it is impossible to apportion the growth to particular factors it is possible to group them. These drivers are demographic, technological, political and economic in nature.

Along with an increase in the number of people reaching retirement age an obvious contributory factor is the increase in life-expectancy conditional upon reaching this age (see King et al. 2000 and Rowthorn 2009). Rowthorn (2009) states that the proportion of elderly people in the EU is projected to increase from 16.5% in 2000 to 30% by 2050. Statutory retirement age has itself until recently been falling in many countries. Lately Moro (2007) notes that the European Commission has begun to urge member states to raise their official age of retirement and discourage early exit from work.

Another important consideration is that air travel within Europe is now cheaper facilitating seasonal migration and regular return journeys. It is much easier than before to invest in the housing market of Mediterranean countries. IRM has arguably responded to the revolution in communications technology with low cost telephone calls and satellite television (King et al. 2000).

IRM from Northern Europe to the Mediterranean is also underpinned by a number of important European Union treaties. These include articles 48 and 49 of the Treaty of Rome allowing free movement; the Single European Act removing barriers to the ownership of property across the European Union (http://www.hri.org/MFA/foreign/treaties/Rome57/) and the 1994 Maastricht treaty bestowing electoral rights on the non-national residents from other EU member states (see http://www.eurotreaties.com/maastrichtec.pdf). Some authors have reported increases in United Kingdom state pensioners to some countries after they joined the EU (Sriskandarajah and Drew 2006; Balkir and Kirkulak 2009).

Access to the welfare state and a variety of benefits and health care increased with the creation of bilateral relationships between countries within the European Union. Pensions are paid from abroad and critically, the receipt of a state pension does not require residency. There has anyway been an increase in the importance of private and employer-pensions. Uneven access to other social entitlements however might yet influence the pattern of IRM. The quality of health care and eligibility requirements are likely to be especially important considerations for elderly migrants.

Researchers also point to what were at one time clearly very considerable differences in the price of property between Northern Europe and the Mediterranean (Balkir and Kirkulak 2009; Flower 1988; King et al. 2000; Williams et al. 1997). The inflow of retired migrants has, in preferred destinations such as Tuscany, caused the price of housing to soar to the point that it is now choking off IRM in that part of Italy (King and Patterson 1998).

International tourism provides important information on living abroad and alternative lifestyles. The familiarity of Northern Europeans with Mediterranean has probably increased as a result of the post-war boom in international tourism (Warnes 2009). It is reasonable to assume that countries visited by tourists will also be those countries attractive to retired migrants. The rate of 'winter sun' holidays has been increasing faster than those in the traditional holiday period and many international retirement migrants may equally be described as semi-residential tourists.

16.3 Defining International Retirement Migration

The preceding section illustrated the rapidity of the growth in IRM and pinpointed a number of factors all contributing to that outcome. Nevertheless, despite some claiming that IRM is 'easily' described as the movement of people retired abroad it is surprisingly difficult to define IRM.

A detailed analysis of the difficulties associated with attaching a precise meaning to the phrase 'international retirement migration' was contained in a recent report by Warnes (2009). It was suggested that of the three words the word 'international' poses little or no ambiguity compared to the other two words 'retirement' and 'migration'.

Retirement might refer to an individual reaching the age at which he or she is entitled to state-related age benefits and occupational pensions. Retirement can also mean enforced career separation, withdrawal from the labor market (at any age) or a substantial reduction in the number of hours worked. Not infrequently individuals 'retire' but subsequently return to work through boredom or necessity (see Ekerdt 2009 for a discussion).

The problem of defining 'migration' refers to the fact that retired migrants are free to choose how much time they spend in particular countries. There are long-stay international tourists, second home owners, seasonal migrants, 'snowbirds' and permanent residents (King et al. 2000; Williams et al. 2000). Retirees may or may not retain property in their home country. And individuals may transition from one type to another. There is therefore no single 'correct' definition of IRM although given definitions of IRM may be meaningful from a particular policy perspective. And anyway, unless one wishes to engage in primary data collection preferred definitions of IRM need to yield to whatever data is available.

Unfortunately collecting data on IRM from official sources also presents significant difficulty. Both the OECD and EUROSTAT have data on foreign residents present in member states. But these figures are not disaggregated by age and therefore undoubtedly contain a majority of economically active persons (King et al. 2000). United Kingdom port departure statistics do not currently include questions concerning IRM.

Estimates of IRM that rely on national censuses are likely to be flawed because they do not account for individuals who are seasonal migrants. Data drawn from the compulsory registration of foreign nationals staying for more than a certain amount of time may lack information on age and socioeconomic characteristics and may aggregate together people from different countries (King et al. 2000).

Warnes (2009) notes that whereas national censuses, local registers of residents, property tax records and electoral rolls etc. identify migrants these are not always very useful since they seldom record duration of stay, or reasons for taking up residency in the first place. The records do not account for migrants that undertake back and forth movements between countries, dual nationality holders and those who eventually return to their country of origin (referred to as return migrants).

Retired migrants also need to think very carefully whether they describe themselves as permanent residents. There are both advantages and disadvantages of so doing. Key considerations include liability for income and property tax, eligibility for social security payments and subsidized access to anything other than emergency health care. It is believed that currently many United Kingdom expatriates do not declare their residency status in order to maintain the right to non-emergency treatment back in the United Kingdom (Coldron and Ackers 2009; King et al. 2000). Anything other than a short stay abroad jeopardizes entitlement to a range of benefits.

Given the fact that national censuses and registers are potentially unreliable measures of IRM pension disbursement data is the most reliable evidence on the geographical distribution of IRM (Sriskandarajah and Drew 2006). Such figures of course exclude those who retire early and others who are for whatever reason not entitled to a state pension. Seasonal migrants are also excluded.

Discussions contained in empirical papers highlight problems collecting of information on international retired migrants and the possible inaccuracy of official sources of information.

16.4 Methodological Approaches to the Study of International Retirement Migration

Researchers have utilized a variety of methodological techniques to IRM, its features and impacts. However, data problems and disagreements over the appropriate definition make it difficult to estimate the overall extent of IRM from Northern Europe to the Mediterranean. Consequently relatively few papers analyze time trends in IRM or explain the geographical distribution of IRM across countries.

Klinthall (2006) uses the Swedish Longitudinal Immigrant Database (SLID) to study flows from 16 major sending countries over a 28 year period. The investigation employed binomial techniques to establish that as immigrants approach retirement age (which is 65 in Sweden) that there is increased probability of return to country of origin especially for migrants from Greece and Italy. The probability of return migration was found to decline again after the age of 65. Most empirical studies have instead sought to investigate the causes of migration, and to identify the characteristics and behavior of migrants by means of in-situ surveys. For examples of such surveys see Friedrich and Kaiser (2002), Breuer (2003), Casado-Diaz et al. (2004), Huber and O'Rielly (2004), King et al. (2000) and Helset et al. (2005).

De Coulon and Wolff (2006) investigated the determinants of the choice of destination of migrants after retirement using the Multinomial Logit model on cross-sectional survey data on 6,211 individuals aged 45–75 born of foreign nationality and resident in France. Their findings suggest that the location intention of the migrants, after retirement, was largely influenced by the location of their family members especially with those from southern Europe, Northern Africa and the Middle East.

