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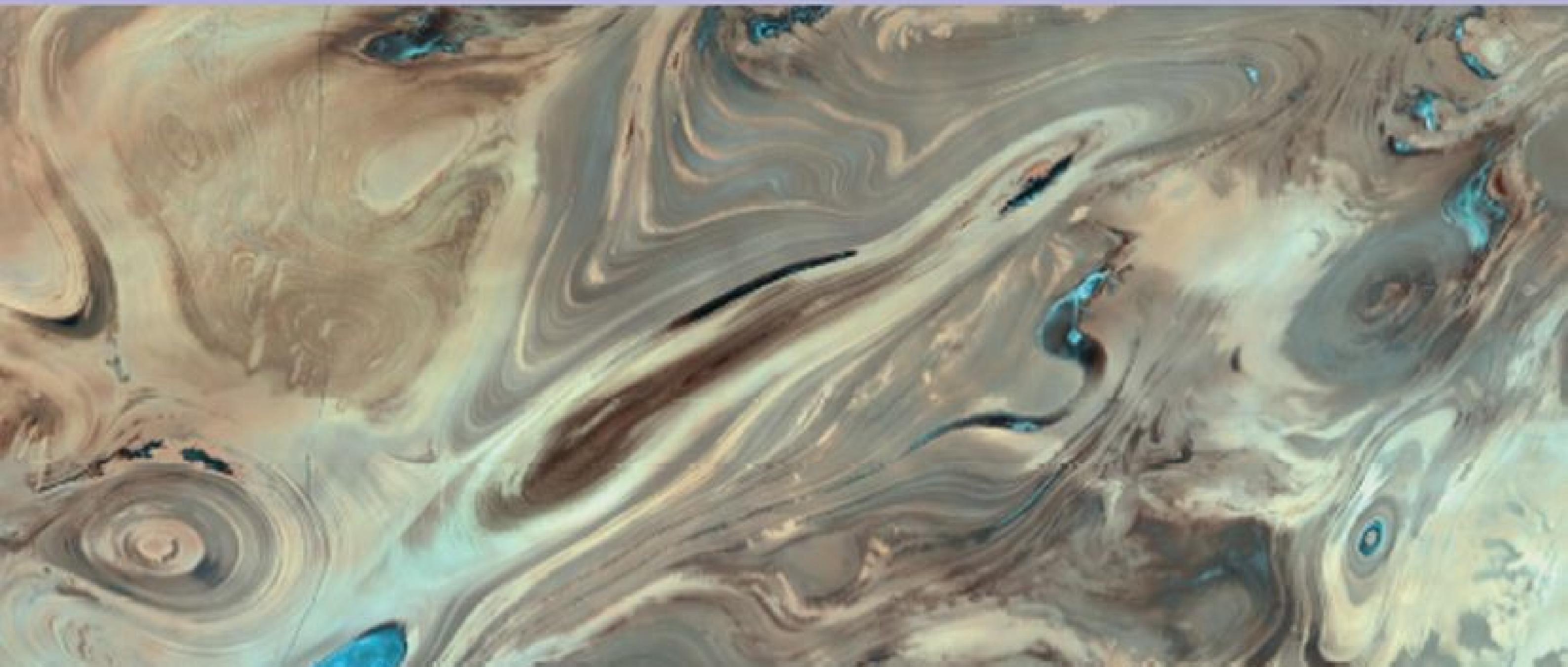
Sabkha Ecosystems

Volume II: West and Central Asia

edited by

M. Ajmal Khan, Benno Böer, German Stanislavovich Kust
and Hans-Jörg Barth



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SABKHA ECOSYSTEMS

Tasks for Vegetation Science 42

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Sabkha Ecosystems

Volume II: West and Central Asia

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Cover photograph caption: The Dasht-e Kevir, or Great Salt Desert, is the largest desert in Iran. It is primarily sabkha, composed of mud and salt marshes. This image was acquired by Landsat 7 Enhanced Thematic Mapper plus (ETM+) sensor on October 24, 2000. It is a false-color composite image made using infrared, green, and red wavelengths. The image has also been sharpened using the sensor's panchromatic band. The image was kindly provided by NASA through the Visibleearth website http://visibleearth.nasa.gov/

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Foreword

The environmental hazards around us cannot be ignored today. They are a threat to our lives as well as to our children and our grand children and future generations of human beings.

Sabkha is an integral part of the natural heritage of West and Central Asia, in particular the Arabian Peninsula, including the State of Qatar.

In times of global freshwater scarcity, sabkha is believed to potentially contribute in coastal hyper saline zones to reduce the pressure on limited freshwater resources via the development of seawater irrigated high productivity man-made agricultural ecosystems.

In times of global warming, and a rising sealevel, sabkha can play important roles in monitoring the pace and status quo of sea level rise, providing valuable data for coastal zone planning.

Research on Sabkha Ecology commenced only a few decades ago and sabkha was considered as wasteland. Even though specialized researchers generated recommendations on sabkha management as early as the 1960s, only recently the environmental managers realized that sabkha is an ecosystem with a development, and conservation value.

It is an essential precursor to study these ecosystems, and develop rational recommendations for development planning, research, and conservation, and in particular the sabkha related studies in view of heritage conservation, sealevel changes, and seawater irrigation for biosaline agriculture, and urbanization.

This volume covers the West & Central Asian aspects of biodiversity, botany, geology, bio-geography, vegetation, ecology, chemistry, economics, hydrology, micro-biology, and ecosystem dynamics with compliments of the distribution values, management requirements, and developments prospects of sabkha in the Arabian Peninsula and adjacent Asian countries.

The volume is a valuable guide, and it is important that these scientific findings are available for ecosystem researchers, environmental strategic planners, land developers, and decision-makers, towards sustainable development and conservation.

Finally, I warmly welcome this volume as an important step towards science-based conservation and development of sabkha environments.

Khaled Ghanem Al Ali
Secretary General
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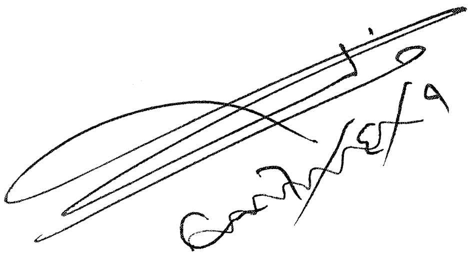
The State of Qatar



Preface

Many ecosystems in the world face severe problems due to environmental and social pressures manifested by non-sustainable economic development and increase in population. However, most ecosystems are important niches for wildlife species that are barely surviving under severe habitat degradation and under threat of extension. An example of such ecosystems is the Sabkha ecosystem, which is the Arabic term "Sabkha"/or "Sabkhat" (plural), that describes a unique coastal ecosystem covering large areas in arid or semi-arid environments in the world. The Sabkha ecosystem is a low flat saline land extending above the level of high tide, with a shallow water table that rises and forms interesting features and sedimentmorphic characteristics. Halophytic vegetation eolian deposits, tidal-flood deposits and evaporates, such as crystalline halite deposits, gypsum, anhydrite, and mineral grains of various sorts, are common characteristics of sabkha sediments.

Most sabkhas in the world are in their pristine stage due to harsh environmental conditions, high salinity of soils and low vegetation cover. Sabkha ecosystems host natural habitats important to migratory birds and coastal marine species. They are important for biodiversity conservation and have potential use in eco-tourism and environment education.

In Volume I of the *Sabkha Ecosystem*, the editors and authors presented a collection of contributions from experts of various disciplines from different countries adjacent to Arabian Peninsula. The volume enhanced the scientific understanding of the sabkha phenomenon and its potential for development. It was a first attempt from the scientific community to gather information and document the value and characteristics of the Sabkha ecosystems in different parts of the world in one document.

In this document, Sabkha Ecosystem Volume II, a broader perspective and geographical distribution of Sabkha Ecosystems in the world is presented. Volume II in the series attempts to broaden our understanding of the Sabkha environment and to appreciate the living organisms that dwell in this niche. Many authors from various disciplines and from different parts of the world contributed to the preparation of this document. The information within its chapters covers: a description of saline ecosystems, sensitivity of Sabkha habitats, wildlife, vegetation, soils and vegetation. The publication will be a basic source of information on Sabkha ecosystems that will broaden scientific knowledge and assist decision makers and environmentalists on the potential use and conservation of Sabkha ecosystems.

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Introduction

M. AJMAL KHAN, BENNO BÖER,
GERMAN KUST AND HANS-JÖRG BARTH

The information on Sabkha ecosystem was so large that all the information could not be gathered in one volume. Therefore it was decided that a detailed account of various regions will be presented in different volumes of Sabkha Ecosystem. The volume 1 entitled "Sabkha Ecosystem: Arabian Peninsula and the adjacent countries" includes ecological, geomorphic, and development studies. The Arabian Peninsula and particularly coastal areas of Arab states in the Gulf have continuously undergone massive land-use changes with projects, converting sabkha into urban lands for the establishment of harbors, settlements and other uses. Therefore this volume is a timely reminder that sabkha are important part of the ecology. The current volume (II) of Sabkha Ecosystem: Central and Western Asia brings information from those parts of central and western Asia, which was little known to English speaking scientists. It consists of twenty chapters ranging from sabkha of Sinai Peninsula up to Siberia. The volume commences with a lucid description of threatened Mediterranean Sabkha of Sinai followed by a detailed and very informative description of Flora of Iran by Hussain Akhani, whose devotion to study the halophytic flora of Iran is unique. He brings a vast perspective of the flora ranging from taxonomic, ecological and physiological point of views. Dr. Shahina Ghazanfar is widely known for her work on the flora of Arabian Peninsula. Despite the recent difficulties faced by the travelers in Iraq she has brought vivid description of sabkha of Iraq. There are two presentations on the Kazakhstan dealing with the zone of impact of Kapchagai reservoir and dust salt transference in the deserts. The description of Pakistani halophytes was strengthened with the inclusion of Prof. M. Qaiser with Ajmal Khan. Prof. Qaiser with his vast experience with the flora of Pakistan and Dr. Khan with halophytes finally brought a comprehensive picture of Pakistani halophytes. Qatar is represented by three excellent presentations including the microorganisms of Qatar by Prof. Mahasneh and co-workers, Dr. Böer and Dr. Saengar describing the biogeography of coastal vegetation and Ms. Al-Yossef and co-worker gave an excellent description of the Northern part of Dukhun sabkha. The Russian Federation was represented by five presentations. Three of them describe the Siberian region; one deals with ancient delta regions of Murghab and Tegden rivers and the last one Aral Sea area. Siberian presentations primarily focused on landscape ecology and natural cartographic analysis of natural salts by Drs. Bulatov, Rotanova and Chernykh while nature and functions of soils, rocks and water was described by Dr. Elizarova and she also shared a paper with Dr. Klenov describing the natural, geographical and halogeochemical feature of western Siberian soils. Contribution by Dr. Dikareva describes the salinization process and the formation of sabkha in delta regions. Dr. Kust and Dr. Novikova dealt with the desertification and sabkha formation in Aral Sea region. Prof. Al-Jaloud and Dr. Hussain gave a good description of halophytic communities of Saudi Arabia and Dr. Brown made an excellent contribution of the vegetation UAE. The last contribution by Morozov and Shirokova described the salinity problem in the irrigated ecosystems of Uzbekistan.

CHAPTER 1

SABKHA ECOSYSTEM AND HALOPHYTE PLANT COMMUNITIES IN SAUDI ARABIA

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Abstract. In Saudi Arabia, sabkhas are widespread, each covering areas from a few hectares to hundreds of square kilometers. In some cases water stands on the surface giving the impression of ponds or lakes. Usually the water table is very close to the ground surface. The salinity of the sabkha groundwater ranges between 50-585 g L^{-1} in different places. Solute chemistry indicates Na and Mg as the major cations and Cl and SO_4 as the major anions. Other ions such as Ca, K, CO_3, and HCO_3 exist in varying proportions besides B, NO_3 and F. Salt is harvested from these sabkhas for multiple uses. The texture of sabkhas soils ranges from coarse (sandy) to fine (sandy-clay-loam) at various places.

A field survey was conducted to determine the halophyte plant communities in sabkha in the Kingdom of Saudi Arabia. Plant species such as *Aeluropus lagopoides, Prosopis farcata, Bienertia cycloptera, Nitraria retusa, Salicornia europaea, Suaeda vermiculata, Tamarix amplexicaula Atriplex leucoclada, Halothamnus (sp), Plantago ovata, Atriplex glaucum, Suaeda fruticosa* and *Suaeda monoica* contain high protein contents (ranging from 4.25-19.75%) besides other mineral elements. The soil EC_e ranges between 8.25-206 dS m^{-1}. Based on the soil and plant analysis, these halophyte plants have an excellent potential for successful growth in a particular sabkha ecosystem. In conclusion, although most of the areas adjacent to sabkhas are heavily degraded, in some cases potential exists for the rehabilitation of either whole sabkhas or parts of sabkhas through halophyte plantation with the adoption of appropriate soil, water and plant management practices.

1. INTRODUCTION

Sabkha (plural: Sabkhas) is an Arabic term for a coastal and inland saline mud flat on playas built up by the deposition of silt, clay and sand in shallow, sometimes extensive, depressions. The sabkhas are commonly saturated with brine and their surfaces often encrusted with several centimeters of thick salt crusts (Chaudhary, 1992; Chaudhary & Aljuwaid, 1999; Al-Jaloud, 1983; Pike, 1970). Two major types of recent sabkha landforms have been distinguished by Kinsman and Park (1969) as coastal sabkha and inland sabkha. Coastal sabkhas are usually formed in coastal areas of arid regions where net evaporation is high and washing of soil is negligible due to limited freshwater supplies coupled with scanty rainfall and poor

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soil drainage. In Gulf Cooperative Countries (GCC), sabkhas constitute around 6% of the coastal areas (Batanouny, 1981). In Saudi Arabia, sabkhas commonly occur in the coastal areas and can also be found inland. Sabkha land is unfit for cultivation due to extremely high salt concentration. No profitable agricultural activity can be carried out in these areas. It is imperative to study these sabkhas to determine their ecological and potential economic value for the country. The main objectives of this paper are to focus on the physico-chemical properties of soils, identify plant communities and develop the relationship between these parameters for optimizing any possible use of otherwise unproductive salty lands.

1.1. Climate of Saudi Arabia

Saudi Arabia has a hot-dry climate and is classified as an arid region occupying about 5% of the world's arid zone (Bashour et al., 1983). Relative humidity is low except along the coastal zone where it sometimes reaches 100%. The average annual temperature is 33°C in summer and 14°C in winter with a wide seasonal and diurnal variation (48°C) (El-Khatib, 1980). The mean solar radiation was recorded as 550 cal cm^{-2} day^{-1} for the months of July and August; and 325 cal cm^{-2} day^{-1} for the months of December and January in the Riyadh region (Water Resources Department, Ministry of Agriculture and Water, 1988). The rate of pan-evaporation was lower along the coastal and high terrain and higher in the interior mainly due to a high presence of desert conditions. The monthly evaporation rates were 540 mm in July at Hail at 988 m elevation, 270 mm in Biljurshi at 2,400 m elevation, and 310 mm in Qatif at 5 m elevation. The rainfall variations between the years are very high and long drought periods have been recorded without any rain.

1.2. Extent and global distribution of salt affected land

Nearly 10% of the total land surface area is covered with different types of salt affected lands. Table 1 shows the distribution of salt affected lands in the world

Table 1. *Salt Affected Lands on the Continents and Sub-Continents (Kovda & Szabolcs, 1979).*

Continent	*Area (ha x 10^3)*
North America	15,755
Mexico and Central America	1,965
South America	129,163
Africa	80,538
South Asia	87,608
North and Central Asia	211,686
South-East Asia	19,983
Australasia	357,330
Europe	50,804
Total	954,832

(Kovda & Szabolcs, 1979). The table also shows that no continent on earth is free from salt affected lands. They are distributed not only in deserts and semi-deserts, but also frequently occur in fertile alluvial plains, river valleys and coastal areas, close to densely populated areas and irrigation systems.

1.3. Characteristics of sabkha soils

Sabkha soils develop due to excessive evaporation from coastal and brine basins where net evaporation rates are very high. Gradual evaporation supersaturates the brine with respect to most insoluble salts such as carbonates of calcium and magnesium followed by highly soluble salts such as sulfate of calcium-gypsum, and or magnesium, and sodium chloride. The excess salinity decomposes organic materials, creates reduced soil conditions and produces hydrogen sulfide with a black color in the system. A comparison of salt concentration in sabkha groundwater at various locations in Saudi Arabia is presented in Table 2. It is clear that salt concentrations vary significantly in different sabkha groundwater at different places.

Table 2. *Comparison of Chemical Composition of Sabkha Groundwater.*

Parameters	*Range of Values*			
	Hussain & Ali (1988)[a] *Western Province, Saudi Arabia*	*KFUPM/RI (1993)*[a] *Eastern Province, Saudi Arabia*	*Seawater*[a] *Gulf Coast, Eastern Province, Saudi Arabia*	*Awshaziyah*[b] *(2001-2002) Al-Qaseem Region, Saudi Arabia*
PH	7.1-7.6	6.8-8.5	8.1	6.5-7.3
Salinity (g/l)	50-155	60.7-283.6	35	124.86-584.73
Calcium (g/l)	0.44-1.80	1.1-3.8	0.41	0.16-16.50
Magnesium (g/l)	1.83-3.31	2.9-6.4	1.28	2.48-60.07
Sodium (g/l)	20-95	20.3-81.7	10.76	15.15-100.00
Potassium (g/l)	0.5-1.90	0.7-7.8	0.4	0.80-10.40
Bicarbonate (g/l)	0.21-0.25	0.1-0.3	0.14	0.08-0.74
Chloride (g/l)	27.5-49.6	37.6-173.8	19.35	73.10-266.00
Sulfate (g/l)	3.21-4.35	2.4-10.12	2.71	2.77-51.80

(Source: [a] Sadiq, 1992; [b]Al-Harbi et al., 2002)

Besides other limitations, restricted aeration is one of the main features of sabkha soils. High sodium concentration causes dispersion of clay and blocks the soil pore space. This blockage interferes with exchange of gases between the atmosphere and sabkha soils. Hossain and Ali (1988) compared the chemical composition of the air in the Obhr sabkha in western Saudi Arabia along the Red Sea coast and in normal soil (Table 3).

Table 3. *Chemical Composition of Air in Sabkha Soils.*

Parameters	Sabkha Soil	Normal Soil	Normal Air
Nitrogen (%)	95	82	80
Oxygen (%)	4.7	15	20
Carbondioxide (%)	0.2	3	0.03

1.4. Chemical composition of halophytes

The chemical composition of plants depends on many plant growth factors. The most important are soil type and soil salinity, irrigation water quality and quantity, the internal atmosphere of soil (Chaudhry & Aljuwaid, 1992), the plant species and the climatic conditions of the area involved.

The mean chemical composition of some halophyte plant species in different areas is summarized in Table 4. High variability in plant elemental composition shows the influence of solute concentration around the plant root zone.

Table 4. *Ranges of Elemental Composition (%) of Halophyte Plants in Different Regions of Saudi Arabia.*

Parameters	*Al-Noaim, et al., 1991 East Province, Saudi Arabia*	*Al-Homaid, et al., 1990 Eastern Province, Saudi Arabia*	*Ali, et al., 2001 East, West and Central Region, Saudi Arabia*	*Ali, et al., 1994 East, West and Central Region, Saudi Arabia*	*Saudi Arabia*	
					E. Province	*W. Province*
N	0.58-2.02	—	0.48-1.70	0.73-3.64	0.44-3.17	0.68-2.64
P	0.04-1.18	—	0.05-0.12	0.01-0.35	0.03-0.31	0.05-0.26
K	0.46-2.00	0.20-2.74	0.09-1.55	0.30-4.50	0.40-2.88	0.05-0.26
Ca	0.5502.36	0.75-6.64	0.07-0.77	0.45-4.85	0.26-6.71	0.55-2.36
Mg	0.16-1.24	—	0.10-1.64	0.09-1.13	0.12-3.54	0.05-10.53
Na	0.10-0.98	0.07-2.75		0.04-5.05	0.02-13.25	0.68-2.64

** Al-Jaloud et al. (2002), paper submitted for publication.

The main factors for hypersaline conditions of sabkha soils are high evaporation rate, flushing of land by seawater and capillary movement of salts from a high groundwater table in coastal sabkhas. Besides these factors, inland sabkhas also receive salts by washout of outcrop from the surrounding areas during heavy rains and floods. Some important chemical characteristics of sabkha soils are given in Table 5.

Table 5. *Important Chemical Characteristics of Sabkha Soils.*

Parameters	*Ali, et al., 2001. East, West and Central Region, Saudi Arabia*	*Saudi Arabia***	
		East Province	*West Province*
PH	7.95-9.85	7.10-8.50	7.25-7.40
ECe dS m^{-1}	8.25-37.65	30.40-206.00	65-161
Ca mg L^{-1}	240-1452	79-10,010	490-1,186
Mg mg L^{-1}	103-601	23.4-4,121	290-1,532
Na mg L^{-1}	993-9269	108-58,042	13,753-35,383
Cl mg L^{-1}	1,418-14,345	556-91,661	21,959-51,894

** Al-Jaloud et al. (2002), paper submitted for publication.

To ascertain the influence of the ecosystem on the halophyte plant community, the chemical composition of some halophytes is presented in Table 6. A critical review of Table 6 reveals that some halophyte plant communities are growing successfully under a wide variety of plant growth conditions in the coastal salt marsh lands and in the inland sabkhas. Among the various species identified, *Atriplex leucoclada*, *Halothamnus sp*., *Nitraria retusa*, *Atriplex glaucum*, *Salicornia europaea*, *Suaeda fruticosa* and *Suaeda monoica* contain high protein contents (ranging from 4.25-19.75%) besides other mineral elements.

Table 6. *Chemical Composition (%) of Halophytes at Different Locations.*

Plant sp.	Ca	Mg	Na	K	N	Protein	P
Zygophyllum coccineum[1]	2.19	3.58	0.53	0.37	ND	ND	0.05
Heliotropium strigosum sp.[1]	4.04	0.63	0.31	2.29	ND	ND	0.07
Atriplex leucoclada[2]	1.37	1.13	5.05	1.8	2.77	17.31	0.19
Halothamnus sp.[2]	0.99	0.47	4.54	2.90	2.38	14.88	0.19
Salsola tetrandra.[2]	1.51	0.41	2.30	0.40	1.01	6.31	0.04
Traganum nudatum[2]	1.23	0.74	3.40	1.00	1.07	6.69	0.05
Hamada elegan[3]	2.36	1.24	0.87	0.77	1.81	11.31	0.04
Prosopis farcata[3]	1.00	0.16	0.12	0.62	1.92	12.00	0.11
Panicum turgidum[3]	0.55	0.28	0.98	0.46	1.18	7.38	0.08
Plantago ovata[3]	1.96	0.31	0.30	2.00	2.02	12.63	0.12
Aeluropus lagopoides[4]	0.79	0.53	4.90	0.60	0.79	4.94	0.12
Limonium sp.[4]	1.01	0.67	4.78	1.33	0.97	6.06	0.11
Nitraria retusa[4]	3.20	1.78	3.98	0.99	1.30	8.13	0.09
Tamarix amplexicale[4]	1.39	2.04	10.53	0.99	0.68	4.25	0.08
Zygophyllum sp.[4]	3.38	0.91	5.73	0.69	0.74	4.63	0.06
Atriplex glaucum[4]	0.70	0.78	12.34	1.15	2.28	14.25	0.18
Bienertia cycloptera[4]	0.76	0.97	13.25	1.95	0.94	5.88	0.09
Halocnemum strobilaceum[4]	0.85	1.00	9.71	1.45	1.07	6.69	0.09
Salicornia europaea[4]	1.15	0.99	10.18	1.71	1.14	7.13	0.09
Suaeda fruticosa[4]	0.94	1.04	11.36	1.75	1.40	8.75	0.09
Suaeda monoica[4]	0.67	0.53	8.71	0.80	3.16	19.75	0.11

Sources: 1. Al-Homaid et al. (1990); 2. Al-Jaloud et al. (1994); 3. Al-Noaim et al. (1991); 4. Al-Jaloud et al. (2003, unpublished data); ND = Not determined.

These plants can be grown to develop rangelands in the sabkha ecosystem where soil and water salinity are the main limitations for plant growth along with adequate fresh irrigation water supplies. In order to rehabilitate the sabkha soils, promising halophyte plants are listed in Table 7 for consideration and practical use.

Table 7. *Salt Tolerance of Some Selected Species (Extracted from Firmin, 1971).*

Plant Species	*Mean Salt Tolerance (mg L^{-1})*	*Plant Species*	*Mean Salt Tolerance (mg L^{-1})*
Avicennia marina	40,000	*Kochia indica*	19,000
Prosopis juliflora	32,000	*Acacia pendula*	12,000
Zygophyllum	31,000	*Acacia salicina*	11,500
Tamarix maris-mortui	26,000	*Parkinsonia aculeata*	11,500
Atriplex nummularia	23,000	*Acacia arabica*	9,000
Avicennia vesicaria	22,500	*Acacia stenophylla*	8,000
Prosopis tamarugo	22,000	*Eucalyptus annulata*	6,500
Eucalyptus sargentii	11,500	*Ficus carica*	6,400
Prosopis juliflora	19,000	*Eucalyptus cornuta*	6,000
Eucalyptus calicultrix	10,000	*Eucalyptus grossa*	5,500
Eucalyptus coolabahs	9,500	*Eucalyptus robusta*	5,400
Tamarix arvensis	23,000	*Prosopis spicigera*	5,100
Tamarix deserti	22,000	*Acacia deani*	3,800
Tamarix florida	22,400	*Eucalyptus oleosa*	3,700
Acacia ligulata	19,500	*Tecoma stans*	3,700
Eucalyptus longicornis	3,200	*Populus cuphratica*	3,200
Bombax malabaricum	2,900	*Acacia tortilis*	1,900
Salix alba	1,900	*Acacua cyclopis*	1,600
Eucalyptus geradii	1,300	*Acacia radiana*	1,600

2. CONCLUSIONS

The sabkha soils and groundwater are highly saline in Saudi Arabia. A wide variety of plant communities were observed in the coastal sabkhas and inland sabkha ecosystem. The sabkha ecosystems are characterized by a very high percentage of insoluble and soluble salts, diversified types of plant communities, and varying soil conditions (i.e. soil texture and total salinity) and water quality. Some of the halophytes show that they have developed some kind of mechanism enabling them to tolerate high salinity and provide possible clues to combating salinity problems for the rehabilitation of salt affected soils in arid regions. The study also stressed the need for future investigation of the plant communities dominated by the potential halophyte plants containing high protein in the coastal and inland sabkhas. Further, the promising plant species should be used as a basis for planning future research programs making use of these halophytes. Also, these halophytes can be classified as xerohalophytes (plants in a dry saline habitat) and hygrohalo-phytes (plants in wet saline habitats). The establishment of gene banks of promising halophytes may be an appropriate preposition to combat desertification and promote greenery in the coastal and inland sabkhas.

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4. REFERENCES

Al-Harbi, O.A., Al-Sagaby, I.A., Hussain, G., Khan, M.M. & Allafoza, O. 2002. A comprehensive study of Al-Awshaziyah sabkha in Al-Qaseem Region, Kingdom of Saudi Arabia. Technical Report. NRERI, KACST, Saudi Arabia.

Al-Homaid, N., Sadiq, M. & Khan, M.H. 1990. Some desert plants of Saudi Arabia and their relation to soil characteristics. Journal of Arid Environment 18: 43-49.

Al-Jaloud, A.A. 1983. Effect of reclamation on Al-Hassa saline soil in Saudi Arabia. M.Sc. Thesis. California State University, Fresno, California, U.S.A.

Al-Jaloud, A.A., Chaudhry, S.A., Bashour, I.I., Qureshi, A. & Al-Shanghitti, A. 1994. Nutrient evaluation of some arid range plants in Saudi Arabia. Journal of Arid Environment 28: 299-311.

Al-Jaloud, A.A., Al-Saiady, M.Y., Assaeed, A.M. & Chaudhry, S.A. 2001. Some halophyte plants of Saudi Arabia, their composition and relation to soil properties. Pakistan Journal of Biological Science 4: 531-534.

Al-Jaloud, A.A., Hussain, G., Shalaby, M.N., Beg, A. & Baig, M.S. 2003. Chemical composition and soil environment of plant communities of coastal areas of Saudi Arabia. (Unpublished Data: paper prepared for publication).

Bashour, I.I., Al-Mashhady, A.S., Parasad, J.D., Miller, T. & Mazroa, M. 1983. Morphology and composition of some soils under cultivation in Saudi Arabia. Geoderma 29: 327-340.

Batanouny, K.H. 1981. Ecology and Flora of Qatar. The Center for Scientific and Applied Research. University of Qatar. 12-13pp.

Chaudhary, S.A. 1992. The Empty Quarter. In: Natural History of Saudi Arabia - An Introduction. Ministry of Agriculture and Water, Riyadh.

Chaudhary, S.A. & Aljuwaid, A.A. 1999. Vegetation of the Kingdom of Saudi Arabia. Ministry of Agriculture and Water, Riyadh.

Chaudhary, S.A. (Edit). 1999. Flora of the Kingdom of Saudi Arabia. Ministry of Agriculture and Water, Riyadh.

El-Khatib. 1980. Seven Green Spikes. Ministry of Agriculture and Water, Riyadh, Saudi Arabia.

Firmin, R. 1971. Afforestation. Report to the Government of Kuwait. The United Nations Food and Agriculture Organization, Rome.

Hossain, D. & Ali, K.M. 1988. Shear strength and consolidation characteristics of Obhr sabkha, Saudi Arabia. Quarterly Journal of English Geology 21: 347-359.

KFUPM/RI. 1993. Investigation of the size of industrial wastes in the industrial City of Jubail. KACST Project PN-AR-09-059, The Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Kinsman, D.J.J. & Park, R.K. 1969. Studies of recent sedimentology and early diagenesis, Trucial Coast, Arabia Gulf: 2^{nd}. Regional Technical Symposium Society Ptr. English of AIME, Saudi Arabia Section.

Kovda, V.A. & Szabolcs, I. 1979. Modelling of soil salinization and alkalization. Agrokemia es Talajtan, 28, Suppl. Ministry of Agriculture and Water. 1990. Animal Resources Department, Ministry of Agriculture and Water, Riyadh, Saudi Arabia.

Pike, J.G. 1970. Evaporation of groundwater from coastal playas (sabkhas) in the Arabian Gulf Journal Hydrology 11: 79-88.

Sadiq, M. 1992. Toxic Metal Chemistry in Marine Environments. Marcel Dekker Inc., New York. Water Resources Department. 1988. Weather Atlas of Saudi Arabia. Ministry of Agriculture and Water, Riyadh, Saudi Arabia.

CHAPTER 2

AN OVERVIEW OF THE HALOPHYTES IN TURKEY

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Abstract. Nearly 4.3 million ha of agricultural land in Turkey are degraded, out of which 1.5 million ha are arid and 2.8 million ha saline-alkaline. Plant diversity studies show that these areas include 300 halophytic taxa, belonging to 150 genera and 40 families. The dominant families are Poaceae (16.6%), Chenopodiaceae (14.0%), Asteraceae (12.0%), and Fabaceae (7.6%), while the dominant genera with highest number of taxa are *Limonium, Juncus, Salsola, Plantago, and Trifolium.* Phytogeographically, 50.67% of these taxa are imperfectly known, 9.33% are cosmopolitan, 8% Mediterranean, 7.67% Euro-Siberian, 3.33% East Mediterranean, and 2% Irano-Turanian. The life form spectrum reveals that 40% of the halophytes are therophytes, 28.33% hemicryptophytes, and 23% cryptophytes, with the majority being hygrohalophytes followed by xerophytes and psammohalophytes. The number of endemic taxa is about 39, the highest in Asteraceae (8 taxa), and Plumbaginaceae (6 taxa). The red data book of Turkish plants shows that 33 endemic and 11 non-endemic halophytes are in danger of extinction. Species like *Limonum bellidifolium* are collected in spring for indoor decorations due to their attractive floral shoots. *Halocnemum strobilaceum*, *Aeluropus littoralis* and *Arthrocnemum* sp. are grazed by cattle, and species of *Juncus* are used for basket making. A large number of people in the Aegean region have started using *Salicornia europaea* as salad. In some markets *Arthrocnemum fruticosum* is sold in place of *Salicornia europaea* for this purpose, and one has to be careful in this connection because consumption of the former in place of the latter may create health problems related to the digestive system. The littoral halophytic taxa, which occupy habitats immediately following the psammophytic plant communities, serve as a reclusive area for many animals and can serve as indicators of salinity-sodicity, whereas areas with high ground water salinity could be used for halophytic forage crop production. Some halophytic taxa can be used in erosion control alongside the coastal zones because of their deep root systems. There is great potential in the halophytic plant cover for consumption as well as amelioration of degraded lands in Turkey. Some work has already started in this direction but we have a long way to go.

1. INTRODUCTION

Turkey embodies 26.5 million ha of potential agricultural land and nearly 4.3 million ha of these soils have become unproductive; 1.5 million ha are faced with aridity and have inadequate drainage. This amounts to 20% of Turkey's irrigable land (Gungor & Erozel, 1994; Kaynak et al., 2000; Ozturk & Guvensen, 2002; Topraksu, 1980). The present situation is the outcome of longterm overirrigation. These degraded lands are mainly inhabited by littoral and inland halophytic taxa,

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some of which are obligate and others facultative and are generally regarded as a group of useless plants in Turkey in spite of the fact that elsewhere in the world they are used for food, fiber, fuel, animal feed, medicine, bread making, etheric oil and gum production (Somers, 1982). The fodder value of some halophytes has been exploited by humans for hundreds of years, but lately advances have been made through introduction, selection, proper management, and new application techniques. Some halophytes are rich in proteins as well as minerals, produce high biomass and show great adaptivity to a wide range of environmental stresses. The data base of salt tolerant plants of the world compiled by Aronson (1989) contains more than 1,560 species in 550 genera and 117 families and focuses on economic uses as well as life form, plant type, geographic distribution, maximum reported salinity tolerance and photosynthetic pathways. Dagar (1995), Ozturk & Guvensen (2002) and NRC (1990) have also worked on these lines.

Although a huge amount of literature is available on the flora of Turkey (Davis, 1965, 1988; Demiriz, 1993), very few papers have been published on the halophytes, notable among them being Beyce (1960), Birand (1960), Gehu & Uslu (1987), Guvensen (1994), Guvensen & Ozturk (2004), Guvensen et al., (1996), Ozturk et al., (1995), Yurdakulol & Ercoskun (1990), Zeybek (1969) and Zeybek et al., (1976). In this paper an attempt will be made to evaluate the halophytic plant cover of the country.

1.1. Study area

Turkey, with an area of 783,577 km^2, is situated between the 26^o-45′ east meridian and 36^o-42′ north parallels in the northern hemisphere, bridging Asia and Europe. It is geographically placed in the temperate zone embodying three climatic regions: the Mediterranean, Euro Siberian and Irano-Turanian. The Euro-Siberian region extends from Georgia to Bulgaria with a coastline of 1,500 km. There is no dry period in this area and the climatic regime resembles the Atlantic coastal regime of Europe. Annual precipitation exceeds 1,000 mm, but decreases from east (2,200-2,400 mm) to west (1,000-1,370 mm). Summers are warm and winters mild. Summer rains average 200 mm. The Mediterranean area extends from Canakkale up to the Syrian border and shows a typical Mediterranean climate in an area of 480,000 km^2, which corresponds to 20.8% of the whole Mediterranean belt (Akman & Daget, 1971). The climate is dry and hot in summer and mild in winter. Annual precipitation is around 300-1,000 mm. The Irano-Turanian region, which includes the coldest parts of Turkey, is characterized by a continental climate. The winters are very cold, and summers are hot. Precipitation as snow occurs in winter while rains are common in spring and autumn. Mean annual precipitation is 430-790 mm (Figure 1). However, southeast parts of this region experience a steppe climate with very hot summers. Aridity is also severe and evaporation reaches up to 1,000-2,000 mm (DIE, 2000). A map with representative climatic diagrams prepared according to Walter (1967) is given

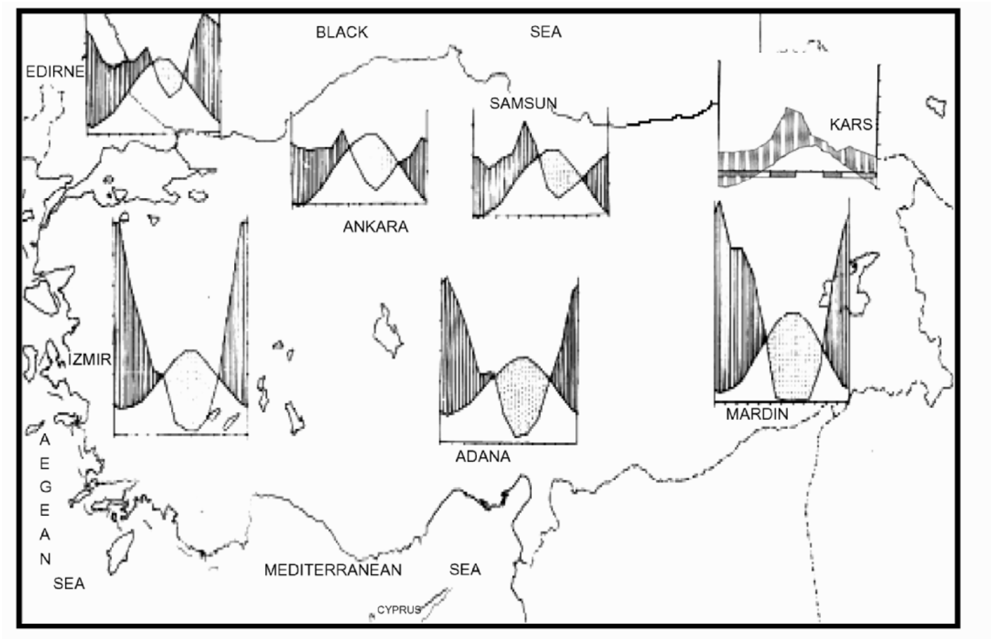

Figure 1. *Map showing climatic diagrams of representative areas in Turkey.*

below. These were compiled from the data covering the last 40 years obtained from the national meteorological survey, Ankara.

1.2. Salinity and alkalinity problems

Although the first classification of Turkish soils was given by Caglar (1949) on the basis of dominant ions, more detailed studies were conducted by Oakes (1954). He classified soils as saline hydromorphic alluvial (650,200 ha), solonchacks (69,700 ha), young alluvial (820,400 ha), hydromorphic alluvial (681,280 ha), and beaches, sand dunes, and marsh complexes (89,800 ha). The saline areas in Turkey are smaller in size than in neighboring countries like Iran (27,085,000 ha) and Iraq (6,726,000 ha), but larger than in Syria (532,000 ha) and Bulgaria (25,000 ha). Some investigations on the salinity-alkalinity problems were carried out earlier in Turkey (Okur, 1989; Ozturk et al., 1995, 1998; Saatci & Tuncay, 1971). The factors responsible for the salinity-alkalinity problems can be summarized as: accumulation of salts in plains due to heavy rains, a long standing high water table, the impact of sea water on the coastal alluvial plains, and geological features of Turkey, in particular the existence of saline areas as internal seas or sodic lakes, and over irrigation practices. The size of individual saline areas is generally less than 500 ha in Thrace, Southeast Anatolia, and the East Black Sea regions, but more than 100 thousand ha in Konya, Nigde (Central Anatolia) and Adana (South Anatolia) (Figure 2; Tables 1, 2). In these last regions, arid and semiarid climatic conditions play a great role in the formation of saline-alkaline soils, because precipitation and leaching are very low. Arid and

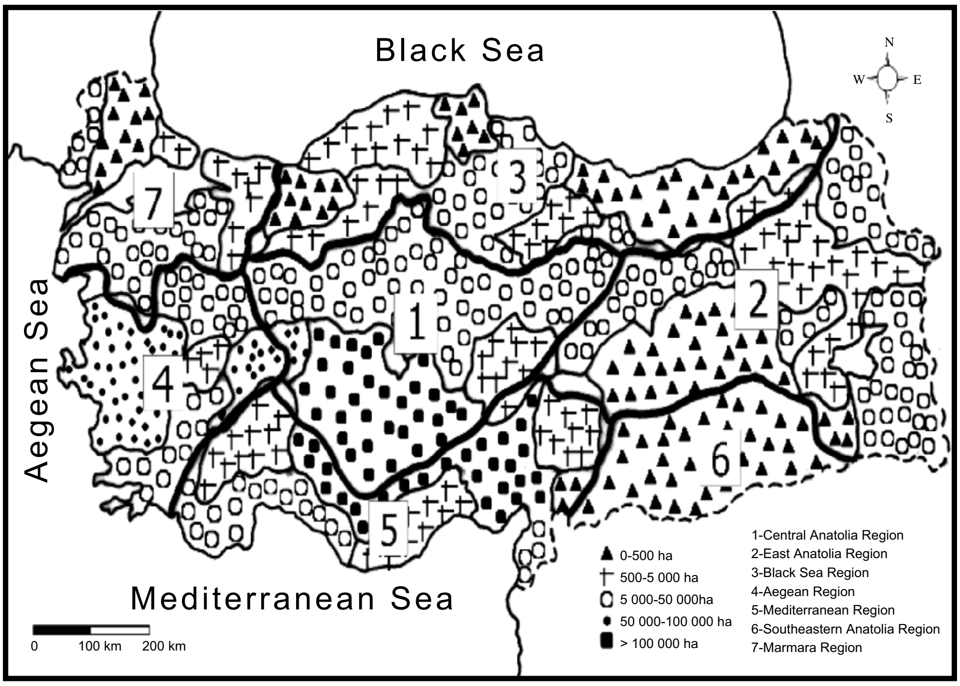

Figure 2. *Map showing the distribution of saline-alkaline soils in different geographical regions of Turkey (Modified from Ayyildiz, 1983).*

alluvial soils affected by salinity are most present in the Konya basin, followed by the Kizilirmak and Great Menderes basins (Figures 3, 4). In the Konya, Firat, Kizilirmak, Van Lake and Sakarya basins hydromorphic alluvial soils affected by slinity cover large areas (Figure 5).

Soil characteristics of representative samples (0-30 cm) from the Meric, Gediz, Antalya, Kizilirmak, Konya and Seyhan basins reveal that pH varies between 7.5-7.9, and that EC, Na^{+}, K^{+}, Ca^{++}, Mg^{+}, Cl, SO_4 and ESP values range between 9.65-60.7 (mmhos/cm), 2.4-20.50 (meq/100gr), 0.01-0.86 (meq/100gr), 1.5-31.97 (meq/100gr), 10.82-84.75 (meq/100gr), 0.58-29.41 (meq/100gr), 1.68-21.55 (meq/100gr), and 10.82-84.75 respectively (Dizdar, 1978).

1.3. Halophyte diversity

True halophytes are plants that are able to live under elevated salinities (greater than 0.5% NaCl), but also vary in their salt content from slight to brackish to medium to severe to above seawater salinity. In general 2,500-3,000 species of halophytes are found in the world (Khan & Duke, 2001). Nearly 700 species are distributed in the Mediterranean climatic zone (Choukr-Allah, 1991).

These include the species with high salt tolerance belonging mainly to the Chenopodiaceae, Potamogetonaceae, Hydrocharitaceae, Plumbaginaceae,

Table 1. *Area of degraded and saline soils in different geographical divisions of Turkey.*

Geographical Divisions	*Area (ha)*	*Saline Soils*		*Total degraded soils*	
		(ha)	*(% of total area)*	*(ha)*	*(% of total area)*
Marmara	6,700,000	65,698	0.98	351,678	5.24
Central Anatolia	15,100,000	681,147	4.51	1.614,181	10.68
Aegean	7,900,000	351,353	4.44	907,033	11.48
Southeast Anatolia	7,500,000	236	0.003	6,336	0.08
East Anatolia	16,300,000	168,270	1.03	449,884	2.76
Black sea	14,100,000	41,074	0.29	352,500	2.5
Mediterranean	12,000,000	209,510	1.74	635,197	5.29
Total	79,600,000	1,517,288	1.90	4,316,809	5.42

Table 2. *Area covered by saline-alkaline soils in different states of seven geographical divisions.*

Geographical Divisions							
Marmara	*Central Anatolia*	*Aegean*	*Southeast Anatolia*	*East Anatolia*	*Black Sea*	*Mediter-ranean*	*Saline and sodic soils covered areas (ha)*
Tekirdag Kirklareli			Adiyaman, Urfa Gaziantep, Siirt Diyarbakir, Mardin	Malatya, Elazig, Tunceli, Bingol	Ordu, Sinop Giresun, Bolu Trabzon, Artvin Gumushane, Rize		>500
Kocaeli Istanbul Bilecik Sakarya		Usak		Erzurum, Bitlis, Agri	Tokat Zonguldak Kastamonu	K. Maras, Isparta Burdur	500-5,000
Canakkale Balikesir Bursa Edirne	Eskisehir Ankara Kırsehir Nevsehir Sivas Corum Cankiri	Mugla Denizli Kutahya		Erzincan, Kars Mus,Van, Hakkari	Samsun Amasya	Hatay Antalya	5,000-50,000
	Kayseri	Izmir Aydin Manisa Afyon				Mersin	50,000-100,000
	Konya Nigde					Adana	100,000>

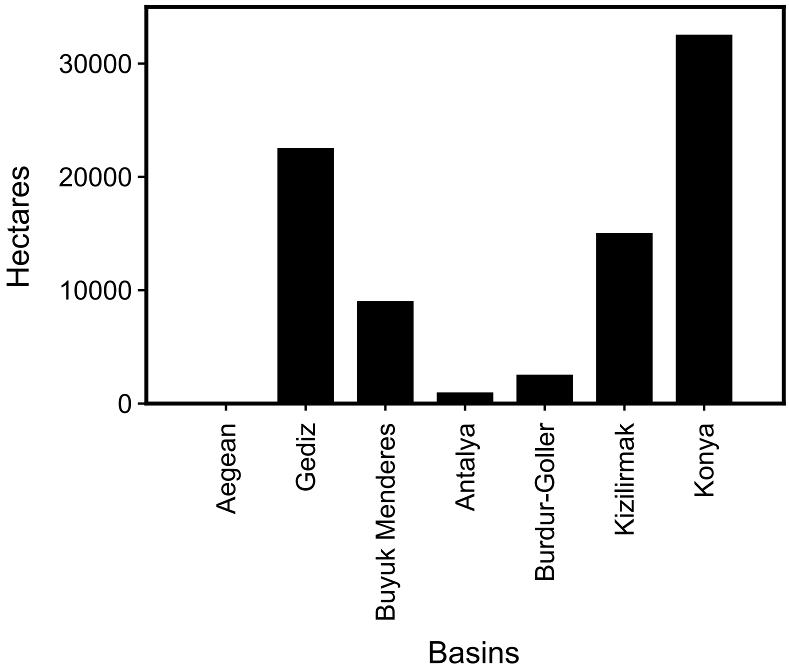

Figure 3. *Distribution of saline soils in different basins (modified from Dizdar, 1978).*

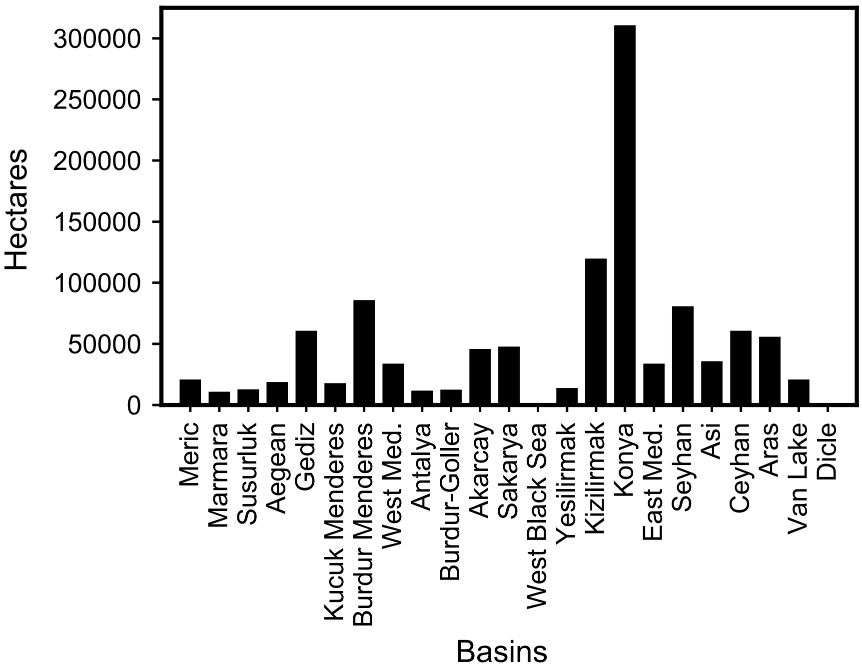

Figure 4. *Alluvial soils affected by salinity (total soluble salts 0.15-0.35%; ESP around 15%) in different basins (modified from Dizdar, 1978).*

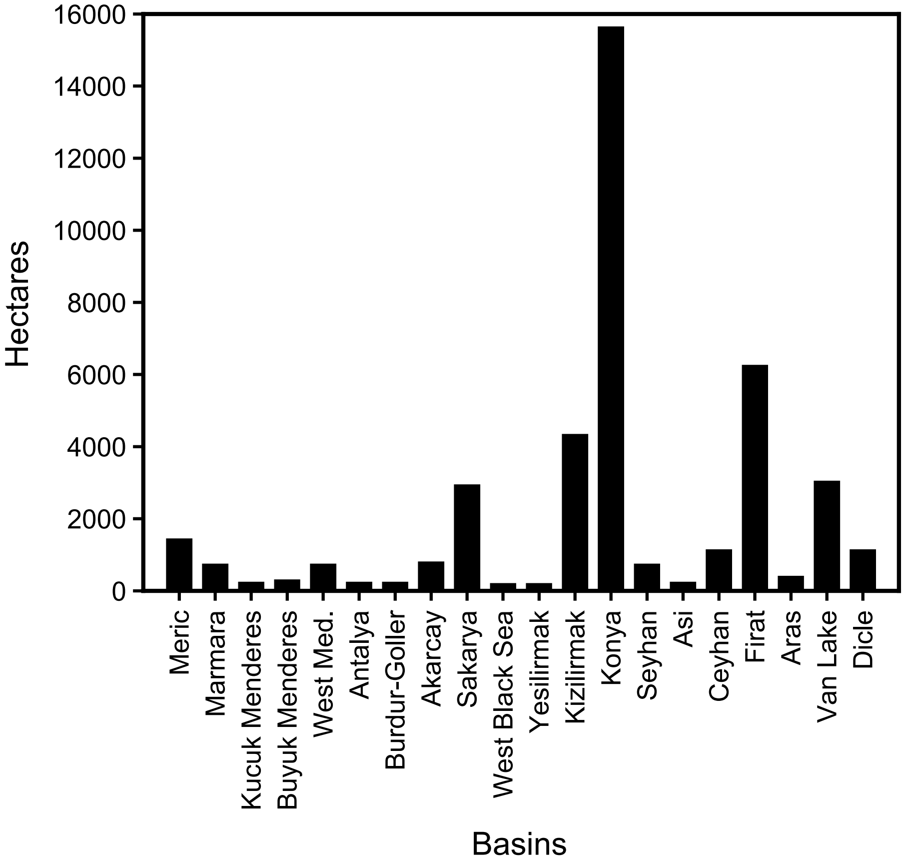

Figure 5. *Hydromorphic alluvial soils effected by salinity (total soluble salts 0.15-0.35%; ESP around 15%) in different basins (modified from Dizdar, 1978).*

Zygophyllaceae, Tamaricaceae, Frankeniaceae and Rhizophoraceae families (Waisel, 1972). Characteristics of vascular halophytes found in Turkey have been evaluated here with special reference to their ecological features. The present study has revealed that more than 300 halophytic taxa occur in Turkey. These belong to 150 genera and 40 families (Table 3). Out of these the Poaceae (16.6%), Chenopodiaceae (14.0%), Asteraceae (12.0%), and Fabaceae (7.6%) top the list. A similar situation is seen in Iran and Greece (Babalonas et al., 1995; Breckle, 1986). The genera with the highest number of taxa are *Limonium, Juncus, Salsola, Plantago* and *Trifolium. Orobanche minor, Anagallis arvensis* var. *arvensis, Glaux maritima* and *Samolus valerandi* are not true halophytes; we have observed them to be facultative halophytes in the ecotone zone between psammophytic-halophytic plant communities. Phytogeographically 50.67% of these taxa are imperfectly known, 9.33% are cosmopolitan, 8% Mediterranean, 7.67% Euro-Siberian, 3.33% East Mediterranean, and 2% Irano-Turanian. The life form spectrum reveals that 40% of the halophytes are therophytes, 28.33%

hemicryptophytes, and 23% cryptophytes, the majority being hygrohalophytes followed by xerophytes and psammohalophytes (Table 4). The number of endemic taxa is about 39. The highest number of these is found in Asteraceae (8 taxa), and Plumbaginaceae (6 taxa) (Table 5).

Table 3. *List of halophytic taxa together with their ecological features.*

Families	*Taxa*	*Life form*	*Chorotype*	*Ecotype*	*Altitude (m above sl.)*	*Flowering time(months)*
Apiaceae	*Apium nodiflorum*	H	IN	HG	1-1,400	5-8
Apiaceae	*Bupleurum semicompotisum*	T	IN	H	200	3-6
Apiaceae	*B. euboeum*	T	EM	H	1-1,500	6-8
Apiaceae	**B. Heldreichii*	T	IT	H	800-1,200	5-7
Apiaceae	*B. tenuissimum*	T	IN	H	1-300	7-9
Apiaceae	**B. turcicum*	H	IT	H	900-1,100	6-7
Apiaceae	*Eryngium campestre* var. *virens*	H	IN	X	1-1,800	7-9
Apiaceae	*Falcaria falcaroides*	H	IN	HG	380-1,250	6-8
Asteraceae	**Achillea goniocephala*	H	IT	X	1,300-1,900	6-8
Asteraceae	**A. Sieheana*	H	IT	X	950-1,200	6-9
Asteraceae	*Artemisia campestris*	H	IN	PH	1-1,500	6-9
Asteraceae	*A. santonicum*	CH	ES	PH	1-1,300	7-10
Asteraceae	*Aster tripolium*	H	ES	PH	-	6-9
Asteraceae	*Bellis annua*	T	M	HG	1-300	2-5
Asteraceae	*B. sylvestris*	T	M	HG	800	9-1
Asteraceae	*Bidens cernua* var. *radiata*	T	IN	HG	610-1,060	8-9
Asteraceae	*Carlina lanata*	T	M	X	10-800	6-8
Asteraceae	*Carthamus persicus*	T	IT	X	340-1,750	6-9
Asteraceae	*Centaurea balsamita*	T	IT	X	650-1,900	7
Asteraceae	*C. drabifolia* subsp. *detonsa*	T	IN	X	800-900	6-8
Asteraceae	*C. pterocaula*	T	IT	X	900-1,200	7-8
Asteraceae	*C. virgata*	T	CM	XH	100-2,000	6-9
Asteraceae	**Cousinia birandiana*	H	IT	HG	850-1,200	6-8
Asteraceae	**C. humilis*	H	IT	HG	-	-

Asteraceae	**C. İconica*	H	IT	X	850-2,000	5-9
Asteraceae	*Cirsium alatum* subsp. *alatum*	H	IT	HG	900-1,800	6-9
Asteraceae	*Crepis foetida* subsp. *commutata*	T	IN	X	1-1,200	4-6
Asteraceae	*C. foetida* subsp. *rhoeadifolia*	T	IN	PH	1-2,000	5-10
Asteraceae	*C. sancta*	T	IN	XH	-	-
Asteraceae	*Filago eriocephala*	T	EM	R	1-1,200	4-6
Asteraceae	*Hedypnois cretica*	T	M	PH	1-900	3-5
Asteraceae	*Inula aucherana*	C	IT	XH	550-1,900	7-9
Asteraceae	*I. crithmoides*	CH	IN	HG	sea level	9-11
Asteraceae	*I. graveolens*	T	M	PH	1-800	8-10
Asteraceae	*Onopordum bracteatum*	H	EM	R	150-1,500	7-8
Asteraceae	**O. polycephalum*	H	IT	R	1,400-2,130	6-8
Asteraceae	*O. turcicum*	H	IT	R	800-1,250	7-8
Asteraceae	*Pulicaria dysenterica*	H	CM	HG	1-1,600	7-9
Asteraceae	*Scariola orientalis*	CH	IT	X	800-2,700	7-9
Asteraceae	*Sonchus oleraceus*	H	IN	X	1-1,300	3-5
Asteraceae	*Taraxacum bessarabicum* var. *bessarabicum*	H	IN	XH	900-3,000	7-11
Asteraceae	**T. farinosum*	H	IT	XH	800-1,200	6-9
Asteraceae	**T. mirabile*	H	IN	XH	800-1,300	-
Asteraceae	*Tripleurospermum decipiens*	H	IN	XH	700-2,350	5-8
Boraginaceae	*Cynoglossum creticum*	H	IN	PH	1-1,000	3-7
Boraginaceae	*Heliotropium dolosum*	T	IN	PH	1-1,640	5-9
Boraginaceae	*H. lasiocarpum*	T	IT	PH	50-1,050	6-8
Boraginaceae	*H. europaeum*	T	M	R	1-1,400	6-9
Brassicaceae	**Alyssum pateri* subsp. *pateri*	CH	IT	X	500-3,000	5-6
Brassicaceae	*A. linifolium* var. *linifolium*	T	CM	X	100-2,700	3-7
Brassicaceae	*Cakile maritima*	T	IN	PH	sea level	6-8
Brassicaceae	*Clypeola jonthlaspii*	T	CM	X	1-500	4-5
Brassicaceae	*Erysimum crassipes*	H	CM	PH	1-2100	5-7
Brassicaceae	**Lepidium caespitosum*	H	IT	XH	800-1,300	5-6
Brassicaceae	*L. cartilegineum* subsp. *crassifolium*	H	IN	X	1,000	4-6
Brassicaceae	*L. latifolium*	C	CM	H	1-1,500	5-7
Brassicaceae	*Malcolmia africana*	T	CM	X	1-2,800	3-6

(Continued)

Brassicaceae	*Sisymbrium altissimum*	H	IN	X	1-1,400	3-6
Caryophyllaceae	*Cerastium anomalum*	T	IN	HG	1-2,500	4-7
Caryophyllaceae	**Gypsophila oblanceolata*	C	IT	XH	950-1,050	6-8
Caryophyllaceae	*G. perfoliata*	H	IN	XH	350-1,500	6-8
Caryophyllaceae	*Minuartia hybrida* subsp. *hybrida*	T	IN	X	1-2,200	2-5
Caryophyllaceae	*M. urimiensis*	T	IT	XH	1,000	5-6
Caryophyllaceae	*Silene aegyptica* subsp. *ruderalis*	T	IN	X	600-1,900	5-7
Caryophyllaceae	*S. alba* subsp. *divaricata*	T	IN	X	500-3,500	6-8
Caryophyllaceae	*S. nocturua*	T	M	PH	1-200	5-6
Caryophyllaceae	**S. salsuginea*	H	IT	XH	900	7
Caryophyllaceae	*S. supina* subsp. *pruinosa*	H	IN	X	100-2,100	5-7
Caryophyllaceae	*S. viscosa*	H	IN	X	-	8
Caryophyllaceae	*Spergularia marina*	H	CM	XH	1	3-6
Caryophyllaceae	*S. media*	H	CM	XH	1	5-8
Caryophyllaceae	*S. rubra*	T	IN	XH	1-2,500	4-8
Chenopodiaceae	*Arthrocnemum fruticosum*	CH	IN	HG	1-1,100	8
Chenopodiaceae	*Atriplex davisii*	T	IT	PH	900-1,000	5-7
Chenopodiaceae	*A. hastata*	T	IN	H	1-50	5-8
Chenopodiaceae	*A. laevis*	T	IN	H	900-1,200	5-7
Chenopodiaceae	*A. lasiantha*	T	IN	R	1-1,800	5-7
Chenopodiaceae	*A. rosea*	T	IN	R	1-1,800	6-8
Chenopodiaceae	*A. tatarica* var. *tatarica*	T	IN	H	1-1,200	5-8
Chenopodiaceae	*Camphorosma monspeliaca* subsp. *lessingii*	CH	IN	*H*	1-1,400	6-8
Chenopodiaceae	*Chenopodium album* subsp. *album*	T	IN	PH	1-2,000	5-8
Chenopodiaceae	*C. botrys*	T	IN	PH	1-1,900	5-7
Chenopodiaceae	*C. chenopoides*	T	IN	H	1-900	5-8
Chenopodiaceae	*C. foliosum*	T	IN	R	1,200-2,800	5-7
Chenopodiaceae	*C. opulifolium*	T	IN	R	1	5-8
Chenopodiaceae	*Halanthium kulpianum*	T	IN	H	900-940	-
Chenopodiaceae	*Halimione portulacoides*	CH	IN	H	1-900	6-8
Chenopodiaceae	*H. verrucifera*	CH	IN	H	1-1,000	6-8
Chenopodiaceae	*Halopeplis amplexicaulis*	T	IN	HG	1	6-8
Chenopodiaceae	*Halocnemum strobilaceum*	CH	IN	HG	1-1,100	7-9
Chenopodiaceae	**Kalidiopsis wagenitzii*	CH	IN	H	940	5-6

Chenopodiaceae	*Kochia prostrata*	CH	IN	X	1-1,900	6-8
Chenopodiaceae	*Microcnemum coralloides* subsp. *anatolica*	T	IN	HG	940-1,000	5-7
Chenopodiaceae	*Noaea minuta*	T	IN	X	1,300	6-8
Chenopodiaceae	*N. mucronata* subsp. *mucronata*	*CH*	IN	X	500-2,000	5-7
Chenopodiaceae	*Panderia pilosa*	T	IN	H	900-1,200	5-8
Chenopodiaceae	*Petrosimonia brachiata*	CH	IN	H	0-900	6-9
Chenopodiaceae	*Salicornia europaea*	T	IN	HG	-	7-9
Chenopodiaceae	*S. prostrata* subsp. *prostrata*	T	IN	HG	1	6-9
Chenopodiaceae	*S. fragilis*	T	IN	HG	-	-
Chenopodiaceae	**Salsola anatolica*	T	IT	H	1,000	6-8
Chenopodiaceae	*S. crassa*	T	IN	H	1,000	5-7
Chenopodiaceae	*S. inermis*	T	IT	H	900-950	5-7
Chenopodiaceae	*S. kali*	T	IN	R	0-1,010	5-7
Chenopodiaceae	*S. laricina*	CH	IT	HG	950	5-7
Chenopodiaceae	*S. macera*	T	IT	X	850-950	5-7
Chenopodiaceae	*S. nitrarira*	T	IT	H	900-1,200	6-8
Chenopodiaceae	*S. soda*	T	IN	H	1	5-7
Chenopodiaceae	S. ruthenica	CH	IN	PH	1-1,750	5-7
Chenopodiaceae	*Suaeda altissima*	T	IN	H	900-1,250	7-9
Chenopodiaceae	*S. carnosissima*	T	IN	H	900-1,200	5-8
Chenopodiaceae	*S. confusa*	T	IN	H	800	6-8
Chenopodiaceae	*S. eltonica*	T	IN	H	900	5-7
Chenopodiaceae	*S. prostrata* subsp. *prostrata*	T	IN	H	1	6-9
Convolvulaceae	*Cressa cretica*	T	IN	XH	1	6-8
Cuscutaceae	*Cuscuta campestris*	T	IN	X	100-1,500	5-10
Cyperaceae	*Bolboschoenus maritimus* var. *maritimus*	C	CM	HG	1-2,000	-
Cyperaceae	*Carex capitellata*	C	ES	HG	1,600-2,900	-
Cyperaceae	*C. distans*	C	ES	HG	1-2,150	-
Cyperaceae	*C. divisa*	C	ES	HG	1-2,800	-
Cyperaceae	*C. extensa*	C	IN	HG	1-70	-
Cyperaceae	*C. vesicaria*	C	IN	HG	1,550-2,300	-
Cyperaceae	*Cladium mariscus*	C	IN	HG	1-1,000	-
Cyperaceae	*Cyperus capitatus*	C	IN	HG	6-8	1-5
Cyperaceae	*C. longus*	C	CM	HG	1-1,850	5-9

(Continued)

Cyperaceae	*Eleocharis mitracarpa*	C	CM	HG	1-2,400	4-9
Cyperaceae	*E. palustris*	C	CM	HG	1-2,400	-
Cyperaceae	*Schoenoplectus litoralis*	C	IN	HG	1-1,370	4-10
Cyperaceae	*Schoenus nigricans*	H	IN	HG	1-2,000	3-7
Cyperaceae	*Scirpus holoschoenus*	C	CM	HG	1-3,050	4-8
Ephedraceae	*Ephedra major*	CH	IN	X	300-3,000	-
Euphorbiaceae	*Euphorbia paralias*	H	M	PH	1-10	4-9
Euphorbiaceae	*E. macroclada*	H	IT	HG	250-2,500	5-9
Euphorbiaceae	*E. pubescens*	H	IN	HG	1-1,400	4-9
Euphorbiaceae	*E. virgata*	H	IN	HG	1,000-3,000	4-9
Fabaceae	*Alhagi pseudalhagi*	CH	IT	XH	1-1,200	6-8
Fabaceae	*Astragalus hamosus*	T	M	R	1-1,300	3-7
Fabaceae	**A. karamasicus*	H	IT	R	450-2,060	6-7
Fabaceae	**A. micropterus*	CH	IT	X	850-1,860	6-7
Fabaceae	*A. tribuloides*	T	IT	PH	920-1,050	5-6
Fabaceae	*Lotus corniculatus* var. *tenuifolius*	H	CM	HG	1-2,750	4-9
Fabaceae	*L. strictus*	H	IN	HG	500-1,300	6-8
Fabaceae	*Medicago minima* var. *minima*	T	IN	PH	1-1,750	3-5
Fabaceae	*Melilotus officinalis*	H	CM	PH	1-1,750	5-9
Fabaceae	*M. messanensis*	T	M	PH	1	2-4
Fabaceae	*Ononis spinosa* subsp. *leiosperma*	H	CM	X	1-2,250	5-8
Fabaceae	*Sophora alopecuroides* var. *alopecuroides*	C	IN	PH	1-1,750	4-7
Fabaceae	**Sphaerophysa kotschyana*	H	IT	HG	1,000	6
Fabaceae	*Tetragonolobus maritimus*	H	IN	HG	800-1,750	6-7
Fabaceae	*Trifolium bullatum*	T	IN	R	400-1,100	3-4
Fabaceae	*T. campestre*	H	CM	X	1-2,200	2-4(-9)
Fabaceae	*T. fragiferum* var. *fragiferum*	H	IN	HG	1-1,350	4-8
Fabaceae	*T. repens* var. *repens*	H	IN	X	500-2,700	3-9
Fabaceae	*T. resupinatum* var. *resupinatum*	T	IN	HG	1-1,500	5
Fabaceae	*T. scabrum*	T	CM	X	1-1,100	1-6
Fabaceae	*T. tomentosum*	T	IN	HG	1-1,000	2-4
Fabaceae	*Trigonella orthoceras*	T	IT	X	1,200-1,900	6
Fabaceae	*Vicia sativa* subsp. *sativa*	T	Cosm.	X	1-1,600	3-5(-6)

Frankeniaceae	*Frankenia hirsuta*	CH	IN	H	1-1,400	-
Frankeniaceae	*F. pulverulenta*	T	IN	H	1-1,000	7-8
Gentianaceae	*Blackstonia perfoliata* subsp. *serotina*	T	IN	HG	1-700	6-10
Gentianaceae	*Centaurium spicatum*	T	IN	HG	1-1,070	7-8
Gentianaceae	*C. erythraea* subsp. *erythraea*	H	ES	HG	1-900	5-8
Gentianaceae	*C. pulchellum*	T	CM	HG	1-2,600	4-7
Gentianaceae	*C. tenuiflorum* subsp. *tenuiflorum*	T	IN	HG	1-1,150	6-8
Geraniaceae	*Geranium dissectum*	T	IN	X	1-400	4-5
Guttiferae	**Hypericum salsugineum*	H	IT	XH	900	8
Iridaceae	**Gladiolus halophilus*	C	IT	HG	900-1,200	6-7
Iridaceae	*Iris orientalis*	C	EM	HG	800-1,900	5-7
Juncaceae	*Juncus acutus*	C	IN	HG	1-150	3-5
Juncaceae	*J. articulatus*	C	ES	HG	1-3,000	4-8
Juncaceae	*J. fontanesii* subsp. *pyramidatus*	C	EM	HG	1-1,200	4-7
Juncaceae	*J. gerardi* subsp. *gerardii*	C	CM	HG	1-2,100	5-7
Juncaceae	*J. gerardi* subsp. *libanoticus*	C	IT	HG	50-2,500	5-8
Juncaceae	*J. heldreichianus* subsp. *heldreichianus*	C	EM	HG	1-1,600	4-7
Juncaceae	*J. littoralis*	C	M	HG	1-50	4-6
Juncaceae	*J. maritimus*	C	IN	HG	1-1,050	5-7
Juncaceae	*J. subnodulosus*	C	IN	HG	1-100	6-7
Juncaceae	*J. subulatus*	C	M	HG	1	4-6
Juncaginaceae	*Triglochin palustris*	C	IN	HG	800-2,400	5-9
Lamiaceae	*Mentha aquatica*	C	IN	HG	1-1,300	8-10
Lamiaceae	**Salvia halophila*	H	IT	XH	950-1,000	8-10
Lamiaceae	*Teucrium polium*	H	CM	PH	1-2,050	6-9
Lamiaceae	*T. scordium*	C	ES	PH	50-2,350	5-9
Liliaceae	**Allium cupani* subsp. *hirtovaginatum*	C	IT	HG	950-1,650	6-8
Liliaceae	*A. macrochaetum* subsp. *macrochaetum*	C	IT	HG	950-1,650	6-8
Liliaceae	**A. nevsehirense*	C	IT	R	800-1,900	7-8
Liliaceae	**A. sieheanum*	C	IT	HG	900-1,200	7-8
Liliaceae	**Asparagus lycaonicus*	H	IT	HG	1,000	8
Liliaceae	*A. persicus*	H	IT	XH	800-1,700	5-7
Linaceae	*Linum bienne*	H	M	HG	1,900	3-5

(Continued)

Linaceae	*L. seljukorum*	T	IT	HG	1,100	6-8
Lythraceae	*Lythrum salicaria*	H	ES	HG	100-2,000	6-8
Orchidaceae	*Epipactis palustris*	C	ES	HG	1-2,000	5-7
Orchidaceae	*Orchis palustris*	C	CM	HG	1-1,950	6-7
Orobanchaceae	*Orobanche minor(a parasite)*	T	IN	X	1-1,200	4-6
Papaveraceae	*Fumaria vaillantii*	T	IN	R	360-1,650	5-6
Plantaginaceae	*Plantago coronopus* subsp. *commutata*	T	EM	PH	1-800	2-7
Plantaginaceae	*P. coronopus* subsp. *coronopus*	T	IN	HG	1-1,750	4-11
Plantaginaceae	*P. crassifolia*	H	M	PH	1-900	5-10
Plantaginaceae	*P. lagopus*	H	M	HG	1-2,000	4-8
Plantaginaceae	*P. lanceolata*	H	IN	HG	-	
Plantaginaceae	*P. major* subsp. *irtermedia*	H	CM	HG	1-2,200	4-9
Plantaginaceae	*P. maritima*	H	IN	H	1-2,400	5-8
Plumbaginaceae	**Acanthalimon halophilum*	CH	IT	X	900-110	6
Plumbaginaceae	**Limonium anatolicum*	CH	IT	H	900-1,000	6-9
Plumbaginaceae	*L. angustifolium*	H	M	H	1	5-10
Plumbaginaceae	*L. bellidifolium*	H	ES	H	1-1,010	6-9
Plumbaginaceae	**L. effesum*	H	EM	H	1-750	7-8
Plumbaginaceae	*L. globuliferum*	H	IT	H	900-1,100	6-9
Plumbaginaceae	*L. gmelinii*	H	ES	H	1-1,450	5-10
Plumbaginaceae	**L. iconicum*	H	IT	H	900-1,040	6-9
Plumbaginaceae	**L. lilacinum*	H	IT	H	900-1,200	6-9
Plumbaginaceae	*L. sieberi*	CH	EM	H	1-5	5-7
Plumbaginaceae	*L. sinuatum*	H	M	H	1-100	5-7(10)
Plumbaginaceae	**L. tamaricoides*	H	IT	H	-	-
Plumbaginaceae	*L. virgatum*	H	M	H	1-20	6-10
Poaceae	*Aeluropus littoralis*	C	IN	PH	1-1,200	5-10
Poaceae	*Agrostis stolonifera*	C	ES	HG	1-2,390	6-8
Poaceae	*Aira elegantissima* var. *elegantissima*	T	M	PH	1-300	4-5
Poaceae	*Alopecurus myosuroides* var. *myosuroides*	T	ES	HG	1-1,850	3-8
Poaceae	*Ammophila arenaria* subsp. *arundinacea*	C	M	PH	1	6-8
Poaceae	*Avena sterilis* subsp. *sterilis*	T	IN	X	1-1,800	3-8
Poaceae	*Bromus arvensis*	T	IN	XH	1-2,900	6-8
Poaceae	*B. japonicus* subsp. *japonicus*	T	IN	X	1-2,300	5-7

Poaceae	*B. inermis*	C	IN	PH	1,800-2,700	6-8
Poaceae	*B. rubens*	T	IN	PH	1-1,000	3-6
Poaceae	*B. scoparius*	T	IN	X	1-2,250	4-7
Poaceae	*B. tectorum*	T	CM	PH	1-2,000	3-6
Poaceae	*Calamagrostis pseudophragmites*	C	ES	PH	230-2,200	6-8
Poaceae	*Catabrosa aquatica*	C	IN	HG	1-2,600	5-8
Poaceae	*C. faktorovskyi*	T	IN	HG	360	6-8
Poaceae	*Crypsis aculeata*	T	IN	PH	1-1,510	6-10
Poaceae	*Cynodon dactlylon* var. *dactylon*	C	IN	PH	1-1,830	4-9
Poaceae	*C. dactlylon* var. *villosus*	C	IN	PH	1-3,050	5-9
Poaceae	*Elymus elongatus* subsp. *elongatus*	C	IN	PH	1-100	4-7
Poaceae	*E. elongatus* subsp. *ponticus*	C	IN	XH	1-1,800	5-8
Poaceae	*E. hispidus* subsp. *hispidus*	C	IN	XH	1,400-2,300	6-7
Poaceae	*Eragrostis collina*	C	IN	XH	840-1,600	7-9
Poaceae	*Festuca arundinacea* subsp. *arundinacea*	C	IN	HG	300-2,100	6-7
Poaceae	**F. rubra* ssp. *pseudorivularis*	C	ES	HG	650-2,000	6-7
Poaceae	*Holcus lanatus*	C	ES	PH	1-2,000	5-8
Poaceae	*Hordeum marinum* var. *marinum*	*T*	IN	PH	1-830	5-6
Poaceae	*H. murinum* subsp. *murinum*	T	IN	PH	-	
Poaceae	*Imperata cylindrica* subsp. *cylindrica*	C	IN	PH	1-760	4-7
Poaceae	*Lagurus ovatus*	T	M	PH	1-50	4-6
Poaceae	*Lolium rigidum* var. *rigidum*	T	IN	XH	1-1,850	4-7
Poaceae	*L. subulatum*	T	EM	XH	55	5
Poaceae	*Molinia caerulea*	H	IN	HG	1-1,600	8-10
Poaceae	*Phalaris arundinaceae*	C	IN	XH	1-2,700	5-9
Poaceae	*P. canariensis*	T	IN	XH	1-1,000	5-7
Poaceae	*Phleum exaratum* subsp. *exaratum*	T	IN	XH	1-2,300	5-7
Poaceae	*Phragmites australis*	C	ES	HG	1-2,400	8-10
Poaceae	*Poa annua*	T	IN	PH	1-2,200	3-8
Poaceae	*P. bulbosa*	C	IN	X	1-3,000	5-7
Poaceae	*P. trivialis*	C	IN	XH	1-2,210	5-8

(Continued)

Poaceae	*Polypogon maritimus* subsp. *maritimus*	*T*	ES	PH	1-400	5-6
Poaceae	*P. monspeliensis*	T	ES	XH	1-1,200	4-8
Poaceae	*Prapholis incurva*	T	IN	XH	1-100	4-7
Poaceae	**Puccinellia bulbosa* subsp. *caesarea*	H	IN	XH	1,100-1,200	7-8
Poaceae	*P. convoluta*	H	IN	XH	1-1,000	6-8(9)
Poaceae	*P. distans* subsp. distans	H	IN	XH	670-1,350	7-8
Poaceae	*P. intermedia*	H	IN	XH	1-900	5-6
Poaceae	*Rostraria cristata* var. *cristata*	T	IN	PH	1-1,200	4-7
Poaceae	*Sphenopus divaricatus*	T	IT	HG	1-1,000	-
Poaceae	*Sporobolus virginicus*	C	IN	HG	1-950	4-10
Poaceae	*Stipa bromoides*	C	M	X	1-1,060	5-8
Polygonaceae	*Polygonum aviculare*	T	Cosm.	PH	1-700	7-11
Polygonaceae	*P. bellardi*	T	IN	HG	500-1,800	5-8
Primulaceae	*Anagallis arvensis* var. *arvensis*	T	IN	PH	1-1,400	4-9
Primulaceae	*Glaux maritima*	C	IN	HG	1-1,720	5-8
Primulaceae	*Samolus valerandi*	H	Cosm.	HG	1-900	5-9
Ranunculaceae	**Consolida glandulosa*	T	IT	X	800-1,600	6-9
Ranunculaceae	**Delphinium verulosum*	T	IT	X	200-1,200	7-8
Ranunculaceae	*Ranunculus constantinopolitanus*	C	CM	HG	1-2,000	4-6
Ranunculaceae	*R. marginatus* var. *marginatus*	T	CM	HG	0-850	3-6
Ranunculaceae	*R. neapolitanus*	H	IN	HG	1-1,200	5-6
Ranunculaceae	*R. scleratus*	T	IN	HG	1-1,750	5-7
Ranunculaceae	*Thalictrum lucidum*	C	IN	HG	1-1,400	6-7
Ranunculaceae	*T. simplex*	C	IN	HG	6	-
Rosaceae	*Potentilla reptans*	C	CM	HG	1-2,300	5-8
Rubiaceae	*Galium odoratum*	C	ES	X	600-2,400	5-7
Rubiaceae	*G. tricornutum*	T	M	X	10-1,800	4-7
Santalaceae	*Thesium compressum*	T	IT	XH	1,000-2,200	6-8
Scrophulariaceae	*Bellardia trixago*	H	IN	X	680-1,930	5-8
Scrophulariaceae	*Pedicularis comosa* var. *acmodonta*	H	IN	HG	1,000-3,600	5-8
Scrophulariaceae	**Verbascum campestre*	H	IT	X	860-1,370	5-6
Scrophulariaceae	*V. cheiranthifolium* var. *cheiranthifolium*	H	IN	X	680-1,930	5-8

Scrophulariaceae	**V. helianthemoides*	H	IT	HG	960-1,200	6-8
Scrophulariaceae	**V. pyroliforme*	H	IT	HG	1,000	6-9
Scrophulariaceae	*V. sinuatum*	H	M	PH	1-1,100	5-10
Tamaricaceae	*Tamarix hampeana*	P	IN	H	-	4
Tamaricaceae	*T. parviflora*	P	M	H	1-300	3-6
Tamaricaceae	T. *smyrnensis*	P	IN	H	1-1,000	4-8
Tamaricaceae	*T. tetrandra*	P	IN	H	1-1,300	5
Thymelaeaceae	*Thymelaea passerina*	T	IN	HG	10-2,000	4-8
Typhaceae	*Typha latifolia*	C	IN	HG	1-1,850	6-10
Typhaceae	*T. laxmannii*	C	ES	HG	0-1,660	6-10
Typhaceae	*T. minima* var. *gracilis*	C	ES	HG	970-1,440	5-7
Zygophyllaceae	*Nitraria schoberi*	CH	IT	PH	200-1,000	-

Life Forms: ***H*** hemicryptophytes, ***CH*** chamaephytes, ***T*** terophytes, ***C*** cryptophytes, ***P*** phanerophytes. **Chorotypes:** ***IT*** Irano-Turanian, ***ES*** Euro-Siberian, ***M*** Mediterranean, ***EM*** East Mediterranean, ***Cosm*** cosmopolitan, ***IN*** imperfectly known, ***CM*** common. **Ecological Types:** ***H*** halophyte, ***HG*** hygrohalophytes, ***X*** xerophyte, ***R*** ruderal, ***XH*** xerohalophytes, ***PH*** psammo-halophytes. ***FL*** flowering time, * Endemic.