Sometimes these surveys are geared towards investigating a specific research topic. For example, using a questionnaire based approach Ackers and Dwyer (2002) attempt to establish the legal status of a sample of 210 retired migrants in 6 European countries whilst Coldron and Ackers (2008) interviewed 17 migrants to understand their experiences of living in Catalonia. Using in-situ surveys Hunter (2010) explains why retired labor migrants in France originating from West Africa refuse to return to their country of origin despite maintaining strong ties with their home countries. Other studies are much more general in nature. Some in-situ surveys take the form of self completed questionnaires whereas others take the form of in depth interviews.

Independently funded research tends to be undertaken by researchers on fellow-nationals in the most favored areas for retirement migration in southern Europe (Warnes 2009).

Regarding in-situ surveys, collecting data typically involves contacting expatriate associations and individuals and then 'snowballing' outwards (see Warnes and Williams 2006 for a discussion). The weakness of this approach is that the sample might be unrepresentative. And it is from studies such as these that researchers attempt to identify the socio-economic characteristic of international retired migrants. There is furthermore a risk that researchers are drawn to unrepresentative forms of IRM simply because they are more visible and easier to recruit e.g. retirees concentrated in coastal resorts or attending timeshare conventions (Warnes 2009). This may be why international retired migrants are typically referred to as amenity seekers despite diverse forms of international retirement.

The majority of empirical studies of IRM from northern Europe to the Mediterranean consider retired migrants within single receiving countries. Aiming to identify commonalities however, some studies adopt a multi-country approach. Usually this involves coordinating what would otherwise be independent studies (see for example Casado-Diaz et al. 2004).

Obviously not every paper on IRM involves collecting primary data. Some use secondary data including data collected by official sources and even data obtained other researchers engaged in in-situ surveys. In an example of the latter Coldron and Ackers (2009) discuss how retired migrants are actively negotiating their European and national social rights. Their report concentrates on policy issues that affect the destination countries of retired migrants.

Few papers employ purely theoretical approaches to studying the IRM phenomenon. Using an overlapping generation model Moro (2007) describes the economic impact of IRM within the European Union. This research takes as its point of departure the social and legal framework of the European Union that operates on the principle of non-discriminatory access to welfare systems. People in their younger years live in countries with high capital per capita and on retirement prefer to move to countries with lower capital per capita (and a better environment). Such behavior places prolonged and significant pressure on host countries.

16.5 Policy Concerns of International Retirement Migration

Fears have been raised because of the sheer number of international retired migrants moving from Northern Europe to the Mediterranean (Rodriguez et al. 1998). Policy concerns relating to international retired migrants are primarily associated with the economy, housing, health and welfare (Mullan 1992; King et al. 1998). Although the focus of research seems to be on costs to the receiving countries IRM brings forth both costs and benefits. Interestingly there appears to be little or no research on the impact of IRM on the sending countries.

Dealing first with the benefits, income transfers, in the form of pension payments as well as investments in property, provide a major boost to the economy of the receiving country. It is claimed that over 70% of international retired migrants now own their own home (Casado-Diaz et al. 2004). King et al. (1998) suggest that such transfers, although not fully quantified, are likely to be substantial.

Given that international retired migrants appear well educated Bahar et al. (2009) argues that migrant communities can be viewed as agents of knowledge, values and norms of behavior to receiving countries. Whether such transfers are possible is open to question since international retirement migrants do not invariably integrate with host communities particularly where language barriers exist. According to King et al. (1998) most international migrants live in established enclaves with fellow nationals, who in most instances provide local services. This inhibits migrants from learning the local language of the host communities as compared to migrants who settle in the countryside and interact more with the locals. Balkir and Kirkulak (2009) further add that the availability of satellite TV stations and foreign newspapers further diminishes the need for the migrants to learn the local language and integrate. Socio-cultural differences between the migrants and the locals further inhibit integration.

Turning now to the costs, IRM presents a policy challenge in the form of locals competing with very affluent migrants in the housing market. Rodriguez et al. (1998) observed a boom in housing and real estate markets throughout the Mediterranean. Many retired migrants spend a considerable amount of time (over 4 months) in the region which makes them semi-permanent (if not permanent) residents.

The costs associated with IRM to the Mediterranean which have received the most attention involve the provision of free health care and the impact on welfares services. This is because European Union citizens are generally entitled to state benefits in other European Union countries (King et al. 1998). Coldron and Ackers (2009) describe how welfare and healthcare systems are placed under pressure by international retired migrants. They also highlighted the problems associated with international migrants who 'abuse' and 'manipulate' the system to their own advantage.

The scenery and natural environments of the coastal towns of the Mediterranean are particularly attractive to retired migrants from the United Kingdom. In some regions however IRM has, it is claimed, inflicted significant impacts on vulnerable landscapes, caused a reduction of natural spaces and increased anthropogenic disturbances, fragmented ecosystems, and caused soil degradation and water imbalances (Zasada et al. 2010). Some have argued however that the rapid urbanization and therefore environmental degradation of such areas is more than offset by the creation of thousands of jobs and the setting up of businesses and markets to cater for the consumption needs of the migrants (Lardies 1999).

Finally, that a foreign migrant from a European Union member state retains the right to vote poses an interesting set of political questions. And although King et al. (1998) observe that such rights are not normally exercised, retired migrants have been known to exert a considerable influence in some communities.

16.6 The Influence of Climate on International Retirement Migration

Several in-situ studies address IRM from Northern European to Mediterranean countries. These take a methodologically quite different approach to the one that we shall adopt by asking migrants residing in a particular area to explain their motives for moving to that location. Usually climate is not the sole or even the main focus of such investigations but almost invariably turns out to be the single most important factor.

Casado-Diaz et al. (2004) reports findings from a suite of studies looking at IRM from Northern Europe to the Mediterranean. Although each study was executed independently the authors collaborated over survey design thereby facilitating direct comparison. Protocols adopted defined an international retired migrant as 55 years and over living at least 4 months a year in the destination countries.

Taken together these studies provide evidence on the importance of climate to international retired migrants in a number of European regions (see Table 16.1). Nearly all of the respondents interviewed mention climate as the main reason for migrating in the first place and the main reason for choosing to live in the selected area. The implication is that climate operates both as a 'push' and a 'pull' factor. The only exception is Tuscany, a fact which might be due to the fact that winters there are unusually severe by Mediterranean standards (King et al. 1998). Retired migrants in Tuscany tended to be motivated by cultural factors and feelings of antipathy towards their country of origin (King and Patterson 1998)

Additional insights emerge from the in-depth interviews carried out by King et al. (2000) of international retired migrants emanating from the United Kingdom. Such individuals are reported as wanting to escape the cold, grey, damp winters and accompanying long winter nights in the United Kingdom. The study of King et al. also revealed a pattern of seasonal residence involving a return to the United Kingdom during the summer months. Asked why they appreciate the Mediterranean climate interviewees say it promotes health, outdoor recreation and cuts heating costs, as well as for its own sake. Although it is not spelled out in the analysis King et al. (2000) also suggest that the most appreciated aspect of the Mediterranean climate is the sunshine, the dry winters and the absence of frosts.

Bahar et al. (2009) conduct a study of IRM in Turkey. Surveys were implemented in regions of high non-Turkish populations. Once again the main reason for migrating to such regions was retired migrants' preferences for a warmer climate.

Balkir and Kirkulak (2009) adopted a methodologically similar approach to Cassado-Diaz et al. (2004) and Cassodo-Diaz (2006) to investigate the growing wave of international retirees' preference for Turkey. Their investigations administered questionnaires (500) in six municipalities known as hotspots to European retirees. Their findings reveal consistency with other reports on international retired migrants in the Mediterranean in that climate turns out to be the principal factor motivating international retirees coming to Turkey, in addition to the lower cost of living and warm social relations. British, Germans and the Dutch were the dominant retirees encountered.