Table 4. *Chrotypes, life forms, halophyte types, major genera and families.*

Chorotypes	*%*	*Life Forms*	*%*	*Halophyte Type*	*Number of Plant Taxa*	*% of the Halophyte Type*	*Major Genera*	*Major Families*
IN	50.67	T	40.0	HG	102	34%	*Limonium*	Poaceae
CM	9.33	H	28.33	X	51	17%	*Juncus*	Chenopodiaceae
M	8.0	C	23.0	PH	49	16.33%	*Salsola*	Asteraceae
ES	7.67	CH	7.34	H	46	15.33%	*Plantago*	Fabaceae
EM	3.33	P	1.33	XH	37	12.33%	*Trifolium*	
IT	2.0			R	15	5%		
Cosm.	1.0							

IN Imperfectly known, ***CM*** Commonly known, ***M*** Mediterranean, ***ES*** Euro-Siberian, ***IT*** Irano-Turanian, ***EM*** East Mediterranean, ***Cosm*** Cosmopolitan, ***H*** halophyte, ***H*** hemicryptophytes, ***CH*** chamaephytes, ***T*** terophytes, ***C*** cryptophytes, ***P*** phanerophytes, ***HG*** hygrohalophytes, ***X*** xerophyte ***R*** ruderal, ***XH*** xerohalophytes, ***PH*** psammohalophytes.

The red data book of Turkish plants (Ekim et al., 2000) reveals that (Table 6) 33 endemic and 11 non-endemic taxa from the halophytic plant cover are in danger of becoming extinct. The biotic pressures responsible for the destruction of over 10,000 ha along the 8,333 km long coastal sabkha ecosystem in Turkey are: city wastes, industrial effluents, marine traffic, sand extraction, summer houses and tourism (Erdem et al., 1994; Gehu & Uslu, 1987). During the last few decades there has been a great population outburst along this coastal belt and large populations from east, south-east and central Anatolia have migrated to these parts of Turkey. The number of tourists visiting the area has increased eight fold during the last few years (DIE, 2000). Sabkha ecosystem diversity, in particular halophytes, are effected the most by tourism.

2. ECONOMIC POTENTIAL OF HALOPHYTES

Many halophytes, in particular the *Salicornia* species, are used for vegetable oil production as well as forage crop in Kuwait, U.A.E and Saudi Arabia (Pasternak, 1987). *Kochia, Salsola* and *Atriplex* together with *Salicornia* are good sources for leaf protein production (Dagar, 1995); *Salsola* is also used for the production of bioactive compounds and the *Juncus* species for paper, pulp and fibre production (NRC, 1990). The *Atriplex* and *Spartina* species in Africa, Europe and the Americas; the *Distichlis spicata* in Mexico; and the *Prosopis tamarugo* in Chile are used as animal feed (Pasternak, 1987); *Grindelia comporum* is used for the production of glue, polish, paper, ink and soap and *Simmondsia chinensis* for manufacturing cosmetics (Dagar, 1995). Although these uses not been evaluated economically in Turkey, halophytes can at least be used for biological desalination and reclamation of saline-alkaline habitats. The esthetic and natural recreational values of halophytes are very well known in Turkey. *Limonium bellidifolium* is collected in spring for indoor house decoration due to its attractive floral shoots. *Halocnemum strobilaceum* and *Aeluropus littoralis* as well as *Arthrocnemum* sp. are grazed by cattle. The taxa of *Juncus* are valuable for basket making. *Salicornia europaea* is used as salad by a large population in the Aegean region. In some markets *Arthrocnemum fruticosum* is sold in place of *Salicornia europaea*. Some people unknowingly buy former in place of latter. One has to be careful in this connection because consumption of the former in place of the latter may create health problems related to the digestive system. The littoral halophytic taxa occupying the habitats immediately following the psammophytic plant communities serve as a reclusive area for many animal species (Zeybek et al., 1976).

3. CONCLUSIONS

The environmental problems we face today are identical to those of past human history. These problems originated with humanity, grew up with humanity and are with us more than ever today. Worldwide, nearly 12 million people, half of them children, die each year from hunger and starvation or diseases worsened by hunger, and more than 800 million people eat less food than they need to stay healthy (Owen & Chiras, 1995). At the start of the new millennium food and a clean environment are becoming the bases for human welfare. The greatest threat is food shortage. This forces us to focus attention on academic and practical efforts to utilize all available resources and to expand cultivable areas. Saline habitats can be used to produce non-conventional crops of economic value. With large areas affected in arid and semiarid regions, salinization and alkalization constitute a serious global problem, which must be paid more attention worldwide. This problem is a serious threat to food and fiber production.

Table 5. *Number of families, genera, species and endemic taxa.*

Families Found in Halophytic Habitats	*Families Found in the Transition Zone Between Sand Dunes and Saline Habitats*	*Genera*	*Species*	*Endemic taxa*
Poaceae		31	50	2
Chenopodiaceae		17	42	2
Asteraceae		20	36	8
Fabaceae		12	23	3
Caryophyllaceae		5	14	2
Cyperaceae		8	14	-
Plumbaginaceae		2	13	6
Brassicaceae		7	10	2
Juncaceae		1	10	-
Apiaceae		4	8	2
Ranunculaceae		3	8	2
Plantaginaceae		1	7	-
Scrophulariaceae		3	7	3
	Liliaceae	2	6	4
	Gentianaceae	2	5	-
Boraginaceae		2	4	-
Euphorbiaceae		1	4	-
	Lamiaceae	3	4	1
Tamaricaceae		1	4	-
	Primulaceae	3	3	-
Typhaceae		1	3	-
Frankeniaceae		1	2	-
	Iridaceae	2	2	1
Linaceae		1	2	-
	Orchidaceae	2	2	-
Polygonaceae		1	2	-
Rubiaceae		1	2	-
Convolvulaceae		1	1	-
Cuscutaceae		1	1	-
	Ephedraceae	1	1	-
Geraniaceae		1	1	-
Guttiferae		1	1	1
Juncaginaceae		1	1	-
Lythraceae		1	1	-
	Orobanchaceae	1	1	-
	Papaveraceae	1	1	-
	Rosaceae	1	1	-
Santalaceae		1	1	-
Thymelaeaceae		1	1	-
Zygophyllaceae		1	1	-
Total :		150	300	39

Table 6. *Endangered endemic and nonendemic halophytic taxa of Turkey.*

ENDEMIC TAXA	*Threat Categories*	*NON-ENDEMIC TAXA*	*Threat Categories*
Acanthalimon halophilum	VU	*Bidens cernua* var. *radiata*	VU
Achillea goniocephala	LR (lc)	*Bupleurum semicompotisum*	DD
A. sieheana	VU	*Bupleurum tenuissimum*	VU
Asparagus lycaonicus	EN	*Halopeplis amplexicaulis*	EN
Astragalus karamasicus	LR (lc)	*Limonium sieberi*	VU
A. micropterus	LR (lc)	*Linum seljukorum*	VU
Allium nevsehirense	LR (lc)	*Lolium subulatum*	VU
A. sieheanum	LR (lc)	*Microcnemum coralloides* subsp. *anatolica*	VU
Bupleurum heldreichii	LR (cd)	*Noaea minuta*	VU
B. turcicum	LR (nt)	*Plantago crassifolia*	VU
Consolida glandulosa	LR (lc)	*Salsola inermis*	VU
Cousinia birandiana	LR (lc)		
C. humilis	CR		
C. iconica	LR (cd)		
Delphinium verulosum	LR (lc)		
Festuca rubra ssp. pseudorivularis	CR		
Gladiolus halophilus	VU		
Gypsophila oblanceolata	VU		
Hypericum salsugineum	VU		
Limonium anatolicum	VU		
L. effesum	VU		
L. iconicum	LR (lc)		
L. lilacinum	LR (lc)		
L. tamaricoides	EN		
Onopordum polycephalum	LR (lc)		
Puccinellia bulbosa subsp. caesarea	CR		
Salvia halophila	VU		
Silene salsuginea	EN		
Sphaerophysa kotschyana	LR (cd)		
Taraxacum farinosum	LR (lc)		
Verbascum campestre	LR (cd)		
V. helianthemoides	VU		
V. pyroliforme	VU		

CR critically endangered, *DD* data deficient, *EN* endangered, *LR* lower risk, *(cd)* conservation dependent, *(lc)* least concern, *(nt)* near threatened.

There are approximately 358 million ha of salinity affected soils in Australia, 320 million ha in Asia, 147 million ha in the Americas, 81 milion ha in Africa and 51 million in Europe (Eroglu, 1994; Szabolcs, 1989). More and more agricultural lands are subject to increasing salinity levels. There is an urgent need to increase crop production under saline conditions in order to meet the greater demand for food at a time when the size of agricultural lands is decreasing due to soil salinization. Halophytes could be evaluated as potential agricultural crops by growing them on saline soils, in particular along coastal areas where sea water is available for irrigation, instead of destroying them as a wasteful group of plants.

During the last twenty years a lot of work has been done on halophytes throughout the world, in particular on biosaline agriculture (Ahmed & San Pietro, 1986). These studies will probably lead to new approaches for more effective solutions to problems of inland saline-alkaline areas and for the evaluation of coastal sabhkas. Halophytes can serve as indicators of salinity-sodicity, and areas with ground waters possessing high salinity could be used for halophytic forage crop production. Halophytes can at the same time serve in erosion control alongside the coastal zones with the help of their strong root systems. We can conclude that there is great potential in halophytic plant cover for consumption as well as amelioration of degraded lands in Turkey. Some work has already begun (Avci et al., 2004; Dogan et al., 2004; Gidirisli et al., 2004; Guven et al., 2001;Ozturk et al., 1998), but many more studies and experiments need to be carried out in order to develop halophytes successfully as agricultural cash crops.

4. REFERENCES

Ahmed, R. & San Pietro, A. 1986. Prospects for Biosaline Research. Shamim Printing Press, Karachi, Pakistan, 587 pp.

Akman, Y. & Daget, P.H. 1971. Quelques Aspects Synoptiques des Climats de la Turquie, Bull. Soc. Lang. Geogr. 5: 269-300.

Aronson, J.A. 1989. HALOPH; Salt Tolerant Plants for the World – A computerised global data base of halophytes with emphasis on their economic uses. University of Arizona Press, Tucson, USA, 77 pp.

Avci, K., Kutbay, G. & Gencoglu, S. 2004. Halophytic vegetation of Bafra plain. Directorate of Rural Services, Ankara, Turkey, Annual Report, 56 pp. (In Press).

Ayyildiz, M. 1983. Quality of irrigation waters and salinity problems. Ankara Univ. Agric. Fac. Publication No: 879, 39 pp.

Babalonas, D., Syroka, K.V. & Papastergiadou, E.S. 1995. Review of Plant Communities from Greek Dunes and salt-marshes, a preminary summarizing list. Annali Di Botanica 3: 107-117.

Beyce, O. 1960. Indicator plants of aridity and water table studies in Alifaki. Agr. Res. Inst.Tarsus-Adana, Publ. 26: 17-53.

Birand, H. 1960. Erste Ergebnisse der Vegetations-Untersuchungen in der zentralanatolischen Steppe; 1-Hlophytengesellschaften des Tuz Gölü.- Bot. Jahrb. 79: 255-296.

Breckle, S.W. 1986. Studies on halophytes from Iran and Afghanistan. Ecology of halophytes along salt gradient. Proceedings of the Royal Society of Edinburgh, 89 B, 203-215.

Caglar, K.O. 1949. Soil Science. Ankara Univ. Agr. Faculty Publ., Ankara, 89 pp.

Choukr-Allah, R. 1991. The use of halophytes for the agricultural development of south of Morocco. In: Plant Salinity Research New Challenges, Hassan II-C.H.A, Agadir, Morocco. 377-387 pp.

Dagar, J.C. 1995. Characteristics of halophytic vegetation in India. In: "Biology of Salt Tolerant Plants" (Khan & Ungar-Eds.), Book Crafters, Michigan, U.S.A. 255-276 pp.

Davis, P.H. 1965-1988. Flora of Turkey and East Aegean Island, Edinburgh Univ., press U.K, 1-10 pp.

Demiriz, H. 1993. An annotated bibliography of Turkish flora and vegetation. TUBITAK, TBAG-DPT, Environmental Section 1, 670 pp.

DIE, 2000. Statistical Yearbook of Turkey. State Inst. of Statistics of Prime Ministry, Publ. 1720, Ankara, 700 pp.

Dizdar, Y. 1978. Soils affected by salinity in Turkey. Topraksu Technical Journal, Directorate of Rural Services, Ankara 47: 36-58.

Dogan, O., Ustun, H., Gurlesen, N., Tomul, F., Tıpırdamaz, R. & Sozeri, S. 2004. Ecology of halophytic vegetation in the Seyfe lake basin and determination of grassland and agricultural plants suitable for growth on arid soils. Directorate of Rural Services, Ankara, Turkey, Annual Report, 67 pp. (In Press).

Ekim, T., Koyuncu, M., Vural, M., Duman, H., Aytac, Z. & Adıguzel, N. 2000. Red data book of Turkish plants, Ankara, 246 pp.

Erdem, U., Ozturk, M., Serifoglu, A., Akbaba, B., Guvensen, A. & Unuvar, H. 1994. Effects of land use rules on structural changes at Pamucak-Kusadası. Proceedings of Kusadası Coastal Zone Symposium, Aydın-Turkey. 21-29 pp.

Eroglu, B. 1994. Studies on the improvement of saline, alkaline and boron soils. Ege University, Agricultural Faculty, Soil Science, B.S. thesis, 28 pp.

Gehu, J.M. & Uslu, T. 1987. Donnés sur la Végétation Littorale de la Turquie du Nord-Ouest, Centre Régional de Phytosaciologie Heendries, F-59270 Bailleul, 75 pp.

Gidirisli, A., Cakır, R. & Yarcı, C. 2004. Halophytic vegetation of saline soils in Gelibolu-Gokbuet and Ipsala region. Directorate of Rural Services-Ankara, Turkey, Annual Report, 53 pp. (In Press).

Gungor, Y. & Erozel, A.Z. 1994. Drainage and land improvement. Ankara University, Agric. Fac. Publ., No. 1346, Ankara, 47 pp.

Guven, E., Vural, M., Bahceci, I. & Sonmez, B. 2001. Ecology of halophytic vegetation in inner Anatolia. Directorate of Rural Services, Ankara, Turkey, Annual Report, 264-280 pp.

Guvensen, A. 1994. General characteristics of halophytes and psammophytes in the Aegean region. Ege Univertsity, Institute of Sciences, M.S. Thesis, 103 pp.

Guvensen, A., Uysal, I., Celik, A. & Ozturk, M. 1996. Environmental impacts on halophytic plant cover alongside the coastal area of Karabiga and Burhaniye. Symposium on Environmental Problems, Canakkale, 8 pp.

Guvensen, A. & Ozturk, M. 2004. Halophytic plant diversity of South Aegean coastal zone in Turkey. Pakistan Journal of Botany, 1-13 pp. (In Press).

Kaynak, L., Imamgiller, B., Ersoy, N. & Yazici, K. 2000. Salinity problems in agricultural soils. GAP Environmental Congress, Sanliurfa, 555-561 pp.

Khan, M.A. & Duke, N.C. 2001. Halophytes – A resource for the future. Wetlands Ecology and Management 6: 455-456.

NRC. 1990. Saline Agriculture. National Research Council. National Academy Press,Washington DC, USA, 239 pp.

Oakes, H. 1954. The soils of Turkey: Rep. of Turkey Ministriy of Agriculture, Soil Cons. and Farm Irrigation Division Pub. No: 1, Ankara, 180 pp.

Okur, B. 1989. Investigations on the distribution of soluble salts and exchangeable Na in the soil profiles and their impact on important soil physical characteristics in the saline-alkaline soils of the Kocarlı and Soke plains in Great Menderes basin. Ph.D. thesis, Ege Univ., Inst.of Sci., Soil Sci. Section, Bornova, Izmir, 93 pp.

Owen, O.S. & Chiras, D.D. 1995. Natural Resource Conservation-Management for a Sustainable Future. Prentice-Hall (sixth edition), USA, 586 pp.

Ozturk, M., Ozcelik, H., Behcet, L., Guvensen, A. & Ozdemır, F. 1995. Halophytic flora of Van Lake basin - Turkey. In: "Biology of Salt Tolerant Plants" (Khan & Ungar-Eds.), 306-315, Book Crafters, Michigan, U.S.A.

Ozturk, M., Guvensen, A., Akbas, F. & Fırattekin, Y. 1998. Relations between edaphic conditions and halophyte occurance in Soke plain, Turkey. In Plant Life in South-West and Central Asia, 139-148, Vth International Symposium-Tashkent, Uzbekistan.

Ozturk, M. & Guvensen, A. 2002. Studies on the Halophytic Vegetation of Saline-Alkaline Habitats in West Anatolia-Turkey. Proc. of the International Symposium on Optimum Resources Utilization in Salt-Effects Ecosystems in Arid and Semiarid Regions (eds. A.M. Hegazi et al.), 241-244, DRC, Cairo, Egypt.

Pasternak, D. 1987. Salt tolerance and crop production – a comprehensive approach. Annual Review of Phytopathology 25: 271-291.

Saatci, F. & Tuncay, H. 1971. Studies on the saline-alkaline soils in the Aegean region. Ege Univ. Agric. Fac. Publ. No:173, Bornova-İzmir, 73 pp.

Szabolcs, I. 1989. Salt-Affected Soils. Boca Raton, Fla.: CRC Press, Florida, USA, 348 pp.

Somers, G.F. 1982. Food and Economic Plants: General Review. In: A. San Pietro (ed.) Biosaline Research, 127-148, Phnelum Press, New York-USA.

Topraksu. 1980. Statistical bulletin of Topraksu. Topraksu General Directorate Publ., 36-58, Ankara.

Waisel, Y. 1972. Biology of Halophytes. Academic Press. New York and London, 437 pp.

Yurdakulol, E. & Ercoskun, T. 1990. Ecological and syntaxonomical studies on the vegetation of arid lands in central Anatolia. Tr. J. of Botany 14: 109-123.

Zeybek, N. 1969. Coastal halophytes of Aegean Sea. VI. Turkish Nat. Biology Congress, İzmir, 3-7 pp.

Zeybek, N., Sheikh, K.H. & Ozturk, M.A. 1976. Coastal Halophytes of the Aegean Region. CENTO Symposium, 148-153, Adana.

CHAPTER 3

THE BIOGEOGRAPHY OF THE COASTAL VEGETATION OF THE ABU DHABI GULF COAST

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Abstract. A survey of the entire coastline resulted in a detailed picture of the biogeography of the coastal flora of the Abu Dhabi Emirate. The coastal flora consists of monospecific *Avicennia marina* (Forssk.) Vierh. mangroves, different salt marshes, as well as beach, reed, and rocky headland vegetation of different plant families. The vegetation is mainly halophytic, and subject to various degrees of seawater inundation. The exact knowledge of the distribution of coastal flora is a precursor for the development of coastal sensitivity maps, and the sustainable management of coastal habitats.

1. INTRODUCTION

Until recently, little was known about the exact distribution of plant species along the Abu Dhabi Gulf Coast. Embabi (1993) and Böer & Gliddon (1997, 1998) provided information regarding the limited bio-geographical research that had been carried out, and which resulted in a few scientific documents on the subject.

The coastline of the Emirate, more than 300 km in length, is characterized by massive land-use development processes and marine pollution. Several settlements of different sizes and shapes have been established over the last decade, causing large natural and semi-natural coastal areas to be converted into urban areas. Furthermore, frequently occurring oil spills, as well as coastal dredging projects, cause changes to the coastal vegetation. In order to utilize the coastal zone of Abu Dhabi sustainably, coastal management plans need to be developed. The exact knowledge of the distribution of flora is a precursor for the development of coastal sensitivity maps and the sustainable management of the coastal habitats, and the biological resources within them. This paper describes the distribution of the coastal mangrove, salt marsh and beach vegetation resources in the Abu Dhabi Emirate in detail.

M. Ajmal Khan et al. (eds.), Sabkha Ecosystems. Volume II: West and Central Asia, 31-36.

2. METHODS

The entire coastline of the Abu Dhabi Emirate was surveyed by car, as close as possible to the water line. A total of 282 survey-points were visited, and the geographical positions were recorded using a Magellan Geographical Positioning System. Data on the presence and absence of intertidal, and other vegetation types were recorded. The intertidal vegetation was sub-categorized into mangroves and salt marshes. For the definition of the term "mangrove" we followed White (1983): "True mangrove species have either pneumatophores, which are exposed at low tide, or are viviparous or almost so", and Tomlinson (1986): "Mangroves ... may thus be defined as tropical trees restricted to intertidal and adjacent communities". For the definition of the term coastal salt marsh we followed Adam (1990): "Coastal salt marshes may be defined as areas, vegetated by herbs, grasses or low shrubs, bordering saline water bodies. Although such areas are exposed to air for the majority of the time, they are subjected to periodic flooding as a result of fluctuations (tidal or non-tidal) in the level of the adjacent water body." For any other vegetation types we followed the suggestions of Roshier et al., (1996), who categorized dominant plants of the region according to the coastal landforms in which they occur (we redefined the category "Intertidal Flats with Freshwater Influence" as "Brackish Water Influence"). The size of the mangrove and salt marsh stands were recorded as values between 0 and 4, where 0 = none, 1 = scattered non stand-forming specimens, 2 = stands <25 m largest diameter, 3 = <100 m largest diameter, and 4 = >100 m diameter, irrespective of the shape of the stand. A stand was defined as a patch of vegetation with >10 specimens, with the distance between the plants of less than 5 m. The presence of other coastal vegetation types was also recorded. Form-sheets were used for the collection of digital data, and transportable satellite images were used to collect annotated data. In addition, data from satellite interpretation and ground-truthing, as well as data from a parallel study on mangroves (Saenger et al., in prep.) collected during helicopter flights were used. All the above information was then entered into a database, and mangrove and salt marsh distribution maps were generated.

3. RESULTS

A total of 59 plant species (without irrigation) was identified along the Abu Dhabi Gulf coast, of which one is classified as a true mangrove, and three are classified as true salt marsh species. There are another 55 plant species occurring in the study area, but these species are neither mangrove nor salt marsh species. Vegetation of sandy beaches or "storm berms" was classified as sand sheet vegetation and others as vegetation of brackish ground, or rocky headlands. In most areas the coastal vegetation forms only a narrow band, which is separated from true terrestrial vegetation by a wider band of coastal sabkha. Distribution maps of each of the above species are available with the Geographical Information System of the Environmental Research and Wildlife Development Agency. The

Table 1. *Shows the most frequent plant species along the Abu Dhabi coastline and the percentage of the extent of their distribution within the area. The major ecosystems in which the species occur are abbreviated as follows: H = (Rocky) Headlands, SS = Sand Sheets, M = Mangrove, SM = Salt Marsh, BW = Brackish Water Influence.*

Species	*Major Ecosystem*	*No. of Records*	*%*
Suaeda vermiculata	SS	116	40.1
Arthrocnemum macrostachyum	SM, M	109	38.7
Salsola drummondii	SS	96	33.2
Halopeplis perfoliata	SM, SS	87	30.1
Avicennia marina	M, SM	75	26.6
Halocnemum strobilaceum	SM, SS	77	26.6
Zygophyllum qatarense	SS	75	25.9
Anabasis setifera	SS, H	73	25.8
Biennertia cycloptera	SS	58	20.6
Salsola imbricata	SS	43	15.3
Zygophyllum mandavillei	SS	41	14.5
Cyperus arenarius	SS	29	10.3
Heliotropium bacciferum	SS, H	29	10.3
Cornulaca monacantha	SS, H	27	9.6
Limonium axllare	SS	25	8.9
Prosopis juliflora	SS	18	6.4
Tamarix sp.	BW	17	6.0
Cyperus conglomeratus	SS	15	5.3
Salsola cyclophylla	H, I	15	5.3
Cornulaca cf. leucocantha	SS	14	5.0
Halopyrum mucronatum	SS	14	5.0
Panicum turgidum	SS, H	14	5.0
Phragmites australis	BW	14	5.0
Atriplex leucoclada	SS	10	3.6
Stipagrostis sp.	H	9	3.2
Sporobolus spicatus	BW	8	2.8
Dactyloctenium scindicum	SS	6	2.1
Sesuvium portulacastrum	BW	6	2.1
Sporobolus iocladus	SS	6	2.1
Haloxylon salicornicum	H	5	1.8
Seidlitzia rosmarinus	SS	5	1.8
Shpaerocoma aucheri	SS	5	1.8
Ipomea pes-caprae	BW	4	1.4
Suaeda aegyptiaca	SS	4	1.4
Zygophyllum simplex	SS, H	4	1.4
Chloris sp.	BW	3	1.1
Farsetia cf. aegyptiaca	H	3	1.1
Phoenix dactylifera	SS, BW	3	1.1
Pluchea dioscoryides	BW	3	1.1

Sesuvium verrucosum	BW	3	1.1
Aeluropus lagopoides	BW	2	0.1
Arundo donax	BW	2	0.7
cf. Cymbopogon sp.	SS, H, BW	2	0.7
Dipterygium glaucum	SS	2	0.7
Helianthemum lippii	H	2	0.7
Lotus garcinii	H	2	0.7
cf. Ochtochloa compressa	BW	2	0.7
Taverniera spartaea	H	2	0.7
Calligonum comosum	SS, H	1	0.4
Euphorbia serpens	BW	1	0.4
Heliotripium dyginum	SS	1	0.4
Lasiurus scindicus	H	1	0.4
Leptadenia pyrotechnica	SS	1	0.4
Limeum arabicum	SS	1	0.4
Pennisetum divisum	SS	1	0.4
Phyla nodiffora	BW	1	0.4
Prosopis cineraria	SS	1	0.4
Salvadora persica	BW, H	1	0.4

ATLAS of ERWDA (2000) shows the distribution of mangroves, salt marshes, and other coastal vegetation in Abu Dhabi.

4. DISCUSSION

The zonation of the coastal vegetation of the Arabian Gulf has in parts been described by Böer (1994). As the zonation depends on the tidal regime, and as the tidal regime within the Arabian Sea differs locally, more research on the distribution of the coastal vegetation in relation to the height above the chart datum is needed. This information is essential for any coastal vegetation restoration or manipulation projects. Of equal importance are the data presented in the ERWDA ATLAS (2000), which documents the geographical distribution of the major vegetation types along the coastline. The information presented in the two above studies will aid coastal managers in promoting sustainable development of the coastal biological resources.

A total of 59 plant species was identified as naturally occurring along the Abu Dhabi Gulf coast. These relatively few species, in comparison to other areas in the region, such as Bahrain (Abbas, 1992), or the Jubail area (Böer & Warnken, 1992), form the coastal vegetation. Besides mangroves and salt marshes, we recorded the coastal sand sheet vegetation (storm berm vegetation) even more frequently, and there are also some rocky headlands with their characteristic plant species composition, particularly in the western Abu Dhabi Emirate. To the authors' knowledge, no scientific documents dealing with the salt marshes or the coastal sand sheet vegetation exist.

This is not surprising, considering the low number of botanists working in the region, together with the inaccessibility of the coastal vegetation. However, it is surprising when considering the immense potential economic and ecological importance of those vegetation types. These vegetation types need urgently to be researched for their structure, productivity, and phytomass. It is highly likely that the coastal vegetation types do not only show large standing crops, but also feature high primary productivity. This would make the thin coastal vegetation band of importance for marine secondary productivity, as well as for arthropods and migrating birds. The information on the geographical distribution of the coastal vegetation was limited and only areas where mangrove stands occurred were known (Böer, 1991; Embabi, 1993; Dei, 1998). Our results have provided detailed information about the occurrence of a broad range of coastal plant resources.

In this paper we are discussing mangroves, salt marsh plants, and other coastal vegetation types. Worldwide there are different definitions being used for the terms salt marshes and mangroves. In the Arabian Gulf the definition for mangrove is very simple, as only one mangrove species occurs naturally, *Avicennia marina* (Forssk.) Vierh. Thus, the presence of the particular above-mentioned species defines the existence of a mangrove in the Arabian Gulf. However, there are also some spots in the intertidal zone with introduced/re-introduced specimens of other mangrove species within the Abu Dhabi territory, such as *Conocarpus* sp. (three specimens introduced, known as black-mangrove; not a true mangrove), *Laguncularia racemosa* (three specimens introduced), and *Rhizophora mucronata* (>100 specimen re-introduced in two different locations). Rabanal and Beuschel (1978) and Anwahi (1994) first attempted to account for mangrove distribution in the United Arab Emirates, and estimated a total area of 30 km^2 as covered with mangroves. Our more recent project identified a total of to be covered with mangroves, while Blasco et al., (in press) found 31.7 km^2 of mangroves on one SPOT 4 scene of Abu Dhabi alone. The difference is explained through different methods, as well as progress in mangrove development; for example, recently fringing mangroves with a total length of >4km were successfully established on the banks of dredged canals close to the city of Abu Dhabi. With the term salt marsh it is more difficult, since there are different coastal vegetation types present, and each of them has a different salinity and inundation regime. In this paper, we refer to the term coastal salt marsh only, when we talk about plant species that are frequently inundated by tidal waters, such as *Arthrocnemum macrostachyum, Halocnemum strobilaceum*, and *Halopeplis perfoliata*. Other vegetation types are either mangroves, sand sheet vegetation, reed-beds, or others. The importance of the results lies within the frequency of occurrence of certain vegetation types and plant species. Very widespread are the sand sheets (storm berms), with species such as *Suaeda vermiculata, Salsola drumondii*, and *Zygophyllum qatarense*, followed by salt marshes mainly consisting of *Arthrocnemum macrostachyum, Halopeplis petfoliata* and *Halocnemum strobilaceum*. Equally noteworthy from our data is that there are 31 plant species that occurred in less than 2% of all sites investigated. These restricted species may need particular management attention if their continued presence in the Emirate is to be assured. In order to enable coastal land developers and decision-makers to manage the coastline sustainably, it is now of importance to conduct detailed research into the ecology of these, so far neglected, vegetation types. The results can now be used to generate detailed floristic distribution maps, which could be published later in a separate volume, e.g. a plant atlas of the United Arab Emirates.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Adam, P. 1990. Saltmarsh ecology. Cambridge University Press, Cambridge.

Anwahi, A.1994. Seedling emergence and growth of mangrove Avicennia marina (Forssk.) Vierh. under different environmental conditions in the United Arab Emirates. Unpublished M.Sc. Thesis, United Arab Emirates University, AI Ain.

Böer, B. 1994. Status, environmental factors and recovery of the intertidal and terrestrial vegetation between Ras az-Zaur and Abu Ali Island after the Gulf War oil spill. 229-253 pp.

Böer, B. & Gliddon, D. 1997. Abu Dhabi's Coastal Zone - Conservation Requirement and Land Use, Potentials. International Conference on Water Management, Salinity and Pollution Control Towards Sustainable Irrigation in the Meditarranean Region. Instituto di Bari, Italy, 22-26, September, 1997.

Böer, B. & Gliddon, D. 1998. Mapping of coastal ecosystems and halophytes (case study of Abu Dhabi, United Arab Emirates). Marine and Freshwater Research 49: 297-302.

Deil, U. 1998. Coastal and Sabkha Vegetation. pp. 209-228. In: S. Ghazanfar and M. Fisher: Vegetation of the Arabian Peninsula. Geobotany 25. Kluwer Academic Publishers, Dordrecht/Boston/London. 362 pp.

Embabi, N.S. 1993. Environmental aspects of geographical distribution of mangrove in the United Arab Emirates. pp. 45-48. In: H. Lieth and A.A. AI Masoom (eds): Towards the rational use of high salinity tolerant plants. Tasks for Vegetation Science 27. Kluwer Academic Publishers, Dordrecht/Boston/London. 521 pp.

Feldkamp & Krupp, F. Establishment of a marine habitat and wildlife sanctuary for the Gulf Region. Final Report for Phase II, submitted to the Commission of the European Union, Brussels, and NCWCD, Riyadh.

Rabanal, H.R. & Beuschel, G.K. 1978. The mangroves and related coastal fishery resources in the United Arab Emirates. FAG, Rome.

Saenger, P., Blasco, F., Loughland, R. & A. Youssef, 2000. The mangrove resources of the UAE with particular emphasis on those of Abu Dhabi Emirate. Paper presented at the "Coastal Habitats Conference" of the Emirates Heritage Club, Abu Dhabi, April 8-12, 2000.

White, F. 1983. The vegetation of Africa. A descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa. UNESCO, Paris. 356 pp.

CHAPTER 4

THE SABKHA VEGETATION OF THE UNITED ARAB EMIRATES

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Abstract. In the United Arab Emirates (UAE), sabkhat are found mainly in Abu Dhabi irate, and they occur along 300 km of coastal plain, as well as inland on interdunal plains. Sabkhat proper are largely devoid of vegetation except where there is a thin surface covering of aeolian sand. However, the margins may support a dense cover of mainly halophytic dwarf shrubs. This study describes in brief the salient features of the flora, including plant adaptations to highly saline environments, and gives an overview of the main vegetation types associated with sabkhat in the country. Chenopodiaceae are best represented in terms of species number, but the Zygophyllaceae also play a prominent role in the vegetation cover. Coastal sabkhat in particular are under severe threat from reclamation and development, and there is an urgent need to document the vegetation associated with sabkhat and coastal environments, as well as to establish representative protected areas before irreparable damage is caused to these valuable ecosystems.

1. INTRODUCTION

The landscape of the UAE is dominated by low-lying, sandy desert, but extensive salt flats (sabkhat) occur in coastal areas. In the east, the Hajar Mountains rise sharply above the surrounding landscape to an elevation of about 2,000 m. The climate is arid to hyperarid, characterized by high temperatures and low rainfall. The summers (May to October) are distinctly hot, with daytime temperatures regularly exceeding 40°C. Rainfall occurs occasionally during the summer, but is generally restricted to the cooler winter months (November to April). Temperatures can drop to 4°C in some areas at night, but frosts are unknown. Annual rainfall amounts vary according to location, but precipitation generally decreases along a northeast to southwest gradient. The mountainous areas in the east receive most rainfall (long-term annual mean of about 154 mm in Masfut, ranging from 4 to 479 mm per year), about 80 mm in coastal areas such as Abu Dhabi and Dubai, but substantially less in more western and southern parts of the country (data obtained from Böer, 1997).

Temporal variation in the seasonal rainfall pattern has a decisive influence on biological activity. In some seasons, rainfall amounts well in excess of long-term

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mean values are recorded, whereas in others, there may be no significant precipitation at all. This is indicated by data provided by Böer (1997) for Al Ain: over a 23-year observation period (1970-1992), total annual rainfall ranged from 1 to 303 mm, with a long-term mean of 100 mm.

Coastal regions experience high humidity, especially in the summer months, but the interior has a much drier climate. Mists frequently cover the mountains, and are also a common occurrence in some areas of the desert, such as to the south and west of Abu Dhabi island. Dewfall is a common phenomenon in coastal localities, and many plants on coastal dunes have shallow, lateral rooting systems that enable them to exploit this regular input of moisture.

1.1. Sabkhat in the UAE

In the UAE, coastal sabkha is a major landscape feature in Abu Dhabi Emirate, and extends for over 300 km from near Sila'a close to the border with Saudi

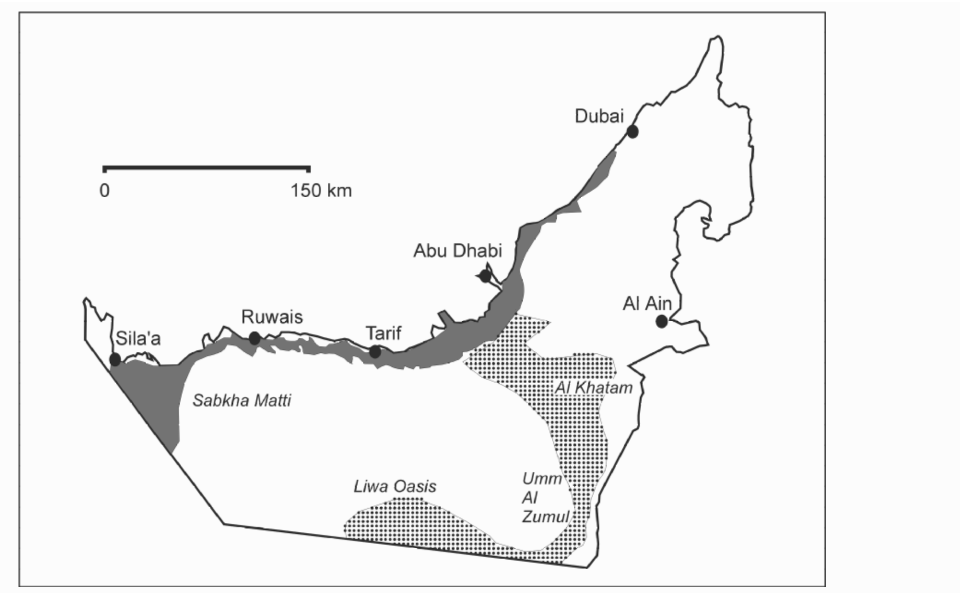

Figure 1. *Map of the UAE showing the extent of coastal sabkha (grey shaded area) and Sabkha Matti, as well as the main areas with inland sabkhat (dotted area).*

Arabia in the west to Ras Ghanada in the east, near the border with Dubai Emirate (Figure 1). It reaches a width of up to about 25 km, and in both the west and east of Abu Dhabi Emirate gradually leads into inland sabkha. Although sabkhat occur in deserts throughout the world, Goudie (2002) describes the coastal sabkha of Abu Dhabi as the best example of this landform type to be found anywhere, deserving World Heritage status. It is less than a few meters above high tide level. After heavy rainfall or severe northerly coastal storms in association with high tides, parts of the sabkha may become flooded.

Large inland salt flats, often referred to as "inland sabkhat", are found in various parts of Abu Dhabi Emirate. Sabkha Matti is the largest of these and, after Umm As Samim in Oman, the largest on the Arabian Peninsula. It is located in the far west of the Emirate, extending from the coast some 100 to 150 km inland into neighboring Saudi Arabia. Satellite imagery shows it to cover an area of about 5,000 km². Inland sabkhat also occur in the south and east of Abu Dhabi Emirate, particularly in the Al Khatam, Umm Al Zumul and Liwa areas (Figure 1), where they are developed on interdunal plains. These sabkhat are often flooded after heavy rainfall, and temporary lakes may persist for several weeks (Figure 12). The Liwa area is famous for its 'sand roses', which formed in sabkhat. These are natural formations resembling stone flowers, and consist of interlocking flat polyhedrons of gypsum-cemented sand.

1.2. Sabkha flora

1.2.1. Taxonomic and phytogeographical aspects

On account of its high salt content and the lack of fresh water, true sabkha is an extremely inhospitable environment for biological activity and supports virtually no higher plants (Barth & Böer, 2002). However, halophytes are able to colonize thin layers of aeolian sand that are deposited locally on the sabkha surface, including around their margins, which can support fairly dense vegetation.

A major problem with halophytic vegetation in this part of the world is the taxonomic uncertainty surrounding certain taxa, as well as the fact that some of the species involved are easily confused and often misidentified. For instance, some members of the Chenopodiaceae display considerable morphological variation, and it is often very difficult to satisfactorily describe key features that may help separate a particular species from another. This problem also applies to other genera. Whereas Mandaville (1990) and Böer (1999) indicate that *Zygophyllum mandavillei* is widespread in parts of the UAE, according to Deil (2000) it is restricted to a small area in the southern part of the Arabian Peninsula east of Sana'a, and that *Z. qatarense* is the taxon involved in the UAE. At present, my own field observations tend to support the view of Deil, in that *Zygophyllum qatarense* appears to be predominant species, at least in Abu Dhabi Emirate, with no clear records of *Z. mandavillei*.

The Chenopodiaceae are particularly well represented in the sabkha and coastal flora, not only in terms of species number, but also in respect of cover. Characteristic species include *Agriophyllum minus*, *Bienertia cycloptera, Cornulaca monacantha*, *Halopeplis perfoliata, Salsola drummondii*, *Salsola imbricata*, *Seidlitzia rosmarinus* and *Suaeda aegyptiaca*. *Anabasis setifera* is particularly common on sabkhat that have been disturbed by reclamation, for instance by covering the surface with sand or rubble. Locally, the species forms extensive stands by the main Sila'a to Abu Dhabi highway, sometimes accompanied by *Salsola drummondii*. Certain Zygophyllaceae, in particular *Zygophyllum qatarense*, also play a key role in the vegetation cover, dominating large tracts of saline substrate throughout the country. The annual *Zygophyllum simplex* is also widespread and common, especially in coastal regions.

In accordance with the phytogeographical division of Arabia by Léonard (1989), the sabkhat of the UAE lie within the Saharo-Sindian regional zone, which can be further subdivided into the Nubo-Sindian local centre of endemism (encompassing the coastal areas of the UAE) and the Arabian regional subzone. The latter covers the interior of the country, but the precise delimitation from the Nubo-Sindian phytochorion is difficult. *Halopeplis perfoliata* is a good example of a species with a Nubo-Sindian distribution pattern, occurring primarily along the coastal belt of the Arabian Peninsula. Certain other Nubo-Sindian taxa are found predominantly along the coasts of the UAE and Oman in Arabia, but also occur in southern Iran and Pakistan. Examples of such "Omano-Makranian elements" (Kürschner, 1998) include *Agriophyllum minus* and *Salsola drummondii*.

1.2.2. Adaptations to highly saline substrates

Most key species inhabiting the margins of sabkhat or similar saline habitats are halophytic perennials (Deil, 1998). Succulent dwarf shrubs, either leaf succulents with woody stems or stem succulents, constitute the predominant life form. Trees, however, are largely absent from sabkhat with the exception of members of the genus *Tamarix*. These grow in moist depressions that have a high salt content, as indicated above. Annual species are also poorly represented, the most notable exceptions being the widespread chenopods *Agriophyllum minus*, *Bienertia cycloptera*, *Salicornia europaea*, *Suaeda aegyptiaca* (although sometimes a short-lived perennial) as well as the facultative ephemeroid *Zygophyllum simplex*.

Both C_3 and C_4 photosynthetic pathways are found in plants associated with sabkhat, and the occurrence of the particular pathway provides insight into the degree of water availability, a key environmental parameter. Species with the C_3 pathway are usually hygrohalophytic ones, such as *Halopeplis perfoliata* and the mangrove *Avicennia marina*, whereas the C_4 pathway is usually developed in xerohalophytes. In contrast to xerohalophytes, hydrohalophytes do not need to conserve water to any significant degree, as it is readily available. The C_4 pathway confers a distinct advantage on plants that regularly face water deficiency, in that it facilitates greater water-use efficiency, as the stomata need only to be open slightly to carry out effective CO_2 fixation (von Willert et al., 1995). However, C_3 plants growing in wet saline environments face a particular problem in connection with their high rates of transpiration, namely the accumulation of potentially toxic concentrations of salts in their aerial organs. This is because the plants cannot reduce the uptake of dissolved salts to any significant degree. Two main mechanisms have evolved in hydrohalophytes to deal with the problem. Firstly, succulence, which is particularly well pronounced in *Halopeplis perfoliata* with its strongly succulent leaves. These plants store large amounts of water and thus dilute the salts in the leaf vacuoles. Other succulent C_3 species of sabkhat or coastal marsh in the UAE include *Arthrocnemum macrostachyum, Halocnemum* *strobilaceum* and *Salicornia europaea*, all of which are characteristic of moister ground.

The second important mechanism is the development of salt-excreting glands, as found in the C_3 species *Avicennia marina*.

Conversely, halophytic chenopods such as *Anabasis setifera*, *Salsola drummondii*, *Salsola imbricata* and *Suaeda vermiculata*, all of which inhabit the drier sections of coastal and sabkha ecosystems, as well as the barely salt-tolerant species of more inland, sandy habitats *Haloxylon salicornicum* and *Haloxylon persicum*, are all C_4 species (Akhani et al., 1997). *Atriplex leucoclada*, which is locally common on the drier regions of saline coastal sands in the UAE, is a C_4 species (Akhani et al., 1997) with salt excreting glands.

Regarding the annual chenopods, *Agriophyllum minus* is a C_3 species; *Bienertia cycloptera* and *Suaeda aegyptiaca* on the other hand are C_4.

Germination is a problem for plants of hypersaline habitats, as the seedlings of many species are often particularly sensitive to elevated salinity. As a consequence, the seeds of most species germinate after heavy rainfall, when salt concentrations are temporally reduced. The observations of Ismail & El-Ghazaly (1990), that seed germination is inhibited in *Zygophyllum qatarense* at higher temperatures, could not be confirmed. Mass germination of *Zygophyllum qatarense* was observed after heavy rain in May 2003 on the edge of the Rub Al Khali, when diurnal temperatures had already reached 45ºC (pers. observation).

1.3. Sabkha vegetation

1.3.1. Coastal sabkhat

The vegetation on the fringes of coastal sabkhat intergrades with coastal vegetation types towards the seaward side. Small-scale vegetation mosaics dominated by one or two species are frequently observed. Such mosaics reflect corresponding heterogeneity in key environmental factors, such as ground level, frequency of inundation and salt content.

Highly saline habitats are generally characterized by azonal vegetation types, i.e. ones that are predominantly determined by extreme edaphic factors and are not associated with particular climatic regions. As outlined, however, in a detailed study of coastal vegetation by Deil (2000), the azonal nature of the vegetation becomes less pronounced from the hydro-to geolittoral. However, on a broader scale, certain distribution patterns can probably be attributed to climate. For instance, *Salicornia europaea* is common on the Arabian Gulf coast further north, and, although present along the coast of the UAE, is gradually replaced by *Halopeplis perfoliata*.

Figure 2 shows a generalized cross section of the coastal flats, as typically found west of Abu Dhabi is land. Figures 3 to 6 illustrate the vegetation composition of the different zones shown in Figure 2, which in the following shall be dealt with starting from the coastline.

Extensive areas of coastal intertidal flats lacking vascular plants occur in many areas along the coast of Abu Dhabi Emirate, particularly in the western section.

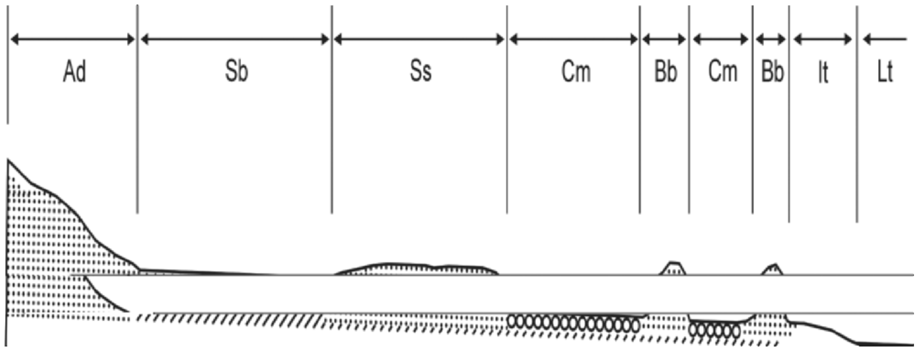

Figure 2. *Schematic profile from the coast through to the inland dunes as typically found west of Abu Dhabi island (not to scale). Lt: sea at low tide; It: intertidal mudflats, occasionally with extensive cyanobacterial mats; Bb: storm beach ridge; Cm: cyanobacterial mat; Ss: sand sheet over sabkha; Sb: sabkha; Ad: aeolian dune.*

Lagoons of varying size are also frequent along the Abu Dhabi coastline, and particularly in eastern parts (roughly east of Abu Al Abyad island), extensive stands of mangroves may occur in lagoons as well as along other areas of protected coastline with shallow water levels. Small stands of mangroves are also present further west, such as in the sheltered bay immediately west of Jebel Dhanna. *Avicennia marina* is the only species of mangrove to occur naturally in the UAE. Whether or not *Rhizophora mucronata* once occurred in the region is still open to question. Coastal lagoons with a muddy substrate are also colonized by dense stands of the chenopods *Arthrocnemum macrostachyum* and *Halocnemum strobilaceum*.

Above the high tide mark, one to several low storm beach ridges rising just a few centimeters to decimeters above the surrounding coastal flats and running parallel to the coast may be present. They consist of shelly sand and are subject to occasional inundation. Depending on the locality and the precise environmental conditions, *Halocnemum strobilaceum*, *Halopeplis perfoliata* or *Suaeda vermiculata* dominate the beach ridges (Figure 3), forming monospecific, sometimes quite dense stands with cover values up to 95% (Figure 4). *Salsola drummondii* may also be present, but appears to be more frequent on higher ground away from the immediate coastline.

Gelatinous cyanobacterial mats occur over extensive areas in slight depressions to form biological soil crusts, for instance between the storm beach ridges (Figure 4) as well as in other sheltered locations. These mats, which overlie a sandy substrate, are rather thin and have a warty surface. In some situations, a veneer of aeolian sand accumulates on the surface of these mats, and higher plants such as *Halopeplis perfoliata* and *Halocnemum strobilaceum* are able to colonize them.

Figure 3. *A storm beach ridge with* Halocnemum strobilaceum *towards the sea. Several lines of dead sea grass deposited at high tide can be seen in the top right-hand corner.*

Figure 4. *Cyanobacterial mat and storm beach ridge with dense growth of* Halocnemum strobilaceum *in background.*

With increasing distance from the coastline, the ground rises virtually imperceptibly and the surface becomes more permanently covered with sand. *Zygophyllum qatarense* is the dominant species on such sandsheets, attaining cover values in excess of 75% in favorable situations (Figure 5).

It is occasionally accompanied by *Halopeplis perfoliata*, which becomes dominant around the edges of hypersaline depressions as well as on thin sand sheets on the edge of the sabkha proper where the moisture conditions are more favorable (Figure 6). In the far west of the country, a community in which *Suaeda vermiculata*, *Seidlitzia rosmarinus*, *Salsola* cf. *arabica* and *Zygophyllum qatarense* co-dominate colonizes thin sand sheets over sabkhat.

Adjacent to this area landwards, ground levels drop very slightly, and a broad plain of sabkha occurs, often many kilometers wide. The sabkha is virtually devoid of vegetation, apart from where, as stated previously, there is a thin accumulation of sand on the surface. This aeolian sand has a much lower salinity

Figure 5. Zygophyllum qatarense *predominates on sand sheets overlying sabkha. Also present are scattered plants of* Halopeplis perfoliata.

Figure 6. Halopeplis perfoliata *(dark plants) is often the dominant species on very thin sand sheets overlying sabkha, presumably where moisture levels are reasonably high. The species is companied by* Zygophyllum qatarense *(lighter plants lacking leaves), which attains dominance on thicker sand sheets, as seen in the top right of the photograph.*

than the underlying substrate. Plants that have become established, or even their stumps after the plants have died off, often act as obstacles for wind-blown sand, leading to the deposition of more sand, allowing other plants to colonize. The most frequent species is *Zygophyllum qatarense*.

Of particular interest are the Tertiary 'jebels' that are surrounded by sabkha (Figure 10). These small rocky outcrops with flat tops vary in height, but are typically up to about 5 to 10 m high, with the largest up to 60 m. A number of plant species occur on the jebels, including halophytic ones such as *Seidlitzia rosmarinus* and *Salsola* spp. The salinity is presumably provided by wind-blown saline dust from the surrounding sabkha. Also present are a number of non-halophytic species that are otherwise absent from the surrounding area, which either grow in small pockets of soil that accumulate behind rocks or in gullies on the smaller jebels, as well as on the plateaux of the larger ones. These include the desert annuals *Savignya parviflora*, *Eremobium aegyptiacum* and the bristly, facultative perennial *Arnebia hispidissima*. Furthermore, the lily *Dipcadi erythraeum* appears abund-antly on the flanks of some jebels after heavy rainfall. *Panicum turgidum* can be dominant on the tops of some larger jebels, often accompanied by *Calligonum comosum* and *Indigofera* sp.

Cyanolichens (i.e. lichens with a cyanobacterium as the photobiont) colonize rocks on the jebels, presumably where the influence of salt is diminished. These lichens are generally poorly developed and are therefore probably unidentifiable. *Buellia subalbula* is widespread on flattish rocks on many jebels, and an unknown species of *Caloplaca* (also recorded from Kuwait by Brown & Schultz (unpublished)) is occasionally present.

1.3.2. Inland sabkhat

Many species that are found on the margins of coastal sabkha are absent inland, so that the number of taxa becomes even more limited. Interestingly, *Seidlitzia rosmarinus* is a species that appears to be absent from most coastal sabkhat with the exception of the far west of the country, but is widespread and sometimes dominant in the immediate vicinity of inland sabkhat in the south (Liwa, Umm Al Zumul, see Böer, 1999). It is probably dotted around other parts of the country, but the species is easily overlooked or confused with others on casual inspection.

Deil (2000) states that *Halopeplis perfoliata* avoids all inland saline habitats. However, conspicuous stands of the species occur on sabkhat by the road towards Sweihan from Abu Dhabi some 40 km from the coast. Here it grows in depressions, and probably receives additional run-off water from the road. According to Jongbloed (2003), the species is also present, but uncommon, in the Liwa area, over 100 km from the coast. In both localities though, it is possible that the species has been inadvertently introduced. The same possibly applies in part to *Suaeda aegyptiaca*, which colonizes plantations in several parts of the country, many of which have been established only in recent decades.

Figure 7 shows a typical cross section of the landscape in the Al Khatam area southwest of Al Ain, with sabkha developed on interdunal plains. The sabkha proper, which may be up to several kilometers in width, is devoid of vegetation (Figure 9), although scattered individuals of *Zygophyllum qatarense* may occur in favorable microsites. Presumably where there is a more permanent water supply, members of the genus *Tamarix* may occur. This is the case where artificial depressions have been created in sabkhat (Figure 8). *Phragmites australis* also accompanies the species in such situations.

At the foot of the dunes (deflated linear mega-dunes that run roughly from west to east, reaching a height of about 12 to 20 m), the margins of sabkhat are covered

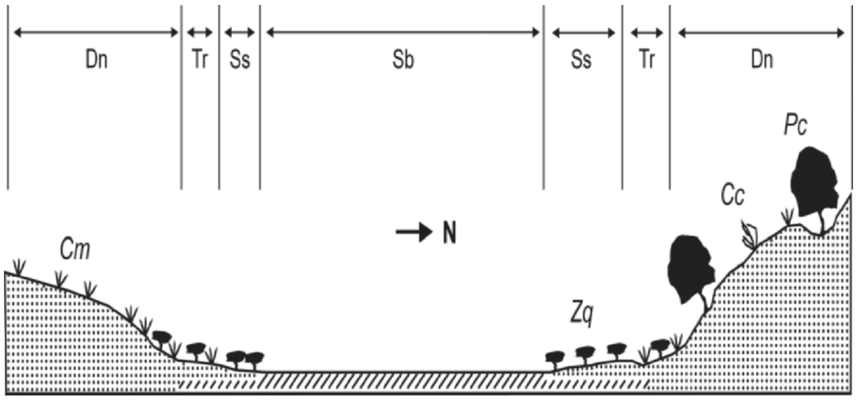

Figure 7. *Cross-section through an interdunal plain in the Al Khatam area of Abu Dhabi Emirate, southwest of Al Ain (not to scale). Dn: dunes (up to 25 m high); Tr: transitional zone; Ss: sand sheet; Sb: sabkha (up to several kilometers wide). Cc:* Calligonum crinitum *ssp.* arabicum*; Cm:* Cyperus conglomeratus*; Pc:* Prosopis cineraria*; Zq:* Zygophyllum qatarense.

Figure 8. *Excavated inland sabkha with* Tamarix sp. *and* Phragmites australis *in the Al Khatam area southwest of Al Ain. The pools of water in the foreground indicate the high level of the groundwater table.*

in sand (Figure 9), and where salinity still exerts its influence, dense stands of *Zygophyllum qatarense* can be quite conspicuous. The species can form substantial micro-nebkhas in such situations. With increasing height above the sabkha and decreasing salinity, *Zygophyllum qatarense* gradually gives way to *Cyperus conglomeratus*, and first individuals of *Prosopis cineraria* may occur on the edges of the dunes. This tree species, a typical Omano-Makranian element, has been regarded by some (e.g. Böer, 2002), as being slightly salt-tolerant. It is a phreatophyte that has its westernmost distribution limits in this part of Arabia (occurring slightly further west in southern Oman). In the Al Khatam-Sweihan area of Abu Dhabi Emirate it grows primarily on sand dunes, and in some areas, these border sabkhat. Further to the northeast, where there is more rainfall, it also grows on gravel plains, and even reaches the coast near Ras Al Khaimah. Whether or not, however, its roots are in contact with the saline groundwater is open to question. It is perfectly feasible that the species exploits ‘perched’ lenses of fresh water stored in the substrate located above the main groundwater table.

In the Al Khatam area, some interdunal plains have jebels (Figure 10), but these are much less common inland than nearer the coast. *Fagonia ovalifolia* may occur in large quantities on the top of these outcrops.

Figure 9. *Inland sabkha on an interdunal plain in the Al Khatam area southwest of Al Ain, looking northwards. In the background,* Zygophyllum qatarense *can be seen on the margins of the sabkha, and some individuals of* Cyperus conglomeratus *are visible on the dunes. The tree is* Prosopis cineraria.

Figure 10. *Jebels surrounded by inland sabkha in the Al Khatam area southwest of Al Ain. The picture was taken from the top of a jebel, about 6 m above the surrounding sabkha, showing the view towards the southeast. Behind the second extended, but lower jebel, sand sheets cover part of the sabkha, and are colonized by* Zygophyllum qatarense.

1.4. Important vegetation types occurring in association with sabkhat

1.4.1. Haloxylon salicornicum-*community*

Haloxylon salicornicum is a widespread species in the northern half of the Arabian Peninsula (north of the Tropic of Cancer), and in the UAE is particularly common on firm, often gritty surfaces in the northern half of the country, especially in the west where it covers extensive areas. The species also grows on stable sandy substrates. Despite its name, the species appears to be barely tolerant of salt, and is usually replaced by *Zygophyllum qatarense* on more saline soils.

As a consequence, *Haloxylon* does not colonize sabkhat, but is frequently found behind a belt of *Zygophyllum* on the margins where there is a slightly deeper covering of sand (Figure 11).

Figure 11. Haloxylon salicornicum *community on sand sheets on the western edge of Sabkha Matti in the far west of the country.*

1.4.2. Haloxylon persicum-*community*

Haloxylon persicum is a shrub that is distributed mainly in central and north-western Saudi Arabia on the Arabian Peninsula. Further east, it is only known from its restricted range in the UAE, and is completely absent from Oman. In the UAE, it occupies a geographically distinct narrow belt on the southern edge of coastal sabkha south of Abu Dhabi island in the east, extending some 100 km further west to Tarif (Figure 1). The width of this belt rarely exceeds 25 km. The species does not occur on sabkhat *per se*, but grows on the low linear dunes that are arranged parallel to the coast and are separated by interdunal sabkha plains (Figure 12).

Haloxylon persicum forms a characteristic species-poor plant assemblage (‘*Haloxylon persicum*-community’), in which *Haloxylon salicornicum* or *Cyperus conglomeratus* are co-dominants, the latter often accompanied by *Limeum arabicum*.

Figure 12. *Flooded area of sabkha after heavy rainfall in May 2003, southwest of Abu Dhabi.* Haloxylon persicum *is the shrub colonizing the low dunes.*

The stands of *Haloxylon persicum* are of outstanding conservation value due to their biogeographical significance, especially as they appear reasonably intact.

1.5. Threats to the sabkha environment

Despite the outstanding conservation value of the coastal sabkha in Abu Dhabi Emirate this unique landform is generally regarded as being of little economic or indeed ecological value (Barth & Böer, 2002). As a consequence, there has been a concerted effort to reclaim substantial swathes for development in recent decades. These activities are not only restricted to the proximity of urban areas, but sabkhat are even under threat from a plethora of engineering projects in remoter parts of the country. A major highway parallel to the coast now cuts across the whole area of sabkha from Shahamah (east of Abu Dhabi island) all the way to the border with Saudi Arabia in the west. The sabkha either side of the highway has partly been filled in with sand, even allowing forestry plantations to be established. This is leading to fundamental changes in the hydrology of the sabkha, which is now often protected from the infrequent natural flooding events.

However, with the predicted rise in sea level over the next century (Rull et al., 1999), it is envisaged that the coastal sabkha will become quickly flooded by the advancing sea, and may thus disappear completely. Rises in sea level will also have severe consequences for the coastal settlements and other infrastructure developments on coastal sabkha.

Close to Abu Dhabi Island, projects on a massive scale are underway to expand urban development, leading to the destruction of large expanses of sabkha. Although such infrastructure development is understandable in view of the economic growth of the country, other activities are of a more dubious nature. For instance, large-scale forestry plantations have been created on sabkhat throughout Abu Dhabi Emirate. Although these efforts can hardly be classified as a success, new plantations continue to be established. Few tree species are able to survive the harsh conditions, especially as the water used for irrigation is often quite saline and usually obtained from wells in the sabkhat. The favored tree species for afforestation on sabkhat is *Salvadora persica*, but tree growth remains severely stunted, even after many years.

1.6. Research and conservation

The halophytic flora of the UAE has been described by a number of authors (Böer & Al-Ansari, 1999), although detailed studies are still lacking. The problem of accessibility to many parts of the coastline, the precise species identity of the notoriously taxonomically difficult chenopods with their pronounced morphological variability, and the paucity of expert botanists in the region do not make research undertakings an easy task.

The 'Coastal Sensitivity Atlas' that was produced by the Environmental Research & Wildlife Development Agency in Abu Dhabi (for Abu Dhabi Emirate) (ERWDA, 2000) was mainly restricted to the marine environment, and included only scant information on the coastal vegetation, apart from outlining the approximate distribution of mangroves. The planned updating of this atlas should therefore provide an opportunity to assess the coastal and associated sabkha flora and vegetation.

At present, no areas of sabkha are formally protected in the UAE. As a matter of urgency, two large protected areas should be established, one protecting large tracts of Sabkha Matti, possibly as a transboundary national park with Saudi Arabia, the other protecting the stands of *Haloxylon persicum* with the adjacent coastal areas to the north. Infrastructure development, seemingly without any sense of planning, is already making serious inroads into both areas, thus underlining the need for rapid action.