Lazarides et al. (1999) explored the use of islands as 'retirement havens' by international retirees. Their methodological approach involved conducting personal interviews with British retired migrants resident on the island of Corfu. Climate was once again the main motivational factor that attracted British retirees. Other motivations were related to their desire for quiet lifestyles in the rural areas along with the friendliness and hospitality of the locals.

Table 16.1 The most common main reasons for moving to the study area

	Tuscany	Malta	Costa del Sol (1)	Algarve	Costa del Sol (2)	Torrevieja	Mallorca	Costa Blanca	Canary Isles
Reasons for moving abroad									
Climate	25.5	62.3	72.8	72.2	91.3	93.9	79.4	70.2	92.4
Financial reasons	5.1	37.4	31.0	42.4	31.5	37.4	9.4	45.7	30.3
Way of life	41.8	19.1	30.3	31.2	60.1	38.0	41.7	10.1	n.c.
Health reasons	9.2	12.8	23.2	19.0	23.0	54.6	25.8	29.9	62.1
Social life	5.1	27.6	8.4	10.7	11.3	n.c.	n.c.	n.c.	n.c.
Work related	25.5	6.2	4.6	8.8	0.0	0.6	6.4	1.9	5.3
Leisure activities	1.0	5.1	5.3	7.8	9.3	n.c.	9.2	n.c.	26.5
Environmental	15.3	2.7	3.7	5.4	0.8	n.c.	21.7	n.c.	n.c.
Advantages of living in the area									
Climate	42.9	75.9	80.2	83.9	42.3	n.c.	80.8	96.0	95.6
Social life	41.8	42.2	39.9	37.6	n.c.	n.c.	2.7	n.c.	37.3
Way of life	62.2	26.5	36.5	47.8	64.9	n.c.	40.0	49.7	48.0
Financial reasons	6.1	38.5	29.4	31.7	n.c.	n.c.	7.5	79.4	59.8
For health reasons	11.2	10.9	18.6	15.6	41.5	n.c.	16.1	57.1	n.c.
Environmental	36.7	2.7	8.0	11.2	58.9	n.c.	21.7	72.2	n.c.
Leisure activities	3.1	4.7	11.1	15.6	n.c.	n.c.	15.8	38.9	95.5
Personal	12.2	5.1	1.5	1.0	n.c.	n.c.	0.0	n.c.	n.c.
Easy access	0.0	1.6	5.3	4.4	n.c.	n.c.	3.6	37.1	67.0
Avoid home country	5.1	0.4	1.5	2.4	2.4	n.c.	3.3	22.4	48.0
Work related	2.0	0.0	0.6	1.5	n.c.	n.c.	1.4	7.6	n.c.

This table is adapted from Casado-Diaz et al. (2004)

Notes: n.c. means not collected. The data are the percentage references to the named factors among three 'main reasons' or 'main advantages'. Many respondents in Tuscany expressed 'admiration of the country'. There were two independent studies of Costa del Sol

Though not uninteresting a key limitation of these survey based studies of IRM resides in the fact that they provide only qualitative insights. And whilst they attest to the overwhelming importance of the climate and hence to susceptibility to climate change they do not generally record exactly what aspect of the climate attracts retired migrants. Lastly, they are often restricted to analyzing the preferences of migrants who have already chosen to live in tourist hotspots and whose behavior may therefore be unrepresentative of the population of international retired migrants to the Mediterranean region.

The methodology employed by CIRCE researchers differs from the single site survey based approach favored by European researchers. The CIRCE approach involves explaining the stock of migrants as a function of destination specific explanatory variables. Many studies undertaken in the United States have already used a similar methodology to investigate the role that climate plays in domestic retirement migration flows. Even though our focus is on retirement migration from Northern Europe to the Mediterranean countries, it seems appropriate to review that literature. There is particular interest in how United States researchers have represented the climate in their empirical models, and whether United States domestic retirement migration and whether international retirees emanating from the United Kingdom are alternately attracted and repelled by the same climate variables as their American cousins.

Graves (1980) is the first empirical study of United States migration having special emphasis on climate. Using data on gross migration Graves analyses these flows by age category including of particular interest for our purposes a ‘retired’ category of over 65s. Climate is found to have a significant impact on retirees’ migration decisions. In particular, retired migrants appear to prefer a lower temperature variance across the year.

Clark and Hunter (1992) present another study of migration over the life-cycle. They analyze the importance of a variety of amenities in migration models including several climate variables. Sunnier climates are found to attract those aged over 60. As with Graves (1980) there is a marked preference for a lower variation in temperature across the year.

Cragg and Kahn (1999) observe the preferences for climate displayed by households in a study of the United States. They find that the average senior citizen is benefiting from average February temperatures nearly 2.8 °C higher in 1990 than they were in 1960. In addition expenditure on climate has increased more for retired households as climate becomes increasingly capitalized into house rents rather than wage rates.

Rappaport (2005) assesses the significance of particular types of climate in explaining internal migration within the United States. The population growth rates of United States counties is used as a proxy for net migration and Rappaport examines growth rates for particular population sub-groups including retirees. Results show an obvious preference for warmer winter temperatures and a lower summer heat index (which combines both temperature and relative humidity). These preferences are noticeably stronger for retirees than for individuals of working age.

An important feature of all of these United State studies is that they provide quantitative estimates of the sensitivity of retirement migration flows to climate

Table 16.2 Top 10 United Kingdom pensioner destinations

Country	Total pensions
Australia	245,311
Canada	157,435
USA	132,083
Ireland	104,650
Spain	74,636
New Zealand	46,560
South Africa	38,825
Italy	33,989
France	33,854
Germany	33,034

variables. These studies are moreover generally based on statistically representative samples of the population of retired individuals (more precisely retired individuals who chose to relocate). On the other hand different specifications of the climate frustrate attempts to compare studies and some of the climate variables do not seem sensible e.g. temperature variation rather than absolute temperature. Lastly these studies deal with migration within a single country, the United States, and not international retirement migration from Northern to Southern Europe.

16.7 Analyzing IRM Emanating from the United Kingdom

Rather than using surveys to investigate a sample of international retired migrants in-situ or analyzing domestic retirement migration the research undertaken for the CIRCE project analyses the observed behavior of the entire population of international retired migrants emanating from a particular country. More specifically multiple regression analysis is used to explain the observed number of individuals in receipt of a United Kingdom state pension and present in each of 210 foreign countries and territories in the year 2005. This data is obtained from the Institute for Public Policy Research and is based on unpublished Department of Work and Pensions data (Sriskandarajah and Drew 2006). The data indicates there are over one million people living abroad receiving a United Kingdom state pension. Table 16.2 contains a list of the top ten retirement destinations. Interestingly not one of the top four countries is a Mediterranean country.

Some explanation is required regarding the specification of the regression equation predicting the stock of individuals in each country drawing a United Kingdom pension.

Population is included in expectation that more pensioners migrate to larger (more populous) countries. GDP per capita in US dollars is included as a proxy for development. A higher GDP should mean better infrastructure and more public goods. The percentages of individuals 65 years of age are included to determine the extent to which pensioners follow each other into retirement destinations.

Table 16.3 Variables and their definitions

Variable	Definition
TOTPEN	Number of UK state pensioners living in each destination country (2005)
POP	Population in 2005
GDPPC	GDP per capita (2005 USD)
OVER5	Percentage of individuals who are over 65
URBAN	Percentage of population living in urban areas
AREA	Area in square kilometers
DISTANCE	Greater Circles distance from UK midpoint to destination mid-point
COAST	Total coastline (kilometers)
ENGLISH1	Unity if first language is English, 0 otherwise
ENGLISH2	Unity if second language is English or widely understood, 0 otherwise
CWEALTH	Unity if country is in the Commonwealth, 0 otherwise
EU	Unity if a EU, 0 otherwise
LATIT	Latitude (decimalized degrees)
LONGIT	Longitude (decimalized degrees)
LIFEEXP	Life Expectancy in each destination country
HEALTH	Per capita expenditure on health (2005 USD)
MAXTEMP	Mean temperature in the hottest month (°C)
MINTEMP	Mean temperature in the coolest month (°C)
CLOUD	Annual average cloud cover (%)
WETDAY	Annual average wet day frequency (days per month)

Table 16.4 Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
TOTPEN	210	5,009.376	24,147.95	0	245,311
POP	183	34.67464	130.0567	0.01	1,303.7
OVER65	183	7.3660656	4.925933	1	22
AREA	183	713,468	1,969,875	2.59	1.71E+07
URBAN	183	55.30601	23.82524	12	100
ENGLISH1	210	0.266667	0.443273	0	1
ENGLISH2	210	0.252381	0.435416	0	1
CWEALTH	210	0.280952	0.450538	0	1
LIFEEXP	194	67.45856	11.91782	35	82
LATIT	210	−19.0159	25.05902	−72	51.45
LONGIT	210	15.25729	69.21057	−175	178
DISTANCE	210	6,317.073	3,945.793	150.97	185,539.2
HEALTH	175	697.3029	1,284.203	5	6,096
GDPPC	167	11,011.65	11,309.68	667	60,228
EU	210	0.147619	0.355569	0	1
COAST	200	3,703.589	15,825.36	0	202,080
MAXTEMP	194	23.95567	5.976256	−2.2	36.8
MINTEMP	194	12.41624	12.38839	−26.3	28
CLOUD	193	55.77416	13.69466	21.72	87.88
WETDAY	193	10.81807	4.866952	0.76	20.73

The percentage of urbanized area is a proxy for environmental quality. We expect that UK pensioners will prefer countries with superior environmental quality.

Distance is calculated using the greater circles method. Greater distance is expected to serve as a deterrent. Latitude and longitude are included controlling for geographical location. Their inclusion controls for other variables whose values change over space. Latitude also controls for variation in the hours of daylight across the year. We include length of coastline. Insofar as some IRM is prompted by the same set of variables that explain international tourism coastline should be important.

Language is a significant barrier to migration. Retirees from the United Kingdom may therefore be drawn towards English speaking countries or places where English is widely understood. Two dummies are included for countries with English as a first language and countries with English as a second language.

Two dummies are included denoting countries within the British Commonwealth and countries within the European Union. Commonwealth countries, many of which are in the Caribbean, have historical and employment links to the United Kingdom and this variable could therefore help explain the extent of return migration whereas European Union membership requires the free movement of individuals across European Union borders and guarantees access to welfare and health care benefits. Such factors could potentially be very important in determining the geographical distribution of IRM.

Old age inevitably leads to increased dependence on the healthcare system. Two health related variables are therefore included. These are life expectancy and total expenditure on health per capita. It seems likely that pensioners will prefer areas offering a higher life expectancy and higher spending on health.

Climate variables correspond to country averages measured over the period 1961–1990 and are taken from Mitchell et al. (2003). Included are the mean temperature of the hottest and coldest months and the average number of wet days per month. Cloud coverage is also included.

In exercises such as this an important limitation is the assumption that the countries themselves are homogeneous. But different cities in geographically larger countries frequently differ widely in terms of climate. For example, Darwin in North Australia offers a much more tropical climate compared to Melbourne's southern temperate climate. The consequence of such aggregation error is to bias coefficients of interest to an unknown extent.

Turning to technical issues, the pensioner data set includes pensioner counts for 210 different countries of which 61 have less than 10 recorded UK state pensioners. This makes an Ordinary Least Squares an unattractive way of modeling the data pointing instead to the use of Poisson regression techniques. But since over-dispersion often affects the Poisson regression model the research actually employs the Negative Binomial model (Winkelmann and Zimmermann 1995)

Unfortunately, it was not possible to maintain the full dataset for all 210 countries containing United Kingdom state pensioners. This was primarily due to missing climate variables for certain small countries and islands. Dropping observations with missing values for key variables reduces the number of observations from 210 to 166. The results of the Negative Binomial regression are displayed in Table 16.5.

Table 16.5 Regression results

Variable	Coefficient	Std. Error	Z-Value	Prob>Z
POP	0.0157673	0.0033036	4.77***	0.000
OVER65	0.2023064	0.0537905	3.76***	0.000
AREA	1.10E-07	7.86E-08	1.40	0.160
URBAN	0.002916	0.0091553	0.32	0.750
ENGLISH1	2.153868	0.4514923	4.77***	0.000
ENGLISH2	0.5867142	0.4137532	1.42	0.156
CWEALTH	1.947659	0.4114812	4.73***	0.000
LIFEEXP	0.0885815	0.0233329	3.80***	0.000
LATIT	0.0168409	0.0147916	1.14	0.255
LONGIT	0.01088499	0.0028323	3.83***	0.000
DISTANCE	−0.002883	0.0000925	−3.12**	0.002
HEALTH	0.0003904	0.0002679	1.46	0.145
GDPPC	−0.000169	0.0000389	−0.43	0.664
EU	1.569112	0.5588864	2.81**	0.005
COAST	0.0000267	0.0000102	2.62**	0.009
MAXTEMP	−0.3373998	0.0748824	−4.51***	0.000
MINTEMP	0.206339	0.0350547	5.89***	0.000
CLOUD	−0.0671962	0.0191436	−3.51***	0.000
WETDAY	−0.1546852	0.0575921	−2.69**	0.007
CONSTANT	8.890701	2.17731	4.08***	0.000
ALPHA	2.040879	0.191216	–	–

Note: *** indicates statistical significance at the 1% level of confidence; ** indicates statistical significance at the 5% level of confidence; and * indicates statistical significance at the 10% level of confidence

16.8 Discussion

The empirical investigation provides numerous interesting findings. First of all the statistical significance of the alpha parameter indicates that the Poisson model is not an efficient estimator in this case and the negative binomial model is more suitable.

Turning to the explanatory variables, population is positive and significant indicating that United Kingdom pensioners wishing to retire abroad typically migrate to more populous countries. The coefficient on geographical area by contrast is positive but insignificant. The percentage of those over 65 years of age in each country is highly significant. United Kingdom pensioners it seems have a preference in migrating to countries with an already ageing population.

The first dummy variable for language is positive and highly significant. Given the challenge of learning another language in later life (if that is what is required) United Kingdom pensioners are much more inclined to migrate to countries whose first language is English. It is perhaps no accident that four of the top five most popular destinations are English speaking. The dummy variable denoting those countries where English is widely spoken as a second language remains insignificant.

Historical and employment relationships evidently play an important role. The Commonwealth and European Union dummies are both highly significant. In the case of the Commonwealth variable this probably points to the extent of return migration. In the case of the European Union variable however the statistical significance of the dummy probably points to the effect of close political ties and the existence of a variety of treaties described earlier serving to lower the cost of IRM.

Unsurprisingly coastline is highly significant emphasizing the similarity between IRM and international tourism. Proximity to the United Kingdom is important. Retirees desire to be able to return the United Kingdom for frequent visits or if things go wrong.