2. ACKNOWLEDGEMENTS

I am grateful to Prof. M. Ajmal Khan (Karachi) for the invitation to write this chapter and to Dr. Benno Böer (Doha) for encouragement and support. Dr. Peter Cowan (Stirling) and Simon Aspinall (Abu Dhabi) kindly commented on the draft manuscript, and Yasser Othman (Abu Dhabi) helped prepare the map. Many thanks also to the management of ERWDA (Abu Dhabi) for making the study possible.

3. REFERENCES

Akhani, H., Trimborn, P. & Ziegler, H. 1997. Photosynthetic pathways in *Chenopodiaceae* from Africa, Asia and Europe with their ecological, phytogeographical and taxonomic meaning. Plant Systematics and Evolution 206: 187-221.

Barth, H.J. & Böer, B. (eds.) 2002. Sabkha Ecosystems. Volume 1. The Arabian Peninsula and Adjacent Countries. Kluwer, Dordrecht. 354 pp.

Böer, B. 1997. An introduction to the climate of the United Arab Emirates. A review. Journal of Arid Environments 35: 3-16.

Böer, B. 1999. Ecosystems, Anthropogenic Impacts and Habitat Management Techniques in Abu Dhabi. Paderborner Geographische Studien. 141 pp.

Böer, B. 2002. The coastal and sabkha flora of the United Arab Emirates. In: Barth, H.-J. & Böer, B. (eds.), Sabkha Ecosystems. Volume 1. The Arabian Peninsula and Adjacent Countries. Kluwer, Dordrecht. 303-309 pp.

Böer, B. & Al Ansari, F. 1999. The vegetation and flora of the United Arab Emirates - a review. In: Abuzinada, A.H. & Joubert, E. (eds.), Proceedings of the workshop on the conservation of the flora of the Arabian Peninsula. NCWCD & IUCN, Riyadh. 63-77 pp.

Deil, U. 1998. Coastal and sabkha vegetation. In: Ghazanfar, S. & Fisher, M. (eds.), Vegetation of the Arabian Peninsula. Geobotany 25. Kluwer Academic Publishers, Dordrecht. 209-228 pp.

Deil, U. 2000. Halophytic vegetation along the Arabian coast - azonal or linked to climatic zones? Phytocoenologia 30: 591-611.

ERWDA 2000. Abu Dhabi Coastline Oil Spill Protection Priorities. Environmental Research & Wildlife Development Agency. Abu Dhabi. 45 pp.

Goudie, A.S. 2002. Great Warm Deserts of the World - Landscapes and Evolution. Oxford University Press. 444 pp.

Ismail, A.M. & El-Ghazaly. 1990. Phenological studies on *Zygophyllum qatarense* Hadidi from contrasting habitats. Journal of Arid Environments 18: 195-205.

Jongbloed, M. 2003. The Comprehensive Guide to the Wildflowers of the United Arab Emirates. Environmental Research and Wildlife Development Agency, Abu Dhabi. 576 pp.

Kürschner, H. 1998. Biogeography and introduction to the vegetation. In: Ghazanfar, S.A. & Fischer, M. (Eds.), Vegetation of the Arabian Peninsula. Geobotany 25. Kluwer Academic Publishers, Dordrecht. 63-98 pp.

Léonhard, J. 1989. Contribution à l'étude de la flore et de la végétation des déserts d'Iran. Fascicule 8 (Étude des aires de distribution. Les phytochories. Les chorotypes) & Fascicule 9 (Considérations phytogéographiques sur les phytochories irano-touranienne, saharo-sindienne et de la Somalie-pays Masai). Jardin botanique national de Belgique.

Mandaville, J.P. 1990. Flora of Eastern Saudi Arabia. Kegan Paul International. London. 482 pp.

Rull, V., Vegas-Vilarrubia, T. & Espinoza de Pernia, N. 1999. Palynological record of an early-mid Holocene mangrove in Eastern Venezuela. Implications for sea level rise and disturbance history. Journal of Coastal Research 15: 496-504.

vonWillert, D.J., Matyssek, R. & Herppich, W. 1995. Experimentelle Pflanzenökologie. Thieme, Stuttgart. 344 pp.

CHAPTER 5

DESERTIFICATION AND SABKHAT FORMATION IN THE ARAL SEA REGION

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Abstract. The article describes the main reasons for and mechanisms behind recent sabkhat formation in the Aral Sea region, especially in the deltas of the Amu-Darya and the Syr-Darya rivers. Desertification in the region is leading to the destruction and rebuilding of ecosystems. Salinization is one of the main trends of the soil cover and vegetation changes. The patterns of these changes are suggested to describe and predict desertification trends in general.

1. INTRODUCTION

The eastern and southern parts of the Aral Sea region provide an example of present, recent and ancient desertification in the closed basins of saline lakes, with a situation similar to that of the Chad lake basin, the Makkadigadi lake basin, the Tarim lake basin and others. The overregulation of water used for irrigation, changes in the directions of the river flow and climate change are the reasons for the desertification processes, which mainly occur as salinization of ecosystems and ground water, formation of sand dunes and xerofitization of plant communities. All of these phenomena are the result of changes in the narrow equilibrium between the environment's aridity and the amount of river water in the region.

This paper is devoted to the "salinization constituent" of the present desertification in the Aral Sea region that is observed in the so-called former "living" deltas of the Amu-Darya and Syr-Darya rivers.

Desertification in this region resulted from different factors or their combinations. The most important are:

a) Salinization of river waters as a result of drainage water from irrigation systems. This leads to an increase in soluble salt contents in soils and ground water in the deltas.
b) Overregulation of river flow reduced the Aral Sea volume and caused the

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drying of the deltaic lakes. Eventually it leads to the overall draining of the area.

Due to lack of water in lower reaches of the Amu-Darya and Syr-Darya rivers, the regular flooding of deltas stopped and led to the abandoning of irrigated lands. During 1911-1960 the Aral annual tributary from the Amu-Darya and the Syr-Darya was 52 km^3/year; in 1975-1984 it was only 8.5 km^3/year (Popov, 1990) and practically ceased in the latest 1990s and early 2000s. The quantity of natural lakes decreased from 100,000 to 2,000; the swamps in the floodlands and deltas practically disappeared. The level of ground water dropped on average along the delta from 1-2 to 6-7 m. In the 1990s the average water salinity increased from 0.3-0.4 g/l to 2-5 g/l. The irrigation with saline waters in lower reaches of the rivers sharply increased the mineralization of ground waters and soil salinity as well. The increase of salinity of irrigated lands caused a decrease in their productivity, and, ultimately, made their exploitation unprofitable.

1.1. Climate

The examined area is situated in the center of Eurasia close to the northern border of the subtropical zone (Figure 1). The prolonged solar radiation of 2,700-3,100 hours per year (Molosnova et al., 1987) and a high level of ultraviolet radiation of 130-140 kkal/cm^2 (Gytomirskaya, 1964) together with the areas location at a great distance from the oceans are the reasons for the region's aridity and continentality.

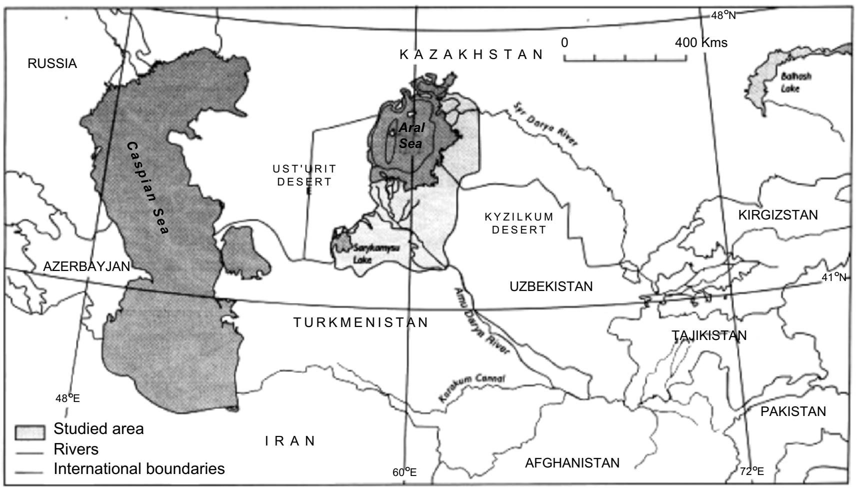


Figure 1. *Location of the studied area.*

Annual precipitation is about 100 mm, with a peak in late spring and late autumn (Molosnova et al., 1987). Summer in this region is hot and dry with a total volume of precipitation of about 15-30 mm per three months (Gytomirskay, 1964) the average daily air temperature is about 29-30°C in July. Evaporation in the Aral Sea region is very low in summer, whereas evaporation is as much as 1500-1600 mm on an annual basis. The surface albedo is high at 0.20-0.40 (Kondratyev et al., 1986).

1.2. Geomorphological peculiarities

The present structures of the Amu-Darya and Syr-Darya river deltas are closely connected with the way irrigation systems have developed. In turn, the development of irrigation systems depended on the natural mechanism of the functioning of the so-called “living” delta in the past. Very few plots of the “living delta” remain in the lowest reaches of rivers at the present time (Figure 2).

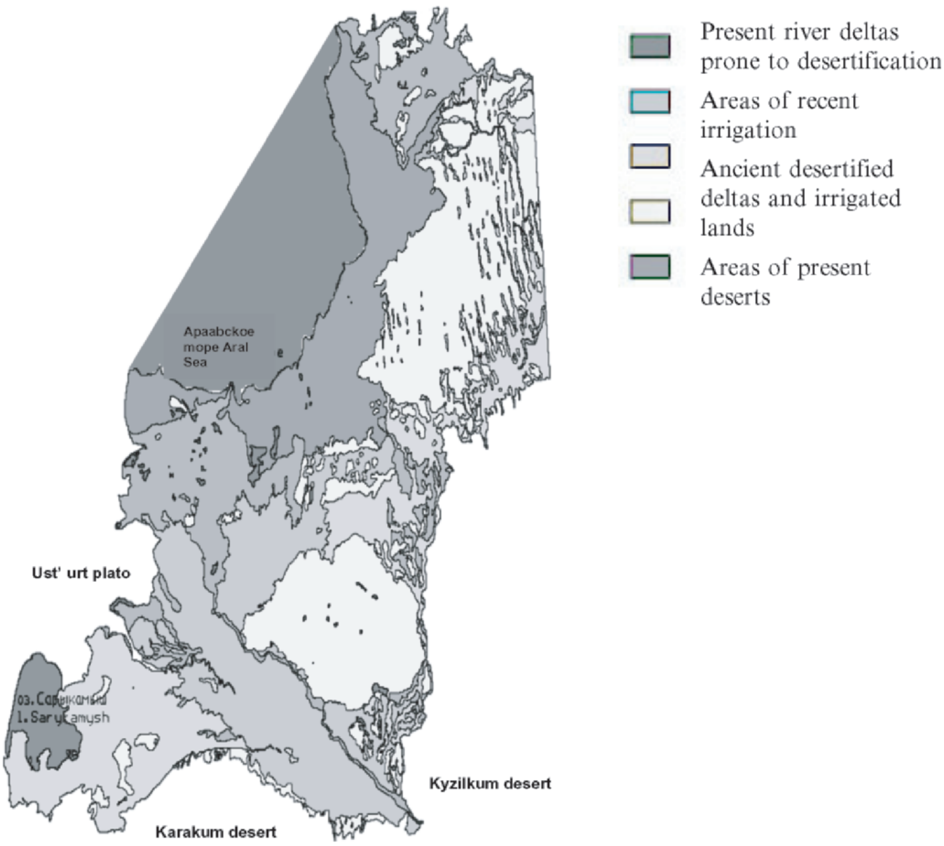


Figure 2. *Types of the areas in the Aral Sea region.*

In the mechanism of the “living delta”, the river and channel beds go through the flat plain and occupy the upper positions of the meso- and microrelief with sandy alluvial deposits. And interfluve depressions are occupied with bogs and meadows underlying fine silty and clayic deposits. A few large depressions are occupied by lakes. In the conditions of the “living” delta, the river’s fluves from time to time break through the lofted sandic bars to the interfluve depressions, beginning the next cycle of deltaic relief and deposits formation. The thickness of alluvial deposits in the deltaic area reaches more than 100 meters. In the upper parts of the deltas the natural deltaic relief has been artificially planed for irrigation. Lands were used mainly for the growing of rice and cotton. So, these parts of the deltas have a typical “irrigation-like” relief with irrigation and drainage canals and inundated areas between them. Sometimes (and this is more typical for transitional lands between ancient and present deltas) river and channel beds were used as irrigation and/or drainage canals and interfluve depressions for growing plants.

1.3. Basic facts about the vegetation of the pre-aral region

The Pre-Aral region is located in the central part of the deserts of the temperate belt of Eurasia and is related to the Sahara-Gobi’s botanical-geographical region. Plants genera of *Haloxylon, Tamarix, Nitraria, Suaeda, Salsola, Alhagi, Cynodon, Aeluropus* and others are widespread on the ancient alluvial plains along this area.

The floristic complex includes about 1,200 species, among which 700 (59%) are characterized as xerophytic indicators, 370 (31%) as psammophytic, 360 (30%) as halophytic indicators, and 328 (27%) as ephemerides and ephemeres.

The most widespread families are: *Chenopodiaceae* (250 species), *Asteraceae* (160), *Brassicaceae* (96), *Fabaceae* (73), *Liliaceae* (72), *Poaceae* (63), *Polygonaceae* (58).

There are several main types of coenosis adapted to various lithoedaphic and climatic conditions in the Pre-Aral region (Biospheric resources, 1984): (1) xerophytic semi-sub shrub communities on the grey-brown automorphic soils on clayic carbonate (or gypsum) eluvium of interfluve flats; (2) xerophytic semi-sub shrub communities on gypsum soils on a cobble eluvium; (3) psammo-xerophytic shrub communities on primitive sandic neo-automorphic soils on alluvial sandic deposits or on shifting sands; (4) psammo-mezoxerophytic grass communities on primitive sand automorphic soils on sandic deposits; (5) xerophytic semi-tree communities on takyr-like automorphic soils on clayic alluvial deposits; (6) communities of semi-sub shrubs and algae on takyrs and on ancient alluvial enclosed plains; (7) halophytic semi-shrub and sub-shrub communities on solonchaks; (8) communities of xero-mezophylic trees, shrubs and grasses of tugai complexes (tugai – thick vegetation) on meadow-alluvial and swamp hydromorphic soils.

The north-turan’s semi-sub shrub eremophytes (*Artemisia terrae-albae* Krasch., *Salsola arbusculiformis, Anabasis salsa* (C. A. Mey.) Benth., *Nanophyton erinaceum, Atriplex cana* C. A. Mey., *Suaeda physophora, Artemisia pauciflora*) are typical dominant species on the Pre-Aral flats. The saxaul trees (*Haloxylon persicum* Bunge, *Haloxylon aphyllum* (Minkw.) Iljin) and the multiplicity species of ephemeres and ephemerides prevail on the sands.

The peculiarities of the northern desert vegetation are: (1) the wide-spread species of *Artemisia* genera from the *Seriphydium* section; (2) the presence of grass synusia (*Agropyrum fragile, Stipa sareptana, S. kirghisorum, Poa bulbosa*) in the plant communities of the sands; (3) the lack of summer dormancy due to heat and dryness. The interchange of small sections with various lithology and salinization determines the complexity of the vegetation cover.

1.4. Soils

The soil classification for the Amu-Darya and Syr-Darya river deltas region is based on the concepts of unified litho-morpho-pedogenesis in deltaic areas. Therefore, the following soil types are distinguished (Table 1):

- meadow-tugaic soils of river bars (more dry on sandic deposits);
- meadow soils of river bar slopes and of interfluve descents;
- bog soils of interfluve depressions and of lake hollows (most wet with high organic content). The present situation in the region is characterized by an increase in the area of various solonchaks and a decrease in the area of meadow and bog soils.

Fast changes in soil salinity result in the total rebuilding of the ecosystems' structure and functioning. The rate and degree of the changes depend on the rate of drying, the soil texture and the soil's position in the deltaic microrelief.

1.5. Soil evolution on the river bars

The light texture of the meadow-tougaic soils on the river bars in the conditions of the periodically flooding regime of the "living" delta protects soils from salinization. An insignificant increase in salinity (to 0.2-0.5%) occurs only in dry periods despite the high level of ground water (from 1.5 to 4 m).

The salt maximum occurs in the upper soil horizon in the conditions of a slow lowering of the ground-water level and the stopping of flooding in the meadow-tougaic soils during the first stages of drying. Usually this takes place when, despite the ending of the spring inundation, the periodical under-flooding of soils continues, temporarily raising the capillary border to the soil's surface. In this case the visible crystals of soluble salts can be observed in the surface horizon, and soils transform into meadow solonchaks. In conditions of intensive drying, the accumulation of salts in the upper layer is feeble. When the lowering of the ground water level is very rapid, the salt maximum in the surface layer does not form (Figures 3 and 4).

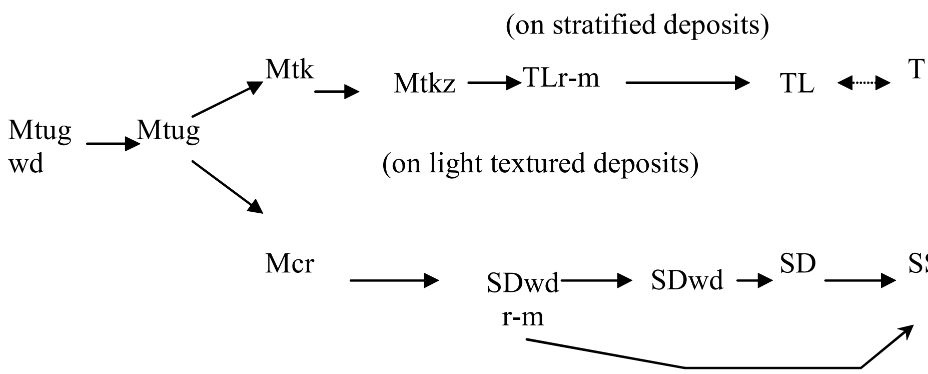


Figure 3. *Diagram of soil evolution on the river bars.*

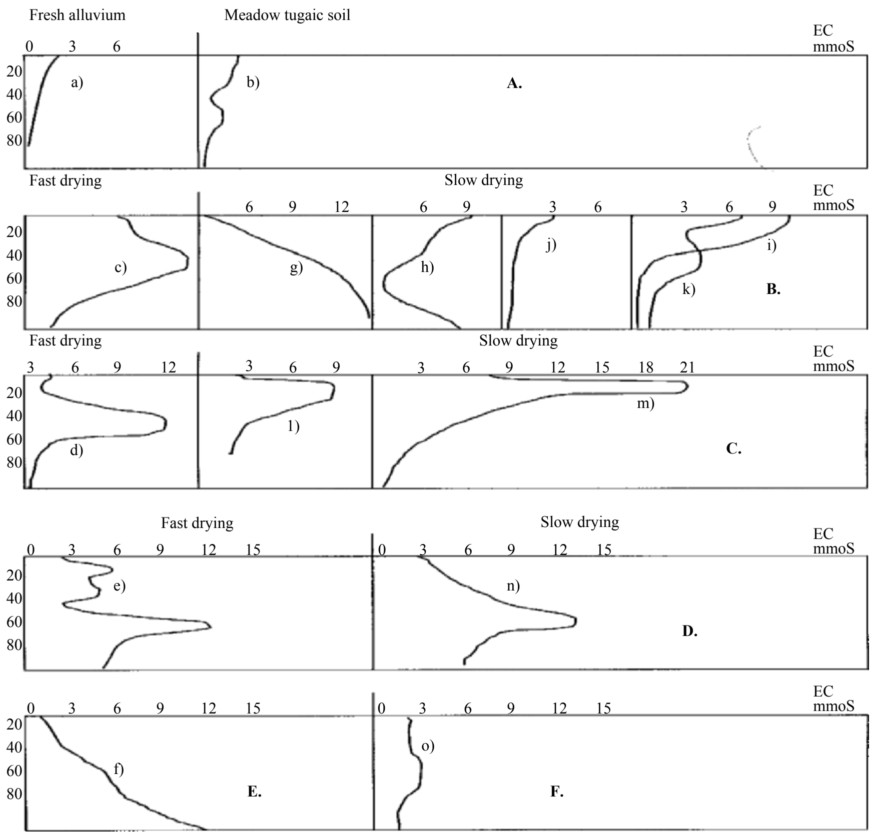


Figure 4. *Dynamics of soil salinity on the river bars. Stages: A – initial, B – Stage 1 (drying – 5-20 years), C – Stage 2 (drying and desertification – 15-30 years), D – Stage 3 (desertification-1 – 25-50 years), E – Stage 4 (desertification-2 – 50-100 years), F – equifinal stage – a few hundred years or more. (a) and (b) – (f) – lowering of the salt maximum level. (g) – in conditions of periodical flooding, (h) – when flooding stopped abruptly, (i) and (j) – the same in conditions of low salinity of ground waters, (k) – on stratified deposits. (l) and (m) – the salt maximum is in the undercrust horizon. (n) – similar to (e) at this stage.*

Table 1. *Systematic list of soils of the Pre-Aral region (with acronyms used in the diagrams below).*

Type	*Subtype*	*Genus*	*Species*
Takyrs (T)	Not determined	ordinary residual- saliniferous with shifted sand cover	by degree of salinity
Takyr-like soils (TL)	Not determined	ordinary residual meadow (r-m) residual-bog (r-b) residual-saliniferous with shifted sand over	by degree of salinity
Meadow-tugaic (Mtug) or Alluvial-meadow-tugaic	Typical weakly-developed (wd) stratified	ordinary saline (sal) crusted (cr)	by degree of salinity
Meadow (M) or Alluvial-meadow	typical bog-meadow (BM) weakly developed (wd) stratified takyrized (tkz)	ordinary saline (sal) takyrizing (tk)	by degree of salinity
Bog soils (B) or Alluvial-bog	peat-swamp silty-bog meadow-bog (MB) meadow-bog peaty weakly developed (wd) stratified takyrized (tkz)	ordinary saline (sal) takyrizing (tk)	by degree of salinity by degree of peat content
Solonchaks authomorphic	typical takyrized (tkz)	ordinary residual meadow (r-m) with shifted sand cover takyrizing (tk)	crust fluff efflorescence
Solonchaks hydromorphic	Typical bog (b) meadow (m) shor (shor) takyrized (tkz) marsh coastal	ordinary residual meadow (r-m) residual-bog (r-b) with shifted sand cover takyrizing (tk)	Crust fluff efflorescence wet black
Shifting sands (SS) Sand desert soils (SD)			
Grey brown soils (GB) Brown soils (BS)			

Further lowering of the ground water level (up to 3-5 m in the dry period) and a gradual deepening of the capillary border lead to partial desalinization of the topsoil and the formation of a desalinized surface crust. Meadow crusting soils with a brittle crust develop on sandy and sandy loam alluvium, and meadow takyrizing soils with more thick (up to 2-3 cm) and firm crusts form on the sandy loamic and stratified deposits.

Further evolution of these soils proceeds to their desalinization and to the development of sandy-desert, weakly developed soils.

1.6. Soil evolution on the slopes from river bars to interfluves lowlands

In the “living” delta, primordially the typical meadow, bog-meadow, and meadow-bog soils formed on the slopes of river bars.

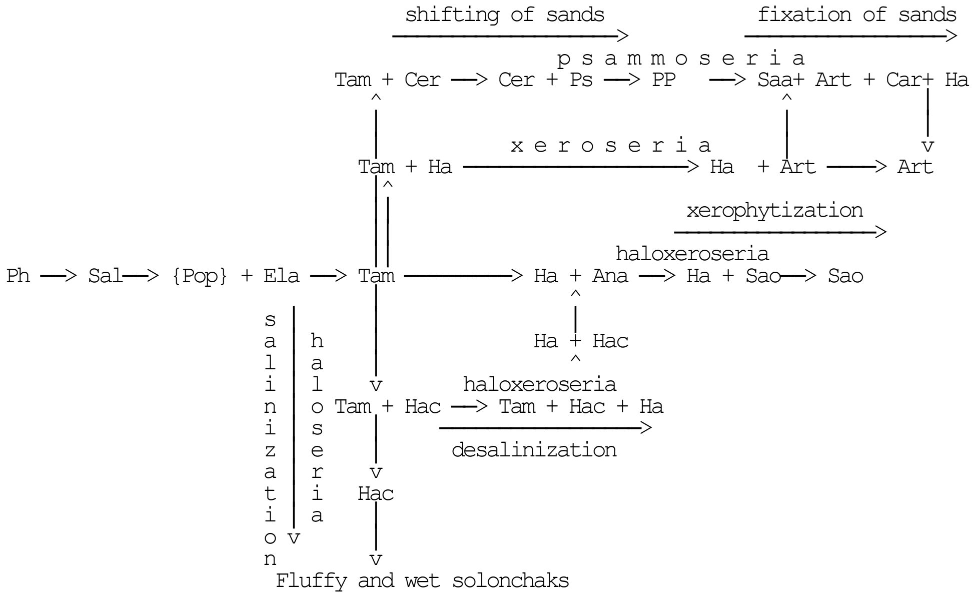
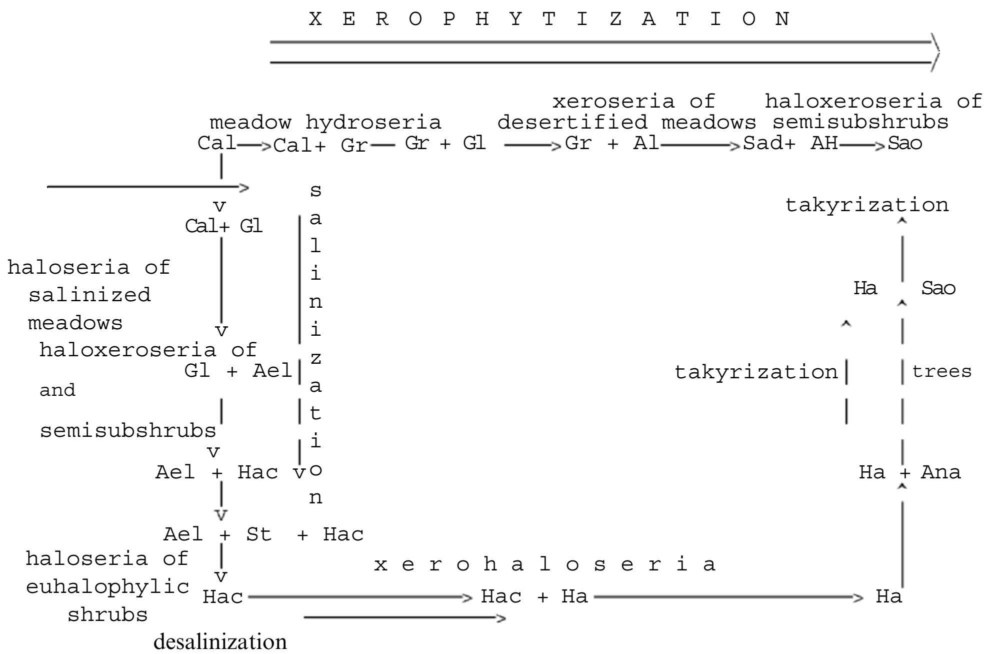


Figure 5. *Diagram of dynamic changes of deltaic vegetation* on the river bars.*
A. Woody-Tougaic variant.



*Here and below – the abbreviations for plants (AD – Amu-Darya river delta; SD - Syr-Darya river delta):

Ael - *Aeluropus litoralis* AH - *annual halophyta* Al - *Alhagi pseudalhagi* Ana - *Anabasis aphylla* Ans - *Anabasis salsa* Ar - *Aristida karelinii* Art - *Artemisia terrae-albae* Atr - *Atraphaxis spinosa* Cal - *Calamagrostis epigeios* Car - *Carex physodes* Cer - *Ceratoides papposa*	Ela - *Elaeagnus turcomanica* -AD *E. orientalis* - SD Gl - *Glycyrriza glabra* - AD *G. uralensis* - SD Gr - grasses Ha - *Haloxylon aphyllum* Hac - *Halostachys caspica* Has - *Halocnemum strobilaceae* Hp - *Haloxylon persicum* Hyg - *Hygrophita* Kal - *Kalidium caspicum*	Lyc - *Lycium ruthenicum*, *L. turcomanicum* Nit - *Nitraria shoeberi* Ph -*Phragmites australis* Phr - *phreatophyta vegetation* (*Glycyrriza glabra, Phragmites austr.*) Po - *Poa bulbosa* Pop - *Populus ariana* PP - *pioneer psammophytic* vegetation (*Aristida karelinii, Ammodendron konollyi*) Ps - *psammophyta*	Saa - *Salsola arbuscula* Sae - *Salicornia europaea* Sad - *Salsola dendroides* Sal - *Salix songorica, S. Wilhelmsiana* Sao - *Salsola orientalis* Sh - shrubs (*Calligonum sp., Salsola richteri*) St - *Statica otolepis* Tam - *Tamarix sp.* Td - *Tortula desertorum* Ty - *Typha sp.*

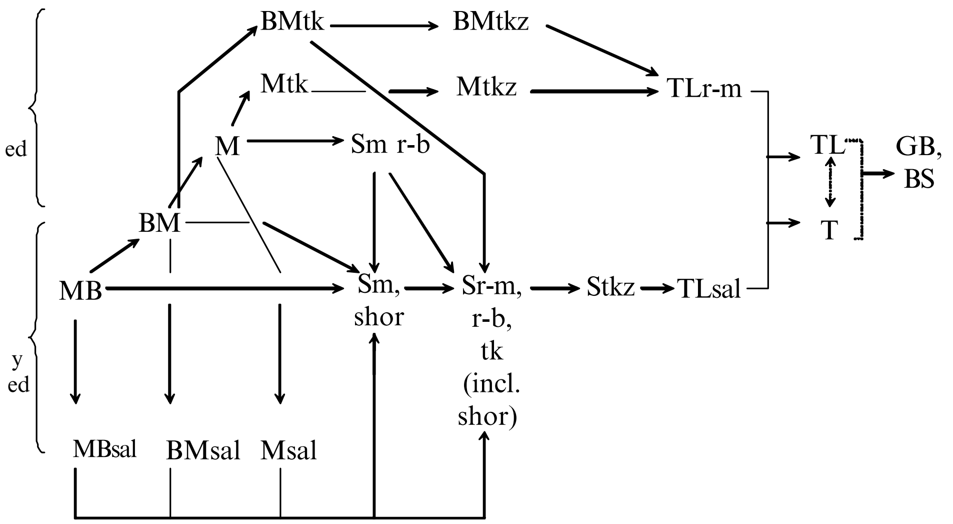
Figure 6. *Diagram of dynamic changes of deltaic vegetation* on the river bars. B. Meadow variant.*

The salinized genues of these soils form in conditions of difficult drainage and high mineralization of ground waters. The salinity degree depends on mezo- and microrelief, ground water level and lithology of the grounds. As a rule the salt distribution along the profile in these soils is more or less uniform with several maximums in the layers of heavy texture. In every soil profile that corresponds to this stage, the increase in salinization depends on the texture: the heavier, the more salinized (Figures 7 and 8).

In the first stages of slow drying of these soils, the tendency toward salinization is clearly observed.

Salinization proceeds with varying intensiveness and reaches various degrees (sometimes up to 40-50%), depending on the ground water mineralization, the level of the capillary border and the time that has elapsed since the moment of the stopping of the spring floods, or artificial watering. Meadow, typical and shor solonchaks form during this stage. As a rule, these solonchaks have the residual features of the meadow or bog soil-forming period: reed root residues and residual gleic features. Different species of solonchaks form as a result of varying degrees and types of salinization and varying levels of ground water; these include crust, fluff, wet, and black solonchaks. The fluff and crust-fluff typical and shor solonchaks are the most widespread in soils of this stage in the deltas of the Pre-Aral region.

After 15-30 years of drying, a new stage in the post-hydromorphic evolution of the soils of the slopes of the interfluve lowlands begins with the appearance of a relatively desalinized hard and pored crust on the surface of the crust-fluff solonchak. At this stage the over - year cycle processes of salinization-desalinization in the soils shift to the desalinization. Ground waters deepen to the



d = under quick drying and weakly salinized ground waters
d́ = under slow drying and strongly salinized ground waters

Figure 7. *Diagram of soil evolution on the slopes of the river bars.*

level at which their capillary border does not reach the surface or root layer. The result is the progressive desalinization of the salted topsoil, which leads to the strengthening and increasing thickness of the upper, relatively desalinized crust. The meadow and typical *takyrizing* solonchaks form first, and then the *takyrized* solonchaks form.

The described "solonchak" form of desertification of the soils of the slopes to the interfluve lowlands occurs in the conditions of a slow lowering of the ground water level.

In the conditions of quick drying the soil evolution of meadow and bog-meadow soils differs from the "solonchak" form. The quick lowering of the ground water level leads first to the sharp oppression or even quick destruction of thick bushes, which consist mainly of *Tamarix sp.* (Figure 9). The nakedness of the surface and sharp drying of the entire soil profile are consequences of this phenomenon. The capillary border does not reach the surface, and there is no biogenic way of carrying the salts away from the mineralized ground waters.

Although salinization takes place, it reaches insignificant values rarely exceeding 0.5% along the soil profile. The salt maximums correspond to the heaviest layers of soil but there is no salt differentiation of the soil profile.

The soils that changed in this way have less strength, thickness and porosity in their takyr-like crust, than soils that have undergone the solonchak stage. The solonchak stage is not the obligate intermediate stage for the quickly drying areas. Soils that form at that time are called takyrizing and takyrized meadow soils.

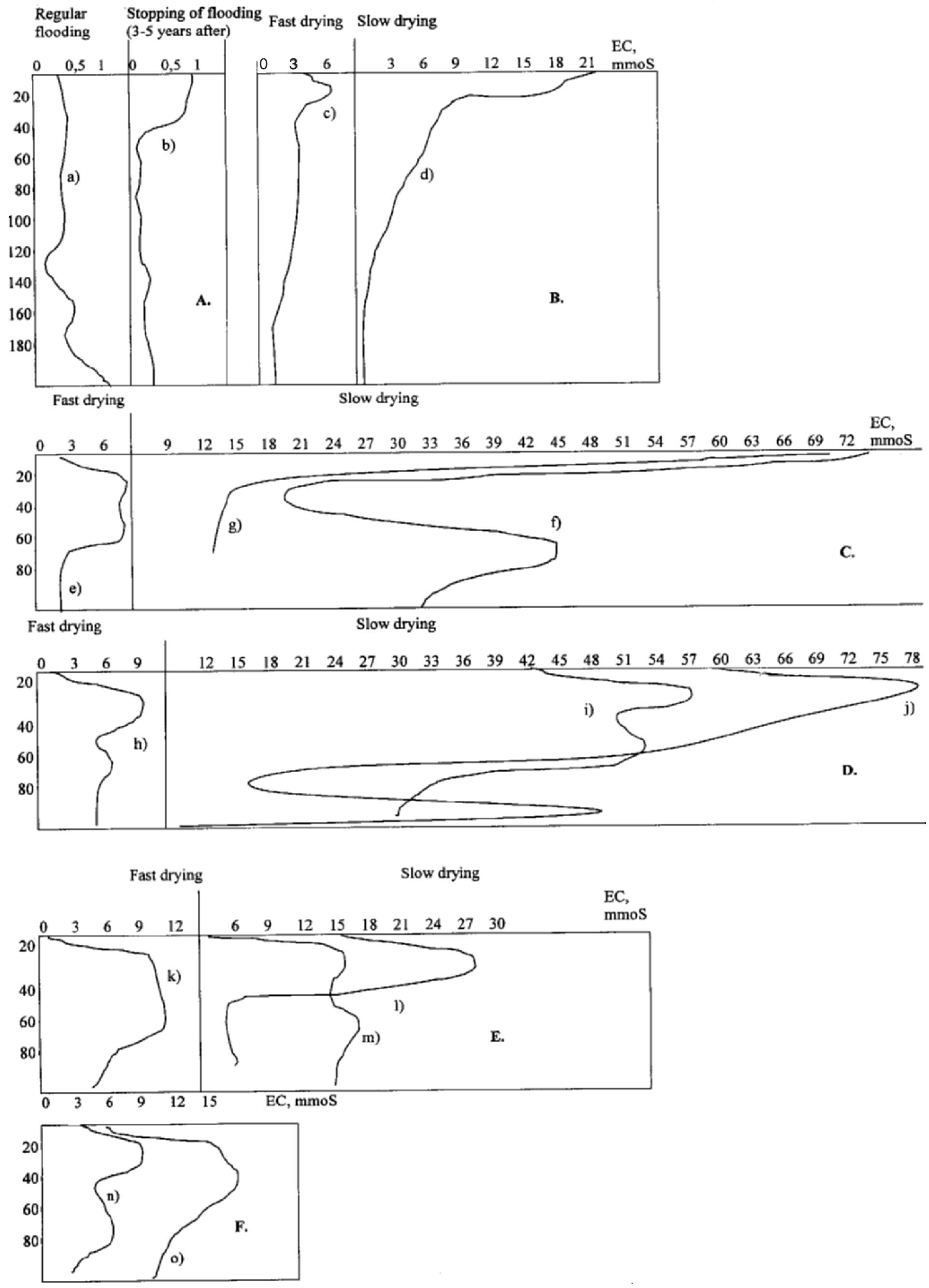


Figure 8. *Dynamics of soil salinity on the slopes to the interfluves lowlands. Stages: A – initial, B – Stage 1 (drying – 5-20(25) years), C – Stage 2 (drying and desertification – 15-40 years), D – Stage 3 (desertification-1 – 30-60 years), E – Stage 4 (desertification-2 – 50-100 years), F – equifinal stage – 500-1,000 years and more.*

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    v      ---------------->         : ||          |
    Hac + Tam + [Kal] ---> dying halophyta   ---> Ha + Sae
              haloxeroseria of trees and shrubs
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Figure 9. *Diagram of dynamic rows of deltaic vegetation on the slopes of river bars.*

1.7. Soil evolution in the interfluves lowlands

The interfluve lowlands are confined mainly to the inner deltas of the lower reaches of the Amu-Darya and Syr-Darya rivers. The “lowlands location” provided the possibility for the accumulation of heavy textured alluvial deposits with a predominance of loams and clays.

The soil cover of the interfluve lowlands is very different. In small depressions, on the slopes of lake depressions and on the bottoms of former lakes, bog, meadow-bog, bog-meadow and meadow soils form (Figure 10). Solonchak complexes as a rule take positive forms of relief as a result of the “wick”-effect. The soils of the meadow-bog seria differ in salinization also: from non-salinized to strongly salinized. Salinization is determined by the ground’s texture and by the intensiveness and salinity of ground water outflow. In the case of high mineralization of shallow ground waters and their poor outflow, the bog soils together with bog salinized soils, as well as shor solonchaks (in which the thickness of the salt stratum can reach 5-7 cm and more) form in the low elements of the relief.

The main directions of soil evolution in the interfluve lowlands in general are similar to the evolution of the soils of the slopes to the interfluve lowlands described above. The peculiarity of soil changes here is the participation of bog soils in the evolutional processes. As a rule, these soils are fine textured, constantly overmoisted (ground waters are no deeper than 0.5-0.7 m) and enriched by peat or humus-clayey organic mass.

In conditions of slow drying these soils stay in the hydromorphic or semihydromorphic regime for a long time (up to several years) and differ in their maximum salinizations. The former bog and meadow-bog soils of the “living” deltas are the basic “source” of rigorous shor and fluffy solonchaks in desertification affected deltas. As a result of long-term drying this stage can last for decades or hundreds of years.

Under slow drying of bog soils the bog solonchaks usually transform into meadow solonchaks, but in conditions of a quick lowering of ground water they transform into the residually bog solonchaks with a typical knobby surface of ruined reeds. The stage of surface takyrizing of such residually-bog solonchaks does not come until the mineralization of the all-peat layer has finished. Usually this process is accompanied by intensive blowing of mineral material, which begins after mineralization of the peat. The rates of mineralization and of the “lowering” of the upper dried peat stratum are rather high in the conditions of quick drying. Sometimes more than 1 m of the peat layer can be mineralized in only 20-30 years.

The changes in the salinity of soils in the drying interfluve lowlands repeat the basic sequences that were described for the soils of the slopes. At the same time the rate of changes are slower, because the transforming soils are located in the depressions, providing for a longer solonchak stage in the row of the posthydromorphic evolution of soils.

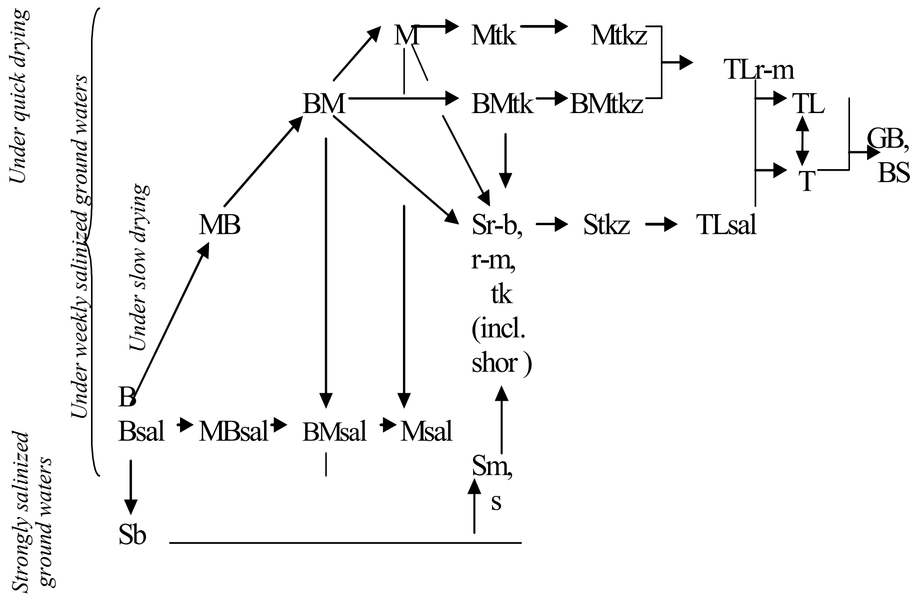


Figure 10. *Diagram of soil evolution in the interfluve lowlands.*

1.8. Peculiarities of present anthropogenic soil changes in the areas of ancient deltas and present deserts

Besides natural tendencies of posthydromorphic and/or postirrigatonal evolution of natural complexes in the deltas of the Pre-Aral region, there are several anthropogenic tendencies that complicate considerably the general picture of desertification of these areas.

So, for example, the new mastering of irrigated lands in the Sarykamysh delta of the Amu-Darya leads to the inundation of adjoined areas and to their secondary salinization right up to the formation of shor solonchaks.

A similar situation is visible along drainage collectors and on the periphery of drainage reservoirs in the areas of the Sarykamysh, Kuvandarya, Janadarya and Akhchadarya ancient deltas, as well as in the adjoined areas of the northern Kizil-Kum desert and the Zaunguz Kara-Kum desert. These phenomena are quite visible on the remote sensing materials.

1.9. Soil-forming processes on the drying aral sea bottom

In general the soil forming processes on the dried Aral Sea bottom appear in the following way. First, marsh wet solonchaks form where the gleic processes and processes of salinization develop. As the level of ground water falls (to 1-2 m), the

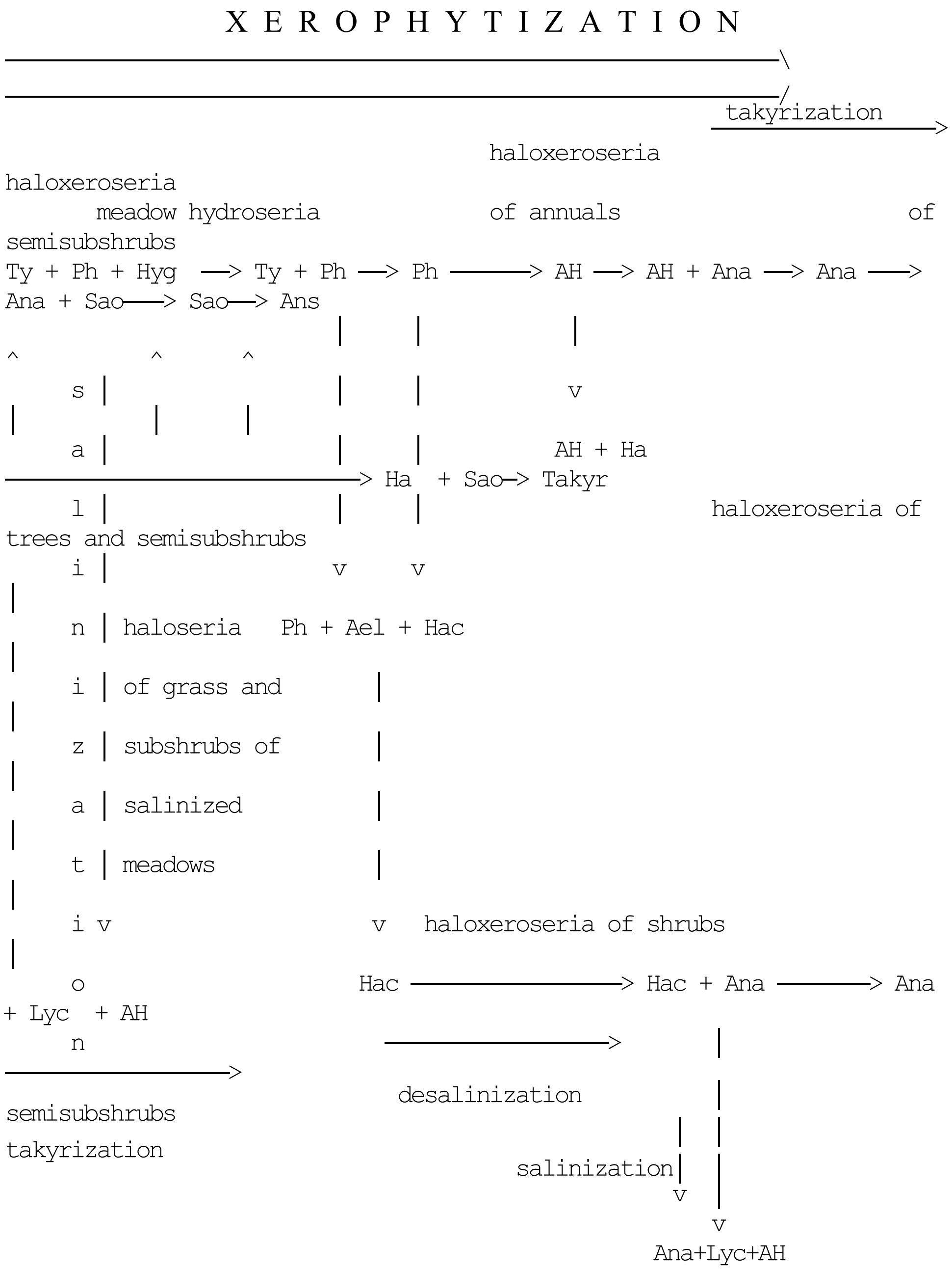
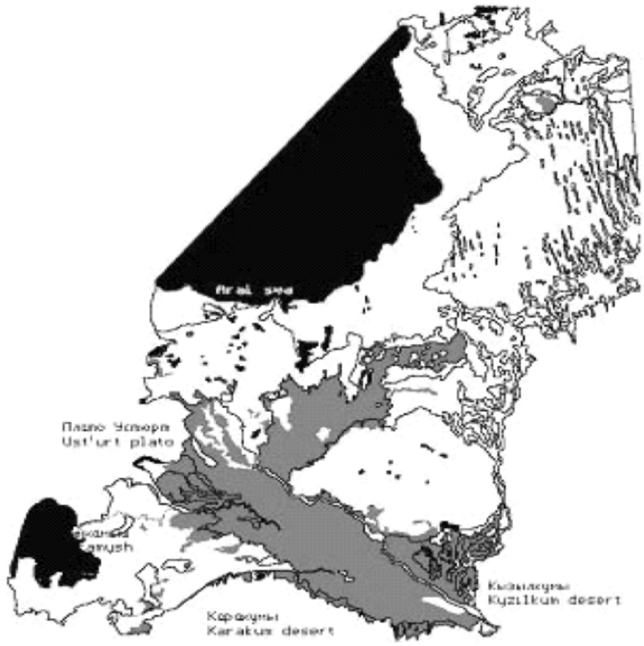


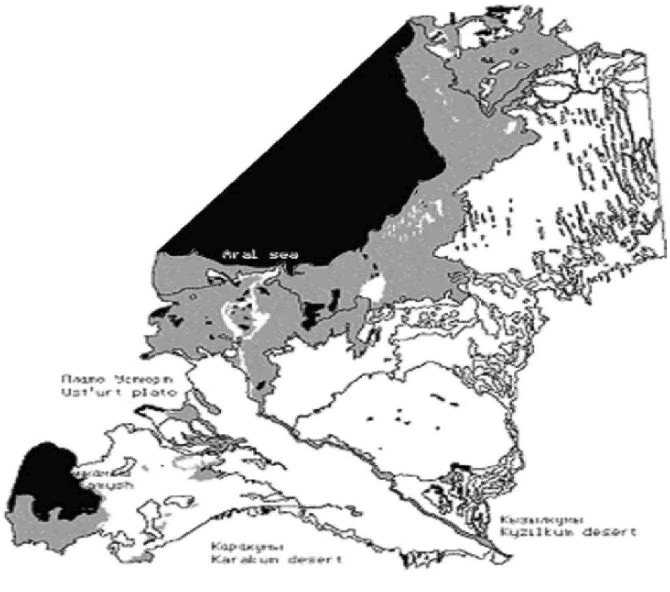
Figure 11. *Diagram of dynamic changes of deltaic vegetation in the interfluve lowlands.*

processes of salinization of the upper horizons become more intensive and lead to the formation of crust, crust-fluff and fluff solonchaks.

The crust-forming process as a result of the cement influence of dehydrated soluble salts in the topsoil is characteristic of the crust solonchaks. If the salinity



Anthropogenic salinization (arising from irrigation activities in the deltas)



Posthydromorphic salinization (arising from the drying of ecosystems)

Figure 12. *The areas prone to salinization in the southern and eastern Aral Sea region.*

bears a sulfate character then the crust of these solonchaks can be characterized by strong cracking and fluffing, and a fluff salt horizon is formed under this crust. Sometimes in this stage, the intensity of salinization reaches the degree of hard salt crust formation.

The formation of crust and fluff solonchaks leads to the dying of pioneer annual halophytes.

Further deepening of the ground waters (from 2 to 4 m depending on the lithology of the grounds) leads to the tearing-off of the capillary border from the soils' surface, which sharply decreases the intensity of the salinization process in the upper horizons, and in conditions of the dying of pioneer hydrophilic vegetation, deflation starts (appearance of the aeolian ripple, ulcers of deflation). The lower the capillary border falls from ground waters, the thicker the upper dried horizon (in the case of light lithology) exposed to deflation.

All of this on a whole leads to the formation of vast zones of abiotic landscapes and to an increase of aeolian salt and dust blowing out with further re-deposition of salt and dust on windward areas.

The blowing out of the salts and atmosphere precipitations gradually provide for the desalinization of the topsoil, which is sufficient for the settling of xerophytes. The appearance of new vegetation delays the processes of deflation, provides the possibility for sand, dust and salt fixation and leads to the appearance of new soil forming processes, e.g. structuring and soil humus formation in the upper horizon, and to weak differentiation of the soil profile in gypsum, calcium carbonates and clayey material. As a rule, eluvial processes touch only the thin topsoil (1-4 cm), leading to the formation of a desalinized takyr-like crust on the soils of heavy lithology.

2. CONCLUSION

The closed character of the Aral Sea basin and the arid environment provide the possibility for sabkhat formation in its lower reaches. The exception of water for irrigation in the upper and middle reaches of the Amu-Darya and the Syr-Darya rivers led to the intensification of the desertification processes in their deltas. Solonchak soils formation is the obligate phase and trend of the desertification phenomenon in the region (Figure 12).

Sabkhat formation in the region is closely related to the deltaic geomorphology and rate of desertification. The diagrams of their development that have been elaborated during our study can be used for the prediction of the further evolution of landscapes and for desertification assessment as well.

3. REFERENCES

Abdullaev, S. 1990. Changes of the salt composition in soils of the Amudarya river issue part as a result of the Aral Sea level lowering // Theses. rep. of 1 deleg. congress of Uzbekistan soil scientists. Tashkent, 192 pp. (in Russian).

Akhramov, Z.M. & Rafikov, A.A. 1989. The past, the present and the future of the Aral Sea. Tashkent: Mechnat, 144 pp. (in Russian).
Andrianov, B.V. & Kes, A.S. 1967. The development of hydrography net of irrigation in the Central Asian plains // Problems of nature reform in Central Asia. M.: Nauka, (in Russian).
Bakhiev, A.B. 01985. Ecology and plant communities changes in the lower reaches of the Amudarya river. Tashkent: Fan, 192 pp. (in Russian).
Bespalov, N.F. 1990. Present ameliorative state of irrigated lands in Central Asia and ways to its improvement // Rep. to 1 deleg. congress of Uzbekistan soil scientists. Tashkent, 103-112 pp. (in Russian).
Biosheric resources of the Central Asia and Kazakhstan deserts. M.: Nauka, 1984. 192 pp. (in Russian).
Borovsky, V.M. & Pogrebinsky, M.A. 1958. The ancient delta of the SyrDarya river and northern Kyzylkumy. V.1. Alma-Ata, Nauka, 514 pp. (in Russian).
Chalidze, F.N. 1974.Changes of vegetation on the interfluve areas of the ancient and present Syrdarya river delta // Ecology. N 3. 29-34 pp. (in Russian).
Drobov, V.P. 1950. Tugaic woody and shrub vegetation in Karakalpakstan // Materials due to productive forces of Uzbekistan. V.I.M.: Nauka, 55-107 pp. (in Russian).
Eshimbaev, D. 1975. The hydro-chemical state of Karakalpakya pounds in water resources management conditions in the Amudarya river basin. Tashkent: Fan, 88 pp. (in Russian).
Geldyeva, G.V. & Budnikova, T.I. 1991. Dynamic changes of the PreAral region landscapes under the influence of desertification. Materials for the technical meeting of the SEPAR project (USSR-UNEP). Funds of general pedology chair, Soil science faculty. Moscow, MSU, 10 pp. (in Russian).
Griaznova, T.P. 1990. Prognosis of present geomorphological processes on the Aral Sea drained bottom based on remote sensing research data // Problems of desert familiarization. 6: 66-73. (in Russian).
Gytomirskaya, O.M. 1964. Climatic description of the Aral Sea region. L.: Hydrometeoizdat, 67 pp. (in Russian).
Hakimov, F.I. 1989. Soil meliorative conditions of desertification in the deltas. Pushino, 218 pp. (in Russian).
Kabulov, S.K. 1990. The desert phytocoenosis change under aridization. Tashkent: Fan, 240 pp. (in Russian).
Kimberg, N.V. 1974. Soils of the Uzbekistan desert zone. Tashkent: Fan, 298 pp. (in Russian).
Kondratyev, K.Ya., Grigoriyev, A.A. & Zhvalev, V.F. 1986. The influence of silt storms on the atmospheric radiation in deserts. // Natural resources of deserts. Ashkhabad. (in Russian).
Levina, L.M. & Ptichnikov, A.V. Dynamics of irrigation and ancient Kuvandarya river beds in natural limit Jetyasar (Eastern Pre-Aral region) // Aral crisis (historical-geographical retrospective). M., 1991. 142-161 pp. (in Russian).
Molosnova, T.I., Subbotina, O.I. & Chanysheva, S.G. 1987. Climatic sequences of economic activity in the Aral Sea zone. M.-L.: Hydrometeoizdat, 120 pp. (in Russian).
Popov, V.A. 1990. The problem of the Aral Sea and the landscapes of the Amudarya river delta. Tashkent: Fan, 112 pp. (in Russian).
Rafikov, A.A. & Tetiukhin, G.F. 1981.The lowering of the Aral Sea level and the changing of natural conditions in the lower reaches of the Amudarya river. Tashkent: Fan, 199 pp. (in Russian).
Victorov, S.V. & Chikishev, A.G. 1990. Landscape indication and its practical application. M.: MSU, 198 pp. (in Russian).
Vinogradov, A.V. & Mamedov, E.D. Changes of climate and landscapes of the interriver plain of the Amudarya and Syrdarya // Aral crisis (historical-geographical retrospective). M, 1991. 66-76 pp. (in Russian).
Zaletaev, V.S. 1989.Ecologically destabilized environment (ecosystems of arid zones in a changing hydrological regime). M.: Nauka, 148 pp. (in Russian).

CHAPTER 6

BIODIVERSITY OF HALOPHYTIC AND SABKHA ECOSYSTEMS IN IRAN

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Abstract. Iran, with a total surface area of 1.6 Mkm^2, is a typical country of large sabkhas, littoral and inland salt marshes, and diverse brackish and salty river ecosystems. According to our present knowledge and evaluation of new data, a total of 365 species within 151 genera and 44 families of Ir anian vascular plants are known to be true halophytes, or species capable of successful growth on salty soils. The Chenopodiaceae family with 139 species ranks first, followed by the Poaceae (35), Tamaricaceae (29), Asteraceae (23) and Plumbaginaceae (14). The genus *Salsola* with 28 species, *Tamarix* with 25, *Atriplex* and *Suaeda* each with 15 and *Limonium* with 10 species, respectively, are the largest halophytic genera in Iran. Diverse eco- and morphotypes, anatomical features, life forms and photosynthetic pathways allow the halophytes of Iran to inhabit various ecological conditions from very high (an EC over 200 ds/m) to low salinity soils, and from sea water to very dry, salty and gypsum soils. In spite of a vast expanse of salty soils, the halophytic communities in Iran are in danger because of extensive damming, which has led to the drying out of many rivers and wetlands, deformation of salt depressions and overgrazing. A list of 28 endangered halophytes is presented here, with the knowledge that some species are on the verge of extinction. A short discussion of the economic and biotechnological potential of Iranian halophytes is given, including the emergence of a new vegetable crop in southern Iran (*Suaeda aegyptiaca*) and the opening of new opportunities in plant biology that have arisen from the discovery of C_4 photosynthesis without Kranz anatomy in *Bienertia cycloptera* and *B. sinuspersici* (Chenopodiaceae).

1. INTRODUCTION

Iran, with a surface area of 1,648,000 km^2, has large areas of salt deserts, sabkhas and salt marshes. Along with the country's geological and environmental history, which has been the main cause of the development of large salty habitats, long-term land use by this ancient civilization has also played a major role in the expansion of saline soils in Iran. The halophytic vegetation of Iran is better known than many other types of vegetation in the country firstly because the halophytic vegetation are poor in species compared with many other species-rich vegetation types and secondly the halophytes attract many scientists wishing to study them from taxonomic, ecological, physiological and agricultural perspectives. Most publications on Iranian halophytic vegetation are regional studies: *Kavire Meyghan, Arak* (Akhani, 1989), *Orumieh Salt Lake*, *Azerbaijan* (Atri et al., 1995;

M. Ajmal Khan et al. (eds.), Sabkha Ecosystems. Volume II: West and Central Asia, 71-88.

Asri & Ghorbanli, 1997), *Garmsar Sabkha* (Ghorbanli et al., 1997), *Touran Protected Area* (Breckle, 1982, 1983, 1986), *Kavir Protected Area* (Asri, 2003), *Khuzestan* (Alaie, 2001), *Heuze Soltan, between Tehran and Qom* (Ghorbanli & Lambinon, 1978); *Maharlu Lake, Fars* (Carle & Frey, 1977; Frey & Kürschner, 1983), *Kavire Lut* (Léonard, 1991,1992), *Mangroves and littoral halophytes along the Persian Gulf* (Frey & al, 1985, 1986) and *Golestan National Park* (Akhani, 1998). Some general information on the major vegetation units of Iran including halophytes is given by Frey & Probst (1986), Zohary (1973) and Akhani & Ghorbanli (1993). In spite of these efforts the halophytic vegetation in Iran is still far from being understood for two reasons: firstly the absence of a common methodological approach in many of the above cited studies and secondly the taxonomic difficulties of many critical halophytic groups. Many of these works were done prior to publication of the Chenopodiaceae volume of Flora Iranica (Hedge et al., 1997), the most important family in salty habitats. However, there are still many unsolved taxonomic problems.

This paper provides an overview of the halophytic biodiversity of Iran with special reference to the flora, threats, conservation and potential economic uses of halophytes. The halophytic vegetation types are discussed in another publication (Akhani, 2004).

1.1. Physical geography

1.1.1. Geographical distribution

Salty and sabkha ecosystems are expanding in most parts of Iran, except in the forested zone of the northern slopes of the Alborz and high mountains. Large salty habitats can be found in the central Iranian great deserts, the "Dashte Kavir" and the "Kavire Lut"; in the salt flat and salt marshes around Orumieh Lake in north-west Iran; in areas along the south-east of the Caspian Sea; in the Khuzestan plain in south-west Iran; and in large parts of the coastal and near-coastal areas along the Persian Gulf and the Oman Sea (Figure 1). According to Krinsley (1970) there are over 60 sabkhas (playas) in the interior of Iran. The salty rivers in Iran are other major salty habitats that support diverse halophytic vegetation with their intermittent or permanent water supply. The halophytic habitats in Iran are located at low and medium altitudes. Large parts of the interior inland salines have altitudes between 600 and 1,000 m above sea level. There are some saline areas with higher altitudes, such as the Orumieh shore (1,313 m); the Kavire Meyghan (1,680 m); the salty river 26 km south of Delijan (1,820 m); and the Shurtangeh located 65 km northwest of Damghan (1,830 m). The highest known saline area in Iran is in the salt meadow and adjoining salty gypsum hills 80 km southwest of Kashan in the Zagros Mountain at an altitude of 2,200 m.

1.1.2. Climate

With the exception of the coastal zone of the South Caspian Sea, Iran has an extremely continental climate. Most of Iranian salty habitats are in the arid and semi-arid parts of Iran with an annual precipitation of under 400 mm. The interior parts of Iran and southern parts receive less than 250 mm mean annual rainfall (Figure 1). The summer months are usually very hot and rain free. As most halophytes have access to some kind of river or underground water source, however, the different rainfall regimes have little influence on the distribution of the halophytes. Temperature seems to play a greater role in determining the range of halophytes. The average annual mean daily temperature varies from 11°C in the northwest of Iran to 26.9°C in Bandar Abbas. But the temperature during active growing seasons (June to September) shows less variation, e.g. 24.0°C in Marand and 34.3°C in Bandar Abbas (Figure 1). Although the southern parts of Iran receive less precipitation and have higher temperatures, most halophytes seem to be capable of surviving there due to the influence of the air humidity due to the proximity of the Persian Gulf and the Gulf of Oman.

1.1.3. Formation and origin

Several factors are responsible for the origin and formation of saline habitats in Iran as follows:

Climate: As a result of the arid and semi-arid climates, high evaporation is a potential cause for dissolved salts rising to the upper soil surface due to the capillary effect. Long-term aridity may also cause the accumulation of the salt content of rainfall in depressions (Breckle, 1981). Usually the cyclic drought periods accelerate the salinization process, particularly when associated with human activity.

Wind: The movement of salt from salt depressions to the surrounding non-salty lands or, conversely, the transport of the salt of weathering rocks by wind and storm are important causes of salinity. These processes usually accelerate when the salt depressions are exposed to wind either through loss of their vegetation or drying because water is prevented from flowing into the depressions, as in the cases of Orumieh lake in the north-west and the Gavkhoni wetland in central Iran (Figures 2, 3).

River flow: Originating from highlands in diverse mountainous areas, extensive rivers leach the salt content of the draining basin and deposit it into the depressions of the interior plains, lakes and agricultural lands.

Littoral and marsh origin: Salt spray and penetration of salty water of the extensive marshlands in Iran are the sources of salinity along the coasts of the Caspian Sea, Persian Gulf, Oman Sea, Orumieh lake and many other inland lakes and riversides.

Geological: Krinsley (1970) summarized the geological history of Iranian salines in the central playas as follows: central Iran was covered by the Eocene Sea. Orogenic activities of the Late Oligocene caused the emergence of the Alborz Mountains. The basin was filled with erosional material from the surrounding mountains during the Neogene. These deposits were subsequently folded by the Late Plio-Pleistocene Phase of the Alpine Orogeny. The central deepest parts of the depressions are covered by playa deposits and associated dunes and alluvium. The Middle Miocene beds of north-central Iran warped into low anticlines whose adjacent depressions were partly filled by playa deposits. A recent faulting cuts across the playas as well as across the adjoining fans. The Middle Miocene beds provide a source of salt from their extensive salt and gypsum beds. The recycled concentration of salts causes the accumulation of salt deposits. Therefore the sabkhas in Iran have a young origin in the Quaternary (Bobek, 1961), but the salty, chalk and marl outcrops that occur in the foothills have an older origin mostly in the Miocene or even in the Palaeozoic.

Anthropogenic factors: The ancient civilization and long history of land use in Persia are certainly among the important causes of salt affects on soils. This has been particularly the case over the last three decades because of several factors, among them population increase, mismanagement and misuse of agricultural lands, irrigation, economic conditions, and the effects of the long-term Iraq-Iran War. Side effects from these factors were accelerated during the drought period in the Middle East and Central Asia in the last decade. Overgrazing; irrigation; transformation of many rangelands into agricultural lands and the subsequent increasing in their salinity; and the construction of dams, which cause desiccation of many lakes and wetlands, are other factors that directly or indirectly contribute to the increasing of salt affected soils in Iran.

1.1.4. Soil

Saline and sodic soils occupy large parts of Iran. According to Dewan and Famouri (1964; Figure 1) about 12% of the country is covered by solonchak and solonetz soils, salt marshes, desert, sierozem and solonchak soils and saline alluvial soils. Some estimate the occurrence of salt affected land in Iran at 25-27 million ha (ca. 15%-17% of the total area of Iran) (Le Houérou, 1993; Sayyari & Mahmoodi, 2002). In Table 1, the physical and chemical features of 24 salty soil samples from various parts of Iran are given. Most soils, especially in the sabkha, are made up primarily of clay and silt. However, towards the outside the soil samples from various parts of Iran are given. Most soils, especially in the sabkha, are made up primarily of clay and silt. However, towards the outside the soil particles are increasingly larger. The pH of salty soils ranges from 6.3 in a soil sample from the Kal Shur River (Table 1, No. 16) in the Touran Biosphere Reserve, from a plant community dominated by *Halocnemum strobilaceum-Tamarix aucheriana*, to 8.2 in some other plant communities. The salinity in soil with well-developed vegetation varies greatly among halophytes, ranging from 2 dS m^{-1} to over 200 dS m^{-1} EC. Besides some soil samples from xerohalophytic communities (Table 1, No. 4, 20), all other samples show an EC above 5 dS m^{-1}. Even soils with very high salt content (above 100 dS m^{-1}), have some kind of vegetation, dominated by species of the Chenopodiaceae family (*Halocnemum strobilaceum, Halostachys belangeriana, Salicornia* spp., *Halopeplis pygmaea*). In lower and moderate salinity, a wide range of species can grow, mostly leaf succulents and salt-excreting halophytes. Both cooking salt (sodium chloride) and

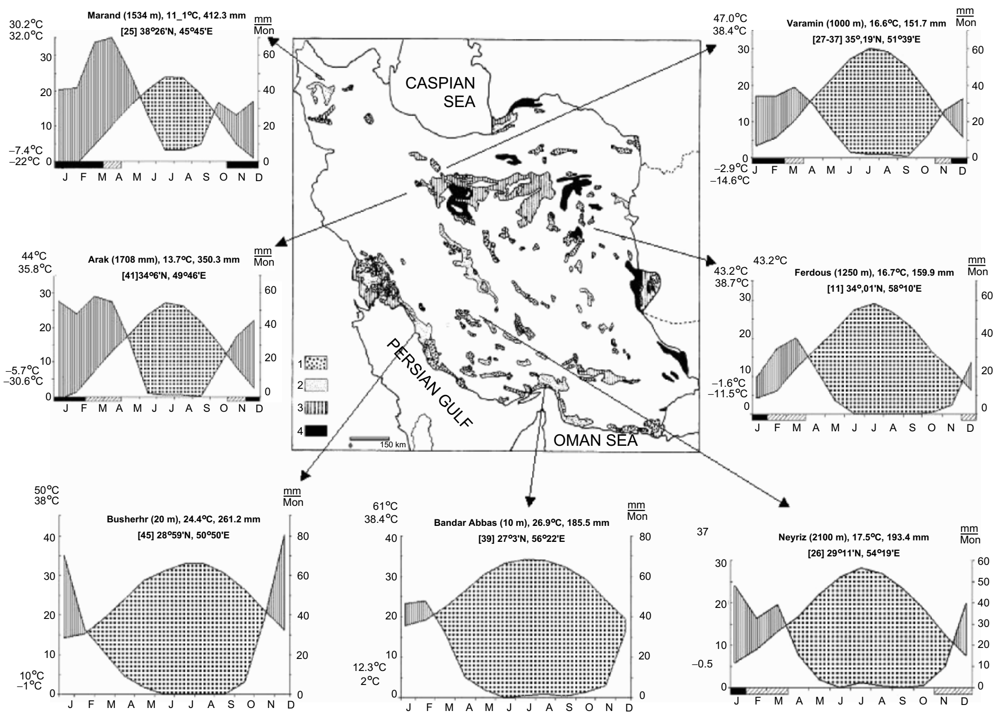

Figure 1. *Distribution of saline soils in Iran and climatic diagrams of areas with saline soils. 1: saline alluvial. 2: solonchak & solonetz soils. 3: salt marsh soils. 4: desert soils: sierozem and solonchalk soils (After Dewan & Famouri 1964, Akhani & Ghorbanli 1993, Akhani et al., 2003).*

sulfate salt are present in Iran. Some places, like Kavire Meyghan in Arak (Table 1, No. 1), are major sources for industrial exploitation of natrium sulfate. Other places, like Lake Orumieh (Figure 2), provide cooking salt for a large part of the country. High amounts of calcium and magnesium cations were found in soil collected from the eastern salt flats of Lake Orumieh (Table 1, No. 8), in salt soils around the Kal Shur River in Semnan (Table 1, No. 16) and around a salty mineral stream near Dalaki (Table 1, No. 22).

1.2. Biodiversity

Since the publication of a first list of Iranian halophytes about 10 years ago (Akhani & Ghorbanli, 1993), which listed 165 species and 73 genera, much more data has been generated as a result of authors' investigations or other published works. Although the publication of the Chenopodiaceae volume of *Flora Iranica* (Hedge et al., 1997) provides much new information on Iranian halophytes, there are still many unresolved taxonomic problems, particularly in some critical genera, such as *Climacoptera* (treated as *Salsola* sect. Belanthera in *Flora Iranica*), *Salicornia*, *Halanthium, Halimocnemis*, *Suaeda* and other non-chenopod genera, such as *Puccinellia*, *Tamarix*, *Asparagus, Limonium* and *Cistanche*.

Figure 2. *Collection of cooking salt from salt flats S. of Orumieh Lake in NE Iran.*

Figure 3. *Formation of polygon salt crusts in Gavkhooni salt depression in Central Iran.*

An updated list of Iranian halophytes and salt tolerant plants, with their biogeographic importance and threat categories, is provided by the author. Below is a summary of the results.