Total expenditure on health is positively signed but not statistically significant. Given the reliance of the elderly on health services this is somewhat of a surprise. GDP per capita is not a statistically significant explanatory variable. One possibility is that GDP per capita and health spending per capita are highly correlated to the extent the statistical technique employed is uncertain which of them is more important.

Finally we turn to the climate variables and to the focus of the analysis. A higher temperature in the hottest month reduces the stock of retired migrants. Conversely, higher temperatures in the coldest month increase the number of individuals drawing a United Kingdom state pension. Retirees are attracted to destinations with fewer wet days. Average cloud cover is negatively signed and significant. Less cloud cover implies more sunshine so it seems that migrants prefer sunnier destinations. These results support the findings from the in-situ surveys conducted in Mediterranean countries at least insofar as ‘climate’ is shown to be a highly significant determinant of IRM.

To summarize the ambition of many retirees from the United Kingdom appears to be to migrate to a populous English-speaking country with dry, sunny weather, not too cold in the winter and not too hot in the summer. Ideally this country has a long coastline and is not too far distant from the United Kingdom itself. Such is the significance of the climate variables that future climate change along with a demographically ageing population, is likely to have a major impact on the geographical pattern of IRM originating from the United Kingdom. In later work we simulate the response of IRM to various climate change scenarios.

16.9 Conclusions

Researchers have made considerable progress towards understanding the factors that motivate international retirees. The empirical evidence appears to confirm that climate is the principal factor propelling retirees from Northern Europe to the Mediterranean.

A wide range of policy concerns are associated with IRM including the impacts on welfare and health care systems along with housing and environmental impacts. The benefits of IRM to the source countries seemed to have received less attention compared to the costs incurred by the receiving countries.

Researchers need to acknowledge the diverse motives of the international retired migrant. Progress made in this regard would allow for a better understanding of the phenomenon. In addition, it should allow for policy considerations to be put in perspective when addressing the impacts and consequences of IRM to host countries.

Results emerging from the CIRCE project make it clear that those who are eligible for United Kingdom state pensions consider many factors when considering where to migrate. The research confirms the existence of the amenity seeking retired migrant drawn to countries with warm winters, cool summers, and dry, sunny days.

Will future climate change lead to the displacement of IRM to other areas? On the basis of these results it seems that climate change could have major implications for retirement migration between Northern Europe and the Mediterranean. Not only will climate change alter the relative attractiveness of receiving countries policies to combat climate change might impact on IRM. For example, will reductions in the cost of long haul flights lead to IRM in other areas currently further from the Mediterranean? Or will increasing the cost of flying, in view of its contribution to carbon emissions, diminish IRM? Lastly, the discussion has drawn attention to the importance of political integration in facilitating IRM. Will changes in European Union legislation further drive down the cost of IRM?

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Chapter 17
Green Growth in the Mediterranean

Carlo Jaeger

Abstract Is green growth an option for tackling the challenge of climate change in the Mediterranean? The chapter investigates this question in two main steps. First, climate change is analysed in a perspective of fear and in a perspective of confidence. Against this background, the most likely but undesirable climate related future for the Mediterranean is outlined. This is contrasted with the opportunity for green growth in the Mediterranean. Particular win-win strategies for the Mediterranean are renewable energies and afforestation.

Keywords Mediterranean green growth • Perspectives of fear and of hope • Win-win strategies • Renewable energy power grids • Afforestation

17.1 Introduction

Analyses of the risks of climate change are often framed by a narrative of fear, if not desperation. Recently, however, a different narrative has begun to influence the climate debate. It's origins lie in the debate about sustainable development, but it has become more forceful with the notion of green growth. South-Korea has explicitly decided a green growth strategy (Kim 2010), and both the UN and the OECD have picked up the slogan. Is green growth an option for tackling the challenge of climate change in the Mediterranean?

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I will investigate this question in two main steps. First, I analyze climate change in a perspective of fear and in one of confidence. Against that background, I then outline the most likely climate related future for the Mediterranean region, and show that it is highly undesirable for more than one reason. Finally, I identify the opportunity for green growth in the Mediterranean region as a preferable alternative and discuss some of its main features.

17.2 Climate Change in a Perspective of Fear

Looking at climate change in a perspective of fear has led to claims like the following ones: presently, about 30,000 people per year die due to climate change in the Mediterranean region – killed by heat strokes in heat waves, by diseases that spread with global warming, by diseases that meet immune systems weakened in the aftermath of bad harvests. This is happening right now. If climate change continues unchecked, in 2050 the number of yearly deaths will rise to 50,000.

One can treat these numbers as straightforward hypotheses about objective facts. This is the approach taken by critics like Buhaug (2010). But if one applies what is known in philosophy as the principle of charity, another reading is more appropriate. There are many possible linkages between climate change and mortality, and we do not know which ones are actually effective. In order to act rationally in the face of those possibilities, it is best to assign subjective probabilities to them and to assess the resulting expected value. As more data become available, those prior probabilities can then be stepwise improved according to Bayes's rule or some similar scheme. And the narrative of fear starts by assigning high prior probabilities to scary prospects. As it also starts with a high degree of risk aversion, it is clear that very prudent actions will be recommended.

In this spirit, one can also assess the number of people suffering from impaired health because of climate change. It is bound to be larger than the number of deaths by an order of magnitude. In the Mediterranean area a wide array of diseases, ranging from Malaria to Tuberculosis, has begun to spread with global warming. Today, the narrative of fear sees the health of at least 200,000 people as affected by climate change. In 2050 the number will grow to 500,000 without drastic action to reduce greenhouse gas emissions.

Then there are economic damages. Floods destroy buildings, streets, and more; droughts reduce agricultural production; heatwaves impair labor productivity, and there is more. Right now, the damages in the Mediterranean region are about 0.5% of GDP, i.e. about 20 billion €. The fraction of GDP affected will increase massively with seal-level rise, ocean acidification, and other effects.

According to the narrative of fear, climate change will lead to huge migration from the Southern to the Northern shores of the Mediterranean. As of today, about three million people from the Southern Mediterranean live in the EU. By 2050, climate change may lead more than ten million people to follow their route – and of course other reasons for migration will persist.

Next, climate change poses huge security risks (Mabey 2008). The likelihood of civil wars in Africa increases with temperature – and of course bad harvests are a major factor for this link (Burke et al. 2009). Moreover, the Mediterranean region is also the theater of the Israeli-Arab conflict. Climate change will foster civil wars, it can trigger large scale wars, and it can lead to comparable disasters even without war.

The risk of large scale wars points to a critical element in the narrative of fear: the danger of sudden catastrophe. Sea level rise leads to more and larger floods, and one of these might mark the end of Venice, another one of Alexandria. Of course, climate catastrophes are not restricted to the Mediterranean: a collapse of the West-Antarctic Ice shield (Barnes and Hillenbrand 2010) would lead to flooding of cities all over the world.

To avoid these impacts of climate change, the narrative of fear claims, greenhouse gas emissions must be reduced as far as possible, wherever possible. This must be established as a social norm. It includes legally binding commitments, but it also includes a moral commitment by every member of the world community – be it a legal or physical person – to act according to that norm in everyday life.

It is instructive to observe how the Arab world has reacted to this narrative: "The Arab World has played a strong role in shaping climate policy since the establishment of the UNFCCC, much to the consternation of emissions reducing countries" (Hmaidan 2009). The fact that oil producing Arab countries consistently oppose international agreements aiming at strong emissions reductions is often interpreted as a form of crude self-interest, as is the claim by those countries that they deserve a compensation for climate policies that reduce demand for their products.