A total of 365 species belonging to 151 genera and 44 families are known to grow in salty habitats in Iran (Table 2). As it is difficult to determine whether a species is a halophyte, a salt tolerant plant, or a ruderal species, those species which usually grow on soils with an electric conductivity (EC) over 4 dS m^{-1}, or species that are associated with known halophytes, are included. At the family level, the Chenopodiaceae with 139 species (38%) and 35 genera ranks first. Poaceae with 35 species (9.6%) and 17 genera; Tamaricaceae with 29 species (7.9%) and 2 genera; Asteraceae with 23 species (6.4%) and 14 genera; Zygophyllaceae with 12 species (3.3%) and 6 genera; and Brassicaceae and Juncaceae, each with 10 species (2.7%), rank from second to seventh. Among all these families, Chenopodiaceae, Tamaricaceae, Zygophyllaceae, Avicenniaceae, Frankeniaceae, Salvadoraceae, Ruppiaceae and Cynomorinaceae are of particular interest, because all, or a large number of species, are halophytes. At the generic level, *Salsola* with 28 and *Tamarix* with 25 are the most species-rich genera, followed by *Atriplex* and *Suaeda*, each with 15 species, *Limonium* with 11 species, *Puccinellia* with 8 species, *Anabasis* with 9 species, and *Juncus* and *Halothamnus*, each with 6 species (Table 3).

Among 365 species, only ca. 30 species (8%) are endemic. This number is much lower than the endemism percentage for the whole country (ca. 22%). As is usual in Iran, the number of endemic species increases on slopes and at higher altitudes. Therefore, the majority of halophytic endemic species in Iran are xerohalophytes and halo-gypsophytes, such as *Anabasis calcarea* (Figure 4.1), *A. haussknechtii*, *Halanthium mamamense*, *H. purpureum*, *Heliotropium sultanense*, *Halimocnemis occulta, Horaninowia platypetra* (Figure 4.2) and *Salsola zehzadii*

(Figure 4.3). The salt marshes in south central Iran, in the Fars province, are interesting due to the presence of endemic species there. *Hypericopsis persica* (Frankeniaceae) (Figure 4.4), as an endemic monotypic genus, together with *Limonium reniforme* (Plumbaginaceae) and the newly described *Salicornia persica* (4.5) (Akhani, 2003a) are noteworthy.

1.3. Life forms and morpho-functional types

Perhaps the most interesting aspects of Iranian halophytes are their diverse functional types and adaptation strategies. These features enable the halophytes to occupy available niches in habitats with diverse salinity, moisture and climatic conditions. The soil analyses also indicate that many of these halophytes are able to grow in a wide range of salinity (Table 1) without changing the ion concentration in assimilating tissues (Breckle, 1986).

The availability of underground or running salt water, even in areas with very low precipitation, provides conditions for growing tree and phanerophytic halophytes in Iran. Tree and shrub halophytes are present in the genera *Avicennia, Haloxylon, Tamarix, Salsola, Phoenix, Lycium, Salvadora, Capparis, and Haloxylon* (with two tree species, *H. ammodendron* and *H. persicum*). These two latter species are very interesting because these are the only known true C_4 tree halophytes in the world (Akhani et al., 1997; Winter, 1981). The author has measured specimens up to 7 m tall near the Touran Protected Area (Figure 4.6). Another interesting C_4 phanerophyte is *Salsola abarghuensis*, an extremely endangered species with separate localities in Abarkuh (Abarghu) and Touran Protected Area (Figure 4.7) (Hedge et al., 1997).

Parasite species are confined to the genera *Cistanche* (with ca. 4 species) and *Cynomorium coccineum* (Figure 4.8). *Cistanche species* are parasitic on roots of *Tamarix* and *Seidlitzia rosmarinus*, but *Cynomorium* is parasitic on *Atriplex verrucifera* (unpublished observation) and *Haloxylon persicum* (Léonard, 1987). *Lianas are rare among halophytes, but there are very interesting lianas such as* Malacocarpus crithmifolius *(Figure 4.9) and* Asparagus griffithii*. Both species grow as liana in* Tamarix thickets.

A large proportion of halophytes are chamaephytes and hemicryptophytes (47%). They occur as small shrubs (e.g. *Seidlitzia rosmarinus, Salsola arbuscula, S. arbusculiformis, S. drummondii, Halothamnus subaphyllus, Nitraria schoberi, Hammada salicornica, Halostachys belangeriana, Suaeda fruticosa, S. microphylla),* subshrubs with a woody base (e.g. *Salsola tomentosa, S. aucheri, S. gemmascens, S. orientalis, Atriplex leucoclada)* and as hemicryptophytes (e.g. *Anabasis eriopoda, A. jaxartica, Salsola dendroides, Limonium iranicum).* A considerable number of halophytes are graminoide hemicryptophytes or rhizomatous geophytes belonging to various monocotyledon genera *Phragmites Juncus, Typha, Cyperus* and *Bolboschoenus.*

The annual life form, with 132 species, comprises 36% of the halophytic flora of Iran. In contrast to many subtropical and coastal areas, where the perennial

Table 1. *Major chemical and physical soil characteristics of 24 soil samples from different parts of Iran. The samples were collected in phytosociological relevés from 0-10 cm soil depth. Abbreviations and units: Cov.: percentage of total vegetation coverage in sampled relevé; EC= electric conductivity (dS/m); the anions and cations (Cl^-, SO_4^{2-}, HCO_3, Ca^{2+}, Mg^{2+}, Na^+) (meq/l); TNV = percentage of total neutralizing value; Sa. = sand; Si. = silt; Cl. = clay; Tex. = texture; L = Loam; n = no data (original data).*

No.	Locality	Dominant species or community	Cov.	pH	EC	Cl^-	SO_4^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	Na^+	TNV	N%	Sa.	Si.	Cl.	Tex.
1	Arak: Kavire Meyghan	Juncus maritimus-Aeluropus littoralis	90	8.2	49.6	108	412	10	24	22	492	30.5	0.178	40	42	18	L
2	Tehran: Qom: Behesht-e Maassoumeh	Halanthium rarifolium	85	8.1	57.2	410	160	30	42	48	516	22.5	0.098	35	36	29	SL
3	Tehran: 18 km from Qom towards Tehran	Suaede arcuata	60	7.3	14.9	103	39	3	23	25	95	25.5	0.039	28	35	37	CL
4	Tehran: Heuze-Soltan, road to Qom	Anabasis setifera	10	7.8	2.28	10	6	8	2	3	13.6	8	0.03	68	22	10	SL
5	E Azerbaijan: 10 km S Aslanduz	Gamanthus pilosus	40	7.8	5.67	40	16	4	11	9	41	3	0.11	14	46	40	SiCl-SiC
6	E Azerbaijan: 6 km E Qezel Dizej	Aeluropus littoralis	90	6.8	14.97	128	26	6	28	20	88	20	0.178	33	30	37	CL
7	E Azerbaijan: 8 km WNW Qezel Dizej	Tamarix ramosissima-Aeluropus littoralis	100	6.7	64.3	616	38	6	120	110	440	21.5	0.123	17	48	35	SiCL
8	E Azerbaijan: Sharafkhaneh shore	Salicornia europaea-Suaeda salsa	60	10	67.4	614	63.8	6	27	25	644	32.5	0.033	28	57	15	Sil
9	Esfahan: 8 km SE Varzaneh	Seidlitzia rosmarinus	30	7.5	26	242	26	2	39	39	198	29	0.19	68	17	15	SL
10	Esfahan: N Gavkhooni, near Shakhkenar	Halocnemum strobilaceum-Halostachys belangeriana	20	7.2	164.2	1800	92	8	221	249	1450	32.5	0.098	38	35	27	CL
11	Esfahan: N Gavkhooni, near Siahkuh	Salicornia persica-Salicornia "europaea"	25	7.3	63.1	680	26	4	111	171	428	38.5	0.069	31	59	10	Sil
12	Yazd: 25 km NE Abarkuh	Seidlitzia rosmarinus, Anabasis setifera	30	7.6	8.03	76	4	3	11	14	60	68.3	0.011	76	20	4	LS
13	Fars: N Tashk Lake, wastelands	Suaeda cochlearifolia	50	7.6	29.4	280	36	4	19	15	280	33	0.055	23	43	34	CL
14	Esfahan: 10 km S Murchekhort towards Esfahan	Anabasis haussknechtii, Artemisia sieberi, Launaea acanthodes	10	8.2	16.06	117	43.5	4.5	22	26	129	33.5	0.031	38	35	27	L-CL
15	Semnan: 27 km W Cheshmeh Ali, Shurtangeh	Salsola dendroides, Acroptilon repens, Artemisia cf. Fragrans	60	7.6	24.2	204	51	5	35	40	195	17.5	0.095	38	35	27	CL
16	Semnan: Touran Biosphere Reserve, Kal Shur	Halocnemum strobilaceum, Tamarix aucheriana	40	6.3	>200	n	n	n	N	n	n	15	0.145	25	37	38	CL
17	Semnan: Touran Biosphere Reserve Daq Biar	Haloxylon ammodendron, Artemisia sieberi	55	7.4	16.6	84.5	72.5	3	52	26	95	16	0.03	30	33	37	CL
18	Tehran: Beginning of Qom-Tehran express way	Halopeplis pygmaea, Cressa cretica	50	8.2	101.8	1000	11	9	40	35	960	16.5	0.03	26	46	28	CL
19	Tehran: Beginning of Qom-Tehran express way	Halanthium rarifolium, Halothamnus auriculus	30	7.5	5.22	26	23	3	15	19	18	24	0.017	42	43	15	L
20	Esfahan: 55 km SW Kashan to Varkan	Anabasis haussknechtii, Salsola tomentosa	10	7.8	2.57	10	15	2	11	13	4.8	15	0.042	22	35	43	C
21	Esfahan: 25 km S Delijan towards Esfahan	Tamarix, Suaede linifolia, Atriplex verrucifera	100	7.3	21.7	192	20.6	5.4	30	40	150	26	0.106	40	33	27	L-CL
22	Bushehr: After Dalaki towards Borasjan	Salsola drummondii, Halocharis sulphurea. Halocnemum strobilaceum	30	7.1	110.5	1100	92	8	110	120	950	59.5	0.077	64	23	13	SL
23	Tehran: Rude Shur near Mardabad	Tamarix, Climacoptera turcomanica	20	7.6	57.4	590	60	2	180	150	350	18	0.038	21	41	38	CL
24	Hormozgan: Along Kol river	Tamarix mascatensis, T.kermanensis, Bienertia sinuspersici	30	8.1	21.7	189	38	3	29	25	180	68.5	low	-	-	-	S

***Table 2.** List of Iranian halophytic and salt tolerant families and their numbers of genera and species.*

Family	*Genera*	*Species*	*Family*	*Genera*	*Species*
Aizoaceae	2	2	Hydrocharitaceae	3	3
Amaranthaceae	2	2	Iridaceae	1	2
Apiaceae	6	6	Juncaginaceae	1	1
Arecaceae	1	1	Juncaceae	1	10
Asphodelaceae	1	1	Malvaceae	1	1
Asclepiadaceae	3	3	Orobanchaceae	1	4
Asparagaceae	1	2	Plantaginaceae	1	3
Asteraceae	14	23	Plumbaginaceae	2	14
Avicenniaceae	1	1	Poaceae	17	35
Boraginaceae	4	8	Polygonaceae	1	2
Brassicaceae	8	10	Primulaceae	2	2
Capparidaceae	1	2	Rhizophoraceae	1	1
Caryophyllaceae	5	6	Ruppiaceae	1	1
Chenopodiaceae	35	139	Salicaceae	1	1
Cistaceae	1	1	Salvadoraceae	1	2
Convolvulaceae	2	3	Santalaceae	1	1
Cynomorinaceae	1	1	Solanaceae	1	3
Cyperaceae	4	7	Tamaricaceae	2	29
Fabaceae	7	9	Thymelaeaceae	1	1
Frankeniaceae	2	3	Typhaceae	1	3
Gentianaceae	1	2	Zosteraceae	1	1
Geraniaceae	1	1	Zygophyllaceae	6	12
Total of 44 families, 151 genera and 365 species					

***Table 3.** List of diverse halophytic and salt tolerant genera and their number of species in Iran.*

Genus	*Species*	*Genus*	*Species*
Anabasis	8	*Puccinellia*	c. 8
Atriplex	15	*Salsola*	28
Halothamnus	7	*Suaeda*	15
Juncus	10	*Tamarix*	25
Limonium	11	*Zygophyllum*	6

species are more prevalent, the annual life form plays a major role in halophytic communities of temperate deserts and semi-deserts. Many of the annual species belong to the Chenopodiaceae, especially the Salsoleae tribe (including many representatives of the genus *Salsola*, and all species of genera *Climacoptera, Petrosimonia, Halimocnemis, Halanthium, Gamanthus, Horaninnowia and Girgensohnia*). It seems that climate and habitat are the main determining criteria for the development of so many annuals in the colder areas of Iran and Central Asia. Many Chenopods (specially the C_4 species) profit from long days and the warm months of the year. These species are ecologically adapted mostly to inundate salty soils, where development of perennial vegetation is not always successful.

The annual halophytic species of other families are rare, but the following species can be encountered: Brassicaceae: *Hornungia procumbens* (Syn: *Hymenolobus procumbens*), *Thellungiella parvula* (=*Arabidopsis parvula*), *Lepidium perfoliatum*; Plumbaginaceae: All three species of *Psylliostachys* (*P. spicata, P. beluchestanica, P. leptostachya*); Zygophyllaceae: *Zygophyllum simplex*, *Tetradiclis tenella*; Aizoaceae: *Messembryanthemum nodiflrum*, *Aizon canariense*. Poaceae: All four species of *Eremopyrum*.

There is great diversity in the eco-morphotypes of Iranian halophytes. Here, most halophytes are classified into five groups (partly following Batanouny, 1993; Breckle, 1986).

Salt recreting: Species of this category protect against the toxicity of high salt in cytoplasm by recreting extra salt via salt glands (exo-recreto-halophytes) or via bladders (endo-recreto-halophytes). Examples of such plants include almost all species of *Atriplex, Tamarix* (Figure 4.10), *Cressa, Reaumuria, Frankenia, Hypericopsis* (Figure 4.4), *Aeluropus, Limonium, Reaumuria, Halopyrum* and *Messembrynthemum*.

Salt accumulating: Several species of leaf and stem succulent Chenopodiaceae have developed adaptive strategies to remove extra salt from cytoplasm, including formation of salt crystals or accumulation of salt in vacuoles. This inorganic concentration of salt has an extra advantage in that it increases the osmotic potential inside the cells, in order to compete successfully with the water-retaining capacity of the surrounding medium (Batanouny, 1993). Salt crystals occur in different cell layers (hypodermis, chlorenchyma layer, aqueous tissues). Examples are species of *Halimocnemis, Halanthium, Anabasis* and *Haloxylon*. In *Seidlitzia rosmarinus*, there is a large amount of salt concentration in the vacuoles via pinocytosis (Kurkova et al., 2002).

Leaf succulents: There are many leaf succulent species in the genera *Salsola* (Figures 4.3, 4.7), *Climacoptera, Halimocnemis, Halanthium, Petrosimonia, Suaeda, Seidlitzia* (all Chenopodiacea) and *Zygophyllum, Malacocarpus* (Figure 4.9), *Lycium, Messembrynathemum, Plantago maritima* and more or less, *Thellungiella parvula*. It has been observed that in several genera of Chenopodiaceae, like Bienertia (Figure 4.11), *Halanthium, Halimocnemis, Climacoptera* and some *Suaeda*, the leaves of young and vegetative plants are large and relatively long, but they shed and are replaced by smaller leaves during flowering time. During that time other organs, such as stems, bracts, bracteoles and even perianths, substitute for the assimilating role of leaves.

Stem succulents with Kranz anatomy: Two genera, *Anabasis* and *Haloxylon*, belong to this group with articulated stems and fleshy fruits with winged perianths. The species of *Anabasis* are xerophytic subshrubs, which preferably grow on halo-gypsum soils.

Stem succulents without Kranz anatomy: This group, called “the stem succulents of Salicornia-type” (Akhani et al., 1997), are characterized by having an articulated stem, fleshy cortex, and reduced leaves; anatomically the cortical network is connected with the lateral branches of the leaf strands (Fahn & Arzee,

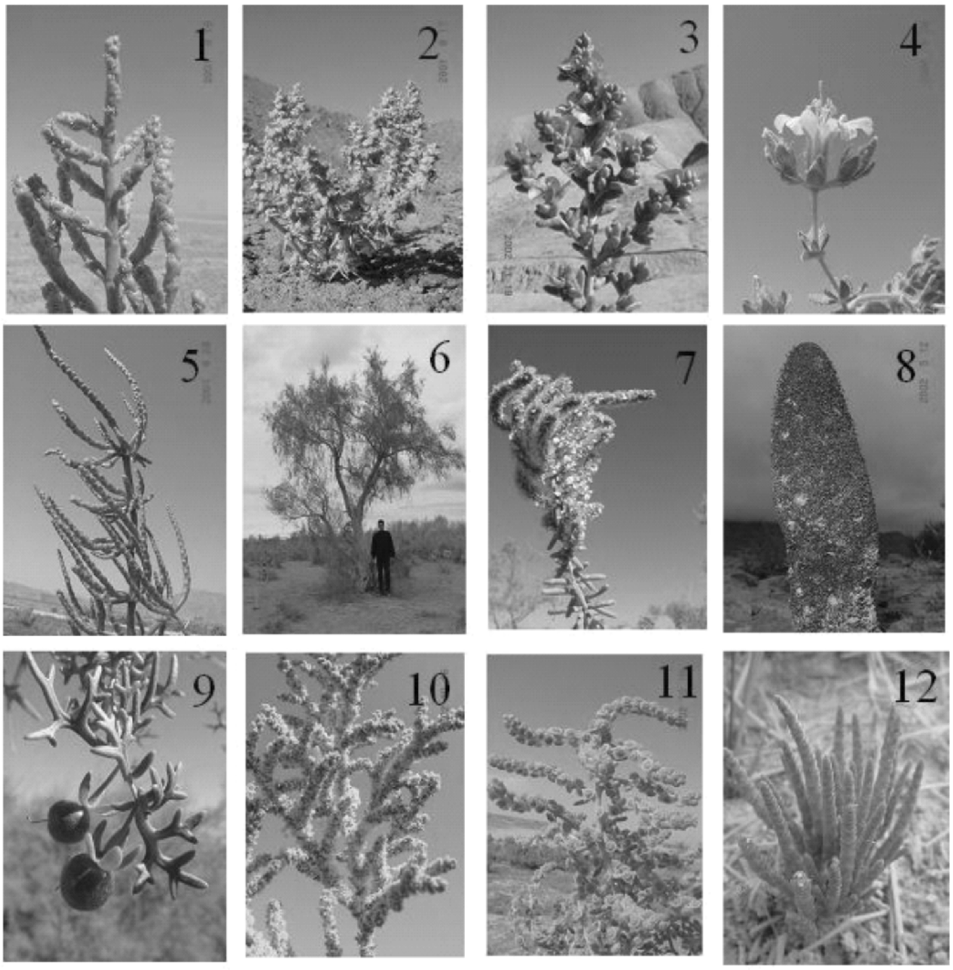

Figure 4. *Selection of some halophytes of Iran 1.* Anabasis calcarea*, a halogypsophilous endemic species in central deserts; 2.* Horaninowia platypetra*; 3.* Salsola zehzadii*, a halogypsophilous species recently described from east of Torba-t Jam, along the Afghan border (Akhani 1996); 4.* Hypericopsis persica*; 5.* Salicornia persica*; 6.* Haloxylon ammodendron*, a C_4 tree up to 7 m; 7.* Salsola abarghuensis*, an endangered endemic species with disjunct localities in Abarkuh and Touran Biosphere Reserve; 8.* Cynomorium coccineum*, a halophytic parasiting mostly on Atriplex verrucifera roots; 9.* Malacocarpus crithmifolius*, a halophytic liana; 10. The branches of a* Tamarix *which is covered by large amount of excreted salt; 11.* Bienertia cycloptera*, an enigmatic C_4 plant without Kranz anatomy; 12.* Microcnemum coralloides*, an endangered halophyte in Kavire Meyghan. Fiqure.*

1959). All members of Salicornioideae belong to this group. Ecologically, they are hygro-euhalophytic plants restricted often to salt marshes or moist inland saline areas.

The photosynthetic pathways of many of Iranian halophytes have been reported in Akhani et al., (1997) and Akhani & Ziegler (2002). Among the halophytic and salt tolerant plants of Iran, 118 species (32%) are C_4 species.

1.4. Threats and conservation

In spite of the large increase in salty soils, halophytic vegetation in Iran faces severe threats. The most significant threats to halophytic habitats are extensive damming and overgrazing. Unfortunately, during the last decade the flow of most rivers in Iran has been disrupted by intensive construction of dams. Since most of these dams were constructed during the recent, long-term drought period experienced in the Middle East, the resulting consequence was the drying up of many rivers, wetlands, lakes and inland saline areas, or a sinking water table (above ground and underground) in these ecosystems. The halophytes are very sensitive to small hydrologic changes. Even a few centimeters change in the above or underground water level is enough to endanger the existence of many halophytes or even a complete saline ecosystem.

Saline habitats have had low priority for consideration as protected areas. Even when salty habitats are within or around a protected area or National Park, the saline parts have had no particular protection priority. The following are only a very few examples to illustrate this dramatic picture.

1) *Kavir Protected Area:* Along the edges of this area, there have been large halophytic communities dominated by *Halostachys belangeriana* and many other halophytes such as isolated populations of *Suaeda fruticosa* (see Rechinger & Wendelbo, 1976). Unfortunately, a reduction in the borders of the protected area in Mabarakieh has caused degradation of these communities and they are being utilized as agricultural land (Figure 5).
2) *Touran Biosphere Reserve:* Despite its status, thousands of camels, sheep and goats are still grazing inside and around the reserve (Figure 6). The most tragic example was observed by the author in the southwest part of the area along the Sahl River, ca. 6 km south of Sahl. This seasonal river is the habitat of an endangered population of *Salsola abarghuensis,* with only 16 living specimens remaining (Figure 4.7). The construction of a watering pool and the daily gathering of many herds around it (Figure 7) may soon lead to the extinction of this small population.
3) In the easternmost parts of Golestan National Park (northeast Iran), there is a vast flat plain harboring a considerable number of halophytes and diverse halophytic communities (Akhani, 1998). Some endangered halophytes such as *Suaeda physophora*, *S. linifolia*, and *Diaphanoptera stenocalycina* (a local endemic species with only a few specimens in this area) inhabit this area of the Park. Unfortunately, the digging of a deep canal and further furrowing of the whole plain in order to cultivate exotic species have damaged large parts of the ecosystem.
4) In Kavire Meyghan (located in the central part of Iran, north of Arak), there is a high altitude saline (1,680 m) in which representatives of ca. one-forth of Iranian halophytes have been found (Akhani, 1989). Three extremely endangered halophytes *Microcnemum coralloides* (4.12), *Thellungiella parvula* and *Asparagus lycaonicus* (Akhani, 1988, 2002) were discovered in this area. The whole of the ecosystem is degraded not only because of

construction of a road to the center of the saline to exploit the natrium sulfate, and the change in its hydrologic balance, but also due to extreme grazing and agricultural activities around it, which will very likely soon cause the extinction of the above mentioned species. Sadly, the author must report that while a few plants of *Microcnemum coralloides* were seen during a visit in 2001, no specimens were found during a repeat visit in 2002.

5) The construction of dams along the Zayandeh Rud (a famous river passing through Esfahan) have caused it to dry up, so most plant communities along the river and in its delta towards the Gavkhooni wetland are being destroyed. This is especially troubling, since there are still undescribed species in this ecosystem (Akhani, 2003).

Following is a list of 28 endangered halophytes in Iran (those on the verge of extinction are indicated by an asterisk). This represents 8% of all halophytic and salt tolerant plants of Iran. The main threat to these species is habitat degradation caused either by changing hydrologic conditions or by overgrazing.

Asparagus lycaonicus P. H. Davis*	*Piptoptera turkestana* Bunge*
Chenopodium chenopodioides (L.) Aellen	*Psylliostachys beluchestanica*
Diaphanoptera stenocalycina Rech. f. & Schiman-Czeika*	*Reaumuria fruticosa*
Gypsophila spec. nov. *	*Salicornia spec*. nov.
Halanthium alaeflavum Assadi *	*Salsola abarghuensis* Assadi* (see text) (Figure 4.7)
Halanthium mamamense Bunge	*Salsola zehzadii* Akhani (Figure 4.3)
Halanthium purpureum (Moq.) Bunge	*Suaeda dendroides* (C. A. Mey.) Moq.
Halimocnemis occulta (Bunge) Hedge	*Suaeda linifolia* Pall.
Halopeplis perfoliata (Forssk.) Bunge ex Aschers	*Suaeda monoica* J. F. Gmelin
Helminthotheca echioides (L.) Holub	*Suaeda physophora* Pall.
Hypericopsis persica Boiss. (Figure 4.4)	*Tetradiclis tenella* (Ehrenbg.) Litw.
Malacocarpus crithmifolius (Retz.) Fisch. & C. A. Mey. * (Halophytic ecotype) (Figure 4.9)	*Thellungiella parvula* (Schrenk) Al-Shehbaz & S. L. O'Kane*
Microcnemum coralloides (Loscos & Pardo) Buen* (Figure 4.12)	*Thesium compressum* Boiss. & Heldr.
Nitraria retusa (Forssk.) Aschers	*Trachyspermum sp*.

1.5. Economic potential, agricultural and biotechnological outlook

The expansion of salt affected soils, the scarcity of fresh irrigation water in largeparts of Iran, and the side effects of normal agriculture which increase the soil salinity are among the arguments for investigation of the potential uses of halophytes. The halophytes of Iran are diverse enough to be considered for a wide range of purposes including forage, vegetable crops, as ornamental shrubs and as ground cover in arid and semi-arid areas. The following presents a summary of current and potential uses:

1. In earlier times, and still in some places, the succulent halophytes of Chenopodiaceae, such as species of *Suaeda*, *Seidlitzia* and *Climacoptera*, have been used for extraction of soda for traditional production of soap (Figure 8). In some parts of Iran, extracts of *Salsola tragus* (known as *S. kali* in much of the literature) is used for sterilization of raisins.
2. The high content of salts in fresh tissues of halophytes causes most of them to be unpalatable to domestic animals, but after they dry and their salt is washed off by rainfall, they become an important source for autumn and winter grazing in many parts of Iran. Many halophytes (in particular *Seidlitzia rosmarinus*) provide an important grazing source for camels living in the deserts (Figure 6).
3. The cultivation of halophytes and psammohalophytes from native and exotic species is a well funded and extensively expanded program in Iran. The two *Haloxylon* species (*Haloxylon ammodendron* for cultivation in saline and *H. persicum* for cultivation in sand dunes) and the exotic New World species *Atriplex canescens*, have been cultivated in many parts of Iran by the Forests and Rangeland Organization. Many of these programs are not based on prior ecological studies. Therefore, in some places where the species were accidentally suitable for cultivation, the results have been good, but for the most part such activities have not been successful. Many *Haloxylon* plantations are being destroyed both because of unsuitable ecological habitats and due to diseases.

   A rehabilitation programme has been underway since the 1980's involving cultivation of *Nitraria schoberi* (local name Qare Dagh) in Kavire Meyghan, near Arak, with native plants growing in the area.

   Other species that are now in cultivation programs are *Atriplex halimus* (a Mediterranean species), *A. lentiformis* (a New World species) and *Tamarix aphylla*.
4. A very interesting historical event in the domestication of crop plants happened in recent years in southern Iran. Traditionally, the young leaves of *Suaeda aegyptiaca* (their local name in Khuzestan is Googaleh and Kakol in Bushehr) have been used as a wild vegetable in many parts of the southern provinces. Recently, the people in Bushehr Province (near Borazjan) began cultivating *S. aegyptiaca* as a new vegetable crop, using saline water for irrigation. As a consequence, it is being sold for food by farmers in the local bazaars (Figure 9).

5. During the 1990's many studies have been aimed at evaluating *Salicornia* as a new oil seed crop plant (Glenn et al., 1991, 1998; Glenn & Watson, 1993). According to these authors, the seeds of *S. bigelovii*, an American species, contain 30% oil and 35% protein. Based on the unpublished results of the author, there are undescribed *Salicornia* species in Iran, in addition to a species recently described (Akhani, 2003). The newly described *S. persica* is one of the good candidates for use as a new crop plant, not only because of its high biomass (it grows up to one meter high in favorable conditions), but also due to the fact that it is normally eaten by goats (Figure 10).
6. The genetic diversity of Iranian salt tolerant plants provides a unique basis for investigation of adaptation strategies of many species in highly salty soils, particularly on a molecular basis. One of the most interesting species is *Thellungiella parvula* (*Arabidopsis parvula*), which was discovered at Kavire Meyghan (Akhani, 1988). This species is very close to *Arabidopsis thaliana,* the flowering plant popularly used in molecular research. *T. parvula* grows on highly salty soils in association with *Halocnemum strobilaceum*. In the grass family, there are also salt tolerant variants of several species, for example, *Hordeum glaucum*, *H. marinum*, *Bromus danthoniae*, *Phalaris minor*, *Boissieria squarrosa* and all four species of *Eremopyrum* spp.
7. The recent discovery of C_4 photosynthesis without Kranz cells in *Borszczowia aralocaspica*, *Bienertia cycloptera* and *B. sinuspersici* (4.11) (Voznesenskaya et al., 2001a,b, 2002; Freitag & Stichler, 2000, 2002; Akhani et al., 2003, submitted) is of great interest (Figure 6). These results indicate that the complicated engineering of the anatomical structure of Kranz cells is not essential to perform C_4 photosynthesis. With the discovery of single-celled C_4 photosynthesis, the task of engineering C_4 plants from C_3 species might be easier than previously thought. This is desirable because C_4 photosynthesis has great advantages for growth under high temperature, drought and saline conditions. Because these species show how C_4 photosynthesis can work in single cells, these curious plants might be key to efforts to introduce the C_4 pathway into C_3 crops (Sage, 2002).

Figure 5. *A community of* Halostachys belangeriana, *just before the beginning of Kavir Protected Area.*

Figure 6. *Grazing of* Seidlitzia rosmarinus *plants in Touran Biosphere Reserve between Torud and Razeh.*

Figure 7. *Extreme grazing and vegetation degradation beside the habitat of the endangered population of* Salsola abarghunesis *(Figure 4.1) in Touran UNESCO Biosphere Reserve!*

Figure 8. *Traditional soap production using the soda extracted from halophytes, Kheirabad (Arak).*

Figure 9. *Young* Suaeda aegyptiaca *plants being sold as vegetables (local name Kakol) in the Bazaar of Borazjan, Bushehr Province, southern.*

Figure 10. *Grazing of* Salicornia persica *by goats around Tashk lake.*

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3. REFERENCES

Akhani, H. 1988. Plant records from Kavire-Meyghan (Arak), new to Iran. Iranian Journal of Botany 4, 105-107.

Akhani, H. 1989. (publ. 1992). A contribution to the vegetation and flora of Kavire-Meyghan (NE, Arak), Iranian Journal of Science University Tehran 18: 75-84.

Akhani, H. 1996. A new species and a synonym in *Chenopodiaceae* from Iran. Sendtnera 3: 5-10.

Akhani, H. 1998. Plant biodiversity of Golestan National Park, Iran. Stapfia 53: 1-411.

Akhani, H. 2002. Notes on the flora of Iran 1: *Asparagus* (Asparagaceae) and *Nitraria* (Zygophyllaceae). Edinburgh Journal of Botany 59: 295-302.

Akhani, H. 2003. *Salicornia persica* Akhani (Chenopodiaceae), a remarkable new species from Central Iran. Linzer Biol. Beitr. 35: 607-612.

Akhani, H. 2004. Halophytic vegetation of Iran: towards a syntaxonomical classification. Annals of Botany. (Rome) (In Press).

Akhani, H. & Ghorbanli, M. 1993. A contribution to the halophytic vegetation and flora of Iran. In: Lieth, H. & Al Masoom, A. (eds.), Towards the rational use of high salinity tolerant plants. pp. 35-44.Dordrecht: Kluwer Academic Publishers.

Akhani, H. & Ziegler, H. 2002. Photosynthetic pathways and habitats of grasses in Golestan National Park (NE Iran), with an emphasis on the C_4-grass dominated rock communities. Phytocoenologia 32: 455-501.

Akhani, H., Ghobadnezhad, M. & Hashemi, S.M. 2003. Ecology, biogeography and pollen morphology of *Bienertia cycloptera* Bunge ex Boiss. (Chenopodiaceae), an enigmatic C_4 plant without Kranz anatomy. Plant Biology 5: 167-178.

Akhani, H., Trimborn, P. & Ziegler, H. 1997. Photosynthetic pathways in *Chenopodiaceae* from Africa, Asia and Europe with their ecological, phytogeographical and taxonomical importance. Plant Systematic and Evolution 206: 187-221.

Akhani, H., Barroca, J., Koteeva, N., Voznesenskaya, E., Franceschi, V., Edwards, G., Ghaffari, S.M. & Ziegler, H. (submitted). *Bienertia sinuspersici* (Chenopodiaceae): A new species from Southwest Asia and discovery of a third terrestrial C_4 plant without Kranz anatomy.

Alaei, E. 2001. Salt marshes and salt deserts of SW Iran. -Pakistan Journal of Botany 33: 77-91.

Asri, Y. 2003. Plant diversity in Kavir Biosphere Reserve. Research Institute of Forests and Rangelands.

Asri, Y. & Ghorbanli, M. 1997. The halophilous vegetation of the Orumieh lake salt marshes, NW Iran. Plant Ecology 132: 155-170.

Atri, M., Asri, Y. & Ghorbanli, M. 1995. Etude préliminaire de la végétation halophile du littorale ouest du lac Oromieh, Iran. Doc. Phytosociologiques 15: 205-210.

Batanouny, K.H. 1993. Adaptation of plants to saline conditions in arid regions. In: Lieth, H. & Masoom, A. Al. (Eds.), Towards the rational use of high salinity tolerant plants, 387-401. Kluwer Academic Publishers. Dordrecht.

Bobek, H. 1961. Die Salzwüste Irans als Klimazeugen. Anz. Österr. Akad. Wiss. 3: 7-19.

Breckle, S.W. 1982. The significance of salinity. In: Spooner, B. & Mann, H.S. (Eds.) Dryland ecology in social perspective. pp. 277-292. Academic Press. London/New York.

Breckle, S.W. 1983. Temperate Deserts and semi-deserts of Afghanistan and Iran. In: West, N. (Ed.), Ecosystems of the world, pp. 271-319. Amsterdam. Elsevier.

Breckle, S.W. 1986. Studies on halophytes from Iran and Afghanistan. II Ecology of halophytes along salt gradients. Proceeding of Royal Society of Edinborough 89B: 203-215.

Carle, R. & Frey, W. 1977. Die vegetation des Maharlu-Beckens bei Shiraz (Iran) unter besonderer Berücksichtigung der Vegetation im Bereich der Süß- und Salzwasserquellen am Seeufer-Beih. Tübinger Atlas Vorderer Orient, Reihe A, Naturwissenschaften 2, Wiesbaden.

Dewan, M.L. & Famouri, J. 1964. The soils of Iran. FAO. Rome.

Fahn, A. & Arzee, T. 1959. Vascularization of articulated *Chenopodiaceae* and the nature of their fleshy cortex. American Journal of Botany 46: 330-338.

Freitag, H. & Stichler, W. 2000. A remarkable new leaf type with unusual photosynthetic tissue in a central Asiatic genus of Chenopodiaceae. Plant Biology 2: 154-160.

Freitag, H. & Stichler, W. 2002. *Bienertia cycloptera* Bunge ex Boiss., Chenopodiaceae, another C_4 plant without Kranz tissues. Plant Biology 4: 121-131.

Frey, W. & Kürschner, H. 1983. Photosyntheseweg und Zonierung von Halophyten an Salzseen in der Türkei, in Jordanien und im Iran. Flora 173: 293-310.

Frey, W., Kürschner, H. & Stichler, W. 1985. Photosynthetic pathways and ecological distribution of halophytes from four littoral salt marshes (Egypt/Sinai, Saudi Arabia, Oman and Iran). Flora 177: 107-130.

Frey, W., Kürschner, H. & Probst, W. 1986. Persische Golfküste. Mangrove. Vegetation. Beispiele. A VI 10. Tübinger Atlas des Vorderen Orients (TAVO) der Universität Tübingen. Dr. Ludwig Reichert Verlag. Wiesbaden.

Frey, W. & Probst, W. 1986. A synopsis of the vegetation of Iran. In: Kürschner, H. (Ed.) Contributions to the Vegetation of Southwest Asia. Beih. TAVO, Naturwissenshaften. 24: 9-24.

Ghorbanli, M. & Lambinon, J. 1978. Premier aperçu de la zonation de la végétation halo-gypsophile du lac Ghom (Province de Téhéran, Iran). Lejeunia Review Botany 92 : 1-22.

Ghorbanli, M., Asri, Y. & Hamzehee, B. 1997. Végétation halophile de la bordure sud de la Sebkha Garmsar (Iran). Colleques Phytosociologiques 27: 491-502.

Glenn, E.P. & Watson, C. 1993. Halophyte crops for direct salt water irrigation. In: Lieth, H. & Al Massom, A. (Eds.), Towards the rational use of high salinity tolerant plants, 379-385. Kluwer Academic Publisher, Dordrecht.

Glenn, E.P., Brown, J.J. & O'Leary, J.W. 1998. Irrigation crops with seawater. Scientific American, August: 76-81.

Glenn, E.P., O'Leary, J.W., Watson, M.C., Thompson, T.L. & Kuehl, R.O. 1991. *Salicornia bigelovii* Torr: An oilseed halophyte for seawater irrigation. Science 251: 1065-1067.

Hedge, I.C., Akhani, H., Freitag, H., Kothe-Heinrich, G., Podlech, D., Rilke, S. & Uotila, P. 1997. Chenopodiaceae. In Rechinger, K.H. (Ed.) Flora Iranica 172. Akademsiche Druck und Verlagsanstalt. Graz.

Krinsley, D.B. 1970. A geomorphological and palaeoclimatological study of the playas of Iran. Washington, D. C.: U. S. Government Printing Office.

Kurkova, E.B., Kalinkina, L.G., Baburina, O.K., Miasoedov, N.A. & Naumova, T.G. 2002. Responses of *Seidlitzia rosmarinus* to salt stree. Izv Akademy Nauk. Series Biology 3: 277-285.

Le Houérou, H.N. 1993. Salt-tolerant plants for the arid regions of the Mediterranean isoclimate zone. In: Lieth, H. & Al Massom, A. Al. (Eds.), Towards the rational use of high salinity tolerant plants, 403-422. Kluwer Academic Publishers, Dordrecht.

Léonard, J. 1981-1989. Contribution à l'étude de la flore et de la végétation des déserts d'Iran: Etude des aires de distribution les phytochories, les chorotype. Fasc. 1-9. Jardin botanique national de Belgique. Meise.

Léonard, J. 1991/1992. Contribution à l'étude de la flore et de la végétation des déserts d'Iran. Etude de la végétation: Analyse phytosociologique et phytochorologique des groupments végétaux. Fasc. 10 (1 & 2). – Jardin Botanique National de Belgique. Meise.

Rechinger, K.H. & Wendelbo, P. 1976. Plants of the Kavir Protected Region, Iran. Irani Journal of Botany 1: 23-56.

Sage, R.F. 2002. C4 photosynthesis in terrestrial plants does not require Kranz anatomy. Trend in Plant Science 7: 283-285.

Sayyari, M. & Mahmoodi, Sh. 2002. An investigation of reason of soil salinity and alkalinity on some part of Khorasan Province (Dizbad-e Pain Region). 17th WCSS, 14-21 August 2002. Paper No. 1981, 12 pp. Thailand.

Voznesenskaya, E.V., Artyusheva, E.G., Franceschi, V.R., Pyankov, V.I., Kiirats, O., Ku, M.S.B. & Edwards, G.E. 2001a. *Salsola arbusculiformis*, a C_3- C_4 intermediate in Salsoleae (Chenopodiaceae). Annals of Botany 88: 337-348.

Voznesenskaya, E.V., Franceschi, V.R., Kiirats, O., Freitag, H. & Edwards, G. 2001b. Kranz anatomy is not essential for terrestrial C_4 plant photosynthesis. Nature 414: 543-546.

Voznesenkaya, E.V., Franceschi, V.R., Kiirats, O., Artyusheva, E.G., Freitag, H. & Edwards, G. 2002. Proof of C_4 photosynthesis without Kranz anatomy in *Bienertia cycloptera* (Chenopodiaceae). Plant Journal 31: 649-662.

Winter, K. 1981. C_4 plants of high biomass in arid regions of Asia. Occurrence of C_4 photosynthesis in Chenopodiaceae and Polygonaceae from the Middle East and USSR. Oecologia (Berlin) 48: 100-106.

Zohary, M. 1973. Geobotanical foundations of the Middle East. Gustav Fischer Verlag.

CHAPTER 7

THE MICRO-ORGANISMS OF SABKHAT IN QATAR

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Abstract. Sabkhat are widely distributed throughout the Qatar Peninsula, and the aim of this study is to give a brief overview of their geographical distribution, geomorphology factors influencing their formation and biological characteristics within the area, with particular reference to their microorganisms. Although there are a large number of individual areas of sabkha, they tend to be small in size. The formation of sabkhat is shown to be a multifactorial process that is affected by several dynamic factors, such as geography, topography, environment and oceanography, as well as various anthropogenic ones.

The microbial communities of the sabkhat in Qatar display a conspicuous horizontal and vertical zonation. Whereas the upper-intertidal zone is composed of cyanobacterial mats, the middle-intertidal zone is dominated by the archaebacterium *Halobacterium salinarium* and the micro-green alga *Dunaliella salina*. The lower-intertidal zone is characterized by a black muddy substrate in which large quantities of sulphur and methane are produced due to the presence of certain bacteria. Analysis of the vertical zonation of the microbial profile has revealed the presence of various characteristic species of bacteria, cyanobacteria and diatoms at specific depths.

1. INTRODUCTION

Qatar occupies the entire Qatar Peninsula, and is situated on the northeastern Arabian Gulf coast of Saudi Arabia, between 24º 40′ and 26º 30′ N, and between 50º 45′ and 51º 40′ E. It extends some 180 km north from the border with Saudi Arabia, and has a maximum width of 85 km. The total land area is 11,437 km^2. A detailed geological description of the country has been given by Cavelier (1970). It is dominated by surface exposures of Tertiary sediments, with large areas covered by aeolian sand. In accordance with the geomorphological classification of Guba & Glennie (1998), the country belongs to the Eastern Arabian Gulf Region. Most of it is dominated by low-lying, gravelly to rocky desert ('hammada') of low relief. Over large tracts of the country, the elevation rarely exceeds 40 m a.s.l., and the topography of these areas is generally flat to slightly undulating. In some areas, such as southeast of Dukhan, the land lies up to 6 m

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below sea level. Elevations in excess of 40 m a.s.l., are almost exclusively found in the south-western part of Qatar, where the maximum altitude is 103 m a.s.l. Flat-topped buffs ('jebels') and ridges are characteristic features of this part of the country, and they extend along the western coastal area to just north of Dukhan. Water drainage channels, referred to locally as 'wadis', are associated with these hilly districts. They tend to be rather flat, but as important sinks for run-off water, vegetation cover is distinctly higher there than in adjacent areas.

Extensive sand dunes occur in the southeastern part of the country, where barchans up to 40 m in height are developed. To a lesser extent, sand dunes are also found in the northeast.

Numerous depressions, which range in diameter from a few hundred meters to about three kilometers, are a prominent feature of the landscape. These depressions, known locally as '*rowdat*', can be almost circular in shape and lie up to 20 m below the surrounding landscape. Such depressions are typical sinks not only for water, but also for younger substrate sediments that are washed down from surrounding areas. The typical soils of these depressions are calcareous loams or clay loams, often interspersed with a substantial fraction of sand. The depth of the soils varies from about 30 cm to 150 cm. frequently; a layer of aeolian sand up to 15 cm in depth is developed on the surface. As a consequence of the more favorable water and substrate conditions, vegetation cover in the depressions is markedly denser than that of the surrounding areas.

The coastline is generally flat, and mangroves, in which *Avicennia marina* forms dense stands, are locally a prominent feature.

Ashoor (1991) has carried out a detailed characterization of the sabkhat of Qatar. As to be expected, the general characteristics (such as level surface and high salt content) of the sabkhat are very similar to those reported from other parts of the world (e.g. West et al., 2000).

Extensive areas of sabkhat occur along the southeastern coast of the country, and inland sabkha is well developed in some central and southern areas, especially in the *rowdat*. Böer & Al-Hajiri (2002) have recently given a brief introduction to the coastal and sabkha flora of Qatar. This contribution will therefore focus on the microorganisms, which, apart from a limited number of general contributions (e.g. Belnap, 2002), have largely been neglected.

1.1. Geographical distribution

There are 42 distinct areas of sabkha in Qatar, and according to Batanouny (1981), they occupy a total area of 701 km^2. The majority (66%) of these areas are small in size, each less than 5 km^2, and about half of them in fact less than 1 km^2. Medium size (5-15 km^2) sabkhat account for about 25% of the areas, and the rest, ranging from 15 to 35 km^2 in size, can be classified as large (Ashoor, 1991). A large area of sabkha, in total about 95 km^2, is situated up to 6 m below sea level (Batanouny, 1981).

As a broad generalization, it is possible to distinguish between coastal and inland sabkhat. Many coastal sabkhat are subject to occasional inundation by the sea during high tide. In contrast, inland sabkhat receive their water supply from high ground water levels, precipitation or run-off from adjacent areas.

1.1.1. Coastal sabkhat

Coastal sabkhat are found predominantly on the eastern coast of Qatar, with the largest site located in the southeast, immediately south of Umm Said. Smaller areas of coastal sabkha also occur along the western coast, mainly south of Dukhan. Depending on the extent to which seawater affects the physical and chemical properties of the sabkha, it is possible to differentiate between internal coastal and external coastal sabkha. The former is in direct contact with the sea, and is therefore regularly affected by tidal action. Shallow intertidal pools frequently develop, but they tend to dry out rapidly, leaving behind a distinct saline surface crust. Good examples of internal coastal sabkhat are found at Al-Khor, Al-Dakhira, and Feshak. With external coastal sabkhat, the influence of the sea is not as prominent, as they are usually located behind sandy or rocky barriers. Examples of this type of sabkha can be observed at, or near, Al-Khor, Al-Dakhira, Umm Said, Dukhan, Umm Bab, Al-Odeid and Al-Zubarah.

Umm Said is the largest coastal sabkha in the country, extending some 55 km in length and between 4 and 14 km in width. It has developed from a former lagoon that gradually became filled with aeolian siliclastic sands. However, the current flatness of the area is controlled by a combination of aeolian factors and the capillary action of the groundwater, which lies only 50 cm below the surface of the sabkha. Moisture absorbed by the sand close to the surface of the sabkha prevents it from being blown away, whereas sand located above the influence of capillary water is subject to rapid wind erosion.

Apart from a saline crust, the sabkha at Umm Said is characterized by a high gypsum content in the subsurface layers. The texture of these layers can be characterized as sandy clay-loam. The high gypsum content probably contributes to the overall stability of the sabkha surface, allowing it to be easily driven over with a motor vehicle, except under wet conditions. Barth (1998) has discussed the factors affecting the development of such gypsum layers in some sabkhat in Saudi Arabia. In other areas of Qatar, the soil profile lacks a gypsum layer.

1.1.2. Inland sabkhat

The numerous (78) patches of inland sabkhat in Qatar account for an area of about 205 km^2. The majority of these patches though are very small, usually less than 1 km^2 in size. Only a handful exceeds 5 km^2. None of the inland sabkhat appears to be influenced by seawater, and they are located beyond land barriers parallel to the coastline (Perthuisot, 1977). Examples of inland sabkhat include Dukhan, Soudanthiland and Kobath.

1.2. Geo-physio-chemical factors influencing the formation of sabkhat

The formation of sabkhat is a complex process, which is affected by a number of interrelated factors. Barth (1998) has discussed in detail the formation of both inland and coastal sabkhat in the eastern province of Saudi Arabia. Factors affecting sabkha development include natural ones, such as topography, climate, and oceanography, as well as anthropogenic ones.

1.2.1. Influence of climate

The general climate of Qatar can be described as extremely hot and dry during the summer months, and mild and dry during the winter. Mean summer temperatures are in the region of 35°C, with absolute maximum values about 49°C (Batanouny, 1981). Temperatures rarely drop below 12°C in the winter. Rainfall is scanty, and characterized by marked annual variability. In dry years, as little as 20 mm is received, and maximum annual rainfall values are about 160 mm. Long-term mean annual precipitation in Doha is about 78 mm (Batanouny, 1981). Humidity is often high, ranging from about 45 to 95%. Potential evapotranspiration far exceeds precipitation, leading to an upward movement of water in the surface layers of the soil. This highly evaporative environment is a prerequisite for the formation of sabkhat (Barth & Böer, 2002). In addition, the prevailing wind direction is from the northwest and northeast. These winds are often laden with sea-borne salt, which is then deposited over the land, thus augmenting soil salinity.

1.2.2. Influence of topography

As with adjacent areas of Saudi Arabia, large areas of Qatar are flat. Furthermore, much of the landscape is situated less than 50 m a.s.l. These topographical features are favorable for the formation of sabkhat.

1.2.3. Influence of oceanographic factors

Apart from topography, the proximity to the sea and thus the influence of oceanographic factors have played a key role in the formation and development of sabkhat through evaporation and sedimentation processes, particularly in conjunction with the hot, arid climate (Alshahan et al., 2001). Wave action, tide, as well as salinity and ionic composition of the seawater in conjunction with the prevailing-wind direction are the main oceanographic factors affecting sabkha formation. During high tide, the coastal sabkhat can be flooded to a height of nearly 4 m above chart datum on the eastern coast, and nearly 1.5 m in the west.

Sand, silt and mud are continuously deposited along both the eastern and western coasts, leading to the formation of shallow saltmarshes, which may eventually develop, into sabkhat. This process is probably accelerated by the high salinity of the Gulf waters, where evaporation is particularly high, but recharge of seawater through the Straits of Hormuz is rather slow. Shallow coastal waters are even more saline (up to 50%). The formation of large gypsum sand crystals ('desert roses') in the sand of a supratidal sabkha at Umsaeed in eastern Qatar has been attributed to the high salinity of the seawater (De Groot, 1973).

1.2.4. Man-made effects on sabkha formation

During the past decades, urbanization has proceeded rapidly in Qatar, and this has been accompanied by a dramatic increase in groundwater abstraction. As a consequence, the salinity of the groundwater has also increased by at least 10% (Mahasneh, 2002). This in turn has had considerable implications for former non-saline habitats, especially those in the characteristic *rowdat*, which have gradually degraded into sabkha, accompanied by a loss of plant productivity. The over exploitation of groundwater reserves near the coast has led to seawater intrusion. The negative physio-chemical changes in groundwater quality, in particular elevated salinity, have favored the recent expansion of sabkhat in coastal areas of Qatar.

1.3. Biological characteristics

1.3.1. Microbial communities zonation of coastal sabkhat: A case study

Three of the largest areas of coastal sabkha were chosen for a detailed study of their microbial communities. These were Umsaeed, Al-Khor and Ras Qutaifan (the latter located close to the Ritz-Carlton Hotel, extending northwards for 15 km, and up to 5 km in width). Extensive field and laboratory studies of these areas were conducted from October 2001 to June 2003.

The results of our research revealed the presence of three characteristic horizontal and one vertical zonation in the microbial profile, which will be discussed in more detail below.

1.3.2. Horizontal zonation of the upper-intertidal zone

This zone is covered with a thick (5-10 mm) black to dark-green cyanobacterial mat that is composed of a number of species of cyanobacteria. These include the nitrogen-fixers *Calothrix parietina*, *C. vigueri*, *C. scopulorum*, *Rivularia atra* and *Anabaena ambigua*, as well as filamentous, non-nitrogen fixers such as *Phormidium* spp., *Microcolueus*, *Oscillatoria* spp., *Lyngbya* spp. and *Scytonema* spp. This cyanobacterial mat is developed over a thick brown layer (20-50 mm) of litter of the seagrass *Halophila* sp. and the degraded leaves of *Avicennia marina*. This ecosystem is an important part in the detritus food chain, and the various biodegradation processes contribute to sustaining diverse, highly productive microbial communities, as well as communities dominated by crustaceans (shrimps, oyster) and other marine organisms. The results of an experiment to measure the degradation rates of the litter of both *Avicennia* and *Halophila* spp. showed that 50% of the dry mass was degraded within 20 days on the soil surface. More than 40 species of detritus fungi were isolated from the degraded litter, among them members of the genera *Aspergillus*, *Choanephora*, *Cladosporium*, *Curvularia*, *Fusarium*, *Nigrospora*, *Penicillium*, *Pestalotiopsis*, *Trichoderma* and *Zygosporium*.

1.3.3. Horizontal zonation of the middle-intertidal zone

This zone is characterized by its conspicuous reddish color (pinky-purple), forming an extensive area with a wavy-laminated soil surface interrupted by occasional green patches. Our field and laboratory tests have shown that the conspicuous pinky-purple color is partially due to the prevalence of the halophilic archaebacterium *Halobacterium salinarium*, which is known to produce a red rhodopsin protein needed for photosynthesis, and also due to the presence of the micro-green alga *Dunaliella salina.* The latter is known to produce orange carotenoids as accessory pigments. The green patches found in this zone can be attributed to the presence of various species of diatoms.

1.3.4. Horizontal zonation of the lower-intertidal zone

This zone is characterized by a conspicuous layer of a thick (20-60 cm), black mud, strongly smelling of sulphur and methane. Sulphur bacteria, such as *Beggiatoa spp., Thiobacillus thioploca*, *Desulfobacter*, *Desulfosomonas*, and methanogenic bacteria, including *Methanogenic brivobacter* and *M. arbolifolus*, are the microorganisms primarily responsible for the production of these gases. Patches with a green-laminated surface (2 mm thick) are created by green sulphur bacteria, such as *Chlorobium* spp. Sulphur bacteria play a crucial role in the biogeochemical cycling of sulphur (Overmann, 2001).

1.3.5. Vertical zonation

To examine the vertical zonation of the microbial profile, soil samples from 20 different locations of the study area were cultured and analyzed for bacterial species composition. The results show that many species of chemolithotropic bacteria were present, including representatives of the green sulphur bacteria (*Chlorobium* spp.), green non-sulphur bacteria (*Chloroflexus, Heliothrix*), purple sulphur bacteria (*Chromatium* spp.), and the purple non-sulphur bacterium *Rhodospirilum rubrum*. Moreover, nitrate reduction tests on soil and water samples were positive, confirming the presence of nitrifying bacteria such as *Nitrosomonas* and *Nitrobacter*, and denitrifying taxa like *Bacillus* spp., *Paracoccus* spp. and *Pseudomonas* spp. The smell of methane indicated the presence of methanogenic bacteria. More specific details of the vertical zonation of microorganisms for the inland sabkhat are given below.

1.3.6. Microbial communities of mangrove and salt marshes areas

Mangrove communities are widespread along the eastern coast of Qatar, and are usually associated with sabkhat. For instance, at Al-Khor and Dakhira, mangrove swamps dominated by *Avicennia marina* occur along sheltered, muddy shores and fringing the waterfronts. The presence of these mangroves serves to reduce tidal impact, causing mud and silt to be deposited. In this respect, mangroves contribute to the formation and extension of tidal flats with interlacing creeks and canals. Mangroves are highly productive areas with a fertile, muddy substrate characterized by high rates of nutrient cycling. The soft substrate is easily penetrated by the aerial roots of *Avicennia*. These roots provide a unique microhabitat for microbial communities, particularly for nitrogen-fixing cyanobacteria such as *Rivularia* spp., *Calothrix* spp., *Gleotrichea* spp., *Anabaena* spp. *and Nostoc* spp. The sulphur bacteria *Beggiatoa* sp. was also detected in the rhizosphere of other plants inhabiting the mangroves, and a strong smell of hydrogen sulphide was evident during field studies, underlining the abundance of these microorganisms.

In many sheltered locations along the coasts of Qatar, intertidal saltmarsh communities are a common feature, and they are dominated by various halophytic chenopods.

1.3.7. Inland sabkha: dukhan as case study

The substrate of the inland sabkha at Dukhan is covered with a salt crust, below which it is composed of mucoid-black clay. This clay is extremely fertile due to the high content of organic compounds. These are produced during a complex biological degradation process in which bacteria and fungi are primarily involved. The distinct smell of H_2S is evidence of the prevalence of anaerobic conditions in the soil, and the enhanced activity of sulphur bacteria. This was tested in the field by measuring the redox potential, and the values were always shown to be below zero. The vertical analysis of mud cores collected from the area revealed the presence of several distinct layers. The upper mucoid-pinky layer is quite thin (1-2 mm), and dominated by the unicellular cyanobacteria *Synecococcus* sp. and *Anacystus nidulans*. This is followed by a subsurface green layer (5-10 mm), in which cyanobacteria of the genus *Microcoleaous* predominate (over 90% of the micro-organisms recorded), accompanied by a few filaments of *Oscillatoria* and remnants of unicellular cyanobacteria such as *Synecococcus* and *Gloeocapsa.* The diatom *Navicula* sp. prevails in the following layer (over 90%), which is between 10 and 50 mm thick. Cores from the most saline sites at the edge of the sabkha are characterized by the dominance (over 90%) of the filamentous cyanobacterium *Phormedium* sp., and the presence of other filamentous species such as *Spirulina* sp. and *Oscillatoria* sp.

1.3.8. Terrestrial microbial communities

Saline habitats are a widespread feature of many parts of Qatar, and these are occupied by halophytic plant communities. At present, 371 species of vascular plants belonging to 236 genera (Abdel Bari, 1999) have been recorded for Qatar. The Chenopodiaceae are well represented, with 22 species belonging to 16 genera. Many of these chenopods, such as *Arthrocnemum macrostachyum*, *Halocnemum strobilaceum*, *Halopeplis perfoliata*, *Salsola imbricata*, *Seidlitzia rosmarinus*, *Suaeda aegyptiaca* and *S. vermiculata*, are typical halophytes, and tolerant or highly tolerant of salinity (Böer & Al-Hajiri, 2002). *Zygophyllum qatarense* is often the dominant species of sabkha and is covered with a thin layer of sand. Böer & Al-Hajiri (2002) provide a comprehensive list of the 49 species that have been identified as halophytes in Qatar. The rhizosphere of many of these plants provides an optimum microhabitat for microbial communities under the prevailing conditions of drought and high salinity. However, it has been shown that plants growing in the *rowdat*, with their fine soils that are able to retain more moisture, are particularly favorable for the growth of micro-organisms, especially mycorrhiza and streptomycetes (Mahasneh, 2002; Al-Thani & Mahasneh, 2002).

1.3.9. Lichen communities

Sabkhat are an extremely inhospitable habitat for lichens, which are therefore absent from the saline surface. However, on small calcareous rocks that occur on the edge of the sabkha or on slightly elevated sites in the sabkha proper, a saxicolous lichen flora can be well developed. This consists mainly of crustose species of the genera *Buellia*, *Caloplaca* and *Lecania*, as well as some cyanolichens. Locally, the fruticose species *Ramalina* cf. *maciformis*, with its characteristic strap-like thallus, is also quite common in Qatar. Preliminary observations suggest that lichens only occur where the rocks do not become inundated, as small rocks on moister areas of sabkha were devoid of lichen growth.

1.3.10. Fungal communities in the soil

Recent studies have shown that the fungal flora is largely similar to that of the neighboring Arab countries (Mahasneh, 2002). A total of 142 species belonging to 53 genera have been detected in Qatar. However, there has been no association of these species with particular habitats. The most common and species-rich genera found in the soil are *Aspergillus*, *Penicillium*, *Fusarium* and *Caldosprium* (Mahasneh, 2002).

1.4. Conservation of sabkha ecosystems in Qatar

Fortunately, the coastal sabkhat of Qatar escaped damage from the oil pollution that occurred during the Gulf War in 1991, although the coastline has been affected by oil contamination from local industrial activities (Hegazy, 1995, 1997). However, most of the impacts that have caused unnecessary damage to the sabkha ecosystem, such as off-road driving, unnecessary construction and dumping of industrial waste, are due to ignorance. Recently, the Qatari authorities have begun taking action to prevent ecosystem degradation by formulating environmental policies and introducing legislation to conserve the natural environment, including sabkhat. A number of governmental organizations are involved in environmental issues, including the Ministry of Municipal Affairs and

Agriculture, the Environmental Protection Committee and the Scientific and Applied Research Center (SARC).

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3. REFERENCES

Abdel Bari, E.M. 1999. Additions to the flora of Qatar. Qatar University Science Journal 17: 303-312.

Al-Thani, R.F. & Mahasneh, I.A. 2003. Biodiversity of Bacteria in the Soil of Qatar. Scientific and Applied Research Center (SARC). University of Qatar. 78 pp.

Alsharhan, A.S., Rizk, Z.A., Nairn, A.E.M., Bakhit, D.W. & Alhajari, S.A. 2001. Hydrogeology of an Arid Region: The Arabian Gulf and Adjoining Areas. Elsevier Science.

Ashoor, M.M. 1991. The Sabkha in Qatar: geomorphological-geological-biological study. University of Qatar, 514 pp.

Barth, H.-J. 1998. Sebkhas als Ausdruck von Landschaftdegradation im zentralen Küstentiefland der Ostprovinz Saudi-Arabiens. Regensburger Geographische Schriften Heft 29. 279 pp.

Barth, H.-J. & Böer, B. (eds.), Sabkha Ecosystems. Volume 1. The Arabian Peninsula and Adjacent Countries. Kluwer, Dordrecht. 354 pp.

Batanouny, K.H. 1981. Ecology and Flora of Qatar. University of Qatar. 245 pp.

Belnap, J. 2002. Biological soil crusts of Arabian sabkhat. In: Barth, H.-J. & Böer, B. (eds.), Sabkha Ecosystems. Volume 1. The Arabian Peninsula and Adjacent Countries. Kluwer, Dordrecht, 227-237 pp.

Böer, B. & Al Hajiri, S. 2002. The coastal and sabkha flora of Qatar: an introduction. In: Barth, H.-J. & Böer, B. (eds.), Sabkha Ecosystems. Volume 1. The Arabian Peninsula and Adjacent Countries. Kluwer, Dordrecht, 63-70. pp.

Cavelier, C. 1970. Geological description of the Qatar Peninsula. Dept. Petrol. Affairs, Government of Qatar, Bureau de Recherches Géologiques et Minières, Paris.

De Groot, K. 1973. Geochemistry of tidal flat brines at Umsaeed, S.E. Qatar, Persian Gulf. 377-394.

Guba, I. & Glennie, K. 1998. Geology and Geomorphology. In: Ghazanfar, S.A. & Fischer, M. (eds.), Vegetation of the Arabian Peninsula. Geobotany 25. Kluwer Academic Publishers, Dordrecht. 39-62 pp.

Hegazy, A.K. 1995. Phytomonitoring and management of tar piles on the Qatari coastal marshes, Arabian Gulf Environmental Pollution 90: 187-190.

Hegazy, A.K. 1997. Plant succession and its optimization on tar polluted coasts in the Arabian Gulf Regional Environmental Conservation 24: 149-158.

Mahasneh, I.A. 2002. Biodiversity of Qatar: A translation to Arabic Version. Scientific and Applied Research Center (SARC). University of Qatar. 175 pp.

Overmann, J. 2001. Diversity and ecology of phototrophic sulfur bacteria. Microbiology Today 28: 116-118.

Perthuisot, J.P. 1977. La Sebkha de Doukhane (Qatar) et la transformation: Gypse-anhydrite-eau. Bulletin Societe Geologic Francaise 5: 1145-1149.

West, I.M., Lashhab, M.I. & Muhan, I.M. 2000. North African sabkhas and lagoons compared to those of the Arabian Gulf. Proceedings of the Sixth Mediterranean Petroleum Conference and Exhibition, November 23-25th, 1999, Tripoli, Libya, 512-530 pp.

CHAPTER 8

SOIL SALINIZATION AND FLOODPLAIN ECOSYSTEMS OF SOUTH-WEST TURKMENISTAN

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Abstract. In the period of scientific and technical progress, the need to make protection of the environment, a habitat of humanity has become extremely urgent. Land ecosystems are extremely vulnerable in arid regions. They respond even to insignificant changes in the environment, which may result in irreversible modifications of ecosystems and often in the complete loss of their scientific, social, and economic value. Intra-zonal hydromorphic landscapes undergo the greatest transformations. Evidence of disruption of the natural functioning of any landscape is clearly visible from an analysis of its most vulnerable components—vegetation and soils.

1. INTRODUCTION

1.1. Hydrological features of the region

The territory of southwestern Turkmenistan is characterized by severe dryness. The only waterway of this region within the arid belt of the subtropical zone is the Atrek river with its tributaries, the Sumbar and the Chandir.The Atrek is among the smallest of the larger rivers of Turkmenistan (Table 1). The main part of its watershed is situated in Iran.

Rivers of the Atrek basin are characterized by sharp lack of water and extremely low average high-water water discharges. This can be explained by the diversion of a significant part of river flow for irrigation abroad.

Several peculiarities typical to the Atrek river and its tributaries determine the physical-geographical features of the southwestern Turkmen territory. Rivers of the basin are characterized by high variability in flow assessment during the year; early and short spring flooding during which more than 50% of the total annual flow is discharged; frequent rain floods during the year, sometimes two or three times more abundant than during the spring floods; an unsteady and long (sometimes up to five months) summer-autumn drought period, during which

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rivers dry up in some parts; and high turbidity and significant water mineralization (Figure 1).

Today the hydrological flow of the Atrek river is completely regulated by a channel in Iran and three small watering reservoirs in Turkmenistan. A catastrophic situation is emerging in the lower reaches of the Atrek, as its water

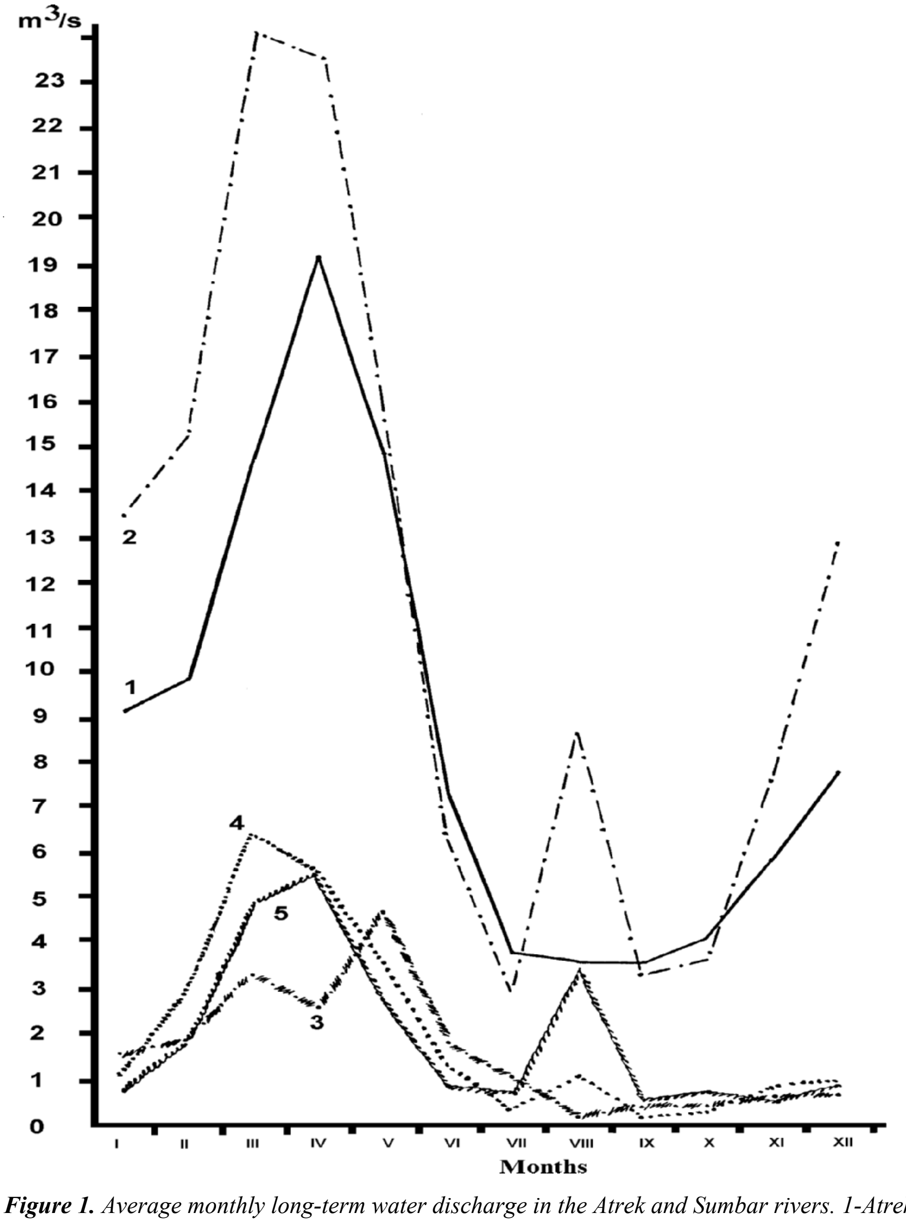

Figure 1. *Average monthly long-term water discharge in the Atrek and Sumbar rivers. 1-Atrek river-Settlements Kizyl-Atrek, 2- Atrek river, mouth of the Sumbar river, 3 - Sumbar river mouth, 4 - Sumbar river Kara-Kala settlements, 5 - Sumbar river Aul Duzlu-Depe.*

Table 1. *Comparative hydrological characteristics of some rivers in Central Asia.*

River	*Length of the river Km*	*The area of watershed basin Thousand sq.km*	*The height of watershed basin m*		*The average charge of water m^3/s*	*The average module of a drain, l/s km^2*	*Volume of a drain at an exit of the river on plain*	*Alimentation of the river*
			Average	*max*				
Amudarya	2540	309,0	3250	7495	1900-1010	12,0	63,0	Glacier-snow
Syrdaya	3019	219,0	2380	5600	618-406	8,0	22,8	Snow-glacier
Iii	1439	140,0	–	5346	469-390	4,1	14,0	Glacier snow
Chu	1186	71,6	1500	4875	66,6-20,4	4,6	3,9	Snow-glacier
Murgab	978	46,9	1400	3750	52,0	1,3	1,7	Snow-rain
Tedgen	1150	70,6	1500	4524	30,0	1,2	0,97	Snow-rain
Atrek	669	27,3	1040	3060	9,2	0,7	0,26	Snow-rain
Sumbar	245	8,27	–	–	1,5	–	–	Underground-snow
Chandir	120	1,82	–	–	0,8	–	–	Underground-snow
Arwaz	45	0,195	–	–	0,5	–	–	Underground-snow

does not reach the Caspian sea; its entire flow (from 0.14 km^3 during low-water years and up to 0.5 km^3 during high-water years) is accumulated in small reservoirs and diverted away for irrigation. Because of its high mineralization, Atrek water is unfit as a supply for drinking water. The water flow of the Sumbar and Chandyr rivers during the spring-summer period is also used completely for irrigation. Anthropogenic transformations in the river valleys have caused valuable and productive floodplain tugai phytocoenoses to disappear. The regime of regulated flooding lasting several days (within the period from July to August) is necessary for the maintenance of the tugai ecosystems in the delta and floodplain on the Atrek and its tributaries.

Both the manner of functioning of floodplain ecosystems and their natural dynamics are completely determined by the hydrological features of the river basin.