It is remarkable, however, that environmental values are being embraced in parts of the Arab world, although not in a perspective of fear. This is well illustrated by Abu Dhabi's Masdar City, touted as the world's first carbon-neutral, zero-waste city powered entirely by renewable energy, and designed by world-famous architect Sir Norman Foster (Ouroussoff 2010) The ambitions of the original plans will most likely be only partially realized; nevertheless, Masdar City will house the secretariat of the International Renewable Energy Agency (Irena), marking the first time an international organization has chosen a Middle East city for its headquarters. It may well be that this kind of symbolism will do more to foster climate policy in the Arab world than tales of grim climate impacts.

17.3 The Idea of Green Growth

As an alternative to the narrative of fear, it is worth considering the way the climate challenge has recently been reframed in South-East Asia. This region is characterized by historically unprecedented economic growth that goes along with alarmingly fast increases in greenhouse gas emissions. For two centuries, the US economy has been growing at a long-term rate of about 2% per year. Europe has a similar pattern, interrupted by the period from the first to the Second World War. Germany achieved growth rates around 5% for a few years after World War II. The Soviet

Union achieved similar growth rates from 1930 to 1970, interrupted by World War II. For about 15 years following the Korea war, the Japanese economy grew even faster, at rates around 10%. But for about three decades, South East Asia has been consistently displaying growth rates above 5%, often even above 10%. While this is certainly welcome from the point of view of poverty reduction, it is more problematic from the point of view of climate policy, as this accelerated growth in GDP went along with accelerated growth of fossil fuel use and therefore of greenhouse gas emissions.

However, the dependency on fossil fuels poses serious threats to fast economic growth, especially in a region with quite limited oil reserves. Against this backdrop, South-Korea has embraced a strategy of green growth based on decreasing energy use and increasing supply of renewable energy (Kim 2010). This strategy has been introduced quite effectively in broader UN debates (ESCAP 2006). The key mechanism on which the green growth strategy is based is increasing investment into green technologies – especially in the fields of energy efficiency and renewable energy, generating enough learning-by-doing effects to allow for high economic growth with quickly decreasing use of natural resources. This refers to the use of the atmosphere as a sink for greenhouse gas emissions, but also to the use of other resources like water and land.

In the high-growth Asian countries, the share of investment in GDP is much larger than in most other countries of the world. Investment drives not only capital accumulation, but also learning-by-doing, as the latter comes mainly with the experience gathered with new equipment. In high-growth countries, then, the green growth strategy means redirecting investment flows towards new sectors, technologies, and products. This can happen through a suitable combination of – positive and negative – financial incentives, regulation, and expectation management. How far it will actually happen in the giant economies of China and India, but also in other Asian countries, including South-Korea itself, remains to be seen. It certainly is a question of major importance for global climate policy.

In Mediterranean countries, growth rates and investment shares are significantly lower than in South-East Asia. Under these conditions, a green growth strategy is less about redirecting existing investment flows than about creating new ones. This makes the strategy even more attractive: it leads to higher growth, thereby facilitating the task of poverty reduction.

17.4 Mediterranean Gloom

The Mediterranean region, however, is likely to watch how South-East Asia and other regions catch up with the highly industrialized countries through spectacular growth without finding ways to emulate them (Brunel 2008). It is useful to rehearse some key numbers in this context. In the decades to come, the world economy is likely to grow somewhat above the long-term American growth rate of 2%, say at a rate of 3%. This may also be the rate of economic growth of the

Northern rim of the Mediterranean. The Southern rim is likely to experience higher growth, in the order of 5% per year. However, population growth in these countries is likely to continue for quite some time at a high rate of about 2%. What is worse, unemployment is likely to stay at levels around 10% both on the Northern and the Southern rim.

For climate policy, this is not a very promising situation. The natural gas available in the Mediterranean region together with oil from the Middle East is likely to remain the main source of commercial energy. Without a speed-up of economic growth, incentives to increase energy efficiency will be quite low. Therefore, energy use will grow at a rate of about 3%, and so will greenhouse gas emissions.

For two reasons, it is highly unlikely that climate policy will affect global climate change in less than a few decades. First, the global climate policy process takes time. While this may be irresponsible, it is nevertheless quite unlikely that serious global emissions reductions will be achieved in less than two decades. Second, even if greenhouse gas emissions were stopped at once today, it would still take decades for temperatures to stop rising. Therefore, some climate change impacts are unavoidable in the next decades.

In the Mediterranean region, one of the most serious impacts is the rise of sea level (El Raey 2010). A more or less uniform sea level rise of about 15 cm in 2050 is quite likely. This will be a serious problem in the Nile delta, although less so in other areas (Venice, e.g., will by then be protected against this amount of sea level rise as well as against the floods that may come with it). Sea level rise of this magnitude will no doubt be countered to some extent by the construction of dams and smaller protective structures. The costs of these measures are not prohibitive, but it is likely that several hundred thousand people will be forced or induced to move farther away from the coast.

Additional pressure on migration is likely to come from increased water scarcity, which is a problem in its own right. While globally climate change is likely to increase overall precipitation, in the Mediterranean region precipitation is likely to slightly decrease, while becoming less regular (Milano 2010; but see the following section). At the same time, evapotranspiration is likely to increase quite substantially (Milano 2010), leading to additional water scarcity.

In parts of Europe, the prospect of sea level rise combined with increased water scarcity in the Mediterranean region raises the specter of uncontrolled trans-Mediterranean migration triggered by climate change. However, careful research by Warner et al. (2009) has shown that climate induced migration is likely to stay within nations. Migration is a major challenge for Europe because of its demographic structure and the difference in well-being between countries around the Mediterranean and beyond. But neither is all trans-Mediterranean migration a threat nor is such migration strongly influenced by climate change.

Beyond 2050, much more serious climate impacts become a matter of concern, with sea level rise of several meters being a serious possibility a few centuries from now. But fear of these impacts will hardly be sufficient to motivate steps towards an effective climate policy in the near future.

17.5 Mediterranean Green Growth?

While the gloomy scenario sketched in the previous section must unfortunately be considered as rather likely, there is an alternative vision that has captured the imagination of at least some environmentalists as well as investors. It is based on the obvious fact that the Mediterranean region, and especially its Southern part, is blessed with sunshine that clearly provides a possible source of renewable energy. Moreover, several Mediterranean countries, most notably Egypt and even more so Morocco, experience winds that offer large amounts of energy available for power production.

However, the natural gas available in the region provides a considerably cheaper source of commercial energy than existing solar and wind power plants can provide. Operating costs are quite comparable for combined cycle gas plants, building integrated photovoltaics systems, solar thermal power plants and on-shore wind power plants. The cost differences are due essentially to the different capital costs (this is still true for off-shore wind, although there operating costs are significantly higher). Nowadays, capital costs per kilowatt installed capacity are in the order of 500 € for gas, 1,000 € for on-shore wind, 1,500 € for off-shore wind, 3,000 € for thermal solar, and 4,000 € for photovoltaics. These costs are bound to decrease in the decades to come, and the decrease may well be stronger for new technologies than for older ones. However, the differences are such that most likely the ranking will remain roughly the same, with the possible exception of photovoltaics, that may outperform thermal solar, but hardly wind and gas.