1.2. Existence of conditions of floodplain vegetation in the lower reaches of the Atrek River

Natural vegetation of hydromorphic landscapes in arid regions of the ancient Mediterranean coast (including North Africa, Asia Minor, and Central and Middle Asia) is represented by tugais—tree and bush communities of desert floodplains.

Typical tugais occur as narrow belts in river valleys and deltas, where they occupy banks, islands, and low terraces and alternate with meadows and tall-grass communities. The main edificators in tugai vegetation are xeromesophillous mesothermic trees: poplar *(Populus ariana, P. diversifolia,* and *P. pruinosa),* oleaster *(Elaeagnus turcomanica, E. orientalis),* and willow *(Salix songarica),* often entwined by lianas *(Cynanchum sibiricum, Clematis orientalis),* as well as bushes and tall grasses including tamarisk *(Tamarix ramosissima, T. meyeri, T. florida, T. laxa, T. elongata et al.), Halimodendron (H. halodendron),* reed *(Phragmites australis),* reed grass *(Calamagrostis dubia, C. epigeios, C. pseudophragmites),* wheat grass *(Elytrigia repens),* and Indian hemp *(Trachomitum scabrum).* In some places giant grasses—plume grass *(Erianthus ravennae)*—can be found.[1]

The definition of tugais or tugai vegetation comprises not only tree and bush communities of desert floodplains and deltas at different stages of endodynamic and exodynamic successions, but also grass communities that are closely related to the arboreous ones, and of which most are anthropogenic derivatives of arboreous communities (Rodin, 1963; Ashirova, 1976; Bakhiev, 1985).

According to some ecological-biological features, tugai flora can develop only on the most moisturized and unsalinized territories. But the West-Turanian lowland does not follow this trend. Its modern and ancient solonchak and takyr-like plains are subjected to periodic processes of desalinization and salinization of soil cover.

Periodic transgressions and regressions of inland water basins influence the natural complexes of surrounding territories and the life of people as well. The Aral crisis can be mentioned as an example. The Caspian Basin is not an exception to the rule.

When coastal level fluctuations are extremely dynamic in time and amplitude, eustatic movements of the Caspian sea define the direction of the evolution process in the soil and vegetation covers of neighboring territories, as the rise in sea level causes the ground water table to rise on the surrounding sea plain and on the ancient deltaic territory as a whole. This process promotes the resumption of the salt accumulation process in soils. It causes hydromorphous solonchaks and territories occupied by halophytic vegetation to broaden. The Caspian regression correspondingly causes the ground water table to lower and promotes the irrigation of territories that are not subject to the influence of deep salinized waters.

Unlike in the majority of Central Asian rivers, the lower Atrek is not characterized by a distribution of tugai tree-bush vegetation massifs; its tugai flora and fauna were typical for the Caspian coast even during the Khvalyn transgression (Fedorovich, 1983). The potential existence and renovation of tugais was limited on one hand by the total salinity of the soils and the naturally weak drainage ability of the territory and on the other hand by anthropogenic activity, which has periodically reconstructed the Pricaspian plain since the second

[1] Latin names of plants are given according to S.K. Cherepanov (1995).

millennium BC (Figure 2). The development of irrigation agriculture made it necessary to develop new territories since those subjected to secondary salinization could not provide the timber needed by the new settlements.

With the continuing smooth rise in the level of the Caspian Sea, which began in 1978 (from 1986 up to –27.9 m), a rise in the ground water table in the floodplain and delta of the Atrek is expected to cause the process of solonchak formation in the soils to resume. The recent rise in the level of the Caspian Sea may lead in the future to the flooding of the Gasan-Kuly lowland in southwest Turkmenistan, as occurred in 1939 (Fedorovich, 1983). Flooding would in turn affect the soil and vegetation covers of the modern Atrek delta.

1.3. Soil salinization and the dynamics of tugai

The most typical soils under grass, tree, and bush tugais are alluvial meadow soils; alluvial boggy-meadow and meadow soils. The latter are the most rich in humus and contain minor accumulations of salts in the upper soil horizons, the content of which increases during development of the plant community (Kovda, 1946; Ashirova, 1976).

There are several stages in the development of tree and bush tugais. At the initial stage of tugai formation, on fresh deposits with high GWL (1-1.5 m) grass and willow- or oleaster-poplar (Table 2), willow or oleaster communities may occur. Soils are alluvial-meadow, non-saline or slightly saline (Table). They are replaced by poplar and tamarisk and poplar communities on soils with lower GWL (2-4 m) and higher salinity. They gradually give way to bush tugais formed by tamarisk, which in natural conditions (lowering of the GWL without active salt accumulation in soils) usually

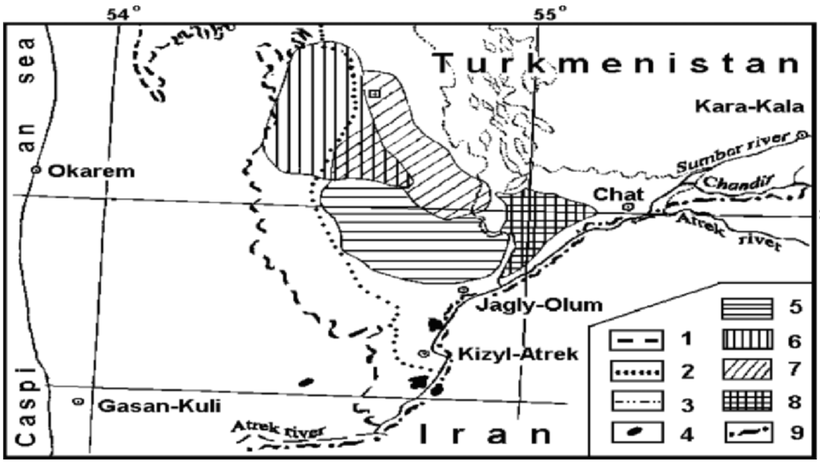

Figure 2. *Distribution of ancient irrigation lands on the Messerian and Chat ancient-deltaic plains. A – Sea level for contours: 1 – O m absolute height, 2 – +50 m absolute height, 3 – +100 m absolute height, 4 – reservoir. B – lands of ancient irrigation: 5 – II –I thousands years BC, 6 – V-VIII century AD, 7 – X-XV century AD, 8 – chat ancient-irrigation region, 9 – modern border of the states.*

degrade, forming desert takyr landscapes (Treshkin & Kuz'mina, 1993). The majority of investigators of plant cover explain the death of tree stands in the Amu-Dar'ya delta by the lowering of GWL (Grave, 1936; Drobov, 1951; Zaktreger, 1927). It is well known that the depth of GWL in floodplains and deltas of aridregions is characterized by both frequent seasonal and yearly fluctuations, which depend on alternating hydrological cycles of rivers (Shul'ts, 1965). Consequently, the root systems of many tugai plant species are large in size, characterized by branching, have several levels, display high plasticity, and are capable, for example, of developing adventitious roots on trunks and stems (Mailun, 1973). Because of these features, both poplar, the main edificator, andspecies of tamarisk can germinate on loamy, sandy loamy, and sandy deposits with different depths of GWL (Table 2). The ground water level under *Populeta diversifoliae* groves on the lower Atrek ranges from 3 to 5-7 m. Stands of Asiatic poplar in a satisfactory state were encountered (Treshkin & Kuz'mina, 1993; Kuz'mina & Treshkin, 1997; Zhollybekov, 1991) with a GWL of 8-11 m deep, both in the lower part of the Amu-Dar'ya river and in the Sumbar valley (Table 2).

Currently, because of regional anthropogenic influences—regulation of river flow—as well as local influences—cutting, overgrazing, fires, freight transport, and others—tugai communities of the Caspian Sea region and of the Aral Sea coastal region are undergoing processes of desertification. These processes are most pronounced in the deltas, where the Amu-Dar'ya and Atrek rivers have become so shallow that their waters do not reach the Aral and Caspian seas. Nevertheless, anthropogenic salinization of soils remains the main process that serves as a "trigger" for tugai ecosystems degradation. Anthropogenic salinization is caused by different factors and may result in the formation of both meadow (hydromorphic) solonchaks and meadow-takyr solonchakous soils, along with residual-hydromorphic takyr-like solonchaks (Table 2).

Meadow solonchaks with extremely high salinity originate in the case of an increase in GWL under the tugais adjacent to irrigated cropland, which is enhanced by the discharge of strongly mineralized wastewater. Moreover, tugai soils are no longer washed during periodical floods (annually or once every 3-5 years, according to location in the relief) by relatively fresh river water. Without such natural washing (and with a gradual decrease of GWL of no more than 1-2 m) active accumulation of salts in tugai soils begins as a result of capillary flow even from slightly mineralized ground water. Alluvial tugai soils become saline and evolve into meadow solonchaks with maximum salt content in their upper 10-30 cm.

In the absence of floods, salinization of tugai soils is enhanced by mineralization of tugai plant residues (which have a high biological sorption capacity), as well as by changes in water consumption by tugai plants from soils and GW. The important role of this factor in tugai soil salinization was noted in the works of Drobov (1950), Rozanov (1951), Rodin (1963) and Ashirova (1976).

When the environment is out of equilibrium, the evolution of soil and plant cover is accelerated and natural tendencies change. Regulation of river flow induces the

Table 2. *Soil and ground water level under tugai vegetation in the lower reaches of the Atrek river and its tributaries.*

	Plant association	Soils	Dry residue*	GWL, m %
1	*Phragmites australis-Typha australis*	Nonsaline loamy alluvial meadow-boggy	1.3-2.07	0.2-1
2	*Phragmites australis-Cynodon dactylon-Elytrigia repens*	Clayey weakly developed medium-saline solonchakous	0.2-0.43	1-1.5
3	*Salix excelsa-Calamagrostis persica*	Nonsaline sandy loamy and loamy weakly developed and alluvial meadow carbonate	0.1-0.15	1.5
4	*Elaeagnus orientalis +E. angustifolia-lmperata cylindrica*	Slightly- and medium-saline loamy and clayey typical meadow	0.27-0.47	1.5-2.5
5	*Populus diversifolia-Elytrigia repens-Mixteherbosa*	Nonsaline and solonchakous alluvial meadow carbonate tugai with takyric features	0.24-0.28	3-5(7)
6	*Tamarix florida-T. meyeri*	Nonsaline carbonate alluvial meadow tugai loamy	0.14-0.19	1-2
7	*Tamarix florida*	Slightly saline from the surface solonchakous, loamy alluvial meadow tugai	0.22-0.25	1.5-2.5
8	*Elytrigia repens-Mixteherbosa*	Nonsaline alluvial desert-meadowish clayey and loamy	0.22-0.25	2.5-3
9	*Tamarix litwinowii*	Solonchakous-saline stratified alluvial meadow carbonate loamy	0.42-0.67	4-5
10	*Tamarix hispida*	Typical and meadow solonchaks and residual-meadow solonchaks, clayey and loamy	1.0-1. 0.45-0.80	1-1.5 4-5
11	*Halostachys belangeriana-Limonium reniforme*	Meadow typical solonchaks clayey	1.7-2.8	0.5-1.5
12	*Halostachys belangeriana-Sphaenopus divaricatus + Spergularia diandra + Eremopyrum orientate*	Residual meadow solonchaks clayey and loamy with takyric features	0.85-1.3	3.5-5(6)
13	*SalsoIa dendroides-Lycium depressum-Alhagi persarum*	Solonetzic-solonchakous meadow serozemic loamy and semihydromorphic solonchaks over former meadow-serozems	0.89-0.98	3-3.5

* Weighted average salinity of soils in the layer 0-100 cm.

transformation of alluvial meadow tugai soils into semihydromorphic ones, defined as alluvial meadow takyr-like tugai soils by some authors (Genusov, 1983; Rafikov and Tetyukhin, 1981). This type of aridization is most widespread in the Amu-Dar'ya delta, where the area of hydromorphic soils has been reduced from 633.8 thousand hectares in 1953 to 77.6 thousand hectares in 1979 (Zhollybekov, 1991).

Since the capillary fringe in this case quickly loses its bonds with the horizon of salt accumulation, formation of takyrs is not usually accompanied by active salinization. Nevertheless, accumulation of salts in the upper horizon is also possible here, owing to aeolian transportation of salts and to their input from leaf debris.

Intensive accumulation of salts in soils causes a rapid replacement of species in tamarisk shrubs by more salt-tolerant ones *(Tamarix hispida, T. litwinowii)* and their subsequent replacement by communities of *Halostachys belangeriana* or, communities of *Salsola dendroides,* in accordance with the depth of the GWL (Table). The last-mentioned communities are not typical for tugais and are assigned to halophytic vegetation. Degradation of tugais is accomplished by the formation of halophytic communities—communities of tamarisk and *Halostachys belangeriana,* of *Halostachys belangeriana,* and of *Salsola dendroides* (Table 2). In Central and Middle Asia, the further evolution of halophytic vegetation results in the formation of intermediate communities of *Halostachys belangeriana* and black *Haloxylon*, which develop near former river beds after complete degradation of tree and bush tugais, and is accomplished with the formation of Haloxylon communities.

Investigations in the southwestern Caspian Sea region (basins of the Atrek, Sumbar, and Chandyr rivers) have shown that disruptions in the regime of flooding in hydromorphic areas result in extremely quick degradation of tugai vegetation. When correlating the features of vegetation with the relationship between soil salinity and ion composition, we have come to a conclusion that in the Atrek river basin the transformation of tree poplar tugais with *Populus diversifolia* is already seen at a weighted average salinity of 0.25% in the upper layer of 1 m thickness (Figure 3). When soil salinity reaches the point mentioned, the stability of a typical tree, the poplar tugai *(Populeta diversifoliae),* begins to decrease. This process is reflected by the susceptibility of tree stands to different diseases and infestation by pests (heart rot, leaf miners, and others), by the drying of different parts of plants resulting in complete disappearance of trees in communities, and by penetration of halophytes—*Lycium turcomanicum, Zygophyllum fabago, Z. oxianum***,** *Peganum harmala, Salsola dendroides*—into bush story and grass cover, accompanied by a decrease in the species diversity of communities. In soil profiles under tree tugais, a change in types of anion composition from hydrocarbonate-chloride to chloride-sulfate (Figure 4) is seen at a weighted average salinity of more than 0.25% in the layer 1 m thick. This regularity indicates the beginning of degradation of soils and plants in tree poplar tugais. At a further increase in weighted average salinity to 0.45%, trees disappear completely in tugai communities of the Atrek and Sumbar rivers. Tugai communities are transformed into bush tugai, composed of halophytic species of tamarisk—*Tamarix hispida, T. litwinowii, T. laxa, and T. elongata*—with grass cover of salt-tolerant perennials *(Suaeda microphylla, Climacoptera lanata, Salsola dendroides)* and ephemeral grasses *(Bromus japonicus, Hordeum leporinum).*

When characterizing the salinity of soils under tugais, it should be pointed out that at the present time, the weighted average total salinity of soils in the lower reaches of the Atrek river does not range above 1.7% (Figure 3). At the same time,

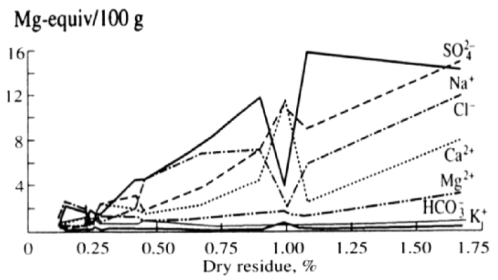

Figure 3. Factual relation between ionic composition and weighted average salinity of soils under tugais (a) in the floodplain and delta of the Atrek River.

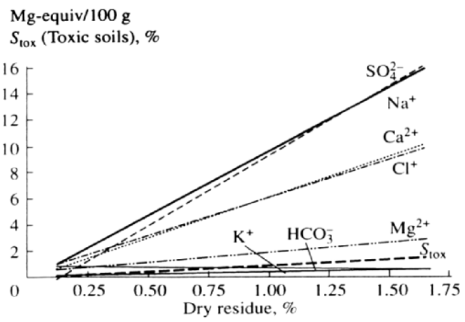

Figure 4. Linear trend of correlation between ionic composition and weighted average salinity of soils under tugais in the floodplain and delta of the Atrek river.

under tugais in the Amu-Dar'ya delta we have discovered soils with salt concentrations as high as 3.5% (Kouzmina and Treshkin, 1997).

With a dry residue salinity of more than 0.9-1.0%, soils under tugai vegetation in both regions usually contain about 1% toxic salts (Figure 4) starting at a depth of 1 m.[2]

1.4. Flora of the tugai of the atrek basin

Floodplain vegetation of subtropical rivers in western Turkmenistan is characterized by high biodiversity (48 associations belonging to 21 formations). Tugai communities are represented by 15 formations and have maximum floristic diversity (Figure 5). They are refuges for many rare, officinal and endangered plant species.

Flora of river floodplains in subtropical western Turkmenistan includes 478 species, 272 genera and 67 families and belongs to typical desert floras. It is characterized by a relatively high level of endemism - 38 plant species (8% of the whole flora). Genetic links reveal the significant impact of the Ancient Thesis sea territory in which 46.4% of the Atrek basin flora originates.

The family spectrum formed by the first five families of the flora of floodplains and deltas of the arid subtropics of southwest Turkmenistan corresponds as a whole to the floristic nucleus of the Turan flora (Bykov, 1978). However, a high share of families, *Asteraceae, Poaceae, Fabaceae*, as well as a low share of species from the *Chenopodiaceae* family make southwest Turkmenistan's flora similar to that of the northern and central Sahara on the one hand, and to the floodplain floras of more northern semidesert Eurasian territories on the other (Bykov, 1978; Ageleuov, 1987).

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2 Content of toxic salts (S_{tox}, %) and gypsum is evaluated according to the classification of E.I. Pankova and V.M. Mazikov (1985).

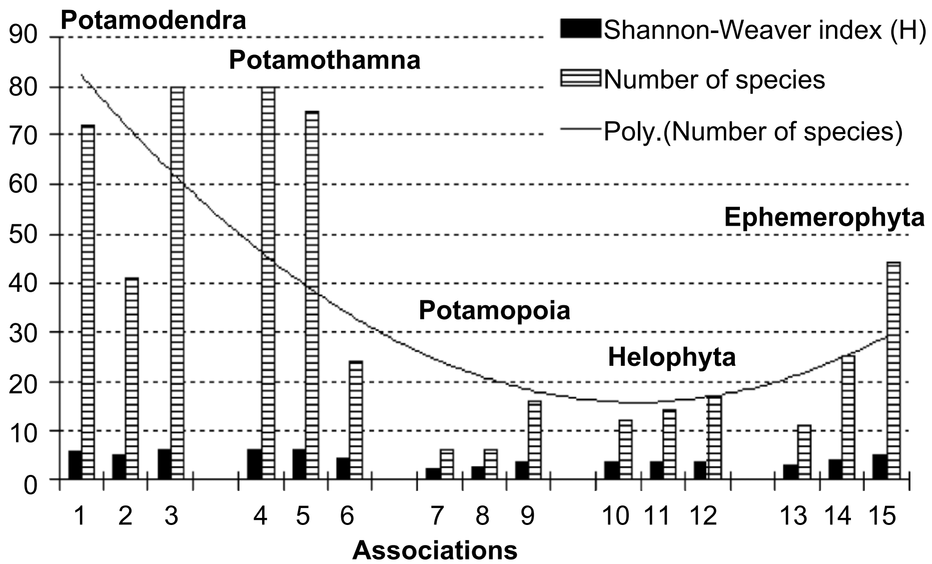

***Figure 5.** Floristic diversity of typical vegetation communities in the floodplains of southwestern Turkmenistan. Potamodendra - Tree Tugai: 1- Ass. Salix aegyptica-Rubus anatolicus-Phragmites australis, 2- Ass. Elaeagnus orientalis-Rubus anatolicus-Cynanchum sibiricum, 3- Ass. Populus diversifolia-Tamarix florida-Elytrigia repens. Potamothamna- Bush Tugai: 4- Ass. Tamarix florida, 5- Ass. Tamarix meyeri, 6- Ass. Tamarix hispida. Potamopoia - Grass Tugai: 7- Ass. Imperata cylindrica-Phragmites australis, 8- Ass. Phragmites australis, 9- Ass. Alhagi persarum-Cynodon dactylon. Helophyta - Vegetation of salt deserts -: 10- Ass. Salsola dendroides, 11- Ass. Halostachys caspica-Limonium reniforme, 12- Ass. Halocnemum strobilaceum. Ephemerophyta - Ephemerals vegetation: 13- Ass. Eremopyrum orientale-Hordeum leporinum, 14- Ass. Phalaris minor-Schismus arabicus-Poa bulbosa, 15- Ass. Poa bulbosa-Schismus arabicus-Spergularia diandra.*

In the composition of the floodplain flora, there are 105 species of herbs and 28 species of wild relatives of cultural plants that are valuable for selection; 38 rare species, 10 of which are listed in the Red Book; and 21 species, valuable for science and agriculture with relict areas or with natural areas being reduced by anthropogenic activity.

We made a list of plant species that grow in the floodplain and delta of the Atrek basin, whose preservation in natural conditions is of great interest for agriculture as well as for science. Preservation of the gene pool of these species helps us to reveal the history of the formation of the flora and vegetation of the region as well as their evolution. We must relate the following species as rare and valuable for the flora of the floodplain of the arid subtropics of southwestern Turkmenistan: *Populus diversifolia*, *Salix songarica*, *Salix aegyptiaca*, *Salix excelsa*, *Elaeagnus angustifolia*, *Elaeagnus orientalis*, *Ulmus minor*, *Platanus orientalis*, *Ficus carica*, *Punica granatum*, *Tamarix hispida*, *Tamarix laxa*, *Tamarix elongata*, *Vitis sylvestris*, *Asparagus brachyphyllus*, *Trachomitum scabrum*, *Glycyrrhiza glabra*, *Arundo donax*, *Erianthus ravennae*, *Imperata cylindrica*, and *Botriochloa ischaemum*.

1.5. State and protection of the floodplain ecosystems

At the end of the 19th century the German naturalist Radde (1898) described the luxuriant thickets of *Tamarix* on the banks of the Atrek river 20 km to the north-west of the Kizil-Atrek settlement. Not a trace of these thickets remains today. By the end of the 19th century high and strong trees of *Ulmus minor* and *Populus diversifolia* had formed the floodplain forest, which grew from 12 km below the Ak settlement along the Chandir river, the valley of which is now completely woodless.

In the 1920s, the tugai forests were rarer in the Atrek basin (Chernyahovskaya, 1924). But in the valley of the Sumbar river and its numerous tributaries, floodplain forests formed by the *P. pruinosa, Salix sp., Colutea gracilis* and *Tamarix* species were still common.

Today the basin of the Atrek river has almost completely lost its tugai tree-bush communities. Only in the middle flow of the Sumbar river (within the limits of the "Tersakan" Sumbar reserve), did we observe thickets of the *Tamarix* and small groves of *Populus diversifolia* with *Ulmus minor* and *Salix excelsa* remaining from the previous rich and extensive floodplain forest.

Along with reduction of the territory of tree-bush tugais during the last decades, significant changes in their structure also took place.

As today we observe a reduction of floodplain vegetation everywhere, it must be kept in mind that under subtropical conditions in western Turkmenistan, the remaining ecosystems of tugai hotbeds are inimitable and unique for preservation of the unity and integrity of the structure, richness and diversity of the region's flora and fauna. The majority of fauna species of southwest Turkmenistan is tightly connected with the river valleys and floodplain ecosystems. Of the region's fauna species, 19 mammals, 17 birds and 11 reptiles are listed in the Red Book of Turkmenistan and the former USSR, including the leopard, hyena, manul, osprey, francolin, central-asian cobra and others. The floodplain tugai communities play important environmental functions, including water-regulation, riparian- and erosion-protection, microclimatic, etc.

Natural self-reconstruction of arboreal-dumetosous vegetation communities is impossible on the patches where they have disappeared because of qualitative transformation of natural habitats. On the new-irrigated territories on the banks of reservoirs (Mamedkul, Delili, Kizil-Ai) and canals new conditions for the growing of *Salix, Populus,* and *Elaeagnus* bushes and for phytomelioration of tugai communities' reconstruction are being created. Such patches, which include reservoirs at least 5-10 years old, are located in the Kizil-Atrek region and in the suburbs of the Chatli, Agach-Arvat, and Karadegish settlements.

For the reconstruction of tugai ecosystems on the disturbed habitats under the reduced flow of the Atrek, it is necessary to reconstruct the floodplain regime in the floodplains and delta for several days during the period from July until August. This will provide an opportunity to wash the soil and to seed the floodplain and deltaic patches. While normal watering is 10,000-12,000 m^3/hectare, the total volume of water on the rivers of the Atrek basin must be not less than 0.5 km^3 (Kouzmina, 1997).

2. RESULTS

1. In the history of the formation and development of floodplain vegetation in the valleys of the rivers of subtropical regions of western Turkmenistan, one can observe tight interrelations between the fluctuations of the hydrological regime and soil-ground conditions. At the present time the regulation of river flow in the basin of the Atrek river is the main destabilizing factor that disturbs the conditions of the vegetation's existence.
2. Human-induced soil salinization is the chief cause for the transformation of tugai ecosystems.
3. For alluvial meadow soils under tugai vegetation in the lower reaches of both the Atrek and the Amu-Dar'ya rivers, soil salinity in the 0-100 cm layer amounting to 0.25% may be considered as the critical point from which the accelerated evolution of soils and of tugai ecosystems as a whole begins toward halophytization.
4. The most complete conservation of slightly saline and non-saline soils (salt content less than 0.4%) is one of the main conditions for maintaining regional floral diversity of tugai communities in the southwestern Caspian Sea region.
5. Salinization of alluvial soils in the southwestern Caspian Sea region violates the natural dynamics of tugai ecosystems. The following processes are observed there:
   - Overall halophytization of tugais at different stages of series, which often results in the disappearance of typical floral differences of tugai communities in different regions;
   - Disappearance of typical tree and bush tugai communities;
   - Development of different grass tugais, which were not formerly widespread;
   - Accelerated irreversible transformation of typical tugais into communities of halophytes;
   - Considerable loss of species diversity in communities of grass tugais and of solonchak deserts in comparison with typical tugais.

3. REFERENCES

Ageleulov, Å.À. 1987. Flora of the flood plain of the Ural river. Alma-Aty: Nauka, 103 pp.

Ashirova, A.A. 1976. Rastitel'nost' doliny i del'ty Amudar'I ee khozyaistvennoe ispoVzovanie (Vegetation of the Amu Dar'ya Valley and Delta and Its Economic Use), Ashkhabad: Ylym, 324 pp.

Bakhiev, A. 1985. Ekologiya i smena rastitelnykh soobshchestv nizov'ev Amudar'i (Ecology and Changes in Plant Communities in the Lower Part of the Amu Dar'y River), Tashkent: Fan, 192 pp.

Bykov, B.A. 1978. The general analysis of Flora of deserts of Turanian lowland // Structure and productivity of the vegetation in the desert zone of Kazakhstan. Alma-Aty: Nauka KazUSR, 3-8 pp.

Cherepanov, S.K. 1995. Plantae Vasculares Rossicae et civitatum collimitanearum (in limicis URSS olim). S. Petropolis "Mir i Semia-XCV" MCMXCV, 992 pp.
Chernyahovskaya, E.G. 1924. Vernal vegetation of the Kara-Kala region of the Caspian area // Izvestija of a main botanical garden. 18 pp.
Drobov, V.P. 1950. Tree and Bush Vegetation of Tugais in Kai akalpak Autonomous Soviet Socialist Republic // Materialy po proizvoditel'nym silam Uzbekistana Karakal pakskaya ASSR (Works on Productive Forces of Uzbekistan: Karakalpak Autonomous Soviet Socialis Republic), Moscow: Akad. Nauk SSSR, 55-107 pp.
Drobov, V.P. 1951. Halophytic Vegetation of River Valleys in Uzbekistan // Byull. Mosk. O-va. Ispvt. Prir., Ser: Biol. (Bulletin of MOIP, Biology) 6: 42-46.
Fedorovicz, B.A. 1983. Dynamics and predictabilities of relief formation of deserts. M.: Nauka, 238 pp.
Genusov, A.Z. 1983. Pochvy i zemeVnye resursy Srednei Azii (Soils and Land Resources of Central Asia), Tashkent: Fan, 134 pp.
Grave, N.P. 1936. Tugainye dzhungli nizov'ev Annular (Tugai Jungles in the Lower Part of the Amu Dar'ya River), Moscow, 78 pp.
Kouzmina, Zh.V. 1997. Conservation of genetic diversity of the flora in the floodplain of south-west Turkmenistan // Arid Ecosystems. 102-117 pp. (in Russian and in English).
Kovda, V.A. 1946. Soil-forming Processes in Deltas and Floodplains of Rivers in Continental Regions of the USSR// Problemy sovetskogo pochvovedeniya (Problems of Soviet Soil Science), Moscow: Akad. Nauk SSSR Publisher, 101-124 pp.
Kuz'mina, Zh.V. & Treshkin, S.E. 1997. Soil Salinization and Dynamics of Tugai Vegetation in the Southeastern Caspian Sea Region and in the Aral Sea Coastal Region // Eurasian Soil Science. pp. 642-649. 1997. Translated from Pochvovedenie. 726-734 pp. (in Russian and in English).
Mailun, Z.A. 1973. Tugai Vegetation // Rastitcl'nyi pokrov Uzbekistan (Plant Cover of Uzbekistan), Tashkent: Fan, 303-375 pp.
Pankova, E.I. & Mazikov, V.M. 1985. Metodicheskie reko mendatsii po ispol'zovaniyu materialov aerofotos "emki dlya otsenki zasoleniya pochv i provedeniya solevykh s "enwk oroshaemykh territorii khlopkoseyushchei zony v krupnykh i srednikh masshtabakh (Methodical Recommendations for Use of Aerial Photos for Assessment of Soil Salinity and for Surveying Salt Content over Irrigated Lands in the Cotton Growing Zone at Large and Medium Scales), Moscow, 74 pp.
Radde, G. 1898.Wissenschaftliche Ergebnisse der im Jahre 1886 allerhoechst befohlenen Expedition nach Transkaspien und Nord-Chorossan // Petermanns Geogr. Mitteilungen, Ergaenzungsheft 126. Gotha, 196 S.
Rafikov, A.A. & Tetyukhin, G.R. 1981. Snizhenie urovnya Aral'skogo morya i izmenenie prirodnykh uslovii nizov'ev Amudar'i (Lowering of the Aral Sea Level and Changes in Natural Conditions in the Lower Part of the Amu Dar'ya River), Tashkent: Fan, 200 pp.
Rodin, L.E. 1963. Rastitel'nost pustyn' Zapadnoi Turkmenii (Vegetation of Deserts in Western Turkmeniya), Moscow: Akad. Nauk SSSR, 309 pp.
Rozanov, A.N. 1951. Serozemy Srednei Azii (Grey desert soils of Central Asia), Moscow: Akad. Nauk SSSR Publisher, 459 pp.
Shul'ts, V.L. 1965. Reki Srednei Azii (Rivers of Central Asia), Leningrad: Gidrometeoizdat, 691 pp.
Treshkin, S.E. & Kuz'mina, Zh.V. 1993. Changes in Flood-plain Forest Ecosystems of the Amu Dar'ya and Sumbar Rivers as a Result of Anthropogenic Influence, Problemy osvoeniva pustyn' (Problems of Desert Development), Ashkhabad: Ylym, N 2. 14-19 pp.
Zaktreger, I.Ya. 1927. Tugainye lesa nizhnego teclieniya rek Amudar'i (Tugai Forests in the Lower Part of the Ami Dar'ya River), Moscow: Akad. Nauk SSSR, 21 pp.
Zhollybekov, B. 1991. Izmenenie pochvennogo pokrova pri morskoi del'ty Amudar'i pri aridizatsii (Changes in Soil Cover of Seaside Delta of the Amu Dar'ya River as a Result of Aridization), Nukus: Bilim, 130 pp.

CHAPTER 9

ECONOMIC HALOPHYTES OF BAHRAIN

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1. INTRODUCTION

Early agriculture began more than 10,000 years ago when people planted wild wheat to overcome the shortage in summer food. Since then, agriculture has developed from primitive practice by early man to very advanced and sophisticated industry. Throughout, man was successful in manipulating environmental conditions, including climate and soil, to grow agricultural crops in large scale. However, mismanagement and lack of proper agricultural and ecological practices could cause salt problems and/ or salt accumulation under any climatic system. This is particularly seen in arid lands and poorly draining soils, which are susceptible to salinization. Salinization refers to the surface or near-surface accumulation of salts such as chlorides, sulphates and carbonates of sodium, calcium and magnesium. It also includes alkalization and sodification, which arises from the dissolved salt load of irrigation water (Chhabra, 1996). In many parts of the world the efficiency of many irrigation schemes is low and land degradation problems are widespread. Poorly designed and implemented irrigation schemes can cause water logging, salinization and alkalization of soils (UNEP, 2002). Each year millions of acres of irrigated lands lose their productivity because of salt accumulation. According to FAO (1995a) estimates, 25-30 million ha of the world's 255 million ha of irrigated land were severely degraded due to accumulation of salts. An additional 80 million ha were reported to be affected by salinization and water logging (FAO, 1995b).

The problem of land salinization and reduction of productivity is not only limited by bad agricultural practice, but the shortage of fresh water is another major obstacle in many parts of the world. In the Arabian Peninsula, the fresh water shortage is a major problem. Water stress in this region is predicted to continue in the next decades as water demands exceed available water resources,

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owing to population growth and expansion of different development sectors (UNEP, 2002). The future expansion of food production will be increasingly dependent upon sound irrigation and water management and upon the concurrent maintenance of the present agricultural resource base and the environment - two of the most challenging tasks facing mankind today (UNEP, 2002).

Three basic approaches are available to fight against salinization (Aronson, 1985). The first is to improve drainage so that salt build up is decreased or halted. The second is to select or breed for greater tolerance in conventional crops through selection, hybridization, back crossing, tissue culture and genetic engineering to make them more salt-tolerant. Examples of early attempts for such approach are wheat and barley (Epstein & Norlyn, 1977); tomatoes (Tal, 1971); or cotton and sugar beets (Ahmad & Abdulla, 1981). A third more recent approach is to find the salt-tolerance gene in wild halophytes and transfer this gene to the conventional glycophyte crops. Based on this approach, ideas were proposed over the past 35 years to use seawater for crop production along coastal deserts (Boyko, 1966; Epstein et al., 1980; Glenn et al., 1995). This approach also opens the possibility of utilizing areas traditionally considered unsuitable for any type of agriculture. More than 1500 salt-tolerant plant species have been identified. Some are able to tolerate salt concentrations above seawater level. Species from several families produce high biomass or seed yield under seawater irrigation (Glenn & O'Leary, 1985; Glenn et al., 1991; Glenn et al., 1997). These plants could be used as a major source in bio-saline agriculture research. Understanding how salts affect water, soils, and plants is important when developing the agricultural practices for the use of saline water for irrigation. It also requires the adoption of proper management protocols to control salinity in the irrigated fields and also in the geohydrologic systems.

1.1. Economic halophytes

There is a wide range of traditional uses of halophytes in different parts of the world (Aronson, 1985). Examples are the mangroves that are used for timber, firewood and charcoal, and as a source of tannin and many minor products. Saltbushes and chenopods are used for forage and fodder, particularly *Atriplex*. Sugar beet is used as food crop. Traditionally, some chenopods such as *Arthrocnemum*, *Salsola*, and *Suaeda* were used in the soap and glass industry. The stems of *Juncus rigidus* have been used to make mats and baskets (Zahran et al., 1979). In addition, some halophytes are used in land reclamation, e.g. *Distichlis spicata*, and landscaping, e.g. *Tamarix* spp. (Aronson, 1985). Batanouny (1993) reported several uses of halophytes in the Arab region, e.g. timber (*Tamarix* spp. and *Avicennia marina*), tannin (*Rhizophora mucronata*). The use of halophytes in traditional medicine in the Arab region is well reported (Batanouny, 1993; Abbas & El-Saleh, 2002; Ghazanfar, 1998).

1.2. Climate, geomorphology, and vegetation of Bahrain

1.2.1. Climate and geomorphology

Bahrain is an archipelago of 33 islands located in the mid-western part of the Arabian Gulf about 25km east of Saudi Arabia at 25° 32′ and 26° 20′ N, and 50° 20′ and 50° 32′ latitude E (Figure 1).

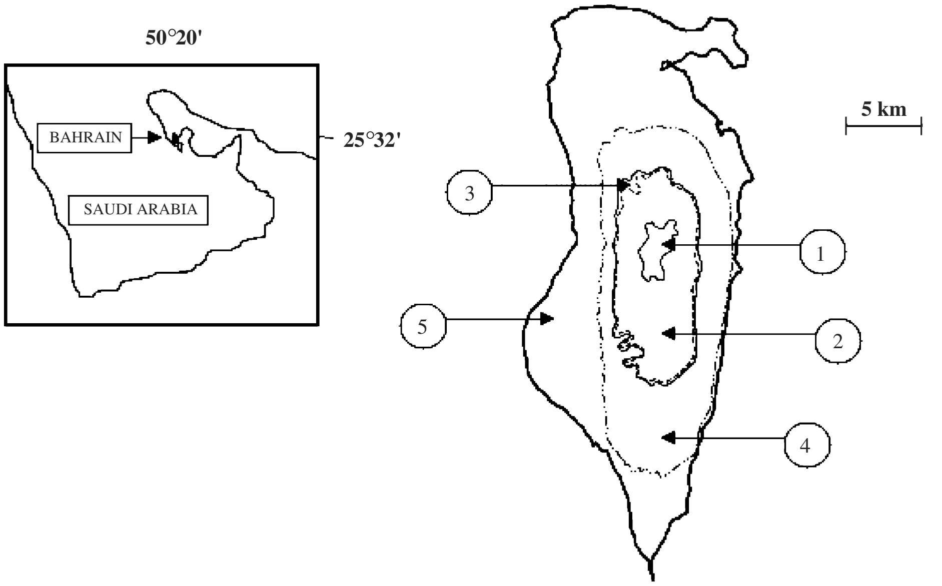

Figure 1. *Location Map of Bahrain Showing Physiographic Zones. 1: Central Plateau and Jabals; 2: Interior Basin; 3: Multiple Escarpments; 4: Backslope; 5: Coastal Lowlands.*

Geomorphologically, five physiographic zones characterize the topography of Bahrain (Figure 1). These are: (a) the central plateau and jabals; (b) the interior basin; (c) the multiple escarpments; (d) the backslope; and (e) the coastal lowlands (Doornkamp et al., 1980). The narrow lowland surrounds the backslope and is widest in the north and west and narrowest in the east. It covers an area of approximately 275 km^2, with general surface elevation below 5 m, composed mainly of loose or partially cemented aeolian or marine sediments. This plain extends from the backslope of the rocky core, where it is at elevations of approximately 10 m, to sea level at the coastline.

Bahrain, like mainland Arabia, falls in the North African-Eurasian dry climate province (McGinnies, 1979). According to climatic norms obtained from the Civil Aviation Directorate (Bahrain), the climate is characterized by the prevalence of mild winters and very hot summers. Figure 2 shows the monthly mean maximum and minimum temperatures. The lowest mean daily maximum temperature is 19.9°C (January) and the highest mean daily maximum temperature is 37.7°C

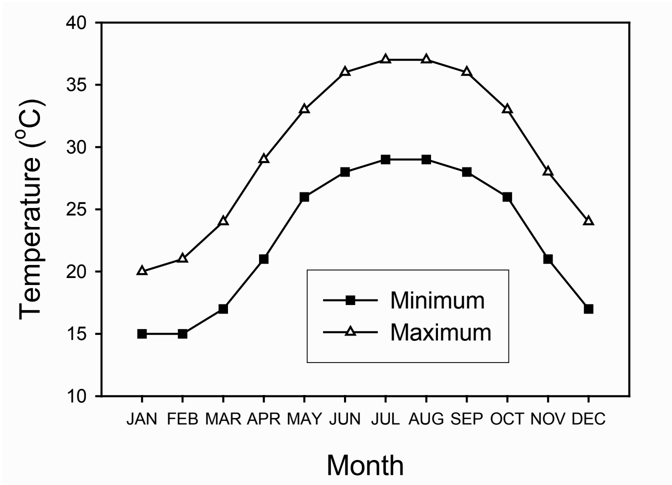

Figure 2. *Mean daily maximum and minimum temperature in Bahrain.*

(August). The lowest mean daily minimum temperature is 14.5°C (January) and the highest mean daily minimum temperature is 30.7°C (August).

Relative humidity is generally high. The highest mean daily maximum relative humidity is 88% (October), and the lowest mean daily minimum relative humidity is 39% (May). Precipitation is low and irregular and mostly in the form of winter rain (Figure 3). The highest monthly rainfall occurs in January (17 mm). The period extending from June to October is characterized by very low rainfall (less than 0.05 mm). Evaporation values exceed those of rainfall during summer months (Figure 3). The highest monthly mean evaporation value occurs in June (10.45 mm). This corresponds to the maximum mean daily hours of sunshine which reach a value of 11.3 h during that month.

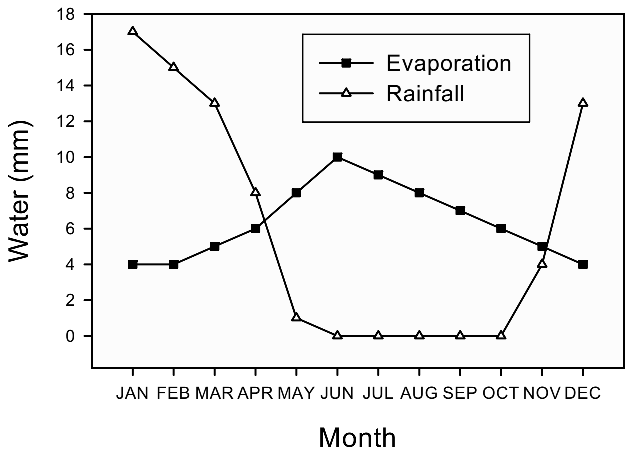

Figure 3. *Mean rainfall and evaporation in Bahrain.*

1.2.2. Flora and vegetation

The flora of Bahrain is represented by 311 species belonging to 193 genera and 51 families (El-Oqlah & Abbas, 1994). Gramineae, Chenopodiaceae, Compositae, Leguminosae, and Caryophyllaceae dominate plant families in the flora of Bahrain (El-Oqlah & Abbas, 1992). The Saharo-Arabian elements comprise 236 species that is 73% of the total flora. Abbas & El-Oqlah (1992) identified 97 halophytic species in the flora of Bahrain (Annex 1). The most abundant species belong to the families Chenopodiacae and Zygophyllaceae. The majority of halophytes are perennials, e.g. *Anabasis setifera*, *Arthrocnemum macrostachyum*, *Avicennia marina*, *Suaeda vermiculata*, and *Zygophyllum qatarense*. Seventeen halophytic community-types were reported (Abbas & El-Oqlah, 1992).

The vegetation of Bahrain may be classified under six vegetation types, which are distinguished on the basis of habitat factors and dominant species. These vegetation types are:

- Sabkha and salt pans vegetation
- Sand dunes vegetation
- Coastal plain vegetation
- Stone pavements vegetation
- Rocky habitats vegetation

1.3. Halophytes with potential economic use

The following is an account of halophytic plants from Bahrain and their traditional uses in Bahrain and Arabia as documented in literature and previous studies by the author (Abbas & Al-Saleh, 2002; Ghazanfar, 1998; Batanouny, 1993; Boulos, 1985):

MEDICINAL PLANTS
Aizoon canariense
Sesuvium verrucosum
Calotropis procera
Glossonema varians
Leptadenia pyrotechnica
Avicennia marina
Arnebia hispidissima
Heliotropium crispum
Moltkiopsis ciliata
Capparis spinosa
Herniaria hemistemon
Atriplex leucoclada
Chenopodium murale
Cornulaca monacantha
Salsola villosa
Suaeda vermiculata
Filago desertorum
Koelpinia linearis
Launaea nudicaulis
Pulicaria undulate
Cressa cretica
Anabasis articulata
Cynodon dactylon
Phragmites australis
Alhagi graecorum
Prosopis farcta
Malva parviflora
Cistanche tubulosa
Plantago ovata
Limonium axillare
Emex spinosa

FOOD PLANTS
Aizoon canariense
Glossonema edule
Capparis spinosa
Chenopodium murale
Alhagi graecorum
Malva parviflora

FORAGE PLANTS
Anabasis articulata
Ifloga spicata
Aeluropus lagopoides
Aeluropus littoralis
Alhagi graecorum
Malva parviflora

FIBER AND TIMBER
Avicennia marina
Juncus rigidus
Tamarix spp.

LANDSCAPING AND RECLAMATION
Haloxylon persicus

FIREWOOD AND FUEL
Cornulaca monacantha
Salsola baryosma
Alhagi graecorum
Tamarix macrocarpa

OIL
Juncus rigidus

2. CONCLUSION

The attempt of scientists in many parts of the world to increase the productivity of lands is continuing. Efforts to use plants that can tolerate salinity are increasing. In general, Bahrain and Arabia have many halophytic plants that have been used traditionally in many ways. These plants could be used as a source of genetic materials in the endeavour to use halophytic plants in agriculture.

3. REFERENCES

Abbas, J.A. & Al-Saleh, F.S. 2002. Medicinal Plants of Bahrain. University of Bahrain Publications. 290 pp.

Abbas, J.A. & El-Oqlah, A.A. 1992. Distribution and communities of halophytic plants in Bahrain, Journal of Arid Environments 22: 205-218.

Ahmad, R. & Abdulla, Z. 1981. Biomass Production of Food and Fibre Crops Using Highly Saline Water Under Desert Conditions, in A. San Pietro (ed.), Biosaline Research: 149-164. New York: Plenum Press.

Aronson, J. 1985. Economic Halophytes - A Global Review, in Wickens, G.E., Goodin, J.R. and Field, D.V. (eds.), Plants for Arid Lands: 177-188. London: George Allen & Unwin. 452 pp.

Batanouny, K.H. 1993. Ecophysiology of Halophytes and their Traditional Use in the Arab World, in: Halophyte Utilization in Agriculture. Tecnomack Bari, Italy.

Boulos, L. 1985. The Middle East, in Goodin, J.R. and Northington, D.K. (eds.), Plant Resources of Arid and Semiarid lands. A Global Perspective Academic Press, Inc. 129-185.

Boyko, H. 1966. Salinity and Aridity. New Approaches to Old Problems. The Hague: Junk.

Chhabra, R. 1996. Soil Salinity and Water Quality. A.A. Balkema, Rotterdam/ Brookfield.

Doornkamp, J.C., Brunsden, D. & Jones, D.K.C. 1980. Geology, Geomorphology and Pedology of Bahrain. Norwich: Geo Abstracts. 443 pp.

El-Oqlah, A.A. & Abbas, J.A. 1992. Preliminary studies on the natural flora and vegetation of Bahrain. Dirasat 19: 123-137.

El-Oqlah, A.A. & Abbas, J.A. 1994. A checklist of vascular plants of Bahrain. Dirasat 21: 95-118.

Epstein, E. & Norlyn, J.D. 1977. Seawater based crop production: a feasibility study. Science 197: 249-251.

Epstein, E., Norlyn, J.D., Rush, D.W., Kingsbury, W., Kelley, D.B., Cunningham, G.A. & Wrona, A.F. 1980. Saline culture of crops: a genetic approach. Science 210: 399-404.

FAO 1995a. Prevention and Disposal of Obsolete and Unwanted Pesticide Stocks in Africa and the Near East. Rome, Food and Agriculture Organization.

FAO 1995b. Planning for Sustainable Use of Land Resources: Towards a New Approach. FAO land and water bulletin 2. Rome, Food and Agriculture Organization.

Ghazanfar, S.A. 1998. Plants of Economic Importance, in S.A. Ghazanfar & M. Fisher (eds.), Vegetation of the Arabian Peninsula. Kluwer Acadimic Publishers. Geobotany 25: 241-264.

Glenn, E., Hicks, N., Riley, J. & Swingle, S. 1995. Seawater Irrigation of Halophytes for Animal Feed. Halophytes and Biosaline Agriculture, Marcel Dekker, New York.

Glenn, E., Miyamoto, S., Moore, D., Brown, J.J., Thompson, T.L. & Brown, P. 1997. Water requirements for cultivating *Salicornia bigelovii* Torr. with seawater on sand in a coastal desert environment. Journal of Arid Environments 32: 107-118.

Glenn, E. & O'Leary, J. 1985. Productivity and irrigation requirements of halophytes grown with seawater in the Sonoran Desert. Journal of Arid Environments 9: 81-91.

Glenn, E., O'Leary, J., Watson, M., Thompson, T.L. & Kuehl, R. 1991. *Salicornia bigelovii.* Torr. an oil seed halophyte for seawater irrigation. Science 251: 1065-1067.

McGinnies, W.G. 1979. General Description of Desert Areas, in: D.W. Goodall & R. A. Perry (eds.), Arid-land Ecosystems. Vol.1. IBP 16: pp.5-19. Cambridge University Press. 881 pp.

Tal, M. 1971. Salt tolerance in the wild relatives of cultivated tomato: response of *Lycopersicon esculentum*, *L. peruvianum* and *L. esculentum* minor to sodium chloride solution. Australian Journal of Agriculture Research 22: 631-638.

UNEP 2002. Global Environment Outlook 3. Earthscan Publications Ltd. London. Sterling, VA.

Zahran, M.A., Wahid, A.A. & El-Demerdash, M.A. 1979. Economic Potentialities of Juncus Plants, in J.R. Goodin and D.K. Northington (eds.), Arid land plant resources. Lubbock: Texas Tech University. 244-260.

ANNEX 1. LIST OF HALOPHYTIC PLANTS OF BAHRAIN

Aizoaceae
Aizoon canariense L.
Aizoon hispanicum L.
Mesembryanthemum forkahlei Hochst.
Mesembryanthemum nodiflorum L.
Sesuvium sesuvioides (Fenzl) Verdc.
Sesuvium verrucosum Raf.

Apocynaceae
Trachomitum venetum (L.) Woodson

Asclepiadaceae
Calotropis procera (Ait.) Ait.f.
Glossonema edule N.E.Br.
Glossonema varians (Stocks) Benth. Ex Hook.f.
Leptadenia pyrotechnica (Forssk.) Decne

Avicennaceae
Avicennia marina (Forssk.) Vierh.

Boraginaceae
Arnebia decumbens (Vent.) Coss. & Kral
Arnebia hispidissima (Lehm.) DC.
Heliotropium kotschyi (Ledeb.) Gurke
Heliotropium crispum (Desf.
Heliotropium curassavicum L.
Moltkiopsis ciliata (Forssk.) Johnst.

Capparaceae
Capparis spinosa L.

Caryophyllaceae
Herniaria cinerea DC.
Silenea arabica Boiss.
Silene villosa Forssk.
Spergularia marina (L.) Griseb.

Chenopodiaceae
Anabasis articulate (Forssk.) Moq.
Anabasis setifera Moq.
Arthrocnemum glaucum (Del.) Ung.-Sternb.
Arthrocnemum fruticosum (L.)
Arthrocnemum salicornicum (Moric.) Moris & Delponte
Atriplex leucoclada Boiss.
Bassia eriophora (Schrad.) Aschers.
Bassia muricata (L.) Aschers.
Binertia cycloptera Bunge
Chenopodium glaucum L.
Chenopodium murale L.
Cornulaca leucocantha Charif & Allen
Cornulaca monacantha Del.
Halocnemum strobilaceum (Pall.) M. Bieb.
Halopeplis amplexicaulis (Vahl) Bunge ex Ung.-Sternb.
Halopeplis perfoliata (Forssk..) Bunge ex Schweinf.
Haloxylon persicum Boiss.
Hamada salicornica (Moq.) Iljin
Panderia pilosa Fisch. & Mey.
Salicornia europaea L.
Salsola baryosma (Roem. & Schult.) Dandy
Salsola imbricata Forssk.
Salsola vermiculata L.
Salsola villosa Del. Ex Roem. & Schultes
Seidlitzia rosmarinus (Erenb.) Solms-Laub.
Suaeda aegyptiaca (Hasselq.) Zoh.
Suaeda maritima L.
Suaeda vermiculata Forssk. Ex J.F. Gmel.
Suaeda moschata A.J. Scott.

Compositae
Filago desertorum (Pomel.) Wag.
Filago spathulata Presl.
Keolpinia linearis Pall.
Launaea capitata (Spreng.) Dandy
Launaea cassiniana (Jaub. & Spach.) Kuntze
Launaea mucronata (Forssk.) Muschl.
Launaea nudicaulis (Less) Hook.f.
Launaea procumbens (Roxb.) Ramayya & Rajagopal
Launaea tenuiloba Boiss.
Pluchea ovalis (Pers.) DC.
Pulicaria crispa (Forssk.) Benth. & Hook.f.
Pulicaria gnaphalodes (Vent.) Boiss.
Pulicaria undulate (L.) C.A. Mey.
Reichardia tingitana (L.) Roth

Convolvulaceae
Cressa cretica L.

Cyperaceae
Cyperus arenarius Retz.
Cyperus conglomerates Rottb.
Cyperus laevigatus L.

Frankeniaceae
Frankenia pulverulenta L.

Geraniaceae
Erodium laciniatum (Cav.) Willd.

Gramineae
Aeluropus lagopoides (L.) Trin. Ex Thw.
Aeluropus littoralis (Gouan) Parl.
Cutandia dichotoma (Forssk.) Trabut
Cutandia memphitica (Spreng.) Benth.
Cynodon dactylon (L.) Pers.
Phragmites australis (Cav.) Trin. Ex Steud.
Phragmites communis Trin.
Sporobolus arabicus Boiss.
Sporobolus spicatus (Vahl) Kunth

Juncaceae
Juncus rigidus Desf.

Leguminosae
Alhagi graecorum Boiss.
Prosopis farcta (Banks & Sol.) Machor.

Malvaceae
Malva parviflora L.

Orobanchaceae
Cistanche phelypaea (L.) Cout.
Cistanche tubulosa (Schenk) Hook.f.
Orobanche cernua Loefl.
Orobanche muteli F. Schultz

Plumbaginaceae
Limonium axillare (Forssk.) Kuntze

Polygonaceae
Emex spinosus (L.) Campd.

Tamaricaceae
Tamarix arabica Bunge
Tamarix macrocarpa DC.
Tamarix pycnocarpa DC.

Typhaceae
Typha domingensis Pers.

Zygophyllaceae
Setzenia lanat (Willd.) Bullock
Zygophyllum qatarense Hadidi

CHAPTER 10

THE MAIN REGULARITIES OF DUST-SALT TRANSFERENCE IN THE DESERT ZONE OF KAZAKHSTAN

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1. INTRODUCTION

The area of Kazakhstan is 272.3 mln.ha. The major part of the territory is represented by plain (93.0%), fringed only in the south, and southeast by the Tyan Shan, Tarbagatai and Altai mountains (7.0%).

The climate is very arid. The soils of saline series are rather widely spread in the structure of the soil cover of all geographical zones. Solonchaks account for more than 8.5 mln.ha (zones of brown and grey-brown soils) of the total area of Kazakhstan. Solonetzes and solonetz-like soils occupy more than 70 mln.ha (especially in the dry-steppe and desert-steppe zones). Maximum participation (51%) of saline soils in soil cover is observed in the light-chestnut soils of the dry desert steppe (semi deserts) where the sum of participation per year makes up 200-230 mm under an evaporation of 800-1,000 mm. Mainly solonetz-like complexes with participation of solonetzes themselves prevail here constituting from 10 to 30% of soil cover. In the desert zone of brown, grey-brown and takyr-like soils, where precipitation is 120-170 mm per year and evaporation is over 1,000 mm per year, the quantity of solonchaks makes up 15% of soil cover and the quantity of solonchaks in complexes makes up 16% of soil cover (Borovsky & Uspanov, 1971).

Solonchaks of different variants are especially widely spread in the deltas of rivers in the desert zone of southern Kazakhstan – the Syr Darya, Talas, Assy, Ili and the lower reaches of the Ural river. Vast areas of solonchaks are located in small and large reservoirs: the Myertvy Kultuk near the Caspian Sea, the saline coasts of the Aral and Balkhash seas and some other places serve as examples. The content of easily soluble salts in crusty-swelling solonchaks ranges from 150 to 400 t/ha in the upper 1 m layer.

M. Ajmal Khan et al. (eds.), Sabkha Ecosystems. Volume II: West and Central Asia, 121-128.

Deserts are not as saline as would be expected, however, despite the high levels of salinity in the soils, landscapes, river valleys, and depressions without outflow and also in the enclosed seas – the Caspian and the Aral – and their adjoining areas. The occurrence in the arid zone of salt accumulation in large amounts in places without outflow together with a comparatively low level of soil salinization still arouses perplexity from investigators and raises the question of where the missing salts from the deserts disappear to the fresh condition of the enclosed Lake Balkhash in the desert was characterized by L.S. Berg as "a geographical paradox".

Estimating the development of salt accumulative processes in the south of Kazakhstan (in the basins of the Caspian and Aral seas), the investigator (Kovda, 1954) writes that it is very surprising that the desert is less saline than would usually be expected. Together with other products of aeolation, the salts from the Tyan Shan, the Ural, the Caucasus and the Obshy Syrt have been accumulating in the Caspian and Aral seas and also in the deserts and semi deserts surrounding them for thousands of years (during the whole alpine orogenesis). The Volga, Amudarya, Syrdarya, Ural, Terek and Kura have delivered about 86 mln.t of salts annually. There are many other examples.

We witnessed the problem of salts flowing off when we calculated the water-balance of the lower reaches of the Chu (renamed Shu) river, where the long-term soil-hydrogeological investigations (1960-1985) were carried out.

On the solonchaks of Kazakhstan, it became possible to solve this riddle, as it was marked in reviews later, "to cut off a Gordian knot". The Ulanbel delta of the lower reaches of the Chu river became a unique natural model (a wonderful enclosed morph sculpture), where we were given the opportunity to estimate all the components of the water-salt balance excluding only one: aeolian removal.

The value of aeolian removal was measured for the first time in 1978; it played the main role in the theoretical calculations.

It was possible to measure the approximate amount of aeolian salt removal with the help of a simple equation, obtained on the basis of the established components of the water-salt balance:

$$Sa - (Sb + Sw)\, I = Sc,$$ (Borovsky & Uspanov, 1971)

Hence

$$Sw = T\,(Sa - Sb) - Sc / T$$ (Kovda, 1954)

Where Sc – static salt reserves in salt-ground thickness,
Sa – annual amount of salts brought by hydro chemical means and with precipitation (and from other sources if they exist),
Sb – removal of salts by hydro chemical means,
T – period of salt accumulation,
Sw – aeolian removal of salts from the territory.

According to the calculations, 728 tons of salt are removed from 1 km^2 of the Ulanbel delta annually, where solonchaks account for 40-50% of the whole territory. In the water-salt balance the removed salts made up 47% of the total amount of the salt arrival – close to the amount of salt arrival due to hydro runoff. Though the water-salt balance is positive, it is close to zero. The total amount of salt arrival was only 5 kg a year per 1 ha. The aeolian removal of salts was only 35 t/km^2 in the lower reaches of the Talas river with less participation of solonchaks in soil cover. But in the water-salt balance this discharge made up 46% of the total amount of salt arrival.

Thus in practice a considerable transit of salts due to powerful factors – hydro chemical runoff and aeolian removal – takes place in the river deltas of desert regions with low sedimentation, but not a catastrophic salt concentration.

The long term stability of salt resources in the soil can be explained by this. Therefore, analyses of materials collected during 12 years of observation on the water-salt regime in the Ulanbel delta (1962-1973) before the improvement of the Chu river, showed that an increase of salt resources in soils during this time did not take place despite the exceeding amount of salt arrival over hydro chemical removal. The long-term "curve" of salt concentration in meadow crusty-swelling solonchaks did not rise and remained at its former level. As annual seasonal observations of this period have shown, the long-term equilibrium is conditioned by spring-summer decreases due to salt removal into the atmosphere.

The amount of aeolian removal of salts directly from solonchaks out of the complex was also determined in 1978 and after by various methods (Orlova, 1983). The removal proved to be immense – 5-7 thousand t/km^2 a year. At that time such a value seemed unbelievable. It was the main component of the salt regime and salt balance of soils, lands and reservoirs of the arid zone. Further investigations confirmed that a considerable salt removal was taking place. In conformity with the investigations performed by the scientists of the Soil Science Institute in 1988, it was determined that the aeolian removal of salts from solonchaks, located on the dry bottom of the Aral sea, made up 6-100 th t/km^2 per year.

The hydro chemistry of lake Balkhash as related to salt removal by aeolian means is of special interest. This "pearl" of Kazakhstan is a wonder for the whole world. A fresh lake in the desert! This lake is located near the most remote point of land from the ocean coasts and is similarly remote from the city of Almaty. As an enclosed reservoir where a profound amount of water-soluble salt is brought with river runoff from the Tyan-Shan (Ili river and other rivers of the Semirechye), the scientists came to the conclusion that Lake Balkhash could transform into a salted lake. As it is reported, the amount of soluble salts brought to Balkhash exceeds its mineralization by 0.04% annually. In connection with this, the existent salinity of the lake could be achieved over 25 years. Sedimentation of calcium and magnesium hydro carbonates was taken into account. Calculations of the rate of salt concentration and the age of Balkhash led to paradoxical results, and the low level of salts in the lake remained a mystery. In reality the solution to this phenomenon was very simple. Discharge of salts in Balkhash occurs through a wise natural process of the lake itself together with aeolian removal. In the western part of the lake, the coasts are very close to each other, forming a kind of a long narrow "appendix", actually providing a natural settling basin with highly saline water. Water discharge from the fresh part of the lake feeds the coast of the settling basin in its full width of 5-10 km, forming a band of solonchaks (crusty-swelling sodium-chloride-sulphate), and the salts are removed from here by wind annually in great amounts, saving the lake and the Ili depression from transformation into a salty field.

There is a supposition that the salts from Balkhash are brought to Almaty from time to time, causing problems for the owners of summerhouses. In April 2002 alkaline rain fell here, and the analysis of the rainwater showed a high level of alkalinity: pH 8.4 instead of the usual 6.6.

Solonchaks are of great value for removal of salts from the territories. Meadow swelling and crusty-swelling solonchaks are actually the same in their processes of seasonal transformation or development. They easily turn from one stage into another due to a change in circumstances. They usually occupy upland sites of the relief and sink moisture, accumulating salts under their evaporation. An evaporation horizon is formed on the surface under evaporation of moisture from the closely located ground waters. The evaporation horizon is the main genetic index of the solonchak that actively contacts the atmosphere. Its thickness ranges from several mm to many cm. The content of salts may also vary, from 0.7-1.0% to 99.9% of the soil weight. The content of salts and type of chemical composition can change during the season. The swelling horizon in spring with abundant sodium sulphate content is usually very loose and can easily be dispelled. By autumn, chlorides, calcium sulphate, carbonates and fine earth are observed in the salt composition together with sodium sulphate. The solonchaks become crusty-swelling with a high content of salts in a sub crusty loose horizon by autumn.

Thus solonchaks can be referred to as the most adaptable type of soils. They undergo changes either by morphologic or chemical indices during the shortest periods of time, especially under extreme conditions: rains, dust storms, etc. In several seconds these "accumulators" can lose weight under the rush of wind (sandstorms). Such an instant decrease has not usually been observed and taken into account in calculations. Regime observations of salt removal from solonchaks in the lower reaches of the Chu river showed that salt removal from solonchaks usually reaches 50-70 t/ha per year. This process is mainly realized during the spring-summer period. It coincides with the data of cosmic observations (Grigoryev & Lipatov, 1982). Dust storms were observed on the southern area of the former USSR in spring and early summer (March, April) and to a lesser degree in autumn (September).

The composition of salts depends on the soil's geochemical province. Thus the evaporation horizon of the Ili river's lower reaches contains a greater amount of soda than the solonchaks of the Chu river's lower reaches, especially in the delta plains, where chloride-sulphate and sulphate-chloride salinization prevails. Solonchaks of deserts are a source for salt atmospheric aerosols. Removal of salts into the atmosphere represents the most important act of earth changes and interrelations. Transference of salts by air from arid territories affected by salts (from solonchaks) to non-saline humid soils takes place. An aerosol map of Kazakhstan shows this vividly. It negatively reflects the soil map of salts. The greatest amount of salts (>20 t/km^2 a year) falls in the forest-steppe and steppe zones in the north and in the zone of piedmonts and Middle Mountain territories of southern Kazakhstan, where the soils are non-saline or low saline. The lowest amount of salts (<10 t/km^2 a year) is observed in the desert zone, where the amount of solonchaks is a tenth as small.

Research performed by Siberian scientists testifies to the transference of salts from deserts to humid regions. According to their opinion (Panin et al., 1977), solonetz-like soils and solonetzes of west Siberia are formed due to aeolian accumulation of salts brought with precipitation. Such a conclusion is justified by the fact that relic accumulations of previous epochs are absent here, and the amount of brought salts in landscape salt exchange prevails over the salts of aeolation products. It is obvious that the salts are brought to the regions of west Siberia from the solonchak deserts of Kazakhstan.

The presence of solonetzes in the northern hemisphere under the Yakutiya permafrost testifies to the interzonal relation in the system of salt transference. Apparently, this phenomenon is connected with salt removal from solonchaks to the province of Kazakhstan.

Solonetzes are more conservative and less saline in comparison with dynamic solonchaks. In most cases solonetzes are derivatives of solonchaks. The salts from solonchaks of the desert in the south of Kazakhstan are, in the first turn, accumulated on the border with the dry-steppe and further to the north in the forest-steppe and steppe zones, where precipitation is 2-2.5 times as great as in the desert. But this amount of precipitation is not enough for the washing of the profile. Solonetzes are stable, complex processes that are not limited by the ion exchange reaction between soil and electrolytes, but are accompanied by synthesis of hydromorphic molecular combinations.

Hydromorphic combinations play the role of peptizators and stabilizators of hydromorphic colloids even in the presence of exchangeable calcium. In comparison with solonchaks these soils have a more complicated nature of synthesis at a high molecular level but not at an atomic one. Connected with this is their complex amelioration and resistance to deflation in contrast to solonchaks (Seifullina).

Self-regulation takes place either in salt concentration or in development of salts. Reverse negative bindings become active at some stages of the geochemical process. The more salts are brought into solonchaks, the greater the amount of salts removed by wind. This stabilizes the salt resources. Some equilibrium is established, and negative reverse binding hampers the development of progressing salt accumulation and leads to its reduction. Stability in the long-term salt regime of soils subjected to salinization can be explained by the existence of reverse negative binding.

Based on the example of Kazakhstan's soils, it has been established (Belgibayev, 1972) that soil material subjected to deflation and re-accumulation is represented as a rule by a fraction of 1 mm. And what do the mixture of salts and fine earth in the evaporation horizon of solonchaks represent? The dust-salt mass of the crusty disturbed and sub crusty swelling horizon of solonchaks (spring generation) was subjected to mechanical analysis under the microscope MBS-1. Its content of water-soluble salts was 94.79% (from the weight of the mass), mainly due to sodium sulphate. The linear size of particles was 0.003 mm, but the total mass was represented by flakes of 0.15-0.225 mm. The linear size of the dust-salt mass of marsh solonchaks in the eastern area adjacent to the Aral sea (from the dry bottom of the Aral sea) ranged from 0.0025 to 0.15 mm with a prevalence of dust fractions. According to the existent dependences on particles removal under different rates of their sedimentation and wind speed, silt particles are characterized by the property of slow sedimentation and long way of flight even under a comparatively weak wind (6 m/Sec). Silt particles of 0.0125 mm have potential for remote flight from 4 to 10,000 km. The finest particles we found, <0.0025 mm, may cover a distance of up to 25,000 km under the same weed speed. Therefore the dust-salt mass of the solonchak evaporation horizon has a high potential for air migration.

This has been confirmed by research data on the determination of the critical rate and level of dust-salt erosivity with the help of an aerodynamic pipe, PAU-3. The dust-salt mass of the sub crusty swelling horizon (0.5-2 and 0-3 cm) under the total sum of salt-sodium sulphate and gypsum carbonates made up 40-60% of the weight of the soil. The critical rate of removal was 2.5-4 m/c. High indices of the swelling horizon's erosivity within 440-2,800 t/km^2 testify to the possibility of intensive removal of salts by wind, and are in accordance with the above mentioned data calculations. In accordance with the observation made by the workers of the Ulanbel meteo station, dust salt columns rose into the air over the solonchakous region of the valley (between Betpakdala and Muyunkum) under a wind of 10 m/s.

Sandstorms play a significant role in salt removal from solonchaks by wind. In April, we had an opportunity to observe how sandstorms sometimes appear over the solonchaks in the form of white swift funnels, carrying salts into the atmosphere. We observed 20 such sandstorms over 1 hour.

Dust transference is mainly considered in current literature. A lot of work is devoted to dust and sand storms. Removal of dust salt mass by wind from land is a complex and poorly studied process, which depends on many factors. These include: level and type of salinization, percentage of salts and fine earth, density, thickness of the crust and sub crust horizon, humidity, fixation by vegetation, size of particles, level of destruction under grazing, etc.

The experiments showed that swelling salt horizons are easily subject to deflation in comparison with usual fine earth. The distance and speed of silt particles' flight is obviously higher and therefore salt particles will leave soil dust behind. But salt particles are more dependent on humidity.

The role of the aeolian factor in the salt regime of the territories is great. The submitted materials of the investigations testify to the fact that two powerful agents of salt transference – water and wind – regulate salt regime and balance.

Their impact is almost equal but directed differently. The salts are mainly brought to arid regions by hydro chemical runoff (with surface and underground waters) from humid regions. The salts, under ascending solutions in deserts, move to the surface and saturate the upper (evaporation) horizons of solonchaks with salts. Solonchaks are mainly represented by dust-salt mass and removed by strong winds (storms, sand-storms are in abundance in deserts) outside the arid zone, where they are brought with precipitation to rivers and underground runoff, which then return them to the arid zone.

The established role of the aeoline factor in the salt regime of the territories enabled us to estimate its significance for the global system of salt transference. The amount of aeoline salt removal from solonchaks and saline soils of the arid zone was calculated. It made up 1.3 mlrd.t/year and represents one of the main components of the world salt balance. For the first time a model of global salt succession was elaborated, taking into account the parameter of -1.3 mlrd.t/year of removed salts from deserts, and according to data in the literature, 3.8 mlrd.t/year removed by hydro-chemical runoff (Kovda, 1954), 12.8 mlrd.t/year of salts brought with precipitation (Berlyand and Lvovich), and 10 mlrd.t/year in pulverization from the ocean (Erikson, Yunge, Glazovsky). According to the model, bonds in view of a zonal aspect between arid and humid zones of lands and ocean are realized in the global system of salt transference. Four blocks have been defined: atmosphere, seas and oceans, humid zones of land, and arid zones of land. They serve as transshipping points of the Earth. This self regulated (on the basis of direct and reverse bonds) gigantic natural "perpetual motion" is realized under the influence of the sun. About 2.8 mlrd.t.of salts are transferred in this succession annually. All the earth's spheres are involved. The schematic model undoubtedly requires further specification and development, as well as new investigations in close connection with the adjacent disciplines of physics, biology and meteorology. Such investigations should be preceded by more in-depth research of soil cover and its chemical composition. According to the determined regularities, not only usual salts, but radionuclides and chemical pests, killers and others will be involved in this cycle. Solonchaks absorb not only normal soda, but common salt, and a sodium sulphate of industrial value. Concentrations of 90 Sr and 137 Cs in easily soluble forms of salt is occurring by solonchak type in the upper horizons of solonchaks (crusty-swelling and radioactive). This was determined in the Ili river's (Otarov) lower reaches. These salts are also potential migrants.

Dust-salt storms, sandstorms and other winds of high speed are a natural phenomenon. They are as necessary and ineradicable as solonchaks. Solonchaks are considered soil "exiles", worthless land; however, they have strategic value in the great succession of salts.

2. REFERENCES

Belgibayev, M.E. 1972. Natural condition of soil deflation and soil-erosion regionalization of the North-Turgai plain. Synopsis of thesis prepared by candidate of geographical sciences. Alma-Ata.

Borovsky, V.M. & Uspanov, U.U. 1971. Soils of Kazakhstan and the ways of their national-economic exploitation. (Report at the Fourth Congress of the USSR Soil Scientists), Alma-Ata.

Grigoryev, A.A. & Lipatov, V.V. 1982. Dynamics and a center of field storms in the region of field storms in the region adjacent to the Aral Sea according to observations from cosmic space. Izvestiya of AS SSR, ser. Geograph.

Kovda, V.A. 1954. Geochemistry of deserts in the USSR. Report at the International Congress of Soil Science.

Orlova, M.A. 1983. Role of the Aeolian factor in the salt regime of the territory. Alma-Ata.

Otarov, A. Radionuclides in soil-vegetation cover of the Ili river's lower reaches. Thesis for a candidate of biology science degree.

Panin, P.S., Elizarov, T.N. & Shkaruba, A.M. 1977. Genesis and amelioration of Baraba solonetzes. Novosibirsk.

Seifullina, S.M. Ecology-genetic bases for solonetz formation in north Kazakhstan.

CHAPTER 11

HALOPHYTES OF PAKISTAN: CHARACTERISTICS, DISTRIBUTION AND POTENTIAL ECONOMIC USAGES

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Abstract. Fresh water resources are becoming increasingly limited and agricultural irrigation systems will steadily increase in salinity in the near future. The time has come to develop sustainable biological production systems that can use low quality saline water for irrigation of halophytic crops in saline lands. A large number of halophytes could be used as cash crop (forage, fodder, fuel, medicine, chemicals, ornamentals etc). Pakistan spans a distance of 1,600 kilometers from the Arabian Sea to the playas of temperate northern mountains across deserts, plains and prairies, to the playas of temperate northern mountains covering an area of 800,000 square kilometers. The varied climatic conditions have resulted in a rich diversity of halophytic flora. Compared to the total 2,200 species reported worldwide, Pakistan alone has about 410 halophytes and 178 of them have not been reported before. About 274 of the total 410 halophytes reported here potentialy have economic usages.

1. INTRODUCTION

In almost all the regions of the world and particularly in arid areas soil salinity is becoming a major problem due to a variety of natural and man caused factors. In addition these arid regions, which naturally have lesser supply of fresh water, are exposed to a rapidly increasing population, which is exerting even more pressure on the supply of water. With the rapidly increasing population, scarcity of water and increasing salinization of agricultural lands is already threatening the food supply (Leith, 1994). Surface and ground water in agricultural areas is rapidly becoming brackish and saline. Furthermore, salt deserts (caused by a lack of fresh water) and saline inland basins (caused by the rising level of saline ground water as a result of leakage of drainage water) are being created. FAO data show that at least 40% of the world is affected by salinization in some form. The actual impact of this estimate is not entirely clear. However, it is known that large areas in Australia, India, Pakistan, Egypt, Central Asia, South America, Mexico and the United States (Menzel & Lieth, 1999) are faced with salinization.

There are growing indications that cultivation of crops with a high salt tolerance can be seen as an economically feasible option for utilizing saline soils

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and conserving fresh water (Glenn, 1987; Glen et al., 1998; Leith, 1994). Saline agriculture is a type of non-conventional crop (halophytes) are grown. Potential halophytic crops could be broadly grouped into three categories 1. Plants with a high salt tolerance: they grow in water with salt contents equal to or even higher than that of seawater; 2. Crops with an average salt tolerance: they grow in brackish water and 3. Crops with a moderate salt tolerance: they grow in slightly brackish water that is not suitable for conventional agriculture. Several efforts were made to compile a list of the halophytic flora of the world (Aronson, 1989; Menzel & Lieth, 1999) as well as a list of regional halophytes. However, the information regarding halophytes is still far from complete. The Flora of Pakistan is near completion and also has information about the halophytes. Currently, effort is being made to compile a list of halophytes in Pakistan, with their distribution, ecology and potential economic usages.

1.1. Physiography, salinity and climate

Pakistan has a varied physiography and climate. It stretches about 1,600 kilometers from the subtropical Arabian Sea to the temperate northern mountains covering an area of 800,000 square kilometers. The country can be divided into seven major landscape units: 1. Coast (Co), 2. Balochistan Plains (BP), 3. Indus Plains (IP), 4. Potwar Plateau (PP), 5. Deserts (Des) including Thal, Thar and Cholistan, 6. Arid and Semi-arid Mountains (ASM) including the northern Balochistan, Sulemania range, Waziristan, Kurram agency, Gilgit, and Chitral (Hindukush) and 7. Moist Mountains (MM) including the Western Himalayas, Swat, Kaghan, Kashmir, Muree and Kaghan. The Indus is a major river, which passes through Pakistan with an approximate annual water flow of 115 billion cubic meters (Ahmed & Chaudhary, 1988; Pasternak, 1990). It originates from the Tibetan plateau at an altitude of about 5,500 meters and flows south to the Arabian Sea. In addition other major tributaries, the Chenab, the Jehlum, the Sutlej, the Beas, and the Ravi join the Indus at the upper Indus plain.

Pakistan is primarily arid and semiarid, except for a narrow belt in the north, with low and variable rainfall. Annual precipitation ranges from 1,500 mm on the southern step of the Himalayas to less than 100 millimeters on the western Balochistan coast. About 69% of the country receives rainfall of less than 250 millimeters per year. The rain primarily falls during the monsoons (June–September). However, the southwestern Balochistan receives winter rain with a Mediterranean trend, and some northwestern areas have both winter and summer rains.

1.2. Definition of halophytes

There are numerous ways of defining halophytes. For our purpose the best definition seems to be "plants that complete their life cycle in saline habitats" (Ungar, 1991), where salt concentration of soil solution is about 5 g/l of total dissolved solids (85 mM NaCl or 7-8 dSm^{-1}, Aronson, 1989). This list is arranged alphabetically by family, and within each family, by genus and species. The nomenclature follows the “Flora of Pakistan”.

1.3. Life form

Only one life form is assigned per species, even though many species show a certain amount of plasticity in this regard. Phanerophytes are further divided into a. Megaphanerophytes (MP, >30 m tall); b. Mesophanerophytes (MSP, 8–30 m tall); c. Microphanerophytes (MIP, 2–8 m tall); d. Nano-Phanerophytes (NP, <2 m tall); e. Epiphytic Phanerophytes (EP); f. Stem Succulent Phanerophytes (SSP); and g. Liana Phanerophytes (LP). Chamaephytes (≤25 cm tall) could be further sub-divided into a. Sub-Fruticose Chamaephytes (SFC, erect shoot fruit at base), b. Passive Chamaephytes (PC, erect but die down and produce horizonal buds), c. Active Chamaephytes (AC, erect shoot absent), d. Cushion Chamaephytes (CC, transition between Chamaephytes and Hemicryptophytes); Hemicryptophytes (HC) Cryptophytes which include a. Geophytes (G), and Hydrophytes (H); and b. Therophytes (TH).

1.4. Plant type

This category is based on the habitats in which the taxon is distributed. Hyphal = hydrohalophytes (present in salt marshes), Xeroh = Xerohalophyte = salt desert species, Psamm = Psammophytes (sand loving plants found on littoral or inland sand dunes), Xero = Xerohalophytes (desert species suspected as halophytes), Chasm = Chasmophytes (cliff-dwelling species), Weedy = Fugitive species, Phrea = and Fibers (8).

1.5. Economic usages

These are denoted by a numerical code as follows: Food (1), Fodder (2), Forage (3), Medicinal (4), Ornamental (5), Chemical (6), Timber and other usages of wood (7) and Fibers (8).

1.6. Halophytes in Pakistan

1.6.1. General overview

The list showed that the halophytic vegetation of Pakistan is quite diverse (Table 1) with 410 species from 58 families. The highest number of halophyte species is present in the Chenopodiaceae family (90), followed by Poaceae (68), Cyperaceae (30), Papilionaceae (29), Asteraceae (24), and Tamaricaceae (23), while other families are represented by less than 10 halophytes (Table 1, Fig. 1). Menzel and Lieth (103) reported that about 2,200 halophytic species were found in the literature worldwide. The halophytes of Pakistan constitute about 19% of the flora. Most of the halophytic species in Pakistan are present in the Blaochistan plains (182), whereas, others are in coastal areas (163), moist mountains (149), arid mountains (93), the Potwar plateau (76), and deserts (65) (Table 1).

The data showed that the Balochistan plains of Pakistan are more diverse in comparison with other areas. In addition among the total 410 halophytes about 140 of them could be classified as Hydrohalophytes, followed by Xerophytes (84), Xerohalophytes (77), Psammohalophytes (75), Weedy (28), Chasmophytes (4), and Phreatohytes (2). Fifty percent of halophytes from the Chenopodiaceae are found in arid environments while all halophytic members of the Cyperaceae are found in aquatic conditions (Table 2).

Life forms of these plants also showed a high degree of variation. Nano-phanerophytes (146) are the dominant life form of Pakistani halophytes, followed by Therophytes (120), Sub-fruticose Chaemephytes (64), Microphanerophytes (27), and Mesophanerophytes (20), and others are represented by less than 10 individuals (Table 1). In most of the regions Nano-phanerophytes dominated the life present in the area followed by Therophytes and Sub-fruticose Chaemephytes. Most of the halophytes present in the Northern Mountains are Hydrohalophytes, followed by Xerohalophytes, and Psammophytes, while halophytic vegetation of Balochistan is equally dominated by three types: Hydrohalophytes, Xerophytes, and Xerohalophytes (Table 1). Hydrohalophytes are the most abundant group among the coastal plants.

Table 1. *Alphabetical listing of halophytes of Pakistan. (Those with an asterisk (*) are included for the first time in any halophyte list).*

Genus, Species and Author	*Distribution*	*Plant Type*	*Life form*	*Economic Uses*	*Ref.*
Aizoaceae					
Aizoon canariense L.	CO	Xero	Th	1	19
Mesembryanthemum crystillinum L.	IP	Xeroh	Th	5,8	
Sessuvium sessuvioides (Fenzl.) Verdc.	CO, IP	Psamm.	HP	5,8	125
Trianthema portulacastrum L.	COS	Xeroh	Th	1,2,4,5	33,46
**Trianthema triquetra* Rottl.ex Willd.	CO, IP, PP, BP	Xeroh	Th	2	111
**Zaleya pentandara* (L.) Jeffrey	COS	Xeroh	H	2,4	111
Amaranthaceae					
**Aerva javanica* (Brum. f.) Juss. ex J.A. Schultes var *javanica*	CO, IP, PP	Xero	NP	8	139
**Aerva javanica* (Brum. f.) Juss. ex J.A. Schultes var. bovei Webb.	CO, ASM, PP	Xero	NP	8	139
Asclepediaceae					
Calotropis procera (Ait.) Ait.	ASM, MM, BP, IP	Xero	NP	4,5,6,8	15,117
Cynanchum acutum L.	MM,	Psam.	V	-	138
**Glossonema varians* (Stocks.) Hook. f.	CO, BP, ASM	Xero	CH	1	9
**Leptadenia pyrotechnica* (Forssk.) Dcne.	CO, BP, Des	Xero	NP	4	9
*Oxystelma esculentum *(Linn. f.) R. Brown*	IP	Xero	V	1,4	9
Pentatropis nivalis(J.F. Gmel.) D.V. Field & J.R.I. Wood	PP, BP, IP,	Xero	V	1,4	43,98
**Pergularia damia* (Forssk.) Chiov	MM, PP, IP	Xero	V	-	9
Pergularia tomentosa L.	CO, BP	Xero	V		98

Asteraceae					
Achillea millefolium L.	MM	Psamm.	NP	4	137
Artemisia scoparia Waldst. & Kit.	MM, IP, PP, BP	Psamm.	NP	2,4	63
**Cymbolena griffithii* (A.Gray) Wagenitz	ASM, MM, BP	Xero	Weedy	-	123
**Grangia* madrasspotensis (L.) Poir.	BP, Des	Hyphal	AC	-	123
**Handelia tricophylla* (Schrenk.) Heimerl	MM	Psamm.	NP	-	54
Inula brittanica L.	MM	Hyphal	SFC	4	54
**Iphiona aucherii* (Boiss.) Anderb.	BP	Xero	123		
Lactuca tatarica (L.) C. A. May	MM	Psamm.	SFC	-	54
**Launea procumbens* (Roxb.) Ramayya & Rajagopal	ASM, MM, BP, CO	Xerohal.	SFC	-	123
**Launea sarmantosa* (Willd.) Alsoton	CO	Psamm.	SFC	-	54
**Microcephala lamellate* (Bunge) Pobed.	ASM, BP	Psamm.	TH	4	54
**Pluchia arguta* Boiss. Subsp. *Arguta*	BP, CO	Xerohal.	NP	-	123
**Pluchia arguta* Boiss. Subsp. *glabra*	COSM	Xerohal.	NP	-	123
**Pulicaria boisseri* Hook. f.	BP, CO	Xerohal.	NP	-	123
**Pulicaria carnosa* (Boiss.) Burkill	ASM, BP, CO	Xerohal.	NP	-	123
**Pulicaria gnaphalodes* (Vent.) Boiss.	BP	Xerohal.	NP	-	123
**Pulicaria undulata* (L.) C.A. Meyer	PP, IP, BP, Des	Weedy	NP	-	123
**Pseudognaphalium leuto-album* (L.) O.M.Hilliard	MM, ASM, BP, PP	Hyphal	Th	-	123
**Seriphidium brevifolium* (Wall. ex DC) Ling & Y.R. Ling	MM	Psamm.	NP	2,4	54
**Seriphidium quettense* (Podlech) Ling	BP	Psamm.	NP	2,4,7	54
**Sonchus asper* (L.) Hill	Cosm.	Hyphal	SFC	-	54
Sonchus maritimus L.	ASM, IP	Hyphal	SFC	-	123
**Sonchus tenerrimus* L.	CO	Hyphal	SFC	-	54
Xanthium sibiricum Patrin.	ASM, BP	Xero	HP	-	63
Avicenniaceae					
Avicennia marina (Forssk.) Vierh	CO	Hyphal	MP	1,2,4	17,76
Boraginaceae					
Heliotropium aucheri DC	BP	Weedy	SFC	-	106
Heliotropium bacciferum Forssk.	CO	Xero	SFC	-	106
Heliotropium currassvicum L.	CO, IP	Weedy	NP	-	106
**Heliotropium remotiflorum* Rech.f. & Riedl.	CO, BP	Xero	NP	-	106
**Sericostema pauciflorum* Stocks ex Wight	CO	Psamm.	NP	-	106
Brassicaceae					
**Conringia persica* Boiss.	BP	Psamm.	TH	-	64
**Coronopus didymus* (L.) Smith	IP, BP, CO	Xerohal.	TH	-	64
**Dilophia salsa* Thompson	MM	Hyphal	CC	-	64
Lepidium cartilagineum (J. May) Thell.	BP	Hyphal	NP	-	106
Lepidium latifolium L.	MM	Hyphal	NP	-	35,96
Lobularia maritima (L.) Desv.	IP	Psamm.	NP	2	141
Raphanus raphanistrum L.	ASM, PP, BP	Psamm.	TH	2,5	141
Caryophyllaceae					
Cerastium glomeratum Thuill.	MM, PP	Weedy	TH	-	42
**Polycarpia spicata* Wight & Arn.	BP, CO, Des	Psamm.	TH	-	55
Spergularia diandra (Guss.) Heldr & Sart.	BP, MM, IP	Weedy	TH	-	126,146
Spergularia marina (L.) Griesb.	IP, BP, CO	Weedy	TH	-	63,106
Spergularia media (L.) Presl.	BP	Hyphal	NP	-	63,106
Caesalpiniaceae					
Caesalpinea bonduc (L.) Roxburgh.	IP, CO	Hyphal	NP	2,4	36,107
**Cassia italica* (Mill.) F.W. Andr.	PP, CO, PP	Xero	NP	4	7
Chenopodiaceae					
**Agathophora alopecuroides* (Dellie.) Fenzl ex Bunge	BP	Xerohal.	NP	-	48

(Continued)

Anabasis haussknechtii Bunge ex Boiss.	BP, IP	Xerohal.	NP	-	106
**Anabasis lachnantha* Allan & Rech.	BP, CO	Xerohal.	NP	-	48
Anabasis setifera Moq.	ASM, BP, CO	Xerohal.	NP	-	93,106
Arthrocnemum indicum (Willd.) Moq.	CO	Hyphal	NP	2	45,106
Arthrocnemum macrostachyum (Moric.) C. Koch	CO	Hyphal	NP	19,117	
Atriplex canescens James	BP	Xerohal.	NP	2	109,114
Atriplex dimorphostegia Kar. & Kir.	BP	Psamm.	TH	3	11,114
Atriplex griffithii Moq.	ASM	Xerohal.	NP	2	11,114
Atriplex halimus L.	Des	Xerohal.	MIP	1,2	108,114
Atriplex hortensis L.	MM	Xero	TH	1	1508,114
**Atriplex lasiantha* Boiss.	MM, IP, BP	Xero	TH	-	48
Atriplex leucoclada Boiss.	CO, IP	Xero	NP	2	19,122
**Atriplex pamirica* Iljin	MM, IP	Xerohal.	TH	-	48
**Atriplex schugnanica* Iljin	MM	Xerohal.	TH	-	48
Atriplex stocksii Boiss.	CO	Xerohal.	NP	-	89,108
Atriplex tatarica L.	MM	Xero	TH	2	63,141
Bassia dasyphylla (Fisch. & Mey.) O. Kuntze	MM	Xero	TH	-	63,141
Bassia eriophora (Schrad.) Ascher	BP	Xero	TH	-	48
Bassia hyssopifolia (Pall.) O. Kuntze	MM	Weedy	TH	-	63,107
Beta vulgaris ssp *maritma* (L.) Arcangeli	BP, IP	Weedy	NP	2	95,122
Bienertia cycloptera (Bunge ex Trautv.) Bunge ex Boiss.	CO	Xerohal.	TH	2	18,106
Camphorosma monspelictum L.	ASM, BP, IP	Xero	NP	2,4	63,106
Ceratocarpus arenarius L.	ASM, BP	Psamm.	TH	-	63
Chenopodium album L.	Cosm.	Weedy	TH	-	63
Chenopodium ambrosoides L.	MM, IP	Weedy	TH	4	101,108
**Chenopodium botrys* L.	ASM, MM, BP	Weedy	TH	-	48
Chenopodium ficifolium ssp *blomianum* (Aellen) Aellen	ASM, MM, IP	Weedy	TH	-	48
Chenopodium glaucum L.	MM, BP	Weedy	TH	-	63,103
Chenopodium murale L.	Cosm.	Weedy	TH	-	48
**Coriospermum korovinii* Iljin	MM	Xero	TH	-	48
**Coriospermum tibeticum* Iljin	MM	Xero	TH	-	48
**Cornulaca aucherii* Moq.	ASM	Xerohal.	TH	-	48
Cornulaca monacantha Del.	ASM, CO, BP	Xerohal.	NP	-	92,106
Gamanthus gamocarpus (Moq.) Bunge	BP	Xerohal.	TH	-	106
Girgensohnia oppositiflora (Pall.) Fenzl	ASM	Xero	TH	-	94,141
**Halimocnemis occulta* (Bunge) Hedge	BP	Xerohal.	TH	-	48
**Halocharis clavata* Bunge	BP	Xerohal.	TH	-	48
Halocharis hispida (Schrenk ex C. A. Mey) Bunge	ASM, BP	Xerohal.	TH	3	135
Halocharis sulphurea (Moq.) Moq.	ASM, BP	Xerohal.	TH	-	106
Halocharis violacea Bunge	BP	Xerohal.	TH	-	106
Halocnemum strobilaceum (Pall.) M. Bieb.	CO, BP	Xerohal.	NP	2,5	94
Halogeton glomeratus (M. B.) C. A. Mey	MM	Xerohal.	TH	4	63,94
**Halogeton tibeticus* Bunge	MM	Xerohal.	TH	-	48
Halopeplis perfoliata (Forssk.) Bunge ex Schweinf.	CO	Hyphal	NP	-	94
Halostachys belangerana (Moq.) Botsch.	CO	Hyphal	NP	-	133,137
Halothamnus auriculus (Mey.) Botch. ssp *acutifolius*	BP	Xerohal.	NP	-	133,137
Halothamnus subaphyllus (Mey.) Botsch ssp *chariffi*	ASM	Xerohal.	NP	-	133,137
**Halothamnus iranicus Botsch.*	BP	Xerohal.	NP	-	48
**Haloxylon griffithii* (Moq.) Boiss. ssp *griffithii*	ASM, MM, BP	Xerohal.	NP	1	48
**Haloxylon griffithii* (Moq.) Boiss.ssp *wakhanica* (Paulsen) Hedge	MM	Xero	NP	1	48
Haloxylon persicum Bunge ex Boiss	ASM	Psamm.	NP	3,8	21,26
Haloxylon salicornicum (Moq.)					

Bunge ex Boiss.	IP, BP	Xerohal.	NP	-	106
**Haloxylon stocksii* (Boiss.) Benth. & Hook.	Cosm.	Xerohal.	NP	1,2	48,87
Kochia indica Wight MM, PP, BP, IP	Xero	TH	5	93,101	
Kochia iranica Litw. ex Bornm	ASM, MM, BP	Xero	TH	5,8	135
Kochia prostrata (L.) Schrad.	ASM, MM	Xero	NP	-	63,106
Kochia scoparia (L.) Schrad.	Cosm.	Xero	TH	-	92,132
**Kochia stellaris* Moq.	MM	Xero	TH	-	48
**Krascheninnikovia ceratoides* (L.) Guldenst.	MM	Xerohal.	NP	-	48
Panderia pilosa Fisch. & C.A. Mey.	CO, IP, BP	Hyphal	TH	-	106,146
Salicornia bigellovi Torr.	CO	Hyphal	TH	1	106
Salicornia brachiata Roxb.	CO	Hyphal	TH	1	68
Salsola arbuscula Pall.	BP	Xerohal.	NP	-	63,106
Salsola chorassanica Botsch	BP	Xerohal.	TH	-	104
Salsola collina Pall.	MM	Hyphal	TH	-	63
**Salsola crassa* ssp *turcomanica* Pall.	BP	Xerohal.	TH	-	48
**Salsola cyclophylla* Baker	BP, CO	Xerohal.	NP	-	48
Salsola drummondii Ulbr.	ASM, BP, IP, CO	Hyphal	NP	-	106
**Salsola griffithii* (Bunge) Freitag &Akhani	ASM, BP, CO	Psamm.	NP	-	48
Salsola imbricata Forssk. *var. imbricata*	Cosm.	Xerohal.	NP	-	48
**Salsola imbricata* Forssk. *var. hirtitepala*	BP, CO	Xerohal.	NP	-	48
Salsola incanescens C.A. Mey	BP	Xerohal.	TH	-	106
**Salsola makranica* Freitag	BP, CO	Xerohal.	NP	-	48
Sa*lsola nitraria* Pall.	BP	Xerohal.	TH	-	104
Salsola orientalis S.G. Gmeln	BP	Xerohal.	NP	-	106
**Salsola paulsenii* ssp *praecox* (Litw.) Rilke	BP	Psamm.	TH	-	48
Salsola richteri (Moq.) Karel.	BP	Psamm.	MIP	-	26
Salsola sclerantha C.A. Mey	BP	Psamm.	TH	-	106
Salsola tomentosa (Moq.) Spach	ASM	Xerohal.	NP	-	106
Salsola tragus L.	ASM, MM, BP	Xerohal.	TH	2	48
Seidlitzia florida (M. Bieb.) Boiss.	BP	Xerohal.	TH	2	106
Suaeda acuminata (C. A. Mey) Moq.	MM	Xerohal.	TH	-	1
Suaeda aegyptiaca (Hasselq.) Zohary	ASM, BP, CO	Hyphal	TH	-	19
Suaeda arcuata Bunge	BP	Weedy	TH	-	48
Suaeda fruticosa (L.) Forssk.	Cosm.	Xerohal.	NP	1,2,6	79,88
Suaeda heterophylla (Kar. & Kir.) Bunge	MM	Hyphal	TH	-	48
Suaeda monoica Forssk.	BP, IP	Hyphal	MIP	-	93,108
**Suaeda olufsenii* Paulsen	MM	Hyphal	TH	-	48
Convolvulaceae					
Cressa cretica L.	Cosm.	Hyphal	SFC	2,4	72
Evolvulus alsinoides L.	Cosm.	Hyphal	AC	4	18
Ipomoea alba L.	Cosm.	Psamm.	EP	4	136
**Ipomoea carnea* L. ssp. *fistulosa*	PP, IP, DES	Psamm.	MIP	-	16
Ipomoea pes-caprae (L.) R. Br.	CO	Psamm.	AC	5	136
Cynomoriaceae					
**Cynamorium coccinium L.*	BP	Psamm.	AC	1,4	127
Cyperaceae					
Blysmus rufus (Huds.) Link.	MM	Hyphal	NP	-	96
Bolboschoenus affinis (Roth.) Drobov	PP, CO, IP	Hyphal	NP	2	135
**Bolboschoenus glaucus*	Cosm.	Hyphal	SFC	2	189
Carex divisa Hudson	BP, MM	Hyphal	NP	2	35,44
Carex songorica Kar. & Kir	MM	Hyphal	NP	-	115
Carex stenophylla ssp. S*tenophyllous* (V. Krecz.) Egor	MM, BP, CO	Hyphal	NP	-	117
**Cyperus arenarius* Retz.	CO, IP	Hyphal	HP	-	90
**Cyperus alopecuroides* Rottb.	CO, IP, Des	Hyphal	NP	-	90
**Cyperus atkinsonii* C.B. Clarke	MM, IP, BP, CO	Hyphal	NP	-	90
**Cyperus aucheri* Jaub. & Spach	BP	Hyphal	PC	-	90
**Cyperus bulbosus* Vahl	CO, IP, BP, Des	Hyphal	NP	-	90

(Continued)

**Cyperus conglomeratus* ssp. *Conglomerates* ottb.	CO, BP	Hyphal	NP	-	90
**Cyperus conglomeratus* ssp. *curvulus* Rottb.	CO, BP	Psamm.	NP	-	90
Cyperus laevigatus L.	IP, PP, CO, BP	Hyphal	NP	-	19,43
Cyperus malaccensis Lam.	CO	Hyphal	NP	-	128
**Cyperus niveus* Retz.	Cosm.	Hyphal	NP	-	90
**Cyperus pachyrhizhus* Nees ex Boeck	CO	Hyphal	NP	-	90
**Cyperus pangorei* Rottb.	CO	Hyphal	NP	-	90
Cyperus rotundus L.	Cosm.	Hyphal	NP	-	63
Cyperus stoloniferous Retz.	CO	Psamm.	NP	-	45
**Eleocharis quenqeflora* (F.X. Hartm.) O. Schwarz	MM	Hyphal	SFC	-	90
Eleocharis niglumis Link.) Schultes	ASM, MM	Hyphal	SFC	-	96
**Fimbristylis complanata* (Retz.) Link	CO	Hyphal	SFC	-	90
**Fimbristylis cymosa* R. Br.	CO, IP	Hyphal	SFC	-	90
**Pycerus dwarkensis* (Sahni & Naithani) Hooper	CO	Hyphal	SFC	-	90
Pycerus polystachyos Rottb.) P. Beauv	CO	Hyphal	SFC	-	63
**Schoenoplectus lacustris* (L.) Palla ssp. *tabernamonti*	MM	Hyphal	NP	-	90
**Schoenoplectus lacustris* (L.) Palla ssp. *happolyti*	MM	Hyphal	NP	-	90
**Schoenoplectus litoralis* (Schrad.) Palla	MM	Hyphal	NP	-	90
**Schoenoplectus triqueter* (L.) Palla	MM	Hyphal	NP	-	90
Elatinaceae					
**Bergia aestivosa* Wight & Arnot	Thal, Des	Xerohal.	NP	-	123
**Bergia ammanoides* Roth.	IP, CO	Hyphal	TH	-	123
Euphorbiaceae					
Andrachne telephioides L.	ASM, MM, BP	Weedy	AC	-	40
Euphorbia ranulata orssk.	Cosm.	Weedy	TH	-	117
**Euphorbia indica* Lam.	Cosm.	Weedy	TH	-	129
Euphorbia erpens Kunth.	IP, PP	Hyphal	TH	-	130
Euphorbia thymifolia L.	ASM, IP, BP, CO	Psamm.	TH	5	128
Frankeniaceae					
Frankenia ulverulenta L.	BP, IP, PP, CO	Psamm.	TH	5	117
Gentianaceae					
**Enicostema hyssopifolium* (Willd) Verdoon	CO, IP, BP	Psamm.	SFC	110	-
Goodeniaceae					
Scaevola plumieri (L.) Vahl.	CO	Psamm.	NP	5	36
Scaevola taccada (Gaertn.) Roxb.	CO	Psamm.	MIP	5	117
Hydrocharitaceae					
**Halophila ovalis* R. Br.	CO	Hyphal	TH	-	52
Juncaceae					
Juncus bufonius L.	IP	Hyphal	TH	-	63
Juncus gerardii Lois.	BP	Hyphal	NP	-	96
Juncus maritimes Lam.	CO, IP	Hyphal	NP	-	96,117
**Juncus punctorius* L.	BP	Hyphal	NP	-	67
Juncaginaceae					
Triglochin aritima L.	MM	Hyphal	NP	1,8	31
Triglochin alustris K.	MM	Hyphal	NP	3	137
Liliaceae					
**Asparagus deltae* Blatter	CO	Psamm.	NP	-	-
**Asparagus gharoansis* Blatter	Des, IP	Psamm.	NP	-	-
**Urginea indica* Kunth.	NM	Psamm.	HP	4	-

Malvaceae					
**Pavonia procumbens* (Wall. ex Wight & Arn.)Wallp.	CO	Xerohal.	SFC	-	3
**Senra incana* Cav.	CO	Xero	NP	-	3
**Gossypium stocksii* Mast.	CO	Xero	NP	-	3
Thespesia populneoides (Roxb.) Kostel.	CO	Hyphal.	MSP	4,8	36,105
Mimosaceae					
Acacia leucophloea (Roxb.) Willd.	Des	Xero	MSP	7	13
**Acacia nilotica* (L.) Delile ss *hemispherica*	CO	Xero	MSP	7	6
Acacia sphaerocephala Schl. & Chem.	IP	Xero	NP	-	135
**Prosopis cineraria* (L.) Druce	PP, IP, CO, Des	Xero	MSP	2,7	6
Prosopis farcta (Banks & Sol.) Macbride	IP	Weedy	MSP	2,4,7	19,38
Prosopis juliflora (Swartz) DC.	IP	Xero	MSP	2,7	19,38
Molluginaceae					
**Glinus lotoides* L.	CO, BP, IP	Psamm.	TH	1,2,4	110
Moraceae					
Ficus microcarpa L.	IP	Hyphal	MSP	5	33
Myrsinaceae					
Aegiceras corniculatus (L.) Blanco	CO	Hyphal	NP	2,6	36,104
**Ardisia solanacea* Roxb.	CO	Hyphal	MIP	5	65
Najadaceae					
Najas graminea Delile	PP	Hyphal	NP	-	105
Najas marina L.	IP, MM	Hyphal	NP	-	105
Najas minor All.	IP	Hyphal	NP	-	135
Neuradaceae					
**Neurada procumbens* L.	ASM, BP, IP	Psamm.	TH	1,2,4	100
Nyctaginaceae					
Pisonia grandis R. Br.	CO	Psamm.	MSP	1	4
Orobanchaceae					
Cistanche ubulosa (Schrenk) Hook	Cosm.	Psamm.	TH	-	106
Palmae					
Cocos nucifera L.	CO	Hyphal	MSP	1,4	32,102
Pheonix dactylifera L.	CO, IP	Hyphal	MP	1	131,140
**Pheonix sylvestris* (L.) Roxb.	CO	Hyphal	MSP	1	11,24
Papilionaceae					
**Aeschynomene indica* L.	MM, Des	Hyphal	TH	-	8
Alhaji maurorum Medic.	Cosm.	Hyphal	NP	2,4,8	19,94
Astragalus fatmanses Hochsr. Ex Blatter	IP, CO	Xerohal.	SFC	-	104
**Crotolaria persica* (Burn f.) Merril	CO	Xerohal.	NP	-	8
Dalbergia sissoo Roxb.	IP, BP	Xero	MSP	2,5,7	118
Erythrina herbacea L.	IP	Hyphal	NP	4	30
**Indigofera argentia* Burn f.	CO	Xerohal.	NP	-	8
**Indigofera cordifolia* Heynes ex Roth.	IP, Des, CO	Xerohal.	TH	-	8
**Indigofera intricata* Boiss.	CO	Xerohal.	AC	-	8
**Indigofera linifolia* (L.F.) Retz.	Cosm.	Xerohal.	TH	-	8
**Indigofera oblongifolia* Forsk.	CO	Xerohal.	NP	-	8
**Lespedeza juncea* var *serica* (Thunb.) Lace & Hemsley	ASM, PP, BP	Xero	NP	-	8
**Lotus garcini* D.C.	CO	Psamm.	NP	-	8
**Macroptilium lathyroides* (L.) Urb.	IP	Hyphal	TH	-	8
Medicago falcata L.	MM	Chasm	NP	-	63

(Continued)

Melilotus alba Desr.	MM	Chasm	TH	-	104
Melilotus indica (L.) All.	Cosm.	Chasm	TH	-	104,137
Melilotus officinalis (Li.) Pall.	MM	Chasm	TH	-	104
Pongamia pinnata (L.) Merrill	IP	Hyphal	MSP	7	36
**Sesbania grandiflora* (L.) Poir	CO	Xero	MSP	-	8
**Sesbania sesban* (L.) Merrill	IP	Xero	MSP	-	8
Sophora alopecuroides L.	MM	Psamm.	NP	-	63
**Tavernaria spartea* (Burm. f.) DC	CO	Xerohal.	NP	-	8
Tephrosia appolinea (Delile) Link	CO, BP	Xerohal.	SFC	-	8
Tephrosia purpurea (L.) Pers.	IP	Hyphal	TH	-	91,131
**Trifolium fragiferum* L.	MM	Psamm.	AC	2	28,96
**Trifolium repens* L.	ASM, MM, BP	Psamm.	AC	2	8
**Vicia sativa* L.	Cosm.	Hyphal	TH	2	8
**Vigna trilobata* (L.) Verdc.	CO, Des	Xero	TH	-	8
Pedaliaceae					
**Pedalium murex* L.	Des, CO, BP	Xerohal.	TH	1,4	1
Plantaginaceae					
Plantago coronopus L.	BP	Xero	TH	-	35
Plantago depressa Willd.	MM	Hyphal	TH	-	63
Plantago lanceolata	L.	MM, PP	Xero	SFC	4105
Plantago major L.	Cosm.	Psamm.	PC	4	146
Plumbaginaceae					
Limonium axillare Forssk.	MM	Hyphal	TH	5	103
**Limonium gilsei* (Hemsl.) Rech	MM	Hyphal	NP	5	22
Limonium sinuatum (L.) Miller	Cultivated	Hyphal	TH	5	117
Limonium stocksii (Boiss.) O. Ktze	CO, BP	Hyphal	NP	5	117,145
Psylliostachys spicata (Willd.) Nevski	BP	Hyphal	TH	5	106
Poaceae					
Aeluropus lagopoides (L.) Trin. ex Thw.	CO, Des, IP, BP	Hyphal	SFC	3,5	59, 62
Aeluropus littoralis (Gouan) Parl.	BP	Hyphal	SFC	3	19,42
**Aeluropus macrostachys* Hack.	BP	Phyphal	SFC	3	34
Agrostis stolonifera L.	MM, PP	Psamm.	NP	3	34
**Aristida mutabilis* Trin. & Rupr	MM, ASM, IP, BP	Psamm.	NP	3	34
**Aristida adsceshoines* L.	Cosm.	Weedy	SFC	3,8	34
Arundo donax L.	MM, BP, IP, PP	Weedy	MIP	1	45, 117
Calamagrostis pseudophragmites (Hall. f.) Koel.	MM	Psamm.	NP	-	63
**Cenchrus biflorus* Roxb.	Cosm.	Psamm.	TH	3	34
Cenchrus ciliaris Rich.	Cosm.	Psamm.	NP	3,5	47
**Cenchrus pennesittiformis* Hochst. & Steud. Ex steud.	IP, CO	Psamm.	SFC	3	34
Chloris gayana Kunth	MM, IP	Psamm.	MIP	3	29
**Chloris quenqesetica* Bhide	CO, IP	Psamm.	SFC	-	34
Chloris virgata Sw.	BP	Psamm.	TH	2	104,133
**Coelachyrum piercei* (Benth.) Bor.	BP	Psamm.	SFC	-	34
Crypsis schoenoides (L.) Lam.	MM, CO, IP	Hyphal	TH	-	63
Cynodon dactylon (L.) Pers.	Cosm.	Weedy	SFC	3	117
Dactyloctenium aegyptium (L.) Willd.	Cosm.	Weedy	TH	3	21,47
**Dactyloctenium aristatum* Link	IP, CO, Des, BP	Psamm.	TH	3	34
Dactyloctenium scindicum Boiss.	Cosm.	Xerohal.	SFC	3	21
Desmostachya bipinnata (L.) Stapf	Cosm.	Xerohal.	NP	3	21,47
Dichantheum annulatum (Forssk.) Stapf	Cosm.	Xero	NP	3	133
Digitaria longiflora (Retz.) Pers.	IP	Hyphal	TH	-	34
Diplachne fusca (L.) P. Beauv.	IP	Hyphal	NP	3	34
**Echinochloa colona* (L.) Link	Cosm.	Hyphal	TH	3	34
**Echinochloa crusgalli* (L.) P. Beauv.	Cosm.	Hyphal	TH	1,3	34
Eleusine indica (L.) Gaertn.	MM, IP, CO	Hyphal	TH	3	34,43
Eragrostis curvula (Schrad.) Nees.	MM, BP, IP	Psamm.	NP	3,8	34

**Eragrostris japonica* (Thunb.) Trin.	Cosm.	Psamm.	NP	3	34
Eragrostis superba Peyr.	IP	Psamm.	NP	3	34
Festuca rubra L.	MM	Psamm.	NP	3	96,117
Halopyrum mucronatum (L.) Stapf	CO	Psamm.	SFC	3	61,86
**Hordeum bogdanii* Wilensky	BP, MM	Hyphal	NP	-	34
**Hordeum brevisubulatum* (Trin.) Link ssp. nevski*anum*	MM	Hyphal	NP	-	34
**Hordeum brevisubulatum* (Trin.) Link ssp. *turkistanicum*	MM	Hyphal	NP	-	34
**Hordeum murimim* ssp *glaucum* (steud.) Tzvelev	MM, PP	Hyphal	TH	-	34
Imperata cylindrical (L.) Raeuschel.	Cosm.	Psamm.	NP	4,8	63
Lasiurus scindicus Forssk.	Cosm.	Psamm	NP	3	133
**Leymus secalinus* (Georgi) Tzvelev	MM	Psamm.	NP	-	34
Lolium multiflorum Lam.	MM, BP	Psamm.	NP	2	19
**Orthochloa compressa* (Forssk.) Hilu	Cosm.	Hyphal	SFC	2	34
Oryza coarctata Roxb.	CO	Hyphal	NP	-	138
**Panicum antidotale* Retz.	Cosm.	Psamm.	NP	8	34
Parapholis incurva (L.) C.E. Hubb.	Des	Hyphal	SFC	-	19
Paspalidium geminatum (Forssk.) Stapf	Des	Psamm.	SFC	-	19
Paspalum pasploides (Michex) Scribner	Cosm.	Hyphal	SFC	3	132
Phalaris arundinacea L.	MM	Hyphal	NP	3	63
**Phalaris minor* Retz.	MM, IP, BP, PP	Hyphal	TH	3	34
Phragmites australis (Cav.) Trin. ex Steud.	MM, IP	Hyphal	MIP	7,8	19,42
Phragmites karka (Retz.) Trin. ex. Steud.	Cosm.	Hyphal	NP	-	105
Poa bulbosa L.	MM, BP	Psamm.	SFC	3	105
Poa pratensis L.	MM, BP	Psamm.	SFC	3	105
Polypogon monspeliensis (L.) Desf.	Cosm.	Psamm.	TH	1,5	119,126
Puccinellia distans (Wahlb.) Parl.	MM	Hyphal	SFC	-	135
Puccinellia gigantia (Grossh.) Grossh.	BP	Hyphal	NP	-	137
**Sacchraum bengalense* Retz.	PP, IP, Des	Hyphal	MIP	3,8	34
Sacchraum spontaneum L.	MM, PP, IP, Des	Hyphal	MIP	8	63
Setaria viridis (L.) P. Beauv.	ASM, MM	Psamm.	TH	-	63
**Sporobolus coromandelianus* (Retz.) Kunth	IP	Psamm.	SFC	3	48
Sporobolus helvolus (Trin.) Dur. & Schinz.	PP, IP	Psamm.	SFC	3	11,45
Sporobolus ioclados (Nees ex Trin.) Nees	BP, CO	Psamm.	SFC	3	19,76
**Sporobolus kentrophyllus* (K.Schum.) W.D. Clayton	CO	Psamm.	SFC	3	34
**Sporobolus tourneuxii* Coss.	Des	Psamm.	SFC	3	34
Sporobolus tremulus (Willd.) Kunth.	PP	Hyphal	SFC	3	21
Sporobolus virginicus (L.) Kunth.	CO, CT	Psamm.	SFC	3	19,114
**Stipa himalaica* Rozhev.	MM	Psamm.	SFC	-	34
Stipa splendens Trin.	BP, MM	Psamm.	SFC	-	136
**Urochondra setulosa* (Trin.) C.E. Hubb.	CO	Xerohal.	SFC	3	60,61
Polygonaceae					
**Bistorta vivipara* (L.) S.F. Gray	MM	Xero	SFC	-	122
**Knorringia sibirica subsp. thomsonii* Laxm.	MM	Psamm.	SFC	5,8	122
Polygonum aviculare L.	Cosm.	Xero	TH	-	42,80
**Polygonum effusum* Meisn.	MM, IP, Des	Xero	TH	-	122
Polygonum maritimum L.	MM	Xero	AC	-	122
**Polygonum plebigum* R. Br.	Cosm.	Xero	AC	-	122
**Rumex crispellus* Rich. f.	MM	Xero	SFC	-	122
**Rumex punjabensis* Vaid & Nathiani	MM	Xero	NP	-	122
**Rumex vesicarius* L.	MM	Xero	TH	1,4	122
Portulacaceae					
**Portulaca quadrifida* L.	IP	Xerohal.	TH	4	49
Portulaca oleracea L.	Cosm	Xero	TH	1,4,6	129
Primulaceae					
Anagallis arvensis L.	MM	Xero	TH	2	42,114

(Continued)

Glaux maritima L.	MM	Xero	AC	-	95,135
Samolus valerandi L.	NM, PP, BP	Hyphal	TH	-	95
Resedaceae					
Ochradenus baccatus Del.	CO, BP, IP	Xero	NP	1	204
Oligomeris linifolia (Vahl) Macbride	CO, IP, BP, PP	Xero	SFC	1,3,4	44
Rhamnaceae					
Zizyphus nummularia (Burm. f.) Wight and Arn.	MM, CO	Xero	MIP	1	11,119
Rhizophoraceae					
Ceriops tagal (Perr.) C.B. Robinson	CO	Hyphal	MSP	4	69
Rhizophora mucronata Poir.	CO	Hyphal	MSP	2	69
Rosaceae					
Potentila anserina L.	MM	Hyphal	V	-	63
Potentila bifurca L.	MM	Hyphal	V	-	63
Potentila supina L.	MM	Hyphal	V	-	63
Rubiaceae					
Galium verum L.	MM	Hyphal	TH	-	63
Ruppiaceae					
Ruppia maritima L.	CO	Hyphal	TH	-	105,135
Salicaceae					
Populus euphratica Olivier	IP, BP, PP	Xero	MSP	2,4,7	10
Salvadoraceae					
Salvadora oleoides Dne.	CO, IP	Xero	MIP	1,7	21
Salvadora persica L.	Des, IP	Xero	MIP	1,3,7	106
Scrophulariaceae					
**Bramia monniera* (L.) Penn.	IP	Hyphal	TH	-	-
Solanaceae					
**Lycium edgeworthii* Dunal	IP, PP, BP	Xero	NP	-	113
Lycium shawii R. & S.	BP	Xero	NP	-	43
Solanum incanum L.	Cosm	Xero	NP	1,4	114
**Solanum surrattense* Burm. f.	Cosm	Xerohal.	AC	4	113
**Withania sominifera* (L.) Dunal	Cosm	Xero	NP	4	113
Sonneratiaceae					
Sonneratia caseolaris (L.) Engl.	CO	Hyphal	MP	4,7	114
Sterculaceae					
**Melhania denhamii* R. Br.	Des, CO, BP	Xero	SFC	4	2
Tamaricaceae					
Myricaria Sp.	MM	Hyphal	SFC	-	106
Reaumaria alternifolia (Labill) Britten	BP	Hyphal	SFC	-	106
**Reaumaria floyeri* S.Moore	CO	Hyphal	TH	-	120
Reaumaria stocksii Boiss.	BP, CO	Hyphal	TH	-	106
**Tamarix alii* Qaiser	Des	Xero	NP	-	120
Tamarix androssowii Litw.	BP	Xero	MIP	-	106
Tamarix aphylla (L.) Karst.	Cosm.	Phrea	MSP	7,8	19
Tamarix arceuthoides Bunge	MM	Hyphal	MIP	7	106
**Tamarix baluchistanica Qaiser*	ASM	Xero	MIP	-	120 *
Tamarix dioica Roxb.	ASM	Xero	NP	-	120
Tamarix indica Willd.	Cosm.	Hyphal	MIP	-	20
**Tamarix karelini* Bunge	BP	Xero	MIP	-	120
Tamarix kotschyii Bunge	BP	Xero	MIP	-	63,106

Tamarix leptostachya Bunge	MM	Xero	MIP	-	63,106
Tamarix mascatensis Bunge	BP	Xero	MIP	5,7	20,106 *
Tamarix pakistanica Qaiser	IP, BP, CO	Phrea	MIP	-	120
Tamarix passernioides Del.ex Desv. var. *macrocarpa*	BP, IP, Des	Hyphal	NP	5,7	19,20
Tamarix ramosissima Ledeb.	MM, BP	Xero	MIP	5,7	19,63
Tamarix salina Dyer	IP, Des	Hyphal	NP	7	120 *
Tamarix sarenensis Qaiser	Des	Hyphal	MIP	-	120
**Tamarix sultanii* Qaiser	Des	Xero	MIP	-	120 *
Tamarix symyrenensis Bunge	ASM	Xero	MIP	-	120
Tamarix szovitsiana Bunge	BP	Xero	MIP	5,7	106
Tamarix tetragyna (Boiss.) Boiss.	BP	Xero	MIP	5,7	19,20
Tiliaceae					
**Corchorus depressus* (L.) Stocks	Cosm.	Xero	T2	4	50
Typhaceae					
Typha domingensis Pers.	Cosm.	Hyphal	NP	7,8	19,20
Typha latifolia L.	MM	Hyphal	NP	-	41,135
Umbelliferae					
Ammi visnaga (L.) Lamk.	ASM	Xero	MIP	4	135, 137
Apium graveolens L.	Cosm.	Hyphal	AQ	1	95
**Centella asiatica* (L.) Urban	MM	Hyphal	HP	4	109
Verbenaceae					
Clerodendrum inerme (L.) Gaertn.	Cosm.	Hyphal	NP	5,8	63,105
Phyla nodiflora (L.) Greene	IP	Hyphal	NP	5	117
Verbena officinalis L.	MM, PP, ASM	Hyphal	NP	4	138
Zygophyllaceae					
Fagonia bruguieri DC. Prodr. Var. *rechingeri* Hadidi	BP	Xero	TH	-	42
**Fagonia indica* ssp. *schweinfurthia* Hadidi	IP	Xero	TH	-	51
Nitraria retusa (Forssk.) Aschers	CO	Xero	SFC	1,3,5	18,92
Nitraria schoberi L.	NM	Xerohal.	SFC	1,5	18,114
Seetzenia lanata (Willd.) Bullock	IP, BP	Xero	SFC	-	115
Tribulus terrestris L.	Cosm.	Xero	TH	4	63
Zygophyllum fabago L.	BP	Xerohal.	NP	-	63
Zygophyllum propinquum Decne	CT, IP	Xerohal.	NP	4	106
Zygophyllum simplex L.	Des, BP, IP, CO	Xerohal.	TH	1,2,4	76,1

1.7. New record of halophytes not yet published

There are about 168 halophytes that were not present in any of the halophyte lists published before (Aronson, 1989; Menzel and Lieth, 1999). They are distributed among 37 families and most of them are from Chenopodiaceae (26), Poaceae (25), Cyperaceae (19), Asteraceae (18) and Papilionaceae (17) while other families are represented by less than 10 new halophytes (Table 1).

1.8. Adaptations

A number of different mechanisms are used by halophytes to achieve osmotic adjustment, including inorganic ion accumulation, synthesis or accumulation of organic compounds and water loss (Ungar, 1991). Classification schemes have been constructed that attempt to match morphological and physiological characters

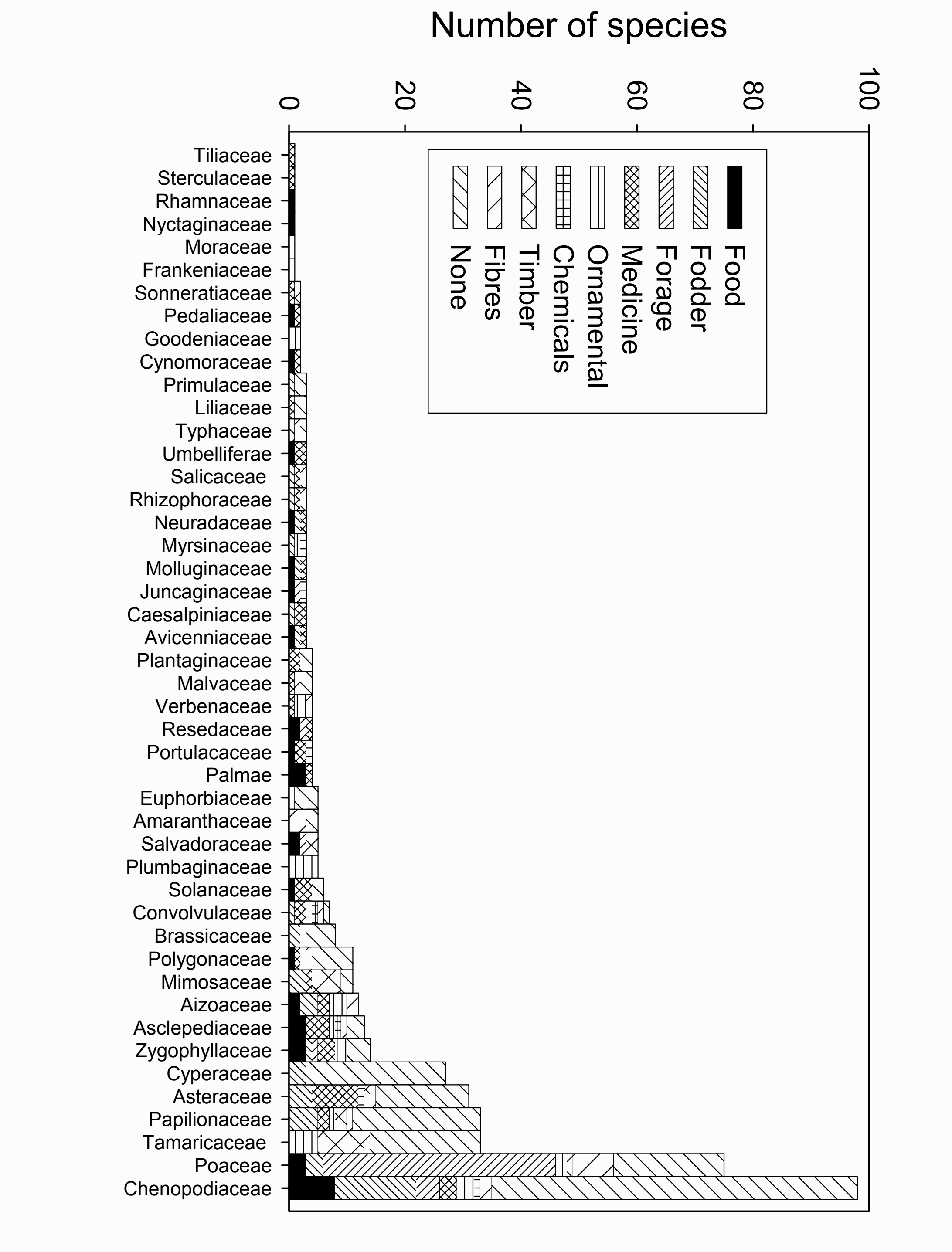
Number of species
0
20
40
60
80
100
Food
Fodder
Forage
Medicine
Ornamental
Chemicals
Timber
Fibres
None
Tiliaceae
Sterculaceae
Rhamnaceae
Nyctaginaceae
Moraceae
Frankeniaceae
Sonneratiaceae
Pedaliaceae
Goodeniaceae
Cynomoraceae
Primulaceae
Liliaceae
Typhaceae
Umbelliferae
Salicaceae
Rhizophoraceae
Neuradaceae
Myrsinaceae
Molluginaceae
Juncaginaceae
Caesalpiniaceae
Avicenniaceae
Plantaginaceae
Malvaceae
Verbenaceae
Resedaceae
Portulacaceae
Palmae
Euphorbiaceae
Amaranthaceae
Salvadoraceae
Plumbaginaceae
Solanaceae
Convolvulaceae
Brassicaceae
Polygonaceae
Mimosaceae
Aizoaceae
Asclepiadaceae
Zygophyllaceae
Cyperaceae
Asteraceae
Papilionaceae
Tamaricaceae
Poaceae
Chenopodiaceae

Figure 1.

to specific halophyte habitats and growth strategies (Breckle, 1983). However, these classifications have little predictive value. Under physical or physiological stress conditions, the leaves of saline plants play an important role and develop certain xeromorphic adaptive characteristics, such as succulence, reduction in surface area, thick cuticle or a cover of waxy layers on the epidermis, hairs on stem and leaves, sunken stomata, salt glands, etc. The succulents often lack the ability to secrete salts, but thwart the rise of salt concentration through an increase of their water content, and become increasingly succulent during their development. *Arthrocnemum, Halogeton, Halopeplis, Halostachys, Haloxylon*, *Heliotropium, Salicornia, Suaeda*, *Salsola*, and *Zygophyllum* are prominent succulent halophytic genera in Pakistan. There is an abrupt reduction in surface area of leaves of some species (e.g. *Salsola imbricata*, *Trianthema triquetra*, *Suaeda fruticosa*) under conditions of extreme salt stress. *Suaeda fruticosa*, *Salsola imbricata*, *Haloxylon stocksii*, *H. salicornicum*, *Cressa cretica*, *Sporobolus ioclados*, *Urochondra setulosa*, and *Aeluropus lagopoides* are characterized by thick cuticles and a cover of waxy layers, while stems and leaves of the last five species remain covered with hairs. Only a small number of halophytes are able to excrete salts through glandular cells. Liphschitz and Waisel (1982) listed active secreting glands in *Avicennia*, *Aeluropus*, *Aegiceras*, *Limonium*, *Rhizophora*, *Ceriops*, *Tamarix* and *Reaumuria*. Salt concentration of the growth medium, light, temperature, oxygen, pressure and the presence of metabolic inhibitors are the governing factors of salt excretion. A similar function of salt recretion is ascribed to bladder trichomes of some Chenopodiaceae, e.g. *Atriplex* species. The basic role of bladders is to protect young developing shoots and leaves from toxic salt levels first in the apoplast and subsequently in the symplast.

Tolerance of salinity by halophyte seeds may be expressed either as the ability of un-germinated seeds to tolerate high salinity without losing viability or the ability of seeds to germinate at high salinities (Khan, 2003). Seeds of halophytes not only germinate at higher salinities but also remain viable for long periods of time when immersed in saline water (Ungar, 1995). Halophytes vary in their upper limits of salt tolerance and an increase in salinity usually delays their germination (Ungar, 1995). Seeds of salt marsh species like *Atriplex stocksii, Polygonum aviculare,* and *Zygophyllum simplex* show little germination above 125 mM NaCl (Khan & Rizvi, 1994; Khan & Ungar, 1997; Khan & Ungar, 1997; Ungar, 1991). However, species like *Aeluropus lagopoides*, *Haloxylon stocksii, Sporobolus ioclados, Suaeda fruticosa, Limonium stocksii*, *Triglochin maritima* and *Urochondra setulosa* were able to germinate in up to 500 mM NaCl (Khan & Ungar, 1996; Khan & Ungar, 1998; Khan & Ungar, 1999; Gulzar & Khan, 2001a,b; Khan et al., 2001; Zia & Khan, 2002). A third group of species like *Arthrocnemum macrostachyum*, *Cressa cretica*, *Halogeton glomeratus*, *Kochia scoparia*, *Salicornia brachiata*, *Salicornia bigelovii*, *Salsola iberica*, and *Tamarix pentandra* could germinate at NaCl concentrations of 800 mM and higher (Khan, 1991; Ungar, 1995; Khan & Gul, 1998; Khan et al., 2000; Khan et al., 2001; Khan et al., 2002; Khan, 2003). Species like *A. stocksii*, *H. stocksii*, and *S. fruticosa* could be classified as moderately salt tolerant and *A. macrostachyum* and *C. cretica* as highly salt tolerant. Sharma and Sen (Sharma & Sen, 1989) observed an extremely fast germination in the seeds of *Haloxylon stocksii* and *H. salicornicum*, occurring within an hour. An ecophysiological adaptive role is assigned to such a phenomenon of germination, which involves the uncoiling of the young embryo out of the testa immediately after contact with water, with an unusually high rate of cell elongation soon after imbibitions. Such fast seed germination indicates an adaptive strategy taken by the plants, as water with reduced NaCl content in soil during the rainy season is available only for a short duration. An increase in salinity leads to dormancy of seeds in halophytes and glycophytes. More investigations with halophytes (Ungar, 1991) have demonstrated that seeds of several species, including *Arthrocnemum macrostachyum, Salicornia bigelovii, Salicornia brachiata, Cressa cretica, Tamarix pentandra, Salsola iberica, Halogeton glomeratus, Kochia scoparia, Aeluropus lagopoides*, *Atriplex stocksii, Haloxylon stocksii, Sporobolus arabicus, Suaeda fruticosa, Limonium stocksii*, *Triglochin maritima* and *Urochondra setulosa* remained dormant at a high salinity, and these will germinate when returned to distilled water (Joshi, 1979; Khan, 1991; Khan & Rizvi, 1994; Khan & Ungar, 1995; Khan & Ungar, 1996; Khan & Ungar, 1997; Khan & Aziz, 1998; Khan, 2001, 2003; Khan & Gul, 1998; Khan et al., 1998; Khan & Ungar, 1998ab; Khan & Ungar, 1999; Khan et al., 2001ab; Khan et al., 2002; Khan & Gulzar, 2003).

Salt tolerance of species varies with the stage of their development. Some species, such as *Suaeda fruticosa, Haloxylon stocksii, Atriplex stocksii* and *Zygophyllum simplex,* were not highly salt tolerant at germination, but showed a high salinity tolerance at the growth stage (Khan, 2003). While other species like *Arthrocnemum macrostachyum,* and *Cressa cretica* showed a higher degree of salt tolerance both at the germination and growth stages (Khan, 1991; Khan & Gul, 1998).

It has been assumed that survival of plants in saline environments depends upon the altered biochemical relations and on the quantitative ratio between toxic and protective compounds like betaine. Khan et al., (1998) while studying *Halopyrum mucronatum, Atriplex stocksii*, *Haloxylon stocksii* and *Suaeda fruticosa* found a high accumulation of betaine with a corresponding increase in salinity. The betaine is said to function as a source of solute for intracellular osmotic adjustment. Betaine accumulation occurs in the tissues of plants exposed to a saline substrate, and there is a positive correlation between betaine content and the amount of Na^+ and Cl^- in the cell sap. It is also estimated that about 200 mM L^{-1} of plant water or higher betaine concentration is needed to achieve osmotic adjustment successfully under saline conditions, and most of the Pakistani species tested have levels of betaine concentration higher than this.

Ungar (1991) described the presence of an ultrafilter in roots of mangroves of the Rhizophoraceae family, enabling only selective absorption of ions. They may retain a low internal salinity by means of salt excluding mechanisms in the roots.

In this type, sodium and chloride concentrations are higher in xylem sap and do not reach the metabolic cellular environment. Another mechanism of salt regulation in mangroves is salt excretion. In species of *Avicennia*, and *Aegiceras*, NaCl concentration in the excreted solution exceeds the NaCl concentration of seawater and this is normally 10 times that of salt exclusion types and also does not reach the metabolic environment (Joshi, 1979). The same holds true for *Aeluropus littoralis*, *Limonium latifolium*, and all species of *Tamarix* and *Reaumaria* (Ungar, 1991).

The stem and leaf succulent halophytes lack the ability to excrete salt and accumulate salt in their tissues. They are highly succulent and thwart the rising of salt concentration with a permanent increase in their water content. They become increasingly succulent in their development and are known as cumulative halophytes. Inland halophytes, such as *Haloxylon stocksii*, *H. salicornicum*, *Salsola imbricata*, *Sesuvium sesuvioides*, *Suaeda fruticosa*, *Trianthema triquetra* and *Zygophyllum simplex* are characterizes by a thickening in leaves, elongation of cells, higher elasticity of cell walls, smaller relative surface areas, a decrease in extensive growth, and a high water content per unit of surface area. Leaves in some species, such as *Suaeda fruticosa*, *Salsola imbricata* and *Trianthema triquetra,* are reduced in surface area when exposed to high salt content in the soil. Because these species lack regulatory mechanisms, salt concentration rises during the growing season, and when a certain level is reached, the plant dies. Among mangroves, species of *Avicennia, Ceriops* and *Rhizophora* absorb and accumulate excessive amounts of salts and the leaves become fleshy.

1.9. Utilization and potential of halophytes

Halophytes have their greatest potential not so much in contributing to the world's food supply but primarily in their utilization of the growing areas of saline land for a range of different goals (Figure 1). The most important opportunities relate to reforestation or replanting and ecological recovery of saline areas that have fallen into disuse, coastal development and protection, and the production of cheap biomass for renewable energy, climate improvement and CO_2 sequestration. Mangroves, besides playing roles in stabilization of coasts and beaches; food chain and life support systems; aquaculture; agriculture; and support to development of wild-life sanctuary and recreation areas; also provide tannin; thatching material; fodder; fish poison; food products; medicine and wood for building purposes, fuel, and boat and canoe making for the residents of coastal areas. There are 272 halophytes out of a total 410 reported from Pakistan and about 51 could be used for extracting medicine, 48 as forage, 47 as fodder, 38 as food, 34 as ornaments, and others as fibers, timber and other usages of wood, and various chemicals (Figure 1).

1.9.1. Food yielding halophytes

Of conventional crops, the only species with halophytic ancestors are beets (*Beta vulgaris*) and the date palm (*Phoenix dactylifera*), which can be irrigated with brackish water. The seed bearing species, which are used as food, include *Salvadora oleoides, S. persica, Trianthema portulacastrum, Oxystelma esculentum* and *Zizyphus nummularia*. The young leaves and shoots of *Salicornia bigellovi, S. brachiata, Sesuvium portulacastrum*, *Chenopodium album*, *Atriplex hortensis, Triglochin maritima, Arundo donax, Rumex vesicarius, Apium graveolens, Portulaca oleracea*, and *Suaeda maritima* have also been used for vegetables, salads and pickles in various parts of the country. *Suaeda fruticosa* and *Haloxylon stocksii* are used to prepare a kind of baking soda, which is used in the preparation of food. Radicles of *Rhizophora mucronata*, *Zizyphus nummularia* and *Ceriops tagal* and tender leaves of *Thespesia populnea*, *Hibiscus tiliaceus* are also used as salad.

1.9.2. Forages and fodders

There are about 95 halophytic species that could be used as either forage or fodder and most prominent among them are mangroves. The foliage of such species as *Avicennia marina*, *Aegiceras corniculata*, *Ceriops tagal*, and *Rhizophora mucronata* are used as camel and cattle feed. Among trees, species of *Acacia*, *Prosopis*, *Salvadora* and *Zizyphus* are traditional fodder of arid regions. Many species of *Alhagi, Salicornia*, *Chenopodium*, *Atriplex*, *Salsola*, *Suaeda* and *Kochia* are common fodder shrubs. Among grasses *Leptochloa fusca*, *Aeluropus lagopoides*, *Dactyloctenium sindicum*, *Cynodon dactylon*, *Paspalum vaginatum*, *Sporobolus marginatus*, *Chloris gayana*, *C. virgata*, *Echinochloa turnerana*, *E. colonum* and *Puccinellia distans* are common species found in saline and alkaline areas and used as forages. However, most of the 68 grasses found in Pakistan are browsed by animals Aronson (1985) recorded 1.26 to 2.09 Kg m^{-2} dry matter, and 15.5 to 39.5% fiber, and 10.2 to 19.5% crude protein in some species of *Atriplex*. *Kochia indica* has been field tested for domestic livestock and found to produce good fodder with fresh biomass of 8.5 kg per bush from March through August (Dagar, 1995). Kallar grass (*Leptochloa fusca*) has gained much attention as a fodder on salt affected soils (both saline and alkaline) in Pakistan (Malik et al. 1986) and yields about 46.5 t ha^{-1} of green forage when planted in extreme alkali soil (pH > 10) for 5 years.

1.9.3. Oil seeds

Production of vegetable oil from seed-bearing halophytes appears promising. Seeds of various halophytes, such as *Suaeda fruticosa, Arthrocnemum macrostachyum, Salicornia bigelovii, S. brachiata, Halogeton glomeratus, Kochia* scoparia, and Haloxylon stocksii possess a sufficient quantity of high quality edible oil with unsaturation ranging from 70-80% (Weber et al., 2001). Seeds of *Salvadora oleoides* and *S. persica* contain 40-50% fat and are a good source of lauric acid. Purified fat is used for soap and candle making and is a potential substitute for coconut oil.

1.9.4. Fuel wood

More than a billion people in developing countries rely on wood for cooking and heating. Quite often fuel wood is obtained from salt tolerant trees and shrubs, which may include species of *Prosopis*, *Tamarix*, *Salsola*, *Acacia, Suaeda*, *Kochia*, *Capparis* and *Salvadora* (Dagar, 1995). In addition species like *Dalbergia sisso, Pongamia pinnata, Populus euphratica, Tamarix aphylla, T. indica, T. mascatensis, T. pakistanica, T. passernoides, T. ramosisima, T. salina, T. stricta, T. szvoitsiana*, and *T. tetragyna* could provide good quality wood. In coastal areas the mangroves are used frequently for fuel and timber, which has contributed significantly to the deforestation of these habitats. Species of *Rhizophora*, *Ceriops*, *Avicennia* and *Aegiceras* are good fuel woods and also contribute to charcoal production.

1.9.5. Medicinal uses

Many workers have reported the medicinal uses of halophytes while describing the economic importance of plants (Dagar, 1995). Halophytic plants are known to provide relief in the following diseases: Cold, flu & cough: (*Achillea mellifolium, Microcephala lamellate, Phylla nodiflora, Caesalpinea bonduc, Plantago lanceolata, Portulaca quadrifida, Portulaca oleracea, Solanum surratense, Withania sominifera, Tribulus terrestris, Capparis decidua, Zygophyllum simplex, Salvadora persica* & *S. oleoides*), vermifuge (*Artimesia scoparia, Portulaca quadrifida, Seriphidium brevifolium, S. quetenses, Cocos nucifera, Portulaca oleracea, Evolvulous alsinoides, Salsola imbricata, S. tetrandra, Zygophyllum propinqum, Z. simplex*), stomach ailments (*Juncus rigidus, Seriphidium quetenses, Thespesia populnea, Zaleya pentandra*), pain killer; (*Artimesia scoparia*, *Solanum surratense*), diuretic (*Plantago major*, *Portulaca quadrifida, P. oleracea, Withania sominifera, Tribulus terrestris, Juncus rigidus*), snake bite: (*Rumex vesicarius, Verbena officinalis, Zaleya pentandra*), gonorrhea (*Portulaca oleracea, Corchorus depressus*), sedative (*Withania somnifera*), ulcer (*Ceriops tagal, Withania sominifera*), pneumonia (*Corchorus depressus*), heart disease: (*Ammi visnaga, Tribulus terrestris, Capparis decidua, Kochia indica, Zygophyllum simplex*), skin diseases (*Centella asiatica, Salsola imbricata*), laxative (*Capparis deciduas*), eyes (*Zygophyllum simplex*); ear pain (*Artemesia scoparia*); asthma (*Evolvulous alsinoides*, *Solanum incanum*); wound healing (*Plantago lanceolata*) and stimulant (*Kochia indica*).

1.9.6. Products of economic and common use

Suaeda, *Salicornia*, *Salsola*, and *Haloxylon*: a carbonate of soda is obtained in large quantities and used for the soap and glass industry. *Calotropis procera*: parts of the seeds for pillows. The stem and leaves of *Juncus maritimus, Kochia* *scoparia, Aristida adscenscoinis, Imperata cylindrica, Phragmites australis* and *Typha domingensis* have been used since ancient times for the manufacture of mats, baskets thatching and cordage.

1.9.7. Chemicals

Most of the mangrove species are rich in tannin. Its extraction from the bark has been a major use of mangroves.

Aronson (1982, 1985, 1986, 1991) in a recent survey of over 1,600 salt-tolerant plants with economic potential, has identified 290 tree species as being tolerant of 7-8 dS m^{-1} salinity. *Tamarix stricta* has been recorded as yielding 7.2 t DM ha^{-1} yr^{-1}, with a final density of 600 trees ha^{-1} after 5 years. Various species of *Prosopis*, *Casuarina*, *Eucalyptus* and *Acacia* have been evaluated for their salinity tolerance and biomass production. *Prosopis juliflora* could yield up to 52.3 t ha^{-1} biomass in 6 years. *P. juliflora, Acacia nilotica* and *Casuarina equisetifolia* have been found to be most alkali tolerant; *Tamarix indica*, *T. articulata*, *Prosopis juliflora*, *Pithecellobium dulce*, *Parkinsonia aculeata* and *Acacia farnesiana* to be tolerant of salinity levels up to EC 25 to 35 dS m^{-1}; and *Acacia nilotica*, *A. tortilis*, *Casuarina glauca*, *C. obesa* and *Eucalyptus calmadulensis* to be tolerant of salinity levels up to 15-25 dSm^{-1}. *Aegiceras corniculata, Avicennia marina, Ceriops tagal,* and *Rhizophora mucronata* trees could be grown in areas with high salinity and low water tables. In recent years research in the evaluation of halophytes for land reclamation and landscape management has taken a new dimension.

2. REFERENCES

Abedin, S. 1973. Pedaliaceae. In: E. Nasir and S.I. Ali (Eds.), Flora of Pakistan, No. 33. Department of Botany, University of Karachi. 4 pp.