Things may look different if wind energy is used at high altitudes (above about 500 m) by means of kites or similar systems (Archer and Caldeira 2009; Roberts et al. 2007). High-altitude wind is stronger and steadier than wind close to the surface of the earth, and the installation required to harness high-altitude wind is much cheaper than for surface wind – in the order of 500 € per kilowatt installed capacity. This brings high-altitude wind in direct competition to natural gas. So far, this opportunity has not been seized because of the complex control problems engendered by turbulences. These problems have been mastered in aviation, however, and fostering the required engineering research may provide a critical win-win strategy for the Mediterranean area as for other regions. Limited government incentives can suffice to trigger large scale investment along these lines.

A second win-win strategy that can take advantage of specifically Mediterranean conditions is afforestation (Issar 2010; Caparrós et al. 2010; Millán 2007, 2010). Forests provide a hydrological buffer that greatly alleviates the problems generated by the combination of droughts and floods that many expect from climate change. In the Mediterranean region, they can capture a considerable amount of carbon both in the biomass and the topsoil, thereby contributing to mitigation of climate change. Moreover, they can be combined with biofuel production on lands where this does not compete with food production. But perhaps the greatest advantage of afforestation in Mediterranean regions is the possibility to change regional precipitation patterns. Precipitation in Mediterranean regions is fed mainly by evaporation from the Mediterranean, but without forests, the microclimate of Mediterranean coastal zones is such that most of that evaporation leaves the Mediterranean basin before it precipitates again on the surface of the earth. In these regions, therefore, afforestation can lead to an increase rather than a decrease of precipitation in the future decades, with considerable advantages both for agriculture and for general living standards.

The coastal region around the Mediterranean covers about 1.5 mio square km. If afforestation happened in just 10% of this area, with a density of about 1,000 trees per hectare (somewhat less than typical tree density in the Mediterranean), this would result in an additional 15 billions of trees planted. A sapling costs about 2€, but the other costs involved in afforestation are likely to exceed 20€ per tree. An annual investment of 50 billion € over a decade is a reasonable first estimate. The payback period from biofuels and traditional forestry is in the order of 5 years. Again, limited government incentives should be sufficient to trigger the private investment required.

For a successful green growth strategy in the Mediterranean region, the amount of private investment involved in a massive expansion of renewable energy use as well as large-scale afforestation would need to come on top of expanded investment in other areas. Given the low share of investment in the GDP of Mediterranean countries, this is not only possible, but also highly desirable. In a virtuous circle, it requires and facilitates regional economic integration (Rojo 1994). Along these lines, it is possible to overcome the atmosphere of fear that currently paralyses not only the efforts at effective climate policy, but more generally the opportunities for sustainable development in the Mediterranean region.

17.6 Conclusion

The argument of the present chapter is based on research performed in the CIRCE project, but there is a tension between scientific research findings and the orientation required for collective action. Science as it exists today produces myriads of highly specific results, ranging from measurements of sea level in different places through an understanding of how certain forests influence the micro-climate of a coastal region to estimates of migration flows by age groups. The CIRCE project has collected and documented this kind of results with regard to climate change in the Mediterranean region, and it has produced a whole array of new ones: both are documented in this report.

However, the amazing success of scientific research is due to a degree of specialization that is hard to imagine for the general public, including decision-makers. As a result, the different findings do not convey a comprehensive picture of a given situation, like the one of anthropogenic climate change. They are rather like a set of puzzle pieces, and in fact a massively incomplete one. To develop an orientation for collective action out of these pieces is not a trivial task. It requires judgement and creativity, and it builds on earlier orientations that are modified and transformed in the light of new findings. Just as discoveries in mathematics and electronics did not make the success of laptops an obvious and inevitable consequence, the discoveries by the many researchers investigating climate change in the Mediterranean region do not make green growth in this region an obvious and inevitable consequence. In this region as elsewhere, green growth is an option for the coming decades, but the use of this label in political declarations and business plans does not imply that it will ever by realized.

The orientation proposed in the present chapter, then, is not a compelling result of uncontestable scientific research (if there ever is such a thing), but a synthesis that integrates scientific findings by embedding them in different perspectives of collective action. Which of these perspectives will eventually be realized depends on the decisions of many different people. Our research findings as well as their integration into the argument of the present section have been developed to help those people make better decisions.

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Chapter 18
Summary and Major Findings

Sarah Wolf and Carlo Jaeger

People is the common theme in this part of the RACCM. The part gathers results from the CIRCE project that concern socio-ecological systems all around the Mediterranean. Due to the interdisciplinarity of the project, chapters in this part discuss climate change and societies from different perspectives, such as an economic, social science, or the health sector's point of view. The chapters treat such diverse topics as socio-economic assessment, adaptive capacity and adaptation strategies, health, energy demand and mitigation options, water, tourism, retirement migration, and future options for the Mediterranean. Thus, this part offers a broad overview over aspects of human life in the Mediterranean region influenced by, and influencing, climate change. In the present section we first give a brief outline of the different chapters dealing with *People*, then indicate main findings about specific topics, and finally highlight some themes recurring through the different chapters.

The chapter by Francesco Bosello and Mordechai Shechter considers climate change and the Mediterranean from an economics perspective. It introduces the main methodologies used by climate change impact science to economically assess consequences of climate change, and it presents the main findings of the related literature focusing specifically on possible future economic consequences of climate change in the Mediterranean area. Furthermore, it emphasizes the new knowledge in this field brought about by the CIRCE project.

The water chapter by Ana Iglesias and colleagues is concerned with water for people. It presents a framework to evaluate water availability in response to natural and management conditions, with an example of application in the Ebro basin, and

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evaluates adaptive capacity to understand the ability of Mediterranean countries to face, respond and recover from climate change impacts on water resources.

The adaptation chapter, by Raphaël Billé and others, provides a general framework for the implementation of adaptation in the Mediterranean, proposing conceptual clarifications and operational recommendations. It explores the scientific basis of adaptation, and how this basis is currently being used and portrayed. In particular, climate and impact sciences and related uncertainties are briefly reviewed. The chapter maps a panorama of adaptation practices in the Mediterranean, in contrasted contexts of action – typically developed and developing countries. Also, it provides guiding principles for the elaboration of adaptation strategies in the Mediterranean, focusing on timing, integration, uncertainty management and contextualization.

The chapter by Tanja Wolf and colleagues summarizes the CIRCE project work on health. It evaluates the direct and indirect health impacts of climate change using the examples of heat stress and air pollution in Mediterranean cities, as well as climate sensitive infectious diseases. Then, it presents training on methods for assessing health impacts of climate change as an important example of a response and adaptation strategy.

The chapter on energy demand and mitigation options by Leonidas Paroussos and others presents an analysis of the conditions under which energy can be a lever of sustainable development for countries on the Southern shore of the Mediterranean in the context of intensification of greenhouse gas abatement policies. The analysis begins with the identification of the distribution, uses and potential uses of the energy resources in the countries Algeria, Libya, Egypt, Morocco and Tunisia. Then, growth opportunities for their economies are examined in different contexts. An increasing intensity of climate policy and a widening of its geographical scope, providing opportunities for cross border integration of energy markets, are considered alongside an extension of emission permit markets and the use of JI and CDM development mechanisms. Alternative scenario simulations are used to analyze how the five countries may gain from incorporation into Europe's greenhouse gas abatement effort. The analysis is performed by means of a computable general equilibrium model, named GEM-E3-Med, specifically constructed for the CIRCE project. It is a quantitative analysis that focuses on the effect of alternative scenarios on competitiveness, welfare, employment and economic growth of the Mediterranean economies and in particular the above mentioned Northern African countries.