Abedin, S. & Ghafoor, A. 1976. Sterculiaceae. In: E. Nasir and S.I. Ali (Eds.), Flora of Pakistan, No. 99 Department of Botany, University of Karachi. 25 pp.

Abedin, S. 1979. Malvaceae. In: E. Nasir and S.I. Ali (Eds.), Flora of Pakistan, No. 130. Department of Botany, University of Karachi. 107 pp.

Adams, C.D. 1972. Flowering plants of Jamaica. University Press, Glasgow.

Ahmed, N. & Chaudhary, G.R. 1988. Irrigated Agriculture of Pakistan. Shahzad Nazir, Lahore.

Ali, S.I. 1973. Mimosaceae. In: E. Nasir and S.I. Ali (Eds.), Flora of Pakistan, No. 36. Department of Botany, University of Karachi. 41 pp.

Ali, S.I. 1973. Caesalpinaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 54. Department of Botany, University of Karachi. 47 pp.

Ali, S. I. 1973. Papilionaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 100. Department of Botany, University of Karachi. 389 pp.

Ali, S.I. 1983. Asclepiadaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 150. Department of Botany, University of Karachi. 65 pp.

Ali, S.I. 2001. Salicaceae. In: S.I. Ali & M. Qaiser (eds.), Flora of Pakistan, No. 203. Department of Botany, University of Karachi. 60 pp.

Aronson, J. 1989. HALOPH; Salt Tolerant Plants for the World - A Computerized Global Data Base of Halophytes with Emphasis on their Economic Uses. University of Arizona Press. Tucson, USA.

Aronson, J. 1991. The present and future roles of salt tolerant trees and their associated microsymbionts in arid lands. In: Choukr-Allah, R. (ed.), Plant Salinity Research - New Challenges. pp. 363-376. Proc. Intnl. Conf. Agril. Mgt. Salt Affected Areas, Agadir, Morocco.

Aronson, J.A. 1982. Halophytes of Central America and the Caribbean Region. Vol.: BGUN-ARI. Ben-Gurion University of the Negev, Beer-Sheva, Israel. Report.

Aronson, J.A. 1985. Economic halophytes - a global review. In: Wickens, G.E., Goodin, J.R. & Field, D.V. (eds.), Plants for arid lands, pp. 177-188. George Allen and Unwin, London.

Aronson, J.A. 1986. Halophytes - new crops for deserts and coastal areas. FAO, CERES, Rome. Unpublished manuscript.

Austin, D.F. & Ghazanfar, S. 1979. Convolvulaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 126. National Herbarium, Pakistan Agricultural Research Council, Islamabad. 64 pp.

Aziz, I. & Khan, M.A. 2000. Physiological adaptations to seawater concentration in *Avicennia marina* from Indus delta, Pakistan. Pakistan Journal of Botany 32: 151-170.

Baro, D. & Medrano, F.G. 1985. Halophytic flora and vegetation of Tamaulipas, Mexico. Unpublished manuscript.

Batanouny, K.H. 1989. Halophytes and halophytic plant communities in the Arab region: Their potential as a rangeland resource. In: Squires, V.R. & Ayoub, A.T. (eds.), Halophytes as a resource for livestock and for rehabilitation of degraded lands. Tasks for vegetation science 32. pp. 139-163. Kluwer Academic Publisher, Dordrecht.

Baum, B. 1978. The genus *Tamarix*. Israel Academy of Sciences and Humanities, Jerusalem.

Bhandari, M.M. 1978. Flora of the Indian Desert. Scientific Publishers, Jodhpur.

Bokhari, M.H. 1972. Plumbaginaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 28. Department of Botany, University of Karachi. 14 pp.

Bor, N.L. 1968. Gramineae. In: Townsend, C. C. & Guest, E. (eds.), Flora of Iraq 9. pp. 434-435. Ministry of Agriculture and Agrarian Reform, Baghdad.

Boyko, H. 1964. Principles and experiments regarding irrigation with highly saline and seawater without desalinization. In: Transactions of the New York Academy of Sciences Series II /26. pp. 1087-1102. New York Academy of Sciences.

Bramwell, D. & Bramwell, Z. 1974. Wildflowers of the Canary Islands. Stanley Thorne Ltd, London.

Breckle, S.W. 1983. Temperate deserts and semi-deserts of Afghanistan and Iran. In: Goodall, D.-W. & West, N. (eds.). Ecosystems of the world 5, 271-319. Elsevier, Amsterdam.

Breckle, S.W. 1986. Studies on halophytes from Iran and Afghanistan. II. Ecology of halophytes along salt gradients. Proceedings of the Royal Society of Edinburgh.

Burkart, A. 1976. A monograph of the genus *Prosopis* Leguminosae subfam. Mimosoideae. J. Arnold Arboretum 57: 219-249.

Bustanai, M., Waisal, Y., Kuller, Z., Guggenheim, J. & Tillman, A.G. 1971. The use of saline water for growing Rhodes grass on coastal sand dunes. Hassadeh 51: 603-605.

Carlton, J.M. 1975. A guide to common Florida salt marsh and mangrove vegetation. Vol.: 6. Florida Marine Research. St. Petersburg, Florida.

Choukr-Allah, R. 1996. The potential of halophytes in the development and rehabilitation of arid and semi-arid zones. In: Choukr-Allah, R., Malcolm, C. V., Hamdy, A. (ed.), Halophytes and biosaline agriculture. pp. 3-16. Marcel Dekker, Inc. 270 Madison Avenue, New York, New York.

Cintrón, G., Lugo, A.E., Pool, D.J. & Morris, G. 1978. Mangroves of arid environments in Puerto Rico and adjacent islands. Biotropica 10: 110-121.

Cooper, A. 1982. The effects of salinity and waterlogging on the growth and cation uptake of salt marsh plants. New Phytologist 90: 263-275.

Cope, T.A. 1982. Poaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 143. Department of Botany, University of Karachi. 679 pp.

Corre, J.J. 1985. Institut de Botanique, Université de Montpellier, France. Personal communication to Pasternak, D., in Pasternak, D. 1989.

Correll, D.S. & Correll, H.B. 1982. Flora of the Bahamas archipelago: Including the Turks and Caicos islands. J. Cramer, Vaduz, Liechtenstein.

Court, D. 1981. Succulent flora of southern Africa. A. A. Balkema, Rotterdam.

Dafni, A. 1975. Comparative biology of *Prosopis farcta* in four different habitats in Israel. Hebrew University, Jerusalem. Ph.D. diss.

Dagar, J.C. 1995. Characteristics of halophytic vegetation in India. In: Khan, M.A. and Ungar, I.A. pp. 255-276. Biology of Salt Tolerant Plants. (Eds.), University of Karachi, Karachi. 476 pp.

Daoud, H.S. 1985. Flora of Kuwait. In: Dicotyledoneae Vol.: 1.

Doliner, L.H. & Jolliffe, P.A. 1979. Ecological evidence concerning the adaptive significance of the C4 dicarboxylic acid pathway of photosynthesis. Oecologia 38: 23-34.

Dubuis, A. & Simmonneau, P. 1960. Contilbution á l'étude de la végétation halophile des bassins fermes du Plateau D'Oran. Services des Etudes Scientifiques, Clairbois, Algeria.

Feinbrun, N. 1978. Flora Palaestina. Part III. Israel Academy of Science, Jerusalem.

Feinbrun, N. 1986. Flora Palaestina. Part IV. Israel Academy of Sciences, Jerusalem.

Felger, R.S. & Moser, M.B. 1973. Eelgrass (*Zostera maritima* L.) in the Gulf of California: Discovery of its nutritional value by the Seri Indians. Science 181: 355-356.

Ferguson, C.R. 1952. Salt-tolerant plants for south Florida. pp. 306-313. Florida State Horticultural Society.
Fischer, M.J. & Skerman, P.J. 1986. Salt tolerant forage plants for summer rainfall areas. Reclamation and Revegetation Research 5: 263-284.
Frietag, H., Hedge, I.C., Jafri, S.M.H., Kothe-Heinrich, G., Omer, S. & Uotila, P. 2001. Chenopodiaceae. In: S.I. Ali and M. Qaiser (eds.), Flora of Pakistan, No. 204. Department of Botany, University of Karachi and Missouri Botanical Garden, St. Louis, USA. 217 pp.
Ghafoor, A. 1973. Portulacaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 51. Department of Botany, University of Karachi. 8 pp.
Ghafoor, A. 1974. Tiliaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 75. Department of Botany, University of Karachi. 33 pp.
Ghafoor, A. 1975. Zygophyllaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 76. Department of Botany, University of Karachi. 35 pp.
Ghafoor, A. 1985. Hydrocharitaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 169. Department of Botany, University of Karachi. 13 pp.
Ghafoor, A. 1985. Moraceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 171. Department of Botany, University of Karachi. 54 pp.
Ghafoor, A. 2002. Asteraceae (1) – Anthemideae. In: S.I. Ali and M. Qaiser (eds.), Flora of Pakistan, No. 207. Department of Botany, University of Karachi and Missouri Botanical Garden, St. Louis, USA. 172 pp.
Ghazanfar, S.A. & Nasir, Y.J. 1986. Caryophyllaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 175. Pakistan Agricultural Research Council, Islamabad. 125 pp.
Glenn, E.P. & O'Leary, J. 1984. Relationship between salt accumulation and water content of dicotyledonous halophytes. Plant, Cell and Environment 7: 253-261.
Glenn, E.P. 1987. Relationship between cation accumulation and water content of salt tolerant grasses and a sedge. Plant, Cell & Environment 10: 205-212.
Glenn, E.P., Tanner, R., Miyamoto, M., Fitzsimmons, K. & Boyer, J. 1998. Water use productivity and forage quality of the halophyte *Atriplex nummularia* grown on saline waste water in a desert enviroment. Journal of Arid Environment 38: 45-62.
Gulzar, S. & Khan, M.A. 2001a. Seed germination of a halophytic grass *Aeluropus lagopoides.* Annals of Botany 87: 319-324.
Gulzar, S., Khan, M.A. & Ungar, I.A. 2001b. Effect of temperature and salinity on the germination of *Urochondra setulosa*. Seed Science & Technology 29: 21-29.
Gulzar, S., Khan, M.A. & Ungar, I.A. 2003. Salt tolerance of a coastal salt marsh grass. Communication of Soil Science and Plant Nutrition 34: 2595-2605.
Gulzar, S., Khan, M.A. & Ungar, I.A. 2003. Effect of salinity on growth, ionic content, plant-water status in *Aeluropus lagopoides*. Communication of Soil Science and Plant Nutrition 34: 1657-1668.
Hu, C.C. & Chin, T.L. 1995. Halophytes in China - Floristic distribution and vegetation types. Unpublished manuscript.
Jafri, S.M.H. 1973. Brassicaceae, In: E. Nasir and S.I. Ali (eds.). Flora of Pakistan, No. 55. Department of Botany, University of Karachi. 309 pp.
Jafri, S.M.H. & Qaiser, M. 1975. Myrsinaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 89. Department of Botany, University of Karachi. 8 pp.
Jafri, S.M.H. & Qaiser, M. 1976. Orobanchaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 98. Department of Botany, University of Karachi. 25 pp.
Jafri, S.M.H. 1981. Juncaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 138. Department of Botany, University of Karachi. 27 pp.
Joshi, A.J. 1979. Physiological studies on some halophytes. Saurashtra Univ. India. PhD Thesis.
Khan, M.A. 1991. Studies on germination of *Cressa cretica* L. seeds*.* Pakistan Journal of Weed Science Research 4: 89-98.
Khan, M.A. 2003. Halophyte seed germination: success and pitfalls. International Symposium on Optimal. In: El-Shaer et al. (Eds.), Resources Utilization in Salt-Affected Ecosystems in Arid and Semi-Arid Regions" Cairo. Desert Research Institute. 346-358 pp.
Khan, M.A. & Aziz, S. 1998. Some aspects of salinity, plant density, and nutrient effects on *Cressa cretica* L. Journal of Plant Nutrition 21: 769-784.
Khan, M.A. & Aziz, I. 2001. Salinity tolerance of some mangroves from Pakistan. Wetland Ecology and Management 9: 228-332.
Khan, M.A. & Gul, B. 1998. High salt tolerance in the germinating dimorphic seeds of *Arthrocnemum indicum*. International Journal of Plant Sciences 159: 826-832.
Khan, M.A. & Gulzar, S. 2003. Germination responses of *Sporobolus ioclados*: a potential forage grass. Journal of Arid Environment 53: 387-394.
Khan, M.A. & Rizvi, Y. 1994. The effect of salinity, temperature and growth regulators on the germination and early seedling growth of *Atriplex griffithii* Moq. var. *stocksii* Boiss. Canadian Journal of Botany 72: 475-479.

Khan, M.A. & Ungar, I.A. 1995. Biology of Salt Tolerant Plants. Department of Botany, University of Karachi, Pakistan. 424 pp.

Khan, M.A. & Ungar, I.A. 1996. Influence of salinity and temperature on the germination of *Haloxylon recurvum*. Annals of Botany 78: 547-551.

Khan, M.A. & Ungar, I.A. 1997. Germination responses of the subtropical annual halophyte *Zygophyllum simplex*. Seed Science & Technology 25: 83-91.

Khan, M.A. & Ungar, I.A. 1998a. Germination of salt tolerant shrub *Suaeda fruticosa* from Pakistan: Salinity and temperature responses. Seed Science & Technology 26: 657-667.

Khan, M.A. & Ungar, I.A. 1998b. Seed germination and dormancy of *Polygonum aviculare* L. as influenced by salinity, temperature, and gibberellic acid. Seed Science & Technology 26: 107-117.

Khan, M.A. & Ungar, I.A. 1999. Seed germination and recovery of *Triglochin maritima* from salt stress under different thermoperiods. Great Basin Naturalist 59: 144-150.

Khan, M.A., Gul, B. & Weber, D.J. 2001a. Seed germination characteristics of *Halogeton glomeratus*. Canadian Journal of Botany 79: 1189-1194.

Khan, M.A., Gul, B. & Weber, D.J. 2001b. Effect of salinity and temperature on the germination of *Kochia scoparia*. Wetland Ecology & Management 9: 483-489.

Khan, M.A., Gul, B. & Weber, D.J. 2002. Seed germination in the Great Basin halophyte *Salsola iberica*. Canadian Journal of Botany 80: 650-655.

Khan, M.A., Ungar, I.A., Showalter, A.M. & Dewald, H. 1998. NaCl – induced accumulation of glycinebetaine in four subtropical halophytes from Pakistan. Physiologia Plantarum 102: 487-492.

Khan, M.A., Ungar, I.A., & Showalter, A.M. 1999. The effect of salinity on growth, ion content, and osmotic relations in *Halopyrum mucronatum* (L.) Stapf. Journal of Plant Nutrition 22: 191-204.

Khan, M.A., Ungar, I.A., & Showalter, A.M. 2000. Effects of sodium chloride treatments on growth and ion accumulation of the halophyte *Haloxylon recurvum*. Communication of Soil Science and Plant Nutrition 31: 2763-2774.

Khan, M.A., Ungar, I.A., & Showalter, A.M. 2000. Growth, water, and ion relationships of a leaf succulent perennial halophyte, *Suaeda fruticosa* (L.) Forssk. Journal of Arid Environment 45: 73-84.

Khan, M.A., Ungar, I.A., & Showalter, A.M. 2000. Salt tolerance in the subtropical perennial halophyte *Atriplex griffithii* Moq. var. *stocksii* Boiss. Annals of Botany 85: 225-232.

Kukkonen, I. 2001. Cyperaceae. In: S.I. Ali and M. Qaiser (eds.), Flora of Pakistan, No. 206. Department of Botany, University of Karachi and Missouri Botanical Garden, St. Louis, USA. 277 pp.

Lavranos, J. 1986. Bramley, South Africa. Personal communication to Pasternak, D., in Pasternak, D. 1989.

Le Houérou, H.N. 1980. Browse in Africa - the current state of knowledge. International Livestock Center of Africa, Addis Ababa, Ethiopia.

Le Houérou, H.N. 1984. Forage halophytes and salt-tolerant fodder crops in the Mediterranean Basin. In: Squires, V. R. & Ayoub, A. T. (eds.), Halophytes as a resource for livestock and for rehabilitation of degraded lands. Tasks for vegetation science Vol.: 32. Kluwer Academic Publisher, Dordrecht.

Le Houérou, H.N. 1986. Salt-tolerant plants of economic value in the Mediterranean Basin. Reclamation and Revegetation Research 5: 319-341.

Lieth, A.F. 1994. Use of sea water for growth and productivity of halophytes in the Gulf Region. United Arab Emirates University, Faculty of Science.

Lindacher, R. 1995. PHANART Datenbank der Gefäßpflanzen Mitteleuropas. Vol.: 125. Geobotanisches Institut der ETH, Stiftung Rübel, Zürich. Veröffentlichung des Geobotansichen Institutes.

Liphschitz, N. & Waisel, Y. 1982. Adaptation of plants to saline environments: salt excretion and glandular structure. In: Sen, D.N. & RajPurohit, K.S. (eds.), Contribution to the Ecology of Halophytes. pp. 197-214. Dr. W. Junk Publishers. The Hague/Boston/London.

Mahmoud, A., El-Sheikh, A.M. & Isawi, F. 1983. Ecology of the littoral salt marsh vegetation at Rabigh on the Red Sea coast of South Arabia. Journal of Arid Environment 5: 35-42.

Malik, K.A., Aslam, Z. & Naqvi, M. 1986. Kallar grass: a plant for saline land. Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan, 93 pp.

Marwat, Q. & Siddiqui, M.A. 1997. Neuradaceae. In: S.I. Ali and M. Qaiser (eds.), Flora of Pakistan, No. 198, Department of Botany, University of Karachi. 6 pp.

Mason, H.C. 1957. A flora of the marshes of California. University of California, Berkeley.

Menninger, E.A. 1964. Seaside plants of the world. Hearthside, New York.

Menzel, U. & Lieth, H. 1999. Halophyte Database Vers. 2.0. Halophyte Uses in different climates I: Ecological and Ecophysiological Studies. Progress in Biometeriology, Vol. 13. pp. 77-88. Edited by H. Lieth, M. Moschenko, M. Lohman, H. –W. Koyro and A. Hamdy. Backhuys Publishers, The Netherlands.

Mepham R.H. 1983. Mangrove floras of the southern continents. Part 1. South African Journal of Botany 2: 1-8.

Mepham R.H. & Mepham, J.S. 1985. The flora of tidal forests - a rationalization of the use of the term "mangrove". South African Journal of Botany 51: 75-99.
Moghaddam, P.R. & Koocheki, A. 1999. A comprehensive survey of halophytes in Khorasan province of Iran. Unpublished manuscript.
Morton, J.F. 1982. Wild plants for survival in south Florida. Fairchild Tropical Garden, Miami, Florida.
Munz, P. & Keck, D.D. 1968. A flora of California and supplement. University of California, Berkeley.
Nasir, Y.J. 1971. Umbelliferae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 20. Botany Department, Gordon College, Rawalpindi. 169 pp.
Nasir, Y.J. 1973. Molluginaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 40. Botany Department, Gordon College, Rawalpindi. 6 pp.
Nasir, Y.J. 1973. Aizoaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 41. Botany Department, Gordon College, Rawalpindi. 12 pp.
Nasir, Y.J. 1975. Resedaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 90, pp. 9, Botany Department, Gordon College, Rawalpindi.
Nasir, Y.J. 1985. Solanaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 168. National Herbarium, Pakistan Agricultural Research Council, Islamabad. 61 pp.
O'Leary, J.W. 1979. Yield Potential of halophytes and xerophytes. In: Goodin, J.R. & Northington, D.K. (eds.), Arid land plant resources. pp. 574-581. Texas Tech University, International Center for Arid and Semiarid Lands Studies, Lubbock.
O'Leary, J.W., Glenn E.P. & Watson, M.C. 1986. Agricultural production of halophytes irrigated with seawater. Plant and Soil 89: 311-322.
Omer, S. 1995. Gentianaceae. In: S.I. Ali and M. Qaiser (Eds.), Flora of Pakistan, No. 197. Department of Botany, University of Karachi. 172 pp.
Pasternak, D. 1990. Fodder production with saline water. The institute for applied research Ben-Gurion University of the Negev. Project Report.
Pasternak, D. & Nerd, A. 1996. Research and utilization of halophytes in Israel. In: Choukr-Allah, R., Malcolm, C.V., Hamdy, A. (ed.), Halophytes and biosaline agriculture. pp. 325-348. Marcel Dekker, Inc. 270 Madison Avenue, New York, New York 10016.
Peltier, J.P. 1982. La végétation du Bassin Versant de L'Oued Sous (Maroc). Université Scientifique et Medicaie de Grenoble. Unpublished PhD diss.
Qaiser, M. & Nazimuddin, S. 1981. Rhamnaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 140. Department of Botany, University of Karachi. 24 pp.
Qaiser, M. 1982. Tamaricaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 141. Department of Botany, University of Karachi. 65 pp.
Qaiser, M. 2001. Polygonaceae. In: S.I. Ali and M. Qaiser (eds.), Flora of Pakistan, No. 205. Department of Botany, University of Karachi and Missouri Botanical Garden, St. Louis, USA. 190 pp.
Qaiser, M. & Abid, R. 2003. Asteraceae (II) – Inuleae, Plucheae, and Gnaphaleae. In: S.I. Ali and M. Qaiser (eds.), Flora of Pakistan, No. 210. Department of Botany, University of Karachi and Missouri Botanical Garden, St. Louis, USA. 215 pp.
Qureshi, S. 1972. Elatinaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 29. Department of Botany, University of Karachi. 4 pp.
Qureshi, R.H. & Barrett-Lennard, E.G. 1998. Saline agriculture for irrigated land in Pakistan: A handbook. Australian Centre for International Agricultural Research Canberra, Australia.
Quézel, P. 1965. La végétation du Sahara. Fischer, Stuttgart.
Rafiq, R. 2002. Cynomoriaceae. In: S.I. Ali and M. Qaiser (eds.), Flora of Pakistan, No. 208, pp. 4, Department of Botany, University of Karachi and Missouri Botanical Garden, St. Louis, USA. 4 pp.
Raghavendra, A.S. & Das, V.S.R. 1978. The occurrence Of C4 photosynthesis: A supplementary list of C4 plants reported during late 1974-mid 1977. Photosynthetica 12: 200-208.
Radcliffe-Smith, A. 1986. Euphorbiaceae. In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 172. Department of Botany, University of Karachi. 170 pp.
Ragonese, A.E. & Covas, G. 1947. La flora halofile del sur de la provincia de Santa Fe. Darwiniana 7: 401-495.
Saxena, S.K. & Gupta, R.K. 1972. Vegetation of Pachpadra Salt Basin in Western Rajasthan. Journal of Bombay Natural History 70: 104-127.
Schulz, A.G. 1963. Plantas y frutos comestibles de la región chaquena. Rev. Agronómica Noroeste Argeatino 4: 57-83.
Sharma, S.K. & Gupta, R.K. 1971. Effects of salts on seed germination of some desert grasses. Annals of Arid Zone 10: 33-36.
Sharma, T.P. & Sen, D.N. 1989. A new report on abnormally fast germinating seeds of *Haloxylon* spp. - an ecological adaptation to saline habitat. Current Science 58: 382-385.
Shishkin, B.K. 1936. Flora of the U.S.S.R. In: Centrospermae Vol.: 6. Izdatel'stvo Akademii Nauk SSR, Moscow and Leningrad.

St. John, H. 1970. Classification and distribution of the *Ipomoea pescaprae* group (Convolvulaceae). Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeograpbie 89: 563-583.

Szabolcs I. 1994. Salt affected soils as the ecosystem for halophytes. In: Squires, V. R. & Ayoub, A.T. (eds.), Tasks for vegetation science 32. pp. 19-24. Kluwer Academic Publisher, Dordrecht.

The Royal Botanic Garden. 1993. Index Kewensis. Computerized data base.

Townsend, C.C. 1974. Amaranthaceae, In: E. Nasir and S.I. Ali (eds.), Flora of Pakistan, No. 71. Botany Department, Gordon College, Rawalpindi. 49 pp.

Toutain, G. 1977. Éléments d'agronomie Saharienne. Institut National de Recherche Agronomique, Marrakech, Maroc.

Tutin, T.G., Heywood, V.H., Burges, N.A., Valentine, D.H., Walters, S.M. & Webb, D.A. 1964. Flora Europaea. Vol.: I. Cambridge University, Cambridge.

Ungar, I.A. 1991. Ecophysiology of Vascular Halophytes. CRC Press, Boca Raton. 209 pp.

Ungar, I.A. 1995. Seed germination and seed-bank ecology of halophytes. In: Seed Development and Germination, (eds. J. Kigel and G. Galili), pp. 599-627, Marcel and Dekker Inc. New York.

Weber, D.J., Gul, B., Khan, M.A., Williams, T., Wayman, P. & Warner, S. 2001. Composition of vegetable oil from seeds of native halophytic shrubs. In: McArthur, E. Durant; Fairbanks, Daniel J., comps. 2000. Proceedings: Shrubland Ecosystem Genetics and Biodiversity. Proceedings RMRS-P-000. Ogden, Ut: U.S. Department of Agriculture, Forest Service Rocky Mountain Research Station.

Zia, S. & Khan, M.A. 2002. Comparative effects of NaCl and seawater on the germination of *Limonium stocksii*. Pakistan Journal of Botany 34: 345-350.

Zohary, M. 1966. Flora Palaestina. Part I. Israel Academy of Sciences, Jerusalem.

CHAPTER 12

FLORISTIC COMPOSITION OF A THREATENED MEDITERRANEAN SABKHAT OF SINAI

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Abstract. The Mediterranean sabkhat of Sinai are of importance for the conservation of migratory birds due to their unique geographical position. Field observations were used to document the floristic composition of these sabkhat before the execution of the North Sinai Agricultural Development Project (NSAD), which will have an impact on the sabkha ecosystems. A total of 43 halophytic species in 32 genera and 13 families were recorded. The sabkha flora includes endangered and endemic species of Sinai such as *Zygophyllum propinquum, Z. aegyptium* and *Salsola tetrandra.* The ecological consequences of the anthropogenic activities and management of sabkhat are discussed.

1. INTRODUCTION

Sinai is of great interest from a biological point of view. Because of its geographic location at the junction of three continents and the climatic changes throughout its history, the peninsula is currently recognised as one of the central regions for biodiversity in the Middle East by the World Conservation Union (Baha El Din, 1992; Ayyad et al., 2000).

The natural sabkhat in Sinai have a unique combination of physical, chemical and biological features (Evenari et al., 1985; El-Bana et al., 2002). Large expanses of the Sinai are occupied by the coastal and inland sabkhat (Levy, 1977; Evenari et al., 1985; El-Bana et al., 2002). Despite their ubiquitous nature in Sinai, sabkhat have attracted little attention concerning their floristic composition and ecological processes (Evenari et al., 1985).

The Mediterranean coastal region of Sinai extends for about 240 km between Port Said and Rafah (Lat. 31°20′N). Along this coast three main sabkhat extend from west to east: Sabkhat El Malaha (Lake Fouad), Sabkhat Bardawil (Lake Bardawil) and Sabkhat El Sheikh Zawayed (Figure 1). These sabkhat are of international conservation importance for migratory birds. Therefore, Lake Bardawil was designated as a wetland nature reserve under the International Ramsar convention in 1988 (Salama & Grieve, 1996). The Egyptian Government in 1983 declared the eastern part of the lake as a Protected Area (Zaranik).

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Presently, the Mediterranean sabkhat of Sinai are threatened by several factors including continuous land reclamation projects, construction of roads along the north coast, tourism development, pollution and coastal erosion. Since 1992 the Egyptian Government started the North Sinai Agricultural Development Project (NSADP) to reclaim and irrigate 400,000 acres in Northern Sinai depending on fresh water from the Nile mixed with reuse drainage water via the El-Salam Canal (Figure 1).

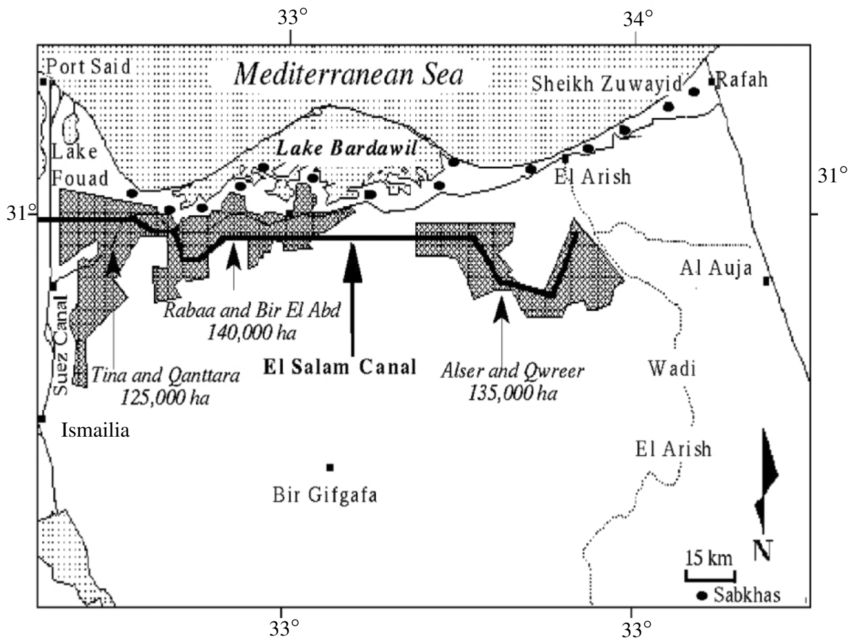

Figure 1. *Map showing the location of the North Sinai Agricultural Development Project (NSADP) and the studied sabkhas.*

It is expected that a groundwater flow of contaminated water (containing pesticides and enriched with nutrients) will reach the sabkhat, and impact on the ecosystems. Therefore the aim of the present article is to document the floristic composition of the sabkhat along the Mediterranean coast of Sinai. Such collection of data before the execution of NSADP has become critically important in order to monitor the future changes in the flora and vegetation of the sabkhat and provide for science based ecosystem management.

2. MATERIAL AND METHODS

2.1. The study area

The study area is located along the Mediterranean coastal land of Sinai that extends for about 220 km between El-Qantara Sharaq to Rafah with an average width ranging between 15 and 20 km in a north-south direction. The climate along this transect varies from a Mediterranean climate with a mean annual rainfall of about 300 mm at Rafah, to an extreme arid climate with a mean annual rainfall of about 60 mm at Port Said (Figure 2).

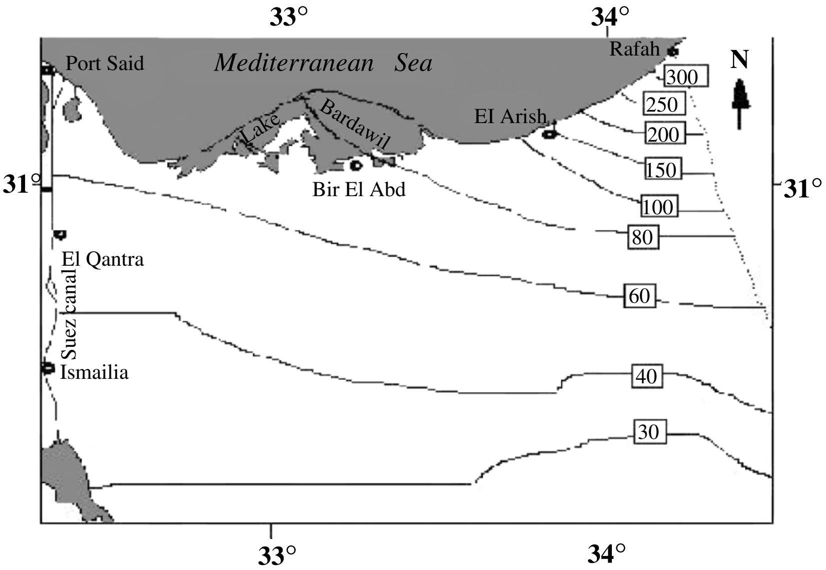

Figure 2. *Isohyets of precipitation along the Mediterranean coast of Sinai.*

In winter, the monthly mean maximum and minimum temperature values are 20°C and 11°C, respectively. In summer, the maximum mean monthly temperature is 32.5°C and the lowest mean monthly is 18.7°C. Strong winds like El-Khamasin storms are warm storms that carry fine sand and dust from one location to another depending on the direction of the wind and generally have high temperatures (up to 42°C in the atmosphere). Their average relative humidity ranges from 68% to 75%.

2.2. Data collection

A total of 15 sabkhat were surveyed along the Mediterranean coast of the Sinai (Figure 1). At each sabkha, ten quadrats of 5 × 5 m were used to sample the vegetation.The decimal scale method was applied to provide estimates of the relative cover and density of the species (Londo, 1976). Plant species were surveyed during April-May 2001. A composite list of the plant species was compiled by life form (Raunkiaer, 1934) and salt tolerance (Steiner, 1934; Zahran, 1982). The analysis of phytogeographical regions of the plant species follows Zohary (1973). Taxonomic nomenclature follows Täckholm (1974) revised by Boulos (1995).

3. RESULTS

The plant species recorded in the sabkhat along the Mediterranean coast of Sinai with their relative abundances are listed in the Appendix. The list includes 43 species representing 32 genera and 13 families. Dicotyledons comprised 78.6% of the total (33 species in 9 families), while the remainder consisted of nine monocotyledons species. The family with the highest number of species was the Chenopodiaceae, with 16 species, while the other 12 families were represented by three or less species (Appendix). The relative distributions were as follows: 6.9% of the species were very common, 23.6% common, 39.5% occasional and 30.2% rare. Six species (14%) of the sabkha flora on the Mediterranean coast of Sinai are considered rare and vulnerable (Gibali, 1988; Boulos & Gibali, 1993). The phytogeographical distribution of the plant species (Appendix) indicated that the majority of the species are of Saharo-Arabian distribution (55.8%). Most of the Saharo-Arabian species are mono-regionals (59.1%). The other mono-regionals are represented by two endemic species (*Zygophyllum aegyptium* and *Z. album*). The life forms ranged from helophytes to phanerophytes (Appendix), with most species being chamaephytes (35%) and therophytes (28%).

4. DISCUSSION

Gibali (1988) recorded 382 vascular plant species on the Mediterranean coastal plain of Sinai. The present survey records 43 species, which constitute about 11.8% of the 382 recorded by Gibali and about 53.7% of the halophytic vegetation of Egypt (Batanouny & Abo Sitta, 1977). Chenopodiaceae, Cyperaceae and Poaceae represent the main part of the floristic structure of the sabkha vegetation in the Arabian Peninsula and Pakistan (Abbas, 2002; Böer & Al Hajiri, 2002; Khan & Gul, 2002). The present study indicates that these families contribute nearly half (51.2%) of the recorded species.

The life form of a plant is usually thought to be the outcome of a hereditary adjustment to the plant's environment and may be considered as a registration apparatus of the habitat (Bakker, 1966). The high percentage of chamaephytes may be related to their ability to resist drought, salinity and sand accumulation (Evenari et al., 1975; Danin, 1996; El-Bana et al., 2002). An adaptive feature of the growth of chamaephytes in or around sabkhat is the accumulation of wind-borne sediments within or around their canopies. The formation of such phytogenic mounds (nebkhas) seems to play an important role in the ecological and evolutionary dynamics of arid ecosystems because they are biologically important for both ecosystem structure (primarily habitat) and process (soil accumulation and nutrient cycling) (Brown & Porembski, 1997; El-Bana et al., 2003a,b).

The importance of the study area from a phytogeographical point of view is due to its position on the Sinai Peninsula, which is located in the intersection of the four phytogeographical regions: the Mediterranean, the Irano-Turanian, the Sudano-Zambezian and the Saharo-Arabian. The Saharo-Arabian phytogeographical distribution of the majority of sabkha plant species indicates that the Mediterranean coastal sabkha flora may be more closely related to the southern desert flora than to the flora of the Mediterranean. According to Gibali (1988), the Mediterranean coastal plain of Sinai can be divided into two plains: desert western (running for 160 km from El Qantara to El Arish), and humid eastern (running for 60 km from El Arish to Rafah). This division coincides with important changes in the structure and composition of vegetation (Gibali, 1988; Dargie & El-Demerdash, 1991; El-Bana et al., 2002). The desert western plain is dominated by xeropsammophytes and xerohalophytes (Gibali, 1988; El-Bana et al., 2000, 2002). The higher number of xerohalophytes in sabkhas may be expected to express a better adaptation to higher salinity and aridity (Zahran, 1982).

Succulence is a common phenomenon in the vegetation of saline habitats (Zahran, 1982). Salt tolerance classification of the floristic data revealed that the succulent forms (46.5%) are the major component of the sabkha floristic structure along the Mediterranean coast of Sinai. Six growth forms can be distinguished: (a) succulent shrubs as in *Arthrocnemum macrostachyum,* and *Zygophyllum album,* (b) succulent annual herbs as in *Mesembryanthemum crystallinum* and *Zygophyllum simplex,* (c) excretive perennial herb growth forms, e.g. *Cressa cretica*, (d) excretive frutiscents as in *Nitraria retusa* and *Tamarix nilotica,* (e) cumulative rhizomatous growth forms, e.g. *Juncus rigidus* and *Cyperus laevigatus* and (f) cumulative stoloniferous growth forms as in *Phragmites australis*.

Land degradation and desertification in the northern Sinai have been severe in the last century (Tsoar, 1995; Tsoar & Karnieli, 1996). The landscape and native vegetation have been significantly altered by agriculture, livestock overgrazing, wood cutting, introduction of exotic species, urbanisation and its attendant effects, and military activities. Seventy-five vulnerable, endangered and endemic plant species have been recorded along the Mediterranean coast and inland desert of northern Sinai (Boulos & Gibali, 1993). Some halophytes that are extinct along the Mediterranean coast of Egypt are recorded in the sabkhat of the Mediterranean coast of Sinai. This may relate to the high salinity and oligotrophication of the sabkhat along the shores of Lake Bardawil (El-Bana et al., 2002).

It is expected that the following threats to sabkhat could be forecasted as a result of the execution of the North Sinai Agricultural Development Project:

a) Inflow of fresh water along the Mediterranean coast of Sinai with contaminants will change the ecology of the sabkhat. It is expected that a groundwater flow of contaminated water (containing pesticides and enriched with nutrients) will reach the sabkhat, and therefore impact on its soil quality.
b) The agricultural systems will tranform sabkha habitats into anthropogenic habitats and may even destroy them. This perturbation process will threaten endemic and non-endemic mono-regional halophytes (Appendix).

c) The greatest threat to sabkha biodiversity will be a dramatic loss of habitats, and fragmentation and isolation of remaining communities. Many of the fragmented remnant vegetation patches will be unable to provide a sufficient habitat to ensure the continued viability of many species. In addition, small, isolated remnants will have a high boundary to area ratio, which will make them more susceptible to outside influences ("edge effects"), such as increased exposure to adverse weather and to invasion by weeds and feral animals.
d) Threats to sabkha biodiversity will come from exotic pathogens and parasites, which will infect croplands, and through genetic contamination of native species. Addition of pesticides and fertilisers can result in loss of halophytes or changes in their species composition.

In the view of the previous forecasts, it is necessary to emphasize that sabkhat in fact demands urgent management action to conserve its threatened and unique ecosystem.

5. REFERENCES

Abbas, J.A. 2002. Plant communities bordering the sabkhat of Bahrain Island. In: Barth, H. & Böer, B. (Eds.), Sabkha Ecosystems, pp. 51-62. Dordrecht: Kluwer Academic Publishers.

Ayyad, M.A., Fakhry, A.M. & Mostafa, A.R.A. 2000. Plant biodiversity in the Saint Catherine area of the Sinai Peninsula, Egypt. Biodiversity and Conservation 9: 265-281.

Baha El Din, S.M. 1992. Notes on the herpetology of North Sinai. British Herpetological Society Bulletin 41: 9-11.

Bakker, D. 1966. On the life forms of hapaxants in the Dutch flora. Wentia 15: 13-24.

Batanouny, K.H. & Abo Sitta, J.M. 1977. Ecophysiological studies on halophytes in arid and semi arid zones. I. Autecology of the salt secreting halophyte *Limoniastrum monopetalum* (L.) Boiss. Acta Botanica Academiae Scientiarum Hungaricae 23: 13-31.

Böer, B. & Al Hajiri, S. 2002. The coastal and sabkha flora of Qatar: An introduction. In: Barth, H. & Böer, B. (Eds.), Sabkha Ecosystems, pp. 63-70. Dordrecht: Kluwer Academic Publishers.

Boulos, L. 1995. Flora of Egypt, a checklist. Cairo: Al Hadara Publishing, 283 pp.

Boulos, L. & Gibali, M. 1993. List of rare, vulnerable, endangered and endemic species of vascular plants in Sinai Peninsula. Proceedings Egyptian Environment 275-282.

Brown, G. & Porembski, S. 1997. The maintenance of species diversity by miniature dunes in a sand-depleted *Haloxylon salicornicum* community in Kuwait. Journal of Arid Environments 37: 461-473.

Danin, A. 1996. Plants of Desert Dunes. Berlin: Springer-Verlag. 177 pp.

Dargie, T.C.D. & El-Demerdash, M.A. 1991. A quantitative study of vegetation-environment relationships in two Egyptian deserts. Journal of Vegetation Science 2: 3-10.

El-Bana, M.I., Khedr, A.A. & Van Hecke, P. 2000. Plant life in two Mediterranean lakes before the construction of the River Nile Canal in Sinai, Egypt. In: Ceulemans, R., Bogaert, J., Deckmyn, G. & Nijs, I. (Eds.), Topics in ecology: structure and function in plants and ecosystems, pp. 281-290. Antwerp: University Antwerp (UIA) Press.

El-Bana, M.I., Khedr, A.A., Van Hecke, P. & Bogaert, J. 2002. Vegetation composition of a threatened hypersaline lake (Lake Bardawil), North Sinai. Plant Ecology 163: 63-75.

El-Bana, M.I., Nijs, I. & Kockelbergh, F. 2003a. Microenvironmental and vegetational heterogeneity induced by phytogenic nebkhas in an arid coastal ecosystem. Plant and Soil 247: 283-293.

El-Bana, M.I., Nijs, I. & Khedr, A.A. 2003b. The importance of phytogenic mounds (nebkhas) for restoration of arid degraded rangelands in Northern Sinai. Restoration Ecology 11: 317-324.

Evenari, M., Schulze, E.D., Kappen, L., Buschbom, U. & Lange, O.L. 1975. Adaptive mechanisms in desert plants. In: Vernberg E.J. (Ed.), Physiological adaptation to the environment, pp. 111-129. New York: Intext Education Publication.

Evenari, M., Gutterman, Y. & Gavish, E. 1985. Botanical studies on coastal salinas and sabkhas of the Sinai. In: Friedman, G.M. & Krumbein, W.E. (Eds.), Hypersaline Ecosystems, pp. 145-182. Berlin: Springer-Verlag.

Gibali, M.A. 1988. Studies on the flora of northern Sinai. M.Sc. thesis, Cairo University. 403 pp.

Khan, M.A. & Gul, B. 2002. Salt tolerant plants of coastal sabkhat of Pakistan. In: Barth, H. & Böer, B. (Eds.), Sabkha Ecosystems, pp. 123-139. Dordrecht: Kluwer Academic Publishers.

Levy, Y. 1977. Description and mode of formation of the supratidal evaporite facies in northern Sinai coastal plain. Journal of Sedimentary Petrology 47: 463-474.
Londo, G. 1976. The decimal scale for relevés of permanent quadrats. Vegetatio 33: 61-64.
Raunkiaer, C. 1934. The life forms of plants and statistical plant geography. Oxford: Clarendon Press. 632 pp.
Salama, W. & Grieve, A. 1996. The Zaranik Experience. Sandgrouse 18: 14-17.
Steiner, M. 1934. Zur Ökologie der Salzmarschen der nordöstlichen Vereinigten Staaten von Nordameria. Fb. Wiss. Bot. 81: 94-202.
Täckholm, V. 1974. Students' Flora of Egypt. Cairo: Cairo University Press. 888 pp.
Tsoar, H. 1995. Desertification in northern Sinai in the eighteenth century. Climatic change 29: 429-438.
Tsoar, H. & Karnieli, A. 1996. What determines the reflectance of the Negev-Sinai sand dunes. International Journal of Remote Sensing 17: 513-525.
Zahran, M.A. 1982. Ecology of halophytic vegetation of Egypt. In: Sen, D.N. & Rajpurohit, K.S. (Eds.), Tasks for Vegetation Science, pp. 3-20. The Hague: Junk Publishers Hardbound.
Zohary, M. 1973. Geobotanical foundations of the Middle East. Stuttgart: Gustav Fischer Verlag. 739 pp.

Appendix. *List of halophytes recorded in the Mediterranean sabkhas of Sinai with their relative abundances (RA) and details of life form (LF), chorotype (CH) and halotype (HT).*

Family	*Species*	*RA*	*LF*	*CH*	*HT*
Moncotyledones					
Arecaceae	*Phoenix dactylifera* L.	C	Ph	SA, IT	CUM
Cyperaceae	*Cyperus laevigatus* L.	R	Ge	M, IT, SA	CUM
	Scirpoides holoschoenus (L.) Sojak	O	He	PR	CUM
	Schoenoplectus littoralis (Schard.) Palla	R	He	M, IT	CUM
Juncaceae	*Juncus acutus* L.	R	Ge	M, IT	CUM
	Juncus rigidus Desf.	C	Ge	M, IT, SA	CUM
Poaceae	*Cynodon dactylon* (L.) Pers.	O	Ge	PR	CUM
	Imperata cylindrica (L.) Raeuschel	O	Ge	PR	CUM
	Phragmites australis (Cav.) Trin ex. Steud	O	He	PR	CUM
Dictyledones					
Aizoaceae	*Mesembryanthemum crystallinum* L.	O	Th	M, ES	SUC
	Mesembryanthemum nodiflorum L.	O	Th	M, ES, SA	SUC
	Opophytum forsskaolii (Boiss.) N.E.Br	R	Th	S	SUC
Brassicaceae	*Cakile maritima* Scop.	O	Th	M, ES	CUM
Caryophyllaceae	*Silene succulenta* Forssk.	R	Hm	M, ES, IT	CUM
	Spergularia marina (L.) Griseb.	O	Th	M, ES, IT	CUM
Chenopodiaceae	*Agathophora alopecuroides* (Del.) Bunge	R	Ch	SA	SUC
	Anabasis articulata (Forssk.) Moq.	C	Ch	SA	SUC
	Arthrocnemum macrostachyum K. Koch	V	Ch	M, SA	SUC
	Atriplex halimus L.	R	Ch	M, SA	CUM
	Bassia muricata (L.) Asch.	C	Th	IT, SA	CUM
	Cornulaca monacantha Del.	C	Ch	SA	CUM
	Halocnemum strobilaceum (Pall.) M. Bieb.	V	Ch	M, IT, SA	SUC
	Salicornia europaea L.	C	Th	M, ES	SUC
	Salsola kali L.	O	Th	PR	SUC
	Salsola longifolia Forssk.	O	Ch	SA	SUC
	Salsola tetrandra Forssk.	O	Ch	SA	SUC

(Continued)

	Sarcocornia fruticosa (L.) A.J. Scott	C	Ch	SA	SUC
	Suaeda aegyptiaca (Hasselq.) Zohary	O	Th	SA	SUC
	Suaeda vera Forssk. ex. J.F. Gmel	R	Th	M, SA, ES	SUC
	Suaeda vermiculata Forssk.	C	Ch	SA	SUC
	Traganum nudatum Del	O	Ch	SA	SUC
Convolvulaceae	*Cressa cretica* L.	C	Hm	M, IT	EXC
Frankeniaceae	*Frankenia hirsuta* L.	R	Hm	M, ES	EXC
	Frankenia pulverulenta L.	O	Th	M, ES, IT	EXC
Plumbaginacae	*Limoniastrum monopetalum* (L.) Boiss.	O	Ch	M	EXC
	Limonium pruinosum (L.) Chaz.	R	Hm	SA	EXC
Tamaricaceae	*Tamarix amplexicaulis* Ehrenb.	O	Ph	SA, S	EXC
	Tamarix nilotica (Ehrenb.) Bunge	R	Ph	SA	EXC
Zygophyllaceae	*Nitraria retusa* (Forssk.) Asch	C	Ph	SA	EXC
	Zygophyllum aegyptium Hosny	R	Ch	EN	SUC
	Zygophyllum album L.	V	Ch	EN	SUC
	Zygophyllum propinquum Decne.	R	Ch	SA	SUC
	Zygophyllum simplex L.	O	Th	S	SUC

V: Very common, C: Common, O: Occasional, R: Rare.Chorotype: IT = Irano-Turanian, M = Mediterranean, SA = Saharo-Arabian, ES = Euro-Siberian, S = Sudanian, PR = Pluriregionals, EN = Endemics. Life forms: Th = therophytes, Ge = geophytes, Hm = hemicryptophytes, Ch = chaemaephytes, Ph = phanerophytes, He = helophytes. Halotype: CUM = cumulative, EXC = excretive, SUC = succulent.

CHAPTER 13

SALT LAKE AREA, NORTHEASTERN PART OF DUKHAN SABKHA, QATAR

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Abstract. The object of this study is to document the mineral and geochemical characteristics of both sediments and brines in a shallow salt lake located in the northeastern part of the Dukhan Sabkha. The lake covers an area of about 12 km^2, and lies some 3.7 km from the Gulf of Zikrit in the north. The lake is probably a relic of a much larger lake that was once present in this part of the region and that later became the Dukhan Sabkha. The depth of the lake is presently less than 1 m and its colour is light pink due to the presence of microbial organisms. The groundwater in the Salt Lake area is composed of both seawater and freshwater.

The lake brine is of a high salinity, with an Na^+ concentration of 130 ppt, a Cl^- concentration of 180 ppt and a total dissolved solid (TDS) concentration of up to 322 ppt. The lake area is dominated by fine deposits of clay, silt and carbonate, in addition to blown sand. Algal-microbial mats mixed with black and light gray fine sediments prevail at shallow depths a few centimeters from the surface. A thin crust of halite, about 0.3 cm thick, covers a wide area of the lake's surface.

Anhydrite (33%), halite (19%) and gypsum (10%) are the dominant evaporite minerals in the salt lake sediments, whereas dolomite (14%) is the dominant carbonate and quartz (18%) is the dominant siliciclastic mineral. Anhydrite has formed in the area as a result of dehydration of gypsum. Formation of anhydrite occurs above the groundwater level, especially in close proximity to the lake. Gypsum crystals of various shapes, mainly lenticular and sublenticular, are prevalent below the nodules. The dolomite has a Ca^{2+}/Mg^{2+} molar ratio of 50:50, and is mainly derived from the Tertiary dolomite abundant throughout Qatar.

SiO_2 and Ca_2^+O are the dominant oxides present in salt lake sediments (26% and 16% respectively), with lesser amounts of the other major elements - Na_2O (10%), SO_3 (8%) and MgO (6%). The most significant trace elements are Sr (923 ppm), Cr (119 ppm) and Ba (90 ppm). Ni (23 ppm), V (20 ppm) and Zr (19 ppm) are also relatively high. Other trace elements of significance include Zr, Rb, Ni and Zn.

1. INTRODUCTION

Saline lakes are common throughout the world, especially in arid regions. They are shallow bodies of water with high concentrations of brine, which periodically evaporate to dryness leaving behind an exposed layer of salt. They vary greatly in size and in their geological, mineralogical and chemical characteristics. Some of the larger and better known saline lakes include: the Asal, Tanganyika and Magadi Lakes in Africa; the Amadeus, Tyrell, Eyre, Frome and Haywaed Lakes in Australia;

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Eskisehir Lake in Turkey; the Gosiute Lake and Ridge Basin in California; Kuchuk Lake in Russia; Qaidam Lake in China; Mormoiron Basin in France; and the Salt Lake in the Sechura desert of Peru (Hardie et al., 1978; Link & Osborne, 1978; Reading, 1978; Stoffers & Hecky, 1978; Truc, 1978; Schreiber et al., 1984; Warren, 1999).

Many sabkhas have been formed as a result of the complete or partial drying out of such lakes. The Egyptian Sabkha, for example, along the southern coast of Sinai Peninsula on the Red Sea, was formed due to marine transgression during the early Holocene (Ali & West, 1983) and (West et al., 2000). The Bristol Dry Lake, a modern continental sabkha rich in evaporite deposits, was formed in the same manner (Handford et al., 1982). In western Australia near the Indian Ocean, the MacLeod Salt Basin, some 60 km long and 30 km wide, was formed due to active precipitation of aragonite and gypsum in 5000 years BP (Moore, 1989). In southern Australia, another lake formed near the coast in 5000-6000 years BP (Schreiber et al., 1984).

Well-known sabkhas in the Arabian Gulf, such as the Abu Dhabi Sabkha in the U.A.E. (Evans et al., 1969), the Umm Said Sabkha on the southeastern coast of Qatar (Ashour et al., 1991), the Dohat Faishakh Sabkha on the western coast of Qatar (Taylor & Illing, 1969), the Kuwait Sabkha in southern Kuwait (Gunatilaka & Mwango, 1987) and the Red Sea Coast Sabkha (Behairy et al., 1991; Ali & West, 1983; West et al., 2000), formed recently due to the separation of lake from sea, as the sea regressed and sand accumulated in the lakes.

This study concerns a saline lake in the northeastern part of the inland Dukhan Sabkha in western Qatar (Figs. 1 and 2). This lake was selected for study for three main reasons: (1) it is the largest saline lake in the inland sabkhas of Qatar, (2) it is distinguished by several important characteristics different from any other part of the Dukhan Sabkha, and (3) it has not been studied before. The aim of this study was identify the origin, biological, chemical and sedimentological characteristics of this lake area. The results show that the sediment characteristics of this lake strongly impact the Sabkha's overall sediment characteristics.

Figure 2. *Shallow Salt Lake in the northeastern part of Dukhan Sabkha (5/4/1997) (Note the water is shallow in the Lake and halite covers the area beside the lake).*

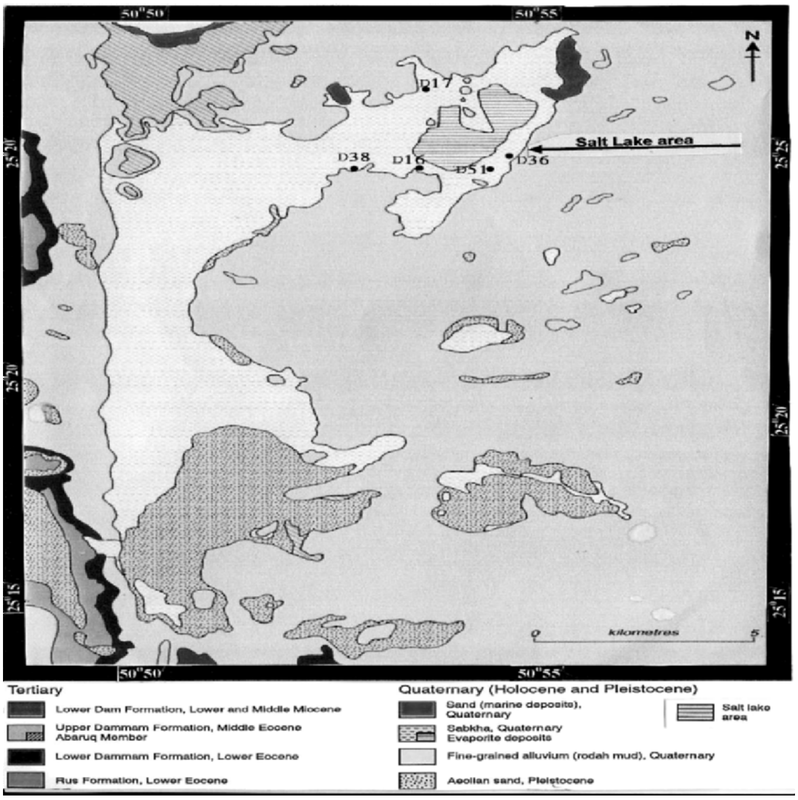

Figure 1. *Location of Salt Lake area and study stations, Dukhan Sabkha.*

2. METHODOLOGY

During April 1996 and April 1997, field studies were carried out in Dukhan Sabkha and in the salt lake area. Observations were made concerning the dominant deposits at the surface and at shallow depths below the surface, noting evaporite, carbonate, and siliciclastic facies, and the presence of microbial mats, marine shells, etc. Sediment samples were taken from shallow cores and three pits at different locations in the area (Figure 3). The geomorphological characteristics of the area were studied, including the dimensions of the salt lake, the depth of the lake, and the depth to groundwater throughout the area. Brine samples were collected from the salt lake, from a pit underneath the sediments and on the northern coast. The temperature range for brines was 21°C-23°C.

In the laboratory, the sediment samples were air dried and examined with a hand lens and a binocular microscope. Grain sizes were estimated and gypsum crystal lengths measured. The principal components were readily identified through the microscope and their relative proportions estimated. More quantitative studies included: (1) XRF analysis for trace and major elements, using a Philips PW 1400 analyser; and (2) X-ray diffraction analyses of bulk sediment samples, using a Philips diffractometer incorporating a PW 1130 generator and a PW 1050 goniometer unit, and a PW 1965 detector linked to a PR 2262 chart recorder. Semi-quantitative determination of each mineral present was by peak area measurement.

The brine samples were analysed for conductivity, pH, Na^{+}, Mg^{2+}, Ca^{2+}, Sr^{2-}, Cl^{-}, SO_4^{2-} and HCO_3. The expandable ion analyzer EA 920 was used to define pH and conductivity, with a standard buffer solution at pH 9.18 and 25°C for calibration. A Philips pv 8060 IEP - AES was used to determine the cations and Sr^{2-} of the water samples. Chemical analyses were carried out to determine the anion content of the water samples after dilution in distilled water at a ratio of 1:5. To define Cl^{-}, potassium chromate (K_2CrO_4) was used as an indicator, and a silver nitrate solution (prepared by adding 10.2 g of silver nitrate - $AgNO_3$ /0.06 - to one litre of distilled water) was used for calibration. The value of Cl^{-} in the samples was defined from the relation between the normality of the water sample and $AgNO_3$ and the volume of silver nitrate and water samples. Methyl orange was

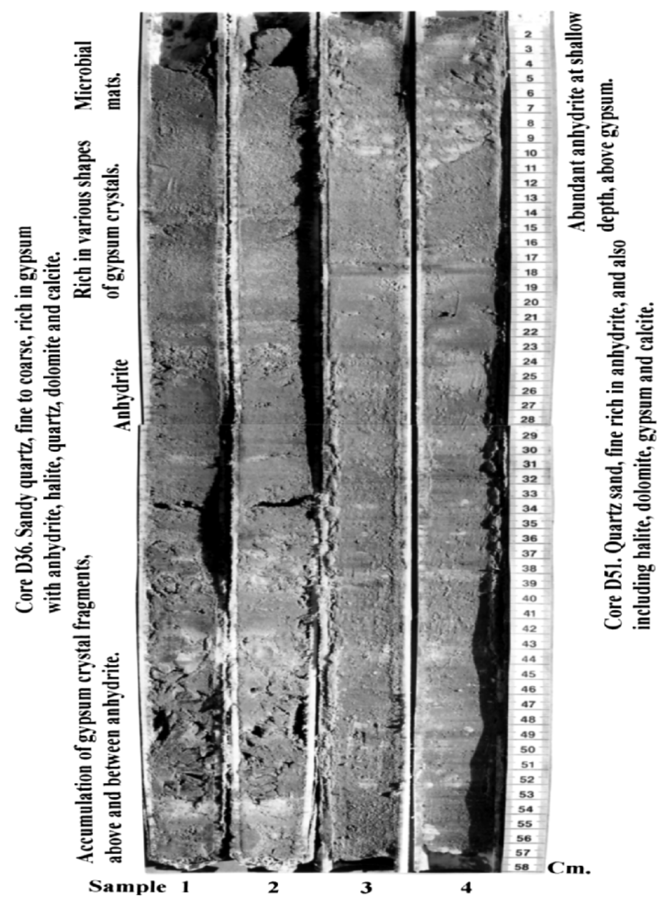

Figure 3. *Core samples from the northern part of Dukhan Sabkha, salt lake area.*

used as an indicator (three drops were added to 10 ml of each diluted water sample) to determine the HCO_3^- of the water samples. The samples were assuaged using sulphuric acid solution (prepared by adding 5.6 ml of concentrated sulphuric acid to one litre of distilled water).

3. RESULTS AND ANALYSIS

3.1. Brine chemistry

The chemical characteristics of the Salt Lake area brines are summarized in Table 1. The brine is concentrated with Na^+ and Cl^-, and the Total Dissolved Solids (TDS) content is high. Most likely the high proportion of Na^+ and Cl^- results from the presence of halite in contact with the brines. The proportion of halite at the surface probably decreases during the winter rainy periods, but the groundwater becomes correspondingly saturated with Na^+ and Cl^- at shallow depths. When subsequent evaporation occurs, halite forms at a shallow depth within the sediment and on the surface.

Gypsum in the sabkha sediments is probably an important source for Ca^{2+} and SO_4^{-2} in the brines, but because the formation of gypsum and anhydrite in the area is currently active, much Ca^{2+} and SO_4^{-2} is utilized in the formation of these minerals. Thus the amounts of Ca^{2+} and SO_4^{-2} are accordingly small in the brine. Calcite could also lead to a relative increase in the amount of Ca^{2+} in the brines, although its proportion in the sediments is small.

In this respect, the characteristics of the salt lake area resemble those in the Faishak Sabkha north of Dukhan Sabkha, where Ca^{2+} and SO_4^{-2} are utilized in the formation of the gypsum, leading to their accordingly lower proportion in the brine (Illing et al., 1965).

Table 1. *Chemical characteristics of brines from the salt lake area (north-eastern part of the Dukhan Sabkha) and from the northern coast of Qatar.*

Station	*Location*		*Depth (cm)*	*pH*	*Cond. (µS)*	*Na^+ (ppt.)*	*Cl^- (ppt.)*	*Ca_2^+ (ppt.)*	*SO_4^{2-} (ppt.)*	*Mg^{2+} (ppt.)*	*Sr^{2+} (ppt.)*	*HCO_3^- (ppt.)*	*TDS (ppt.)*
	Longitude	*Latitude*											
D51	N = 25° 24′ 55″	E = 50° 54′ 28″	24 pit. Sam.	4	247	130	180	1.4	8.8	2.3	0.04	0.05	322
D51	N = 25° 24′ 55″	E = 50° 54′ 28″	Salt lake W.	7	243	122	182	1.2	4.6	4.4	0.03	0.06	314
D56	N = 25° 33′ 66″	E = 50° 52′ 40″	Sea W.	8	80	19	32	1.5	3.9	1.8	0.03	0.2	58
Standard seawater in gram/liter			–	–	–	11	19	0.4	2.7	1.3	0.008	–	34

Dolomite in the Salt Lake area sediments (about 14% including and 43% excluding evaporite minerals) is probably a source of Mg^{2+} in the brines after dissolution in water.

3.2. Sediment mineralogy

In the samples taken, which included 33 shallow core samples (at a depth of 0-55 cm) and 7 pit samples (at a depth of 0-32 cm), the dominant minerals found by XRD analysis are quartz, feldspars, calcite, dolomite, anhydrite, halite and gypsum (Table 2). No Mg-calcite was found and aragonite is only present in two samples of core D51. The proportion of different minerals is also shown excluding carbonates (Table 3) and excluding evaporites (Table 4). More details on the sediment facies and their distribution in the two cores are shown in Figure 3.

Table 2. *Mean percentage of peak areas of clastic, carbonate and evaporite minerals in cores and pit samples from the salt lake area, Dukhan Sabkha (included evaporites). (18 samples from core D36, 15 samples from core D16 and 7 samples from pit D16).*

Sample station	*Depth (cm)*	*Quartz (%)*	*K-feldspar (%)*	*Plagioclase (%)*	*Dolomite (%)*	*Calcite (%)*	*Mg-calcite (%)*	*Aragonite (%)*	*Gypsum (%)*	*Anhydrite (%)*	*Halite (%)*
Core sample D36	1-55	24.11	1.61	4.11	21.95	5.30	–	–	27.99	4.62	10.30
Core sample D51	1-59	16.10	0.26	1.66	9.12	1.64	–	0.52	0.10	58.37	12.22
Pit samples D16	0-32	13.42	0.31	1.55	10.80	1.66	–	–	1.71	37.03	33.52
Overall mean		17.88	0.73	2.44	13.95	2.87	–	0.17	9.94	33.34	18.68
D29/Y anhydrite nodules	23	0	0	0	0	0	0	0	0	89.40	10.58

Table 3. *Mean percentage of peak areas of evaporite minerals in core and pit samples from the salt lake area, Dukhan Sabkha (carbonate excluded). (18 samples from core D36, 15 samples from core D16 and 7 samples from pit D16).*

Sample stations	*Depth (cm.)*	*Gypsum (%)*	*Anhydrite (%)*	*Halite (%)*
Core sample D36	1-55	62.3	10.7	27
Core sample D51	1-59	0.3	75.9	23.8
Pit samples D16	0.0-32	2.9	56	41.1
Overall mean		21.85	47.53	30.62

Table 4. *Mean percentage of peak areas of clastic and carbonate minerals in core and pit samples from the salt lake area, Dukhan Sabkha (evaporite excluded). (18 samples from core D36, 15 samples from core D16 and 7 samples from pit D16).*

Sample stations	*Depth (cm)*	*Quartz (%)*	*K-feldspar (%)*	*Plagioclase (%)*	*Dolomite (%)*	*Calcite (%)*	*Mg-calcite (%)*	*Aragonite (%)*
Core sample D36	1-55	36.5	2.4	7.7	42.7	10.8	-	0.0
Core sample D51	1-59	43.6	1.3	6.6	42.6	4.3	-	1.7
Pit samples D16	0.0-32	39.7	0.8	8.6	45.1	5.8	-	0.0
Overall mean		39.9	1.5	7.6	43.4	7.0	-	0.6

3.2.1. Quartz, feldspar and carbonate

The size of quartz grains in the salt lake area ranges from fine to coarse (about 125 to 750 μm), while most samples contain a small proportion of very coarse grains (1.5 to 2 mm), and some a very fine fraction of sand (<125 μm). The dominant shape of the grains is sub-rounded, but most of the coarse and very coarse grains are rounded and sub-rounded.

The proportion of quartz and feldspars is small in comparison with the proportion of these minerals in the sediments of other parts of Dukhan Sabkha (36% and 2% respectively, including evaporite minerals, Al-Youssef, 2003). This is probably because: (1) the amount of sand covering the surface of the land in front of the salt lake area is small; (2) the Abaruq hills dominant in the north decrease the proportion of sand carried by the wind; and (3) the surface sediments are saturated with brine, which prevents the sand from creeping inside the area. Feldspars usually increase in the sediments where the blown sand is dominant.

The mean percentage of calcite is small, less than that recorded by Al-Youssef (2003) for this mineral in the sediments of the other parts of Dukhan Sabkha (8.8%, excluding evaporite minerals). The origin of calcite in the area is mainly from limestone outcrops throughout Qatar and in part from biogenic debris transported from coastal dunes.

The mean percentage of dolomite is about 14% (or 43% excluding evaporite minerals). Most dolomite occurs in the sediments as fine, white grains. The X-ray diffraction study shows that dolomite occurs at a D-spacing of = 2.886A° ($2\theta = 36.12°$), indicating that dolomites have a Ca_2^+/Mg^{2+} molar ratio of 50:50. Shin (1973) and Ragab et al. (1991) found that the Tertiary dolomite in the sediments of the subtidal area in Qatar have the same molar ratio and concluded that they were derived from the Tertiary dolomite so abundant throughout Qatar. Principally, it could be said that the dolomite of the salt lake area is Tertiary dolomite from the Tertiary rocks present on the surface of Qatar. Sources for dolomite in the Salt Lake area's sediments include: (1) the hills of the Abarug Member of the Upper Dammam Formation to the north of the sabkha; (2) Jabal Dukhan, to the west of the sabkha, mainly consisting of dolomite and limestone of the Rus Formation and (3) the Simsima Member of the Upper Dammam Formation, consisting of dolomite and limestone and covering about 80% of the surface of Qatar.

3.2.2. Evaporite minerals

Anhydrite

The mean percentage of anhydrite in the salt lake area is 33% (or 48% excluding clastic and carbonate minerals). This is significantly higher than the 8.5% recorded by Al-Youssef (2003) in the other parts of the Dukhan Sabkha. Anhydrite is formed in conditions of both high salinity (when Na^+ is 130 ppt, Cl^- is 180 ppt and TDS is 322 ppt) and high temperatures (of over 25°C). The surface of the area is covered with thin deposits of halite. Microbial (algal) mats and fine sediments (clay, silt and fine carbonate) are dominant. All these characteristics have probably formed suitable conditions for anhydrite to form as a secondary mineral from the dehydration of gypsum. The capillarity of fine sediments controls the process, as it slows down the rate of evaporation by slowing the movement of groundwater towards the surface. Accordingly, the water remains for a long time at shallow depths above the water table and becomes even more saturated. This gives gypsum enough time to form above the groundwater level. Subsequently, because of high temperatures and continued evaporation, gypsum will be dehydrated to anhydrite. For this reason anhydrite nodule in the salt lake area of Abu Dhabi Sabkha (Shearman et al., 1966; Kinsman, 1966; Butler, 1969, 1970) and in the Egyptian Sabkha (Ali & West, 1983) formed above the groundwater table, with gypsum crystals usually dominant below the anhydrite nodules.

Anhydrite nodules are dominant in the salt lake area. The nodules are white, soft, variable in diameter from 2-12 cm, and consist of large numbers of spherical accumulations of anhydrite grains with cracks present on the surface of the nodules (Figure 4). The nodules are present at a shallow depth of about 20 cm below the surface, and above the groundwater level in fine carbonate-rich muddy sediments. Algal (microbial) mats are present below the anhydrite nodules, together with gypsum crystals, of both lenticular and sublenticular forms. Halite occurs both within and above the nodular anhydrite layer. The proportion of nodules is greatest adjacent to the salt lake and decreases away from it (Figure 6). The general appearance of the sediment is rather like a poorly mixed mud and porridge, directly overlying the algal (microbial) mats (Figure 5).

The nodules in this part of the sabkha probably formed as a result of the dehydration of gypsum. This is shown by the gypsum crystals of lenticular and sublenticular shape, which are mainly found below the anhydrite in the studied pits (Figure 6), indicating that the gypsum formed prior to the anhydrite. Gypsum formed here because of the more dominant presence in this part of the sabkha of suitable conditions for its formation. Later, gypsum dehydrated to anhydrite because of an increase in temperature. The anhydrite grains accumulated together and formed anhydrite nodules. As a result of the continued accumulation of the

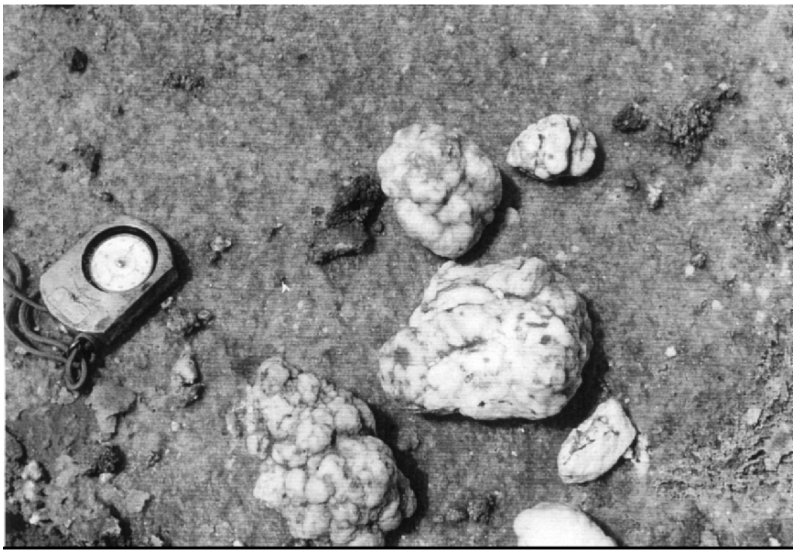

Figure 4. *Anhydrite nodules, Salt Lake area, and northeastern part of Dukhan Sabkha. (Note the shape of nodules and halite crust covers the surface of the area).*

Figure 5. *Salt Lake area, northeastern part of Dukhan Sabkha. (Note halite covers the surface of the land anhydrite nodules present near the surface).*

ineral grains, the nodules increase in size and later cracks appear on the surface of the nodules (Figure 4).

Halite

Halite is the second dominant evaporite mineral in the salt lake area sediments (Figures 2 and 5). It forms both at the surface and at shallow depths as a result of: (1) the shallow lagoon water present in the area; (2) the very high salinity of the shallow salt lake (TDS is about 322 ppt); (3) the very high level of groundwater in this part of the sabkha; (4) the fast evaporation process and the fact that evaporation from salt lake brines is direct rather than from a sabkha surface; (5) the saturation of surface deposits with brines; and (6) the dominance in the area of fine grained sediments of clay, mud and fine carbonate. The fine sediments decrease the vertical movement of surface and shallow groundwater (at a few centimetres depth) towards the ground. Consequently, the sediments at shallow depths remain saturated with high salinity brines for relatively longer periods of time. This increases the probability that halite will form and accumulate on the surface and at a shallow depth by evaporation.

Gypsum

Gypsum is the least abundant evaporite mineral in the salt lake area, averaging 11% (or 22% excluding carbonate and clastic minerals). This is significantly lower than recorded by Al-Youssef (2003) in different parts of the Dukhan Sabkha, and is probably due to the large proportion of gypsum that has changed to anhydrite in the salt lake area.

Gypsum occurs as crystals and crystal fragments at different depths within the sediments, mainly above the groundwater level. The shapes of these crystals include lenticular and sublenticular, acicular, elliptical, semi-elliptical, prism-like, pyramidal, pseudo-tetragonal and intergrown crystals.

The saturation of sediments in this part of the sabkha with brine of high salinity, and the dominance of fine sediments (silt and clay) in addition to the thin surface cover of clays and microbial mats (of rubber-like texture) are important factors in the formation of these crystals (Figure 6). Because there is a high porosity and low permeability in the fine sediments and a surface cover of a rubbery texture, capillarity plays an important role in the formation of gypsum crystals of various habits at shallow depths in the sabkhas. The evaporation process of the groundwater is slowed in these conditions, giving the water near the surface time to become saturated. These conditions increase the probability of gypsum formation at shallow depths.

3.3. Sediment geochemistry

The proportions of major and trace elements in the Salt Lake area sediments are shown in Tables 5 and 6 respectively. SiO_2 and CaO are the two dominant oxides present throughout. The next most common major elements present are Na_2O, SO_3, MgO, Al_2O_3, and these show some variability across the area with mean values between 9.7%, 7.87%, 6.39% and 2.51% respectively. The remaining majors – TiO_2, Fe_2O_3, MnO, K_2O and P_2O_5 – are all present in amounts of less than 1%.

Separate analyses of anhydrite nodules show that SiO_2 is low and CaO is a dominant major element. The percentage of SO_3 is also high, Na_2O is relatively

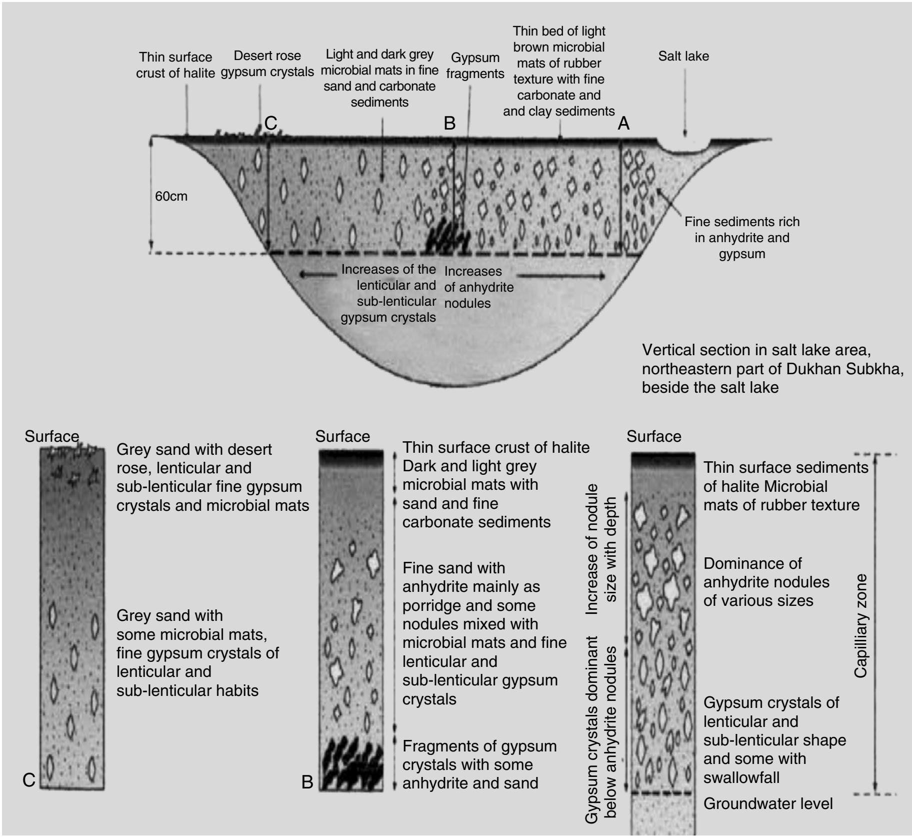

Figure 6. *Cross section in the Salt Lake area, northeastern part of Dukhan Subkha showing the deposits dominate in this part of the Subkha.*

Note that:

1. Anhydrate nodule proportion increases of the Salt Lake direction and decreases of the land direction.
2. Anhydrite porridge increases to the land direction.
3. The size of the nodules decreases with the depth.
4. Gypsum crystals of lenticular and sub- lenticular habits mainly dominant bellow anhydrate nodules.
5. Desert rose gypsum crystals only present beside the western edge of the Subkha to the west from the Salt Lake.
6. Microbial mate of rubber texture dominant bellow halite beside the Salt Lake schematic cross section with no overall depth implied.

high and the percentage of other elements is less than 1%, except for MgO, whose percentage is 1.1.

The most significant trace elements in the samples are Sr, Ba and Cr. The next group of elements include Zr, Ni, V, Rb and Zn. The other elements are less important and show mean values of less than 6 ppm.

The reason for the high proportion of SiO_2 in the salt lake area sediments is almost certainly the quartz of blown sand. SiO_2 values are highest where the sediments are sandy and lowest where they are dominated by evaporites, specifically halite. Cavelier (1970) found that the percentage for silica in the aeolian sands in Qatar varies from 60-70%, and its maximum percentage is 74.40%. The percentage of silica in the sand of the Upper Dam Formation is 78.30%, but it is only one meter thick. These rocks could also form a second local source for SiO_2 in the salt lake area sediments. Ca_2O^+, SO_3 and Na_2O are generally high, as would be expected of evaporite-rich deposits with abundant anhydrite, gypsum and halite.

Table 5. *Mean of major elements in the salt lake area sediments (12 samples), Dukhan Sabkha In wt %. LOL – loss an ignition includes Cl.*

Sample stations	*SiO_2 %*	*TiO_2 %*	*Al_2O_3 %*	*Fe_2O_3 %*	*MnO %*	*Mg^2O %*	*Ca_2^+O %*	*Na_2O %*	*K_2O %*	*P_2O_5 %*	*SO_3 %*	*LOI %*
D36	29	0.14	3	1	0.02	8	20	4	0.71	0.05	14	21
D51	27	0.15	3	1	0.02	7	21	3	0.67	0.04	13	25
D16	23	0.11	2	0.8	0.02	5	13	16	0.50	0.04	2	38
Overal Mean	26	0.13	3	0.9	0.02	6	16	10	0.60	0.04	8	30
Overal mean Of two cores	28	0.15	3	1	0.02	7	20	4	0.70	0.04	14	22
D29.Y	2	0.02	0.3	0.1	0.00	1	27	10	0.25	0.01	21	38

*D29 is pure anhydrite nodule. LOL – Loss an ignition includes Cl.

Table 6. *Mean of trace elements in the sediments (12 samples) of the salt lake area, Dukhan Sabkha.*

Sample stations	*Rb* *ppm*	*Sr* *ppm*	*Y* *ppm*	*Zr* *ppm*	*Nb* *ppm*	*Th* *ppm*	*Pb* *ppm*	*Zn* *ppm*	*Ni* *ppm*	*Ga* *ppm*	*As* *ppm*	*Cr* *ppm*	*V* *ppm*	*Ba* *ppm*	*La* *ppm*	*Ce* *ppm*
D36	16	601	3	22	5	0	5	10	21	5	0	85	20	107	2	4
D51	16	1256	1	12	5	1	3	10	23	5	1	125	17	89	4	1
D16	10	995	1	21	5	0.7	3	10	25	4	0.17	146	20	80	1	5
Overall mean	13	923	2	19	5	1	3	10	23	5	0	119	20	90	2	4
Mean of two cores	16	765	2	20	5	0	4	10	20	5	1	97	17	99	2	2
D29. Y	1	1457	0	0	2	1	3	1	4	0	0	15	1	0	2	0

* D29 is a pure anhydrite nodule.

The source for Al_2O_3 is most probably clay minerals and feldspars, transported to the area by wind or surface drainage. Clays of the Lower Dammam Formation and Midrea (and Sila) Shales have been measured with between 9 and 19% Al_2O_3 (Cavelier, 1970). The average Al_2O_3 in the Miocene argillaceous rocks in Qatar is between 18% and 21% (Al Kuwari, 1987).

The overall mean for $Mg^{2+}O$ in Salt Lake sediments is 7.34%. This percentage is higher than that recorded by Ashour et al. (1991) and Al-Youssef (2003) for the Dukhan Sabkha sediments. A range of minerals probably contributes to the $Mg^{2+}O$ concentrations, including minor evaporites (various $MgSO_4$ minerals species and polyhalite) and carbonate minerals (dolomite and magnesite). Cavelier (1970) mentioned that clay minerals in Qatar included about 8-10% magnesium. The percentage of $Mg^{2+}O$ in the Midra (and Sila) Shales of the Lower Dammam Formation is between 3.3% and 10.9%. In the red and green clays of the Lower Dam Formation, $Mg^{2+}O$ concentrations are between 7.15% and 10.10%. A high percentage of $Mg^{2+}O$ is recorded in some sand dunes in the southwestern part of Qatar, from 1.10% to 14% (Cavelier, 1970). All of these could provide some of the $Mg^{2+}O$ in the salt lake sediments.

Potassium oxide (K_2O) concentrations are low. The source of this oxide is probably clay minerals, or other feldspars and potassium minerals. The percentage of this element in the Midra (and Sila) Shales is 0.70% and it is between 2.05% and 3.95% in the clay of the Lower and Upper Dam sub formation (Cavelier, 1970). These could be simple local sources for K_2O in the salt lake area.

Titanium (TiO_2) is most likely present as an oxide of titanium, in the form of anatase and rutile, and as an oxide of iron and titanium, in the form of ilmenite and other clay minerals. Its mean concentration is low (about 0.12%). The oxide is possibly carried to the sabkhas from exposed rocks in Qatar, where it is present in a range between 0.5% and 9.5%, according to Cavelier, 1970. TiO_2 is possibly also carried to Qatar from the Arabian Peninsula, because the origin for this oxide comes from igneous and metamorphic rocks.

The source of both Fe_2O_3 and MnO oxides is most probably from clay minerals derived from Qatari rocks. The percentage of Fe_2O_3 in the rocks of the Lower Dam Subformation is between 2.65% and 5.75%. It is between 3.50% and 5.60% in the clay minerals of the Upper Dam Subformation and between 3% and 6% in the clay minerals of the Lower Dammam Formation (Cavelier, 1970).

Low but persistent concentrations of P_2O_5 oxide are present in the sediments. The most likely source of P_2O_5 is from phosphate minerals associated with organic material, especially algal debris (Al-Yousef, 2003).

Strontium (Sr) is known to occur as a replacement cation for Ca in both gypsum and anhydrite evaporites (e.g. Butler, 1973). This is most probably the principal source of strontium in the salt lake area sediments. Combined results of XRD, XRF and brine analyses show that the samples with a high proportion of gypsum and anhydrite include a high proportion of Sr.

A third source of Sr is celestite ($SrSO_4$), which is generally formed by the replacement of gypsum or anhydrite. It is usually formed through the selective removal of strontium ions from groundwater, which causes a reaction with deposits of calcium sulphate (West, 1973). Cavelier (1970) has also found celestite in the red and green clays of the Upper Dam Formation and in the Rus Formation in Qatar. Seltrust Engineering Limited (1979) found celestite in the south and southwestern parts of Qatar, in the Dam Formation, the Simsima Limestone, and the Rus Formation. The celestite at outcrop ranges from massive material to impure crystals. Mostly it occurs as a single horizon 2-25 cm thick with some associated iron oxide (limonite), in which the percentage of $SrSO_4$ varies from 74% to 95%. El-Kassas (1992) in his study of the gamma radioactivity of some anomalous locations in the Qatar Peninsula found that most highly radioactive anomalies are recorded in the Dukhan Sabkha and in the coastal sabkhas. The mean values of radioactivity in the sabkhas range from 16 to 75 cps. The range of radioactive intensities is from 37 to 615 cps. This high radioactivity was suggested to be due mainly to the daughter elements of uranium, principally Ra^{226}, which co-precipitated with strontium in celestite crystals. El-Kassas (1992) also observed that small quantities of celestite occur in most sabkha deposits in the Qatar Peninsula. Some celestite, as well as Sr in groundwater, may also be introduced from outside the sabkhas via the normal processes of wind and surface/subsurface drainage.

A fourth potential source for Sr is the aragonite in coral reefs of the Arabian Gulf. These contain concentrations between 7,480 ppm and 8,070 ppm (Kinsman, 1969). The debris from such coral reefs present along the north and northeastern coast of Qatar at shallow depths (6-8 m) could provide an important source for Sr in the salt lake sediments.

The source of the relatively high concentration of Chromium (Cr) in the sediments of the salt lake area is most probably the clay minerals present in the surrounding area. Barium (Ba) is probably derived from the breakdown of feldspars that originated in igneous rocks outside Qatar and feldspars in the Hofuf Formation in the southern part of Qatar Zircon (Zr) is most likely associated with zirconium heavy minerals in the sand facies. Rubidium (Rb) is a common trace element is associated with clays and the trio of V, Ni and Zn, all of which are generally associated with organic matter.

4. DISCUSSION

4.1. Source of water

Some previous studies (FAO, 1981; Harhash & Yousef, 1985; Al-Hajari, 1987; Ashour et al., 1991) have suggested that the Dukhan Sabkha is fed by seawater from the Zikrit Gulf, because of the general slope of the land from northwest to southeast. The general direction of groundwater flow in Qatar is from the middle of the main northern aquifer towards the surrounding Gulf waters to the east and west. They added that the Dukhan Sabkha formed a local collecting place for part of this water. Later, human utilisation of water from the aquifer has allowed seawater from the north to penetrate into the sabkha groundwater.

The groundwater source in the salt lake area is probably from the Zikrit and Dawhat al Husayn Gulfs on the northern coast of Qatar, at a distance of only about 3.7 and 3 km respectively, in addition to the groundwater from the main northern aquifer in Qatar. Rainwater supplies the area with a limited amount of freshwater during rainy periods. Rainfall in Qatar is extremely low and evaporation is high (Al-Yousef, 1994; FAO, 1981). The monthly mean rainfall is 0-17 mm/day (1962-1992) and the yearly maximum is 0.2-80.2 mm (1972-1992). The monthly mean range of evaporation is 3.8-15.5 mm/day (1976-1992) and the yearly mean is 8.6 mm per day (1976-1992) (Al-Yousef, 1994; FAO, 1981).

Al-Yousef (2003) suggested that the groundwater of Dukhan Sabkha is a mixture of salt and fresh water. The situation in salt lake area is similar; but the salt lake area is saturated with brines more than the other part of the sabkha. This is because: (1) the low level of the ground in this part of the sabkha, about 4 m below sealevel, facilitates water collection in the area; (2) this part of the sabkha is closer to the sea than most other parts of the sabkha; and (3) fine-grained sediments (clay, silt and fine carbonate) are more dominant, allowing water to remain in the sediments for a long time.

4.2. Formation of the salt lake

The salt lake in the northeastern part of Dukhan Sabkha may have been either part of the Dukhan Sabkha depression or an independent low-lying area, formed after or during the main depression of the sabkha was formed, and later connected with it. The structural maps of Qatar show that the main part of the sabkha is present along the Zikrit Gulf syncline and the eastern part is situated along the Dohat al Husayn Gulf syncline (Figure 7). The Landsat image shows that the two parts of the sabkha are not completely connected.

The present study favours origin of the salt lake as part of the larger Dukhan Sabkha, and highlights the following factors as probably responsible for its formation:

1) The high level of groundwater in this part of the sabkha. This is because the level of the ground is 4 m below sea level and the lake occupies the Zikrit anticline.
2) This part of the sabkha is also relatively close to the sea Al-Hajari (1990) and Ashour et al. (1991) mentioned that the Dukhan Sabkha received water from Zikrit Gulf, about 3.7 km to the north and from Dawhat al Husayn, about 3 km to the north.
3) Groundwater from the northern aquifer of Qatar passes beneath the sabkha in this region moving generally westwards. This influx of water raises the groundwater level locally. Some irrigation water used in the farms located near this northern part of the sabkha could also reach the sabkha.

4) The salt lake is a relic of a larger lake that was once present in this part of the region that was later to become the Dukhan Sabkha. Because this part is close to the sea, its surface is still saturated by seawater and the salt lake remained in this area.

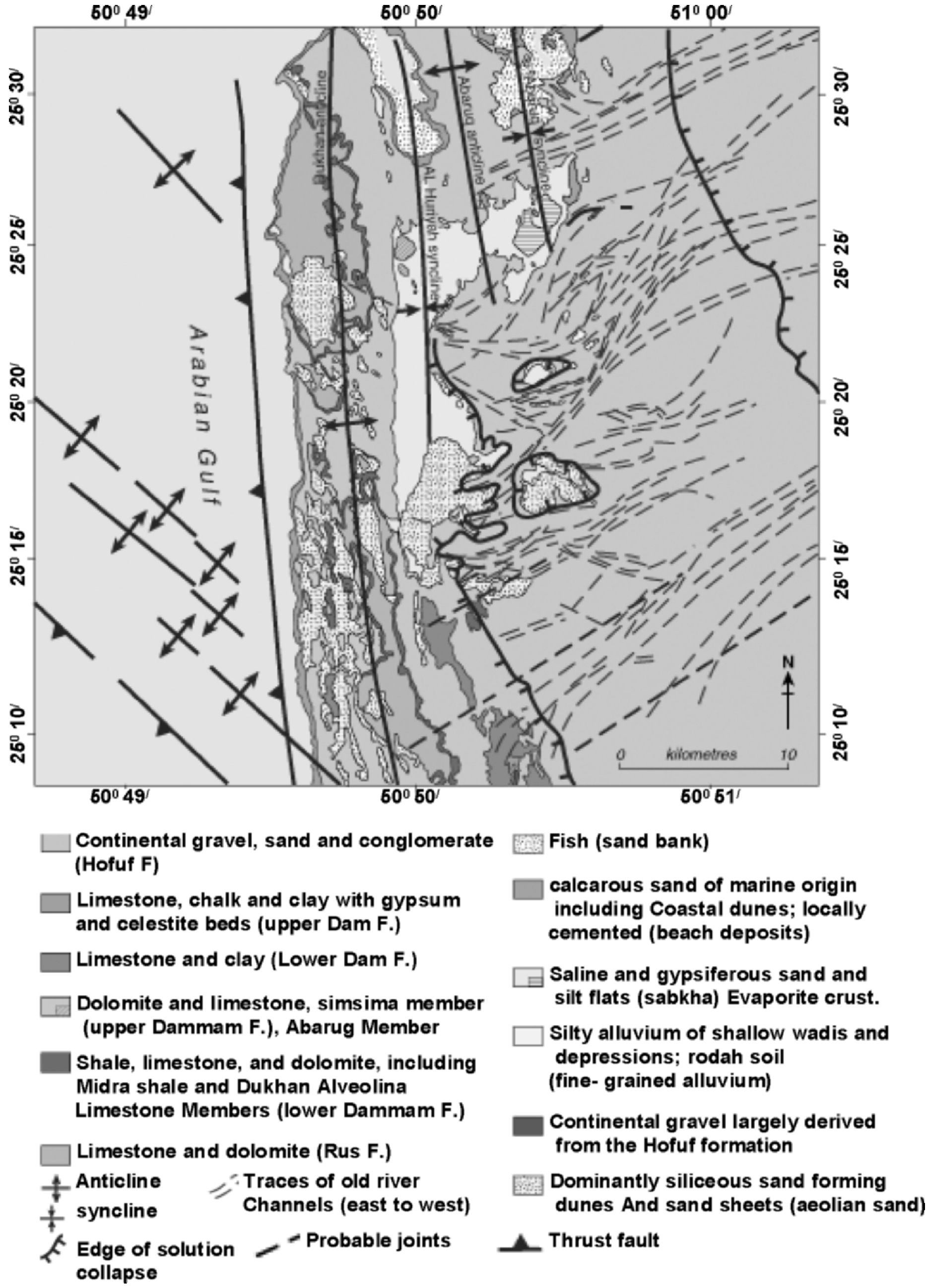

Figure 7. *General structures of Dukhan Sabkha. Note structure affection on the Salt Lake area. (Complied from various source with modification by Al-Yousif, 1994).*

5. CONCLUSIONS

The present study concludes that:

(1) A large hypersaline lake, located in a low-lying depression, about 4 m below sea level in the north-eastern part of the Dukhan Sabkha is probably a remnant of a once much larger lake that dried out to form Dukhan Sabkha. Because this part is close to the sea, its surface was still saturated with seawater and the salt lake persisted.

(2) The source of groundwater in the salt lake area includes both the sea to the north, and the freshwater of the main northern aquifer. A limited amount of runoff could also form a third source of fresh water in the salt lake area, especially after heavy storms. Rainwater forms a simple source for the water in the area.

(3) The chemical activity and sedimentation process in the salt lake area is different from that which occurs in other parts of the Dukhan Sabkha.

(4) The proportion of evaporite minerals in the Salt Lake area is higher than that of carbonate and siliciclastic minerals. The capillarity of fine sediments, consistently high temperatures, low rainfall and high rates of evaporation control the process of formation of dominant evaporite minerals in the area. Anhydrite, halite and gypsum are the dominant evaporite minerals, while dolomite is the dominant carbonate mineral and quartz is the dominant siliciclastic mineral. The proportion of calcite and feldspar is small and Mg-calcite is rare. SiO_2 and Ca_2^+ are the major oxides dominant in the salt lake area sediments and Sr, Cr, and Ba are the most significant trace elements in the sediments.

(5) Various habits of gypsum crystals occur at different locations and depths within the sediments. This variation in shape is, at least in part, related to the varied types of sediments. The evaporation process from fine sediments is slow and this retains the brine in the sediments long enough to form more than one shape of crystal.

(6) Anhydrite nodules are present near to the surface, above the groundwater level as a result of gypsum dehydration. The nodules are formed in high salinity brines and at temperatures of more than 25^oC. The size and proportion of nodules is high beside the lake and becomes finer (similar to gruel) mixed with halite, silt and dark black and grey deposits of microbial mats towards the land.

6. RECOMMENDATIONS

(1) Several deep cores need to be taken at different locations within the salt lake area and Dukhan Sabkha, and radiocarbon dating of carbonate material and microbial organisms present in the cores sediment must be be completed. From the study: the date of formation of the biogenic material and algal-microbial mats will be identified; the history of sea regression from this part of

Qatar will be known; and the recent geological history of the formation of the lake and the Dukhan Sabkha will be recognized.

(2) The connection of the salt lake area with the sea needs to be further studied. The salt lake is mainly fed by water percolating from fro the sea. However, it is still not obvious whether there are underground water pathways (channels) connecting the lake to the sea and if these channels formed as a result of the folding or of the dissolution of evaporite rocks in the area. More information about the reason for the lake's location in this part of the Dukhan Sabkha will be derived from such a study.

(3) Isotopic studies need to be completed on groundwater in the salt lake area. The importance of this work would be to identify the geochemical characteristics of the brines in the area and the factors controlling the lake brine quality.

(4) The percentage of formation and accumulation of anhydrite in the area, and the economic importance of this mineral need further study.

(5) Because the salt lake is located in the northeastern part of the Dukhan Sabkha, the Sabkha has expanded over time**.** It is therefore important to study its annual rate of expansion and to determine the best ways to halt this process.

7. REFERENCES

Al-Hajari, S.A. 1987. The sedimentology of the Lower Eocene Rus Formation and its relationship to the groundwater of the State of Qatar, the Arabian Gulf. M.Sc. Thesis, Department of Geological Sciences, University of South Carolina, Columbia, South Carolina, USA, 121 pp.

Al-Hajari, S.A. 1990. Geology of the Tertiary and its influence on the aquifer system of Qatar and eastern Arabia. Ph.D. Thesis, Department of Geological Sciences, University of South Carolina, Colombia, South Carolina, USA, 220 pp.

Ali, Y.A. & West, I. 1983. Relationships of modern gypsum nodules sabkhas of loess to compositions of brines and sediments in northern Egypt. Journal of Sedimentary Petrology, 1151-1168 pp.

Al-Kuwari, A.J. 1987. Petrological, mineralogical and geochemical studies on the Miocene argillaceous rocks in Qatar, Arabian Gulf. M.Sc. thesis, Geology Dept., Faculty of Science, Ain Shams University, Cairo, Egypt, 339 pp.

Ashour, M.M., Abdul Mogeath, M.S., Metwelly, A.A., Al-Ghzally, A.J., Abdul Gafoor, A.S., Shakespy, R. & Ali, A.A. 1991. El-Sabkhat in Qatar Peninsula (geomorphological study-vitality-geological). Humanities and Documentation Research Center, University of Qatar- Doha, 514 pp.

Al-Yousef, M.M. 1994. Geomorphological study of surface drainage patterns in Qatar peninsula, Arabian Gulf. M.Sc. Thesis, College of Postgraduate Studies, Arabian Gulf University, Bahrain, 324 pp.

Al-Yousef, M.M. 2003. Mineralogy, geochemistry and origin of Quaternary sabkhas in the Qatar Peninsula, Arabian Gulf. Ph.D. Thesis, University of Southampton, School of Ocean and Earth Science, Faculty of Science, U.K.

Behairy, A.K.A., Durgaprasada Rao, N.V.N. & El-Shater, A. 1991. A siliciclastic coastal sabkha, Red Sea Coast, Saudi Arabia. J.K.U., Marine Science, 65-77 pp.

Butler, G.P. 1969. Modern evaporite deposition and geochemistry of coexisting brines, the sabkha, Trucial Coast, Arabian Gulf. Journal of Sedimentary Petrology, 70-89 pp.

Butler, G.P. 1970. Holocene gypsum and anhydrite of the Abu Dhabi Sabkha, Trucial Coast: an alternative explanation of origin. Rau, J.L. and Dellwing, L.F. (eds.), Third Symposium on Salt. Northern Ohio, Geological Society, Cleveland, Ohio, 120-152 pp.

Butler, G.P. 1973. Strontium geochemistry of modern and ancient calcium sulphate minerals. In the Persian Gulf. Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. Edited by Purser. Berlin, 471 pp. Springer-Verlag. 423-452 pp.

Cavelier, C. 1970. Geological survey and mineral substances exploration in Qatar, Arabian Gulf. Government of Qatar, Department of Petroleum Affairs, 100 pp.

El-Kassas, I.A. 1992. A geostatistical study of gamma radioactivity at some anomalous localities in Qatar Peninsula, the Arabian Gulf. Department of Geology, Faculty of Science, University of Qatar, Doha-Qatar. J. King Saud Univversity, Science, 101-112 pp.

Evans, G., Schmidt, V., Bush, P. & Nelson, H. 1969. Stratigraphy and geologic history of the sabkha, Abu Dhabi, Persian Gulf. Sedimentology, 145-159 pp.

FAO 1981. Water resources and agricultural development project, Qatar. Project findings and recommendation. Department of Agricultural and Water Research, Doha Qatar FAO, Rome, 92 pp.

Gunatilaka, A. & Mwango, S. 1987. Continantal sabkha pans and associated nebkhas in southern Kuwait, Arabian Gulf. From Frostick, L. and Reid, I. Desert Sediments. Ancient and Modern, Geological Society Special Publication, 187-203 pp.

Handford, C.R., Loucks, R.G. & Davies, G.R. 1982. Depositional and diagenetic spectra of evaporites a core workshop, 395 pp.

Hardie, L.A., Smoot, J.P. & Eugster, H.P. 1978. Saline lakes and their deposits: a sedimentological approach. In: Modern Ancient Lake Sediments. Edited by Matter, A. and Tucker, M.E., Blackwell Scientific Publications, Oxford, 7-41 pp.

Harhash, I.E. & Yousef, A.M. 1985. Groundwater in Qatar "Summary of Hydrological Studies and Results." Department of Agricultural and Water Research, Qatar, 70 pp.

Illing, L.V., Wells, A.J. & Taylor, J.C.M. 1965. Pencontemporary dolomite in the Persian Gulf. In: Dolomitization and Limestone Diagenesis. Symposium. Edited by Pray, L.C. and Murray, R.C. Society of Economic Paleontologists and Mineralogists. Special Publication. Tulsa, Oklahoma, U.S.A., 89-111 pp.

Kinsman, D.J.J. 1966. Gypsum and anhydrite of Recent age, Trucial Coast, Persian Gulf. Reprinted from the Second Symposium on Salt, pp. 302-326. Northern Ohio Geological Society Cleveland, Ohio.

Kinsman, D.J.J. 1969. Interpretation of $Sr2^{+}$ concentrations in carbonate minerals and rocks. Journal of Sedimentary Petrology, 486-508 pp.

Link, M.H. & Osborne, R.H. 1978. Lacustrine facies in the Pliocene Ridge Basin group. In: Modern and Ancient Lake Sediments. Edited by Matter, A. and Tucker, M.E., Spec. Publs int. Ass. Sediment, 169-187 pp.

Moore, C.H. 1989. Carbonate diagenesis and porosiity. Developments in Sedimentology 46. Elsevier, Oxford, 338 pp.

Ragab, A.I., Hilmy, M.E. & Al-Hitmy, H.H. 1991. Sediment distribution, mineralogy and geochemistry of the sabkha sequence of Umm Said, Qatar. M.E.R.C. Ain Shams University, Earth Science Series, 1-15 pp.

Reading, H.G. 1978. Sedimentary environments and facies. Blackwell Scientific Publications, Oxford, 486 pp.

Schreiber, B.C., Tucker, M.E. & Till, R. 1984. Arid shorelines and evaporites. In: Sedimentary Environments and Facies. Edited by Reading, H.G. (1984). Second Edition. Blackwell Scientific Publications. Oxford, London, 615 pp.

Seltrust Engineering Ltd. 1979. Investigation of the development potential of mineral occurrences in Qatar. Final report. gypsum, celestite and phosphate. Industrial Development, Technical Centre, Doha, Qatar, 36 pp.

Shearman, D.J. 1966. Edited by Kirkland, D.W. and Evens, R. Marine evaporites: origin, diagenesis and geochemistry. Edited by Kirkland, D.W. and Evens, R. Benchmark Papers in Geology. Dowden, Hutchin Son and Ross, Inc. Stroudsburg, Pennsylvania, 61-68 pp.

Shin, E.A. 1973. Sedimentary accretion along the leeward S.E. Coast of the Qatar Peninsula, Persian Gulf, pp.199-209. In: The Persian Gulf: Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea. Edited by Purser, B.H. Springer-Verlag, Berlin, Heidelberg, New York, 471 pp.

Stoffers, P. & Hecky, R.E. 1978. Late Pleistocene-Holocene evolution of the Kivu-Tanganyika Basin. In: Modern and Ancient Lake Sediments. Edited by Matter, A. and Tucker, M.E., Spec. Publs. Int. Ass. Sediment, 43-55 pp.

Taylor, J.C.M. & Illing, V.C. 1969. Holocene intertidal calcium carbonate cementation, Qatar, Persian Gulf. Sedimentology, 69-108 pp.

Truc, G. 1978. Lacustrine sedimentation in an evaporitic environment: the Ludian (Palaeogene) of Mormoiron Basin, southern France. In Modern and Ancient Lake Sediments. Edited by Matter, A. and Tucker, M.E. Spec. Publs. Int. Ass. Sediment, 189-203 pp.

Warren, J.K. 1999. Evaporites: their evolution and economics. Blackwell Science, 438 pp.

West, I. 1973. Vanished evaporites - significance of strontium minerals. Journal of Sedimentary Petrology, 278-279 pp.

West, I.M., Lashhab, M.L. & Muhan, I.M. 2000. North African sabkhas and lagoons compared to those of the Arabian Gulf, p. 512-530. Proceedings of the sixth Mediterranean petroleum conference and exhibition, Tripoli, Libya (G.S.P.L.A.J.), 848 pp.

CHAPTER 14

SALINIZATION PROCESSES AND SABKHAT FORMATION IN THE VALLEYS AND ANCIENT DELTAS OF THE MURGAB AND TEDGEN RIVERS IN CENTRAL ASIA

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Abstract. The oases of Central Asia are sites of ancient civilizations. Irrigational activity in the Tedgen and Murgab oases began in the fourth millennium BC and continues into the present. Irrigational activity caused significant transformations in the relief of the valleys and ancient deltas of these rivers. In the deltas, one can observe traces of ancient irrigational constructions together with modern canals, bars, dams and embankments.

The relief of the Murgab oasis consists of many ramparts, irrigational canals and collectors, all of which are anthropogenic. Some represent cleared and straightened branches of the Murgab as is the case with the Sultan-Yab and Khurmuz-Fary canals and the Dgar and Kese-Yab collectors. These branches had natural levees, which became higher with the reconstruction of the riverbed. These levees are several kilometers long and 0.5-30 meters wide at their tops. At the bottom their width is 300-500 m. Between these levees there are shallow depressions with gentle slopes (0.003-0.001) and flat bottoms, the dimensions of which can reach 103 km^2. The depressions contain salinized lakes in the spring, and sabkhat form during dry periods.

The initial alluvial-deltaic relief remains only on the northwestern edge of the Murgab delta, which has low (up to 1 m), flat ramparts and shallow inter-stream depressions opened to the north. Irrigational relief is found in the central and southern regions, where ramparts attain their maximum heights and inter-stream depressions are closed.

Along the Murgab there are ravines. Young ravines have depths of 3-4 m and vertical slopes. Width of their bottoms in the mouth sometimes reaches 40-50 m. In the 150-200 m wide belt along the floodplain of the Murgab there are suffosion craters 1-1.5 m in diameter.

The Tedgen delta has typical deltaic relief with fan-shaped branches (most of them have been transformed into canals) and natural levees, composed of light material. Many branches are filled, but can be clearly distinguished on satellite photos. Sometimes there are lake depressions filled with clay sediments, which have transformed into solonchaks. At the borders of the modern delta there are barkhans and aeolian sand hills. There are many forms of anthropogenic relief in the Tedgen delta.

Presently new agro-irrigational relief is being formed on the ancient delta.

1. INTRODUCTION AND HISTORY

Territories with high contents of salt in soil and ground water are always present in arid regions. They may be of natural or anthropogenic origin. Territories high in

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salt content are naturally formed by various processes associated with transformation of relief, ground water flow and climate change. In such natural conditions, arid landscapes are self-regulated and maintain a level of salinity that allows for the existence of natural vegetation. Strong anthropogenic impact over a long time period, however, can disturb this self-regulation process, leading to the destruction of natural vegetation communities and causing irreversible geomorphological and soil processes.

The oases of Central Asia are sites of ancient civilization. Irrigational activity in the Tedgen and Murgab oases began in the fourth millennium BC and continues into the present. This activity explains the significant transformations of the relief of the rivers' valleys and ancient deltas, where one can observe traces of ancient irrigational constructions together with modern canals, bars, dams and embankments (Figure 1).

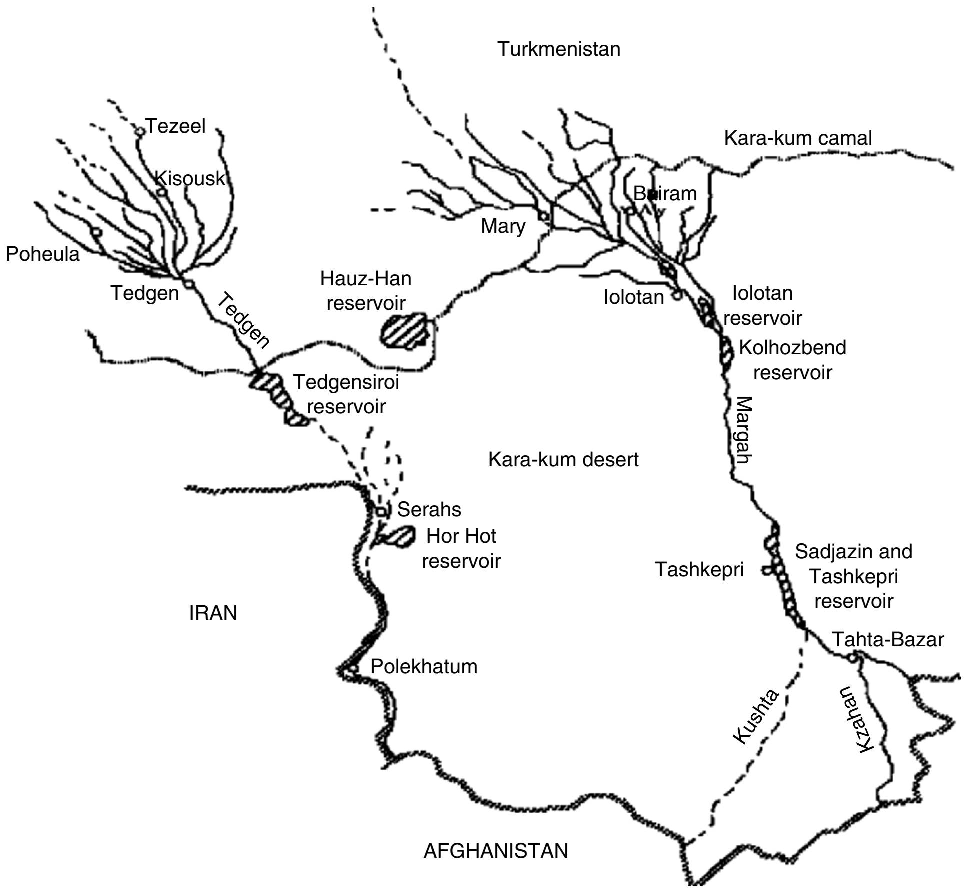

Figure 1. *The Tedgen and Murgab basins - the study area.*

The history of the utilization of the natural oases covers several critical periods, one of which is the modern one. Irrigated agriculture began in the second millennium BC in the Murgab delta and in the fourth millennium BC in the Tedgen delta. At those times the anthropogenic impact on ecosystems was minor, and permitted the ecological balance between nature and society. But with the accumulating changes in the ecosystems, anthropogenic influence contributed to changes in both the regional and global climate. In the end of the Neolithic Age, a period of climate aridization led to the subsequent use of irrigated agriculture in Central Asia.

The pluvial period of the Iron Age at the beginning of the seventh century BC together with a minor ecological crisis in the Murgab delta due to the removal of the ancient Marg to the Zotal, brought improvement of hydraulic engineering and prosperity to the Merv oasis. The abatement of the pluvial period, the reduction of the flow and the lowering of the water level in the Tedgen and Murgab at the beginning of the fourth century BC, as well as migration of the delta's branches, gave impulse to the development of irrigation. In the eighth through the eleventh centuries AD, irrigated agriculture in the deltas reached its peak. The prosperity of irrigation, however, caused changes in the soil salt balance, an increase in the area of wastelands and a disturbance in the hydrological regime. The increase in the effectiveness of the irrigation system caused the most serious disturbance of the ecological balance and accelerated the failure of the civilization.

At the beginning of the eighth century, the civilization of the Tedgen and Murgab oases fell under the onslaught of the Tatar invasion. In the twentieth century, irrigation systems, cascades of reservoirs and collector-drainage networks were constructed in the deltas of the Tedgen and Murgab rivers, with the Kara-Kum canal intersecting the river valleys.

1.1. Murgab delta

The Murgab delta occupies a territory of about 42 thousand km^2. Its northern part is covered with wandering sands, but its southern part is suitable for agriculture. It is here that the Murgab oasis is situated, occupying about 17 thousand km^2.

On the irrigated territory, the upper Quaternary layer is composed of a complex of specific agro-irrigational sedimentation; many relief forms develop as a result of the irrigational transformation of the land, the regime and the character of the ground water. The quaternary sedimentation of the Murgab delta may be divided into three formations. The lower one was formed in the Pleistocene Age and is called the "Kara-Kum" formation. It is composed of layers of clays and sands 3-10 meters thick and is not exposed at the surface. The middle formation, the Sultanbent, was formed in the Quaternary Age. It is composed of fine-grained, layered sands with lenses of clays and pebbles. It is 90 meters thick in the center of the delta, but is thinner toward the edges. Sediments of the upper Iolotan formation form the modern Murgab delta and have a maximum thickness of about

50 meters. The lower layers of this formation are composed of gray fine-grained sands with rare, thin layers of clays (0.1-0.2 meters).

The Iolotan formation is overlaid by a complex of agro-irrigational, young sedimentation. This sedimentation (its thickness reaches 6 meters in the center of the Murgab oasis) can be referred to as an independent geological formation.

A gently convex cone, the Murgab oasis is situated in the Iolotan delta. Heights of the delta reach their maximum point at the town of Iolotan and decline to its north and northwest from 260 meters to 200 meters. There are several massifs of wandering sands, and the oasis is nearly a perfect plain (its surface slope is 0.001-0.005).

In the relief of the Murgab oasis there are many ramparts, irrigational canals and collectors. All are of anthropogenic origin. Some, for example the Sultan-Yab and Khurmuz-Fary canals and the Dgar and Kese-Yab collectors, are cleared and straightened branches of the Murgab. These branches had natural levees, which became higher due to the reconstruction of the riverbed. These levees are several kilometers long, 0.5-30 meters wide at their tops and 300-500 m wide at their bottoms. Between these levees are shallow depressions with gentle slopes (0.003-0.001) and flat bottoms, the dimensions of which can reach 103 km^2. In spring, the depressions contain salinized lakes, and sabkhat form during dry periods.

The initial alluvial-deltaic relief remains only on the northwestern edge of the Murgab delta, where one can find low (up to 1 m), flat ramparts and shallow inter-stream depressions, open to the north. Irrigational relief is found in the central and southern regions, where ramparts attain their maximum heights and inter-stream depressions are closed.

The Murgab floodplain is directed to the northwest and has precipitous banks 15 meters high and a flat bed over 100 meters wide with a meandering river channel. Up until the region of the city of Mari the depth of incising is 2.5-3 meters and the width of the floodplain is 30-60 meters, while the width of the river bed is 20-30 meters. Twenty-five to thirty km downstream of the city of Mari, the channel breaks into sub-channels, which are soon lost in the sands.

Along the Murgab there are ravines. Young ravines have a depth of 3-4 m and vertical slopes. The width of their bottoms at the mouth can reach 40-50 m. In the 150-200 m wide belt along the floodplain of the Murgab, there are suffosion craters 1-1.5 m in diameter.

1.1.1. Ground water

The upper layer of ground water is situated in the Neogene and Quaternary sediments, underlayed by a clay layer. There is intensive movement of salt-water masses under the irrigational canals in the Neogene sediments. Alimentation of ground water comes from filtration waters of the Murgab river, from irrigational systems and from irrigated fields. Since 1958, alimentation of ground water has also come from the Kara-Kum canal and a minor part from precipitation.

Ground-water flow from the oasis into the desert is not large: it is about 0.01 km^3 per year. Most of the water from the oasis evaporates. Annual evaporation from the irrigated lands is 1.92 km^3 and from non-irrigated areas is 0.64 km^3 per year.

Ground water has a mound body stretched along the Murgab valley. The ground water flow has a radial direction from the delta's top, and its rate is not high. Ground-water depth in the central part of the delta is 0-3 m, while on the borders it is 20 m and higher. Local hills of ground water may be detected under the irrigational fields. On the newly irrigated patches, the rate of the ground-water table increase is 1 m per year. Ground-water hills can also be observed under the irrigational canals. Filtration from the canals varies, with lower levels when the canals are filled with silt.

The quantity of salts in the Murgab oasis water is high. According to calculations, their quantity in the 50-meter layer is more than 1 billion tons (Melioration, 1980). Along with fresh water, one can also find water with salt content of up to 50 g/l and higher. The salinization character is sulfate-sodium when salinization is 23-30 g/l and becomes chloride-sulfate and chloride-sodium when salinization is higher.

Under irrigated lands, ground water has a mineralization of 5-7 g/l. Water-freshening under the fields occurs at 20-25 m below the surface. On well-drained patches, mineralization is 1-3 g/l, and the zone of water freshening is 30 m below the surface. On non-irrigated patches evaporation prevails in the water balance, and ground water is salinized up to 30-50 and even 80 g/l.

Before construction of the Kara-Kum canal, the most irrigated part of the oasis was the central and northwestern part. The widest differentiation in ground water mineralization was also observed here. Toward the edges of the oasis, the irrigational net became thinner and the territory of non-irrigated lands became smaller, while the ground water became more mineralized. The process of ground-water freshening under the irrigational canals and irrigated fields was permanent, and the mineralization of irrigational ground water of the under-canal lenses dropped from 0.8-1.2 to 0.6-0.8 g/l over 1948-58. Currently ground water under the Kara-Kum canal has a mineralization of 1 g/l, sometimes reaching 2-3 g/l; in the inter-canal depressions, mineralization is 30 g/l and higher (Figure 2).

The same spatial changes may be noted in the aeration zone from the non-salinized water on the near-canal levees to the solonchaks in the inter-canal depressions. Before the Kara-Kum canal's construction, the Murgab river was the main source of salt input into the oases. Its waters brought about 740 thousand tons of salt per year, 23-35% of which was swept away by ground water (Rogovskaya, 1959). Thus salt output from the oasis was 170-260 thousand tons per year with about 500-570 thousand tons remaining in the ground water. The low index of land use made agriculture possible.

After the Kara-Kum canal's construction, the fresh water input (0.2-0.7 g/l) into the oasis increased. This increase in fresh water input caused ground water mineralization to decrease, but increased the surface salinization of soils and led to the formation of sabkha-like surfaces as follows; as the ground-water table rose to a critical level on vast territories, it led to a junction of surface and ground water;

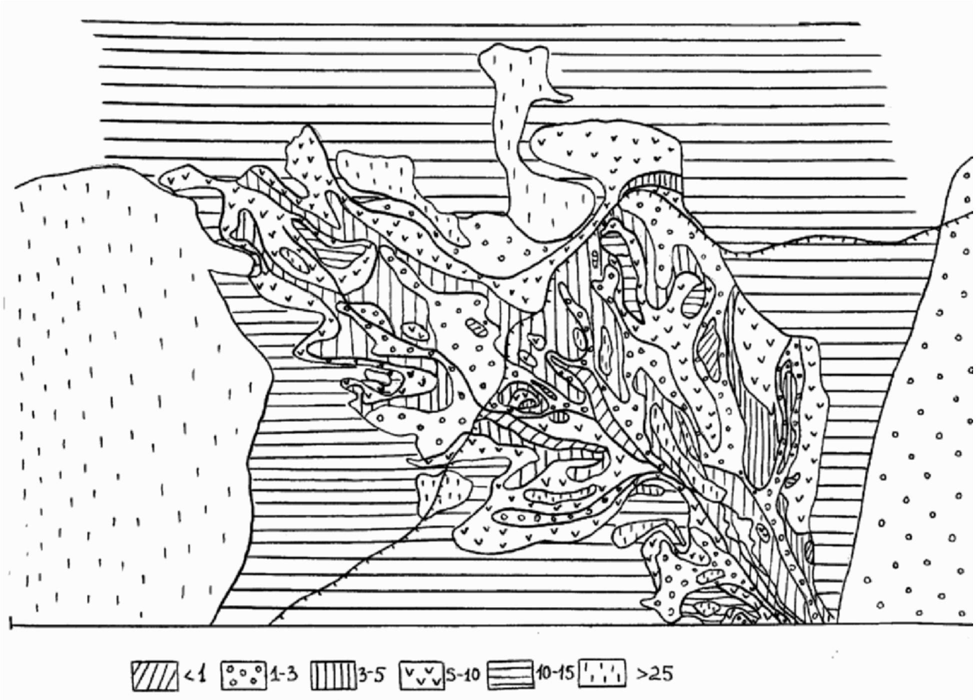

Figure 2. *Schematic map of the ground water mineralization in the Murgab delta (grams per litre).*

as a result, an active vertical salt exchange took place; saline water from the deep layers was brought to the surface and salinized vast territories.

The Murgab oasis is a united natural-anthropogenic complex including fragments of sandy-loamy desert. Irrigational landscapes formed in the central part of the delta and reduced the area of the deltaic landscapes. The landscape of the oasis is a plain dissected by canals of irrigational and collector-drainage construction. The oasis is surrounded by desert with barkhans and barkhan-ridges relief. In some places takyrs can be found. Ground waters are mineralized and are deeper than 15-20 meters, while soils are sandy-desert.

1.2. Tedgen delta

The Tedgen delta occupies about 200 km^2. The natural landscape of the Tedgen valley is less influenced by humans than that of the Murgab delta. Local anthropogenic changes, however, are more intense in the Tedgen than in the Murgab delta.

The Tedgen valley and delta are situated in the edge depression close to the Copetdag mountains. The Tedgen's Quaternary sediments may be divided into Serakhs, Inklab and Tedgen formations (Amurskiy & Raevskiy, 1979). The

Serakhs formation is located in the central and southern parts of the delta. It is composed of coarse-grained sands with layers of clays and pebbles and has a thickness of 200 meters.

The Inklab formation is more widespread and has a thickness of 7 to 35 meters. It is formed by layers of sands, loamy sands, loams and clays. The Tedgen formation (modern) is spread on a limited area mainly near the Tedgen and has a thickness of 15-20 meters. It is formed by fine-grained sands, loamy sands, loams and clays and is characterized by high diversity.

Modern alluvial sediments are spread like a thin belt in the Tedgen valley. They are similar to the Tedgen formation in their lithology and mechanical composition. Within the limits of the Tedgen and the Murgab oases, there are agro-irrigational sediments. These are thin, occupy limited territories and cannot be considered independent formations.

The Tedgen delta is a complicated body, consisting of superimposed deltas of different ages. The most ancient, the Serakhs, is overlaid by the Inklab. The modern Tedgen delta is situated in the central part of the Inklab.

The modern Tedgen delta has typical deltaic relief, including fan-shaped branches (most of them have been transformed into canals) and natural levees, composed of light material. Many branches are full, but can be clearly distinguished on satellite photos. Sometimes one finds lake depressions, filled with clay sediments. Today there are solonchaks. At the borders of the modern delta there are many barkhans and aeolian sand hills. There are many forms of anthropogenic relief in the Tedgen delta, as well as natural levees and others.

On the territory of the Inklab delta, the ancient riverbeds and lake depressions are preserved only in a few places. In the south of the Serakhs oasis anthropogenic relief is well developed. The central part of it is plain. Takyrs are widely spread here. Today this territory is intensively irrigated, and agro-irrigational relief is being formed here. The tail part of the delta is formed by a combination of fluvial forms with aeolian sands.

The Tedgen delta in the southern part is 6-8 meters deep. The floodplain is fragmented, with a height of 1-2 meters and a terrace 4-6 meters high. The riverbed of the Tedgen is 40-60 meters wide and forms oxbow lakes as it meanders. To the north of the Karri-Bend dam the main branch of the Tedgen forms a canyon 6 meters deep. Ancient branches of the Tedgen from 1-2 km to several dozen kilometers long are well preserved in the central part of the delta. Their depth is 1-2 meters, with some branches 4-5 meters deep (Table 1 and 2).

1.2.1. Ground water

The ground-water bearing complex of the Tedgen delta is separated from the deep water under the pressure of a Palaeogene clay layer. Alimentation of the ground water is via filtration from the irrigated fields and, to a lesser extent, via the river and irrigational canals. Input from the deep ground layers occurs only in the upper delta where the ground water flow from the Neogene sediments is transferred into

Table 1. *Territories (km²) with different depths of ground water table in the Murgab oasis. (Kornilov et al., 1978) and authors' data.*

	Depth of ground-water table, m					
Year	*1*	*1-3*	*3-5*	*5-10*	*10-20*	*20*
1948	-	604	1305	816	558	721
1958	83	996	755	830	568	772
1968	572	990	950	708	644	140
1978	362	1366	1124	580	532	40
1988	344	1478	1036	662	436	48

Table 2. *Territories (km²) with different depths of ground water table in the Tedgen oasis (Kornilov et al., 1978).*

	Depth of ground water table, m			
Year	*0-2*	*2-5*	*5-10*	*10*
1958	397	1,316	4,736	2,322
1968	730	3,286	3,646	1,091

the alluvial sediments. The role of precipitation in ground-water alimentation is small.

Ground water discharge takes place only through inter-ground precipitation. This is shown by the high level of water mineralization and by solonchaks situated mainly on the delta's edges and in the central part. Evaporation from the irrigated fields is 0.64 km^3 and from the other territories is 2.78 km^3.

The total ground-water flow from the Tedgen oasis along its whole perimeter is 0.02 km^3. The difference between water input and output is 1.03 km^3 and indicates an increase of water reserves in this region (by 0.42 km^3 in the reservoirs and by 0.61 km^3 in the ground water). Now the average depth of the ground-water table in the territory as a whole is 0.2 m.

The construction of an irrigational net began in 1965 in the Tedgen oasis, but drainage flow plays a small role in the oasis's water balance.

Ground-water flow in the Tedgen delta was parallel to the slope along the riverbed. However, since irrigated agriculture has become more intensive in the central part of the delta and in the territory of the Tedgen and Hauz-Han regions, a hill of ground water has formed and ground water flow has become radial. The form of this hill is rather complicated: it is formed by several separate hills beneath irrigated lands.

Mineralization varies along the flow of the waters of the Tedgen delta from 1-3 to 50 g/l and higher. In the upper part of the delta, in the region of the Serahs oasis along the river bed and near the Hor-Hor reservoir, the ground water is slightly salinized at 3 g/l. Water mineralization increases with depth, reaching 10 g/l, as the slightly-salinized water changes to salinized and then to heavy-salinized. On the eastern edge to the south of the Hauz-Han reservoir, water is heavy-salinized with a mineralization reaching 50 g/l. Along the Tedgen river and the large irrigational canals there are few under-channel lenses of ground water with low mineralization.

The salt reserves in the ground water of the Tedgen delta are rather large. This is due to the high level of ground water mineralization and to the thickness of the water-bearing horizon (from 490 to 875 m). Before construction of the Kara-Kum canal, the main source of salt input into the Tedgen delta was the Tedgen river. As ground-water output was small, the salt balance was positive. After construction of the Kara-Kum canal, the ground-water mineralization decreased while the salt accumulation continued. The net drainage is not sufficient to stop this process.

The landscapes of the Tedgen delta are sandy deserts in the north and loamy-sand deserts in the south. Anthropogenic complexes are represented by two generations: the ancient complexes (the Tedgen and Serakhs) and the young complex (the Hauz-Han).

2. CONCLUSIONS

The fluvial relief of the Murgab and the Tedgen deltas has been thoroughly transformed because of intensive irrigation activity over a long time period. This explains the complicated geomorphologic composition of the oases.

The construction of the Kara-Kum canal in the 1960s set off new processes in the oases, including changes in the ground-water table, transformation of the fluvial relief and soil salinization.

The processes now developing in the region can be considered signs of an ecological crisis. However, we can evaluate the current state of the ecosystems as a threshold state, which precedes active desertification.

3. REFERENCES

Amurskiy, G.I. & Raevskiy, M.I. 1979. “Composition of the Central Part of the Tedgen River Delta”. Bulletin of Scientific-Technical Information of the USSR Ministry for Geology and Resources Preservation 9: 26-39. (In Russian).

Kornilov, B.A., Timoshkina, V.A. & Topalov, G.M. 1978. “Subaeral deltas of the Murgab and the Tedgen” in the book Kara-Kum Canal and Changes in the Environment in the Zone of its Influence*,* Moscow, Nauka 78-116. (In Russian).

Rogovskaya, N.V. 1959. “Principle of Geological-Meliorative Evaluation of the Irrigated Missives (Taking the Murgab Delta as an Example)”. *Works of VSEGINGEO,* Questions of Hydrogeology and Engineer Geology 16: 24-35. (In Russian).

CHAPTER 15

PROPERTIES AND FUNCTIONING OF PEDOLITHOGENIC COMPLEXES OF SOILS, ROCKS AND WATERS OF THE FOREST STEPPE OF WESTERN SIBERIA

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1. INTRODUCTION

This paper deals with the study of soils, soil-forming rocks and groundwater in the territory of the southeast of western Siberia. The territory under study is defined as a region of insufficient moistening; it is characterized by a diversity and contrast of natural factors. Regional spots have developed of sodium, carbonate, sulphate, and chloride as well as of boron salinization. The salinization of soils, grounds and waters; the clay composition of soil-forming rocks; the low table of mineralized ground waters; and the weak degree of drainage are the causes for the essential decrease in stability of the natural system and the limited regulation of agrocenosis productivity.

The soils and rocks of the aeration zone and ground waters themselves represent a system of incorporated bodies (pedolithogenic complex), the formation and functioning of which is determined by outside factors (Elizarova & Magayeva, 1994). For optimum use of water and land resources, the diversity, spatial and temporal exchangeability of properties of pedolithogenic complexes should be taken into account.

2. MATERIALS AND METHODS

The separation of pedolithogenic complexes was performed on the basis of middle-scale thematic maps, including geological-geomorphological, engineer-geological, geomorphological, soil-reclamative, ecology reclamative, quaternary deposits, climatic and vegetation maps, et al.

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The main pedolithogenic complexes indices are based on comprehensive hydrogeodynamic and halogeochemical estimations of the landscapes. The main landscape components are analyzed: vegetation, soils, rocks of the zone of aeration, and ground waters.

3. RESULTS

The soils and grounds of the aeration zone of the southeast of western Siberia, characterized by an inconsistent shallow groundwater table, form a unified dynanamic halogeochemical system of pedolithogenic complexes. The system is characterized by a clear-cut spatially expressed structure and temporal dynamics, which are easily represented cartographically in the form of complexes of soils, rocks of the aeration zone and ground waters.

The geochemical data accumulated by many authors (Szabolcs, 1969; Kovda, 1971; Shishov et al., 1991) point out that in the southern territory of west Siberia, the halogeochemical pedolithogenic systems have been formed over a long period, have a complicated structure of associations, are well-balanced, close to a stationary state, and possess a high capacity of self-regulation. Under slight external pulse influences, the system returns to its initial state. In the soils and grounds of the southern part of the area, a sustainable perennial salt profile is found, characterized by a stable position (over the course of 40-50 years at least) of maximum salt content at a definite depth. This is the most important characteristic of the soil and grounds' transforming and accumulative role in water and salt exchange in the area under natural and technogenic conditions throughout the year, including the winter period.

The history of the development and formation of pedolithogenic complexes on the territory as a whole is reflected in the cyclic structure of underlying loess-like deposits of the pleistocen-holocen age. In the quaternary time, the alternation of several watering stages, the activation of aeolian processes and the formation of soil and vegetative cover took place. These stages are represented in the lithological component of the pedolithogenic complexes as buried horizons and an ancient aeration zone (Structure, functioning and evolution of the Baraba biogeocenoses, V.II, Novosibirsk, Nauka, 1976).

The cyclical climate changes during the pleistocene-holocene period have created conditions for a complicated re-stratification of subaeral and lacustrine-alluvial deposits represented by the spectrum of lithological diversity from sands to clay, with a predominance of heavy varieties. According to stratigrapho-genetic nature, the following varieties can be distinguished:

1. A stratigrapho-genetic complex of subaeral middle-upper quaternary deposits is widely spread on hills and eminences. It is represented by yellow-brown and brown sandy loams, macroporous loams with ferruginization threads (preferentially vertical), grains of manganese compounds, carbonate inclusions from rhizoids to granules, and horizons of buried soils. The deposits are

carbonated, aggregated, often form clayey sand, and possess subsidence properties. The structure of the subaeral layer has its own pattern reflected in the lithological composition of the deposits. The lithological composition along the profile from below upwards changes gradually from sands to heavy varieties and is completed with buried soil. The buried soil is covered by sands, sandy loams or light loam varieties, and further upwards the composition becomes heavier again. Each cycle has a respective ancient zone of aeration (yellow-brown rocks) and a water-bearing horizon (grey rocks, ferruginized horizon). The buried soils are often absent, and the ancient zones of aeration allow us to dismember the section. Only the rocks of the ancient zone of aeration have subsidence properties and are often salinized. The power of the rock complex is 10-15 m.

2. The stratigrapho-genetic complex of lacustrine subaeral deposits of the middle-upper-quaternary/contemporary age has been under water for a long time and bears numerous traces of hydromorphism.
3. The stratigrapho-genetic complex of lacustrine-alluvial deposits of the upper quaternary/contemporery age is spread in lake hollows, depressions and river valleys. The complex consists of grey clay loams with plant remnants, interlayers of sand, debris of shells, and sometimes peat layers. There are soft plastic and fluid plastic loams, sands, and water-saturated floating earth. The power of the rock complex is 5-7 m.

For the first type of pedolithogenic complex, a lithological component has been singled out on the basis of a stratigrapho-genetic complex of subaeral deposits. For the second type of pedolithogenic complex, a lithological component has been singled out on the basis of a stratigrapho-genetic complex of lacustrine-subaeral deposits. For the third type of pedolithogenic complex a lithological component has been singled out on the basis of a stratigrapho-genetic complex of lacustrine-alluvial deposits. The first type of pedolithogenic complexes is characterized by an automorphic and semi-automorphic-automorphic water and salt regime; the second by a semiautomorphic and semihydromorphic-semiautomorphic regime; and the third by a semihydromorphic and hydromorphic regime (Figure 1).

The chemical composition, mineralization and bedding depth of ground waters of the complex are subordinate to the natural climatic zonality, depend on the groundwater's position in the relief and vary in seasonal, annual and multi-annual regimes (Panin, 1977). Ground waters, like the stratigrapho-genetic deposit complexes, may be divided into three water-bearing complexes based on the conditions of their nutrition and unloading regime formation, including paleo-geographical formations; and by water-holding rocks, the hydraulic connection with underground waters of subjacent water bearing horizons and among themselves. These water-bearing complexes are divided as follows:

- the water-bearing complex of middle-upper quaternary subaeral deposits;

- the water-bearing complex of upper-quaternary, contemporary subaeral lacustraine-alluvial deposits;
- The water-bearing complex of modern lacustrine-palustrian, lacustrine-alluvial, and upper-quaternary-contemporary lacustrine-alluvial deposits.

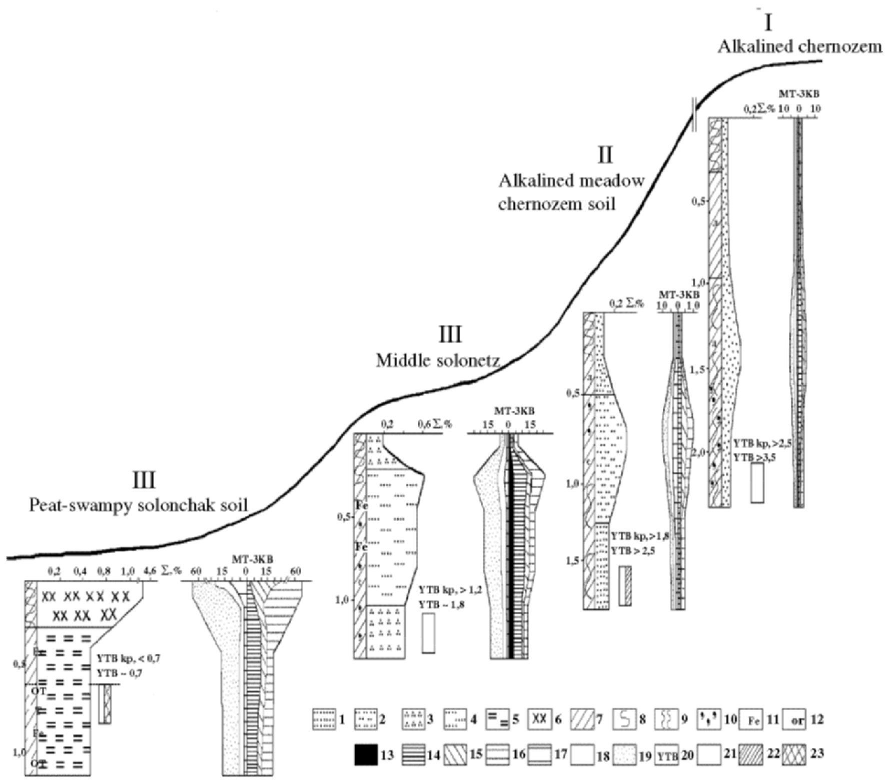

Figure 1. *Types of pedolithogenic complexes (I, II, III).*

Types and degrees of salinization: 1- nonsalinized carbonate; 2 - moderately salinized carbonate; 3 - nonsalinized soda; 4 - moderately salinized soda; 5 - moderately salinized sulfate; 6 - strongly salinized sulfate. Lithological composition of soils and grounds, inclusions and neoplasiae: 7 - loam: л - light, c - middle, т - heavy; 8 - humus-accumulative soil horizon; 9 - root passages; 10 - carbonates; 11 - iron-manganese inclusions; 12 - gleization. Ion composition of soil solution: 13 - CO_3^{2-}, 14 - HCO_3^-, 15 – Cl^-, 16 - SO_4^{2-}, 17 - Ca^{2+} 18 - Mg^{2+}, 19 - $Na^+ + K^+$. Ground water level, m: 20 УГВ - natural, УГВкр - critical. Chemical composition of ground water: 21 - hydrocarbonate type, 22 - sulfate type, 23 - chloride type.

The type, degree and metamorphization stage of salinization of soils and rocks of the aeration zone were estimated. Three large groups of salinization of soils and rocks of the aeration zone were distinguished:

1. Non-salinized soils occupying watershed areas of high plains and eminences, and the relatively well drained part of low plains. On hills with a low level of ground water (>4-5 m) and grey forest soils or alkaline (solodized) chemozems, salinization is of the carbonate, chloride- and sulfate-carbonate type, with the participation of soda. The degree of salinization in the aeration zone as a whole is <0,1-0,15%. On relatively flat areas of watershed surfaces and on hills on meadow-chernozem and alkaline chemozem, soil-grounds of the same salinization type are spread, but with a ground water level of no less than 4 m. These areas are potentially dangerous for use in irrigation in the halogeochemical respect. And, finally, on flat low surfaces, gentle slopes and soils of various degrees of alkalinization, including medow chernozems, meadows, and solods with a ground water level of mainly less then 3 m, salinization is of the carbonate and mixed type and often of the sodium carbonate type. These soil-grounds are not suitable for irrigation.
2. Non-salinized ground-soils in the top part of the profile and a weak and moderate (sometimes strong) mixed type salinization with a wide participation of soda are found at a depth of 1-1.5 m. These soil-grounds are spread in lowlands, suffusion-subsidence hollows, and depressions under solodized meadow-chernozem alkaline, solodized, meadow, solonetz, solod, and deep solonetz soils. Top waters are frequently found with a ground water level of <3 m.
3. Considerably salinized soil-grounds. In this group, four subtypes of salinization are distinguished:

    a) In the superficial layer (0.1-0.3 m) there is no salinization. Lower, strong chloride-sulfate, sulfate-chloride and sulfate-soda salinization is found. Soils in this sub-type are spread on low surfaces with a wide development of solonetz-solonchak complexes (up to 60-80% and more) and a ground water level of less than 3 m;
    b) The degree of salinization of the top and middle parts of the profile is weak and moderate; in the bottom part, the degree of salinization is usually strong. The salinization is of the carbonate, sulfate, chloride-soda, soda and sulfate-chloride types. It is spread in depressions, mainly of suffusion-subsidence origin, in large hollows occupied by solonchak meadow, and often in moistened soils with a ground water level of up to 2.0 m;
    c) The degree of salinization is strong throughout the aeration zone powers, with several salinization peaks. The salinization is of the sulfate-chloride and chloride types, with participation of soda. It is

spread on lowlands occupied by solonchak and swampy meadows and swamps (potentially salinized soils). The ground water level is 0-1 m. The main masses of salinized soils and rocks of this type are connected with various lake hollows, river valleys and adjacent lowlands;

d) Under the conditions of the exsudative regime, a profile is formed with a strong salinization to a depth of 0.5 m below which the degree of salinization is often moderate or even weak. The salinization is of chloride-sulfate, sulfate-chloride and soda types. It is spread in low lands on peat-swampy and meadow-swampy soils with a ground water level of 1-2 m. It is also connected with lake hollows, swamps, and river valleys.

In the investigated territory of the forest-steppe and steppe zones where evaporation prevails over precipitation, there arise several combinations of climatic conditions differing from the zonal ones and accompanied by changes in the functional state of the pedolithogenic complexes. With the change in functional state of pedolithogenic complex and of the type and degree of its salinization, the appearance of the landscape also varies. For example, in parallel with an increase in atmospheric humidification, the landscape changes from moist motley grass meadows to swamps, and with a decrease in atmospheric humidification, it changes to solonchaks with an almost complete absence of plant cover.

The complicated polycyclic development history of soil-ground thickness of the flat plain, its periodical watering and the activization of aeolian processes determine the diversity of the character and degree of the soil's salinization in landscapes and natural zones. The transforming and accumulating role of soil-ground thickness in the water-salt exchange is controlled by the conditions of the inner geochemical run-off. Functional dynamicity of pedolithogenic complexes is implied in the change of intensity in natural processes including soil-forming processes, such as salinization-desalinization, moistening-dessication, solonetrization, swamping, solothization, and humus accumulation in seasonal, annual and perennial cycles. The quazi-equilibrium state of pedolithogenic complexes corresponds to zonal and climatic conditions (precipitation and heat quantity correspond to mean annual data) (Table 1).

4. CONCLUSION

In the area under study a single pedolithogenic, rhythmically organized complex is formed of contemporary and buried soils, rocks of the aeration zone and ground waters.

The structure and properties of the pedolithogenic complexes reflect a qualitative peculiarity of the soil cover, of the lithological features (stratigraphical and genetic)

Table 1. *Functional state of pedolithogenic complexes under changes of climatic conditions.*

Climatic conditions	*Type of pedolithogenic complex*	*Trend of processes*	*Landscape change as compared to the zonal landscape*
Precipitation is higher than the mean annual level and exceeds evaporation; wind velocity is 0-2 m/sec; abundant