The chapter on tourism by Alexandre Magnan et al. estimates trends, impacts of climate change and responses of Mediterranean tourism, with special emphasis on coastal areas. It presents scenarios for future tourism flows on regional and national scales as well as a method for assessing the vulnerability of local destinations.

The migration chapter by David Maddison and colleagues deals with international retirement migration, a growing research area across disciplines such as population geography, social gerontology and town planning. Insofar as this type of migration is driven by differences in climate amenities, it is potentially affected by climate change. The chapter briefly summarizes the literature on international retirement migration. Then, it portrays research undertaken under the auspices of the CIRCE project: a statistical analysis of retirement migration flows from the United Kingdom to the Mediterranean (and beyond) highlights the importance of climate. A case study investigates the extent to which climate is already the principal motivating factor for international retirement migration from Northern Europe to the Mediterranean.

In the final chapter, Carlo Jaeger discusses future options for the Mediterranean from a cultural perspective. Today's Mediterranean is the region of the world where Western and Arab cultures meet. Each culture has its own collective emotions shaping its perspective on the climate change problem. In this context, the chapter outlines two opposing general scenarios for the Mediterranean, one of "Mediterranean gloom" and one of "Mediterranean green growth". The latter proposes several win-win strategies for how the Mediterranean region could meet the challenge of climate change.

Major findings of the CIRCE research on people and climate change are as diverse as the topics treated in the chapters just introduced. Some examples from the different sectors considered in this book are:

- *Economic impacts* to be expected differ between Euro-Mediterranean countries and North African as well as Eastern-Mediterranean countries. Aggregate impacts for the Mediterranean are estimated at 1.2% of GDP, with an average loss of 0.5% by 2050 in the European area. Particularly adversely affected are Cyprus, Albania and the Eastern Mediterranean region (−1.6, −2.4, −1.5% of GDP respectively in 2050). In terms of impact types, tourism is the most affected sector and long-term sea-level rise the most threatening impact. Opportunities to be seized lie in the demand re-composition of energy use: the impact of this phenomenon on GDP is often even positive.
- In the *water* sector, policies have to focus not only on water scarcity, but also on social and economic factors in order to provide countries with the tools necessary to confront part of the challenges of climate change. While social and economic factors may be the main drivers of inequality, the implications of various policies depend on water scarcity levels, too.
- *Adaptive capacity* is generally higher in Northern Mediterranean countries than on the Southern shore. The low values of indicators of social and economic capacity in the South call for the development of strategies to improve these capacities in order to be able to face future climate conditions.
- *Adaptation* in the Mediterranean region has to happen now and for a long period of time. Climate change is not the only driver of change, and solutions and instruments that are not targeted explicitly at climate change may provide serious contributions to adaptation. Examples are the control of urbanization, environmental protection, and the reduction of inequality.
- Impacts of climate change on *health* are already being observed, even at a temperature rise of, to date, about 1°C above the 1850–1899 average in Europe. For instance, the European heatwaves in summer 2003 led to 70,000 excess deaths – and a part of this death toll could have been avoided by better management. The distribution of some infectious disease vectors is already altering. Health effects from extreme weather events are expected to increase, as is malnutrition in areas where populations are particularly dependent on crop and livestock productivity. Also, foodborne

disease patterns are likely to change with climate change. On a positive note, local and immediate health co-benefits can be expected from many of the measures to reduce greenhouse gas emissions.
- Concerning *energy demand and mitigation options*, a common emissions trading scheme that includes North African countries into the European emissions market increases opportunities to find cost effective emission reduction options. The outcome of a scenario including concentrated solar power might be a win-win situation for all countries involved (both Northern African countries and EU27 member states) in terms of both welfare and GDP. Things may look even more positive with a stronger reliance on wind. EU27 would be affected positively by the enlargement of the permit market and by imports of low cost carbon free electricity from Northern Africa.
- Trends in *tourism* scenarios with and without climate change differ largely for some Mediterranean countries. Results from the CIRCE project have reinforced the idea that, for the Mediterranean regions, a higher temperature in northern European countries could discourage international flows from North to South and, at the same time, reinforce flows within Northern Europe. Thus, there is a need for tourism territories to develop adaptation strategies in view of climate change.
- For *international retirement migration,* CIRCE work confirms the existence of the amenity seeking retired migrant drawn to countries with warm winters, cool summers, and dry, sunny days - supporting the hypothesis that climate is the principal factor propelling retirees from Northern Europe to the Mediterranean. This makes the phenomenon highly sensitive to climate change.
- Considering *future options*, afforestation is a major example of a win-win strategy that could be applied in the Mediterranean region. By planting trees, problems generated by drought and floods can be minimized while regional precipitation patterns can be positively influenced, in ways unique to the Mediterranean. Moreover, new trees contribute to mitigation by capturing carbon both in biomass and topsoil.

There are throughout this part of the RACCM also findings that relate to each other across chapters and across topics. These constitute more general insights on the common theme of how climate change influences people. Examples evolve around the topics of capacity, integration, and uncertainty, as summarized in the following.

The authors of several chapters note large differences between countries on the Northern and countries on the Southern shore of the Mediterranean Sea. Climate change is expected to have different impacts mostly due to people's differential capacity to act upon, anticipate and adapt to it. The need to increase or improve capacities is clearly stated for such diverse sectors as health, water, and tourism.

Another frequently occurring theme throughout the book is integration. It is considered necessary at various scales and in various areas. Some authors state the need for integrated methods and tools for assessment. Integration between scientists and stakeholders, which allows sharing best practices, research, data, information, technology and tools, is also desirable. Further, an integrated consideration of problems is strongly suggested: several authors point out that climate change is not the only driver of change in many contexts. They call for mainstreaming of health issues into climate change adaptation measures or consideration of social factors in water policy making, to name just two examples. Such an integrated problem view also integrates different time scales: often, climate change is viewed as a problem that will arise in some far away future, while other problems are considered much more important from a short term perspective. The link between current and future problems can be made by strengthening capacity, which enables societies to better deal with both current and future problems. Finally, an integrated view not only of problems but also of solutions to the climate change problem might make such solutions more attractive and thus easier to implement: benefits of emission reductions should be evaluated not only in terms of economic impacts avoided, but should take into account health benefits, energy security, new employment opportunities, stable agricultural production and food security as well.

Last but not least, a recurring theme throughout the chapters of this book is uncertainty. It poses limits to scientific predictions, in particular in the case of social systems, where the individuals composing the systems can react to predictions and may thus invalidate them or make their realization spurious. Therefore, in the context of climate change and people, the role of science is not primarily that of making predictions upon which policy makers can base their decisions. At least as important are the improvement of societal self-perception, including the perception of opportunities for action (Streeck 2009).

The study of social reality by counting, measuring and observing social facts is useful to policy makers by helping to better understand past experience and future possibilities. Strengthening capacity again arises as a “no regret option”: societies with a higher capacity to act upon problems as they are being discovered is also better equipped to deal with as yet uncertain future problems. To meet the challenge of climate change in the Mediterranean, a process of shaping a positive future based on the available possibilities is needed. This part of the RACCM encourages its readers to support such a process by seizing opportunities pointed out throughout the various chapters.

Reference

Streeck W (2009) Man weiß es nicht genau: Vom Nutzen der Sozialwissenschaften für die Politik. MPIfG working paper 09/11

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Chapter 13
Health

Tanja Wolf, Klea Katsouyanni, Antonis Analitis, Afif Ben Salah, Elsa Casimiro, Sadok Chlif, Daniela D'Ippoliti, Bettina Menne, Paola Michelozzi, Xavier Rodo, and Miquel Angel Rodriguez-Arias

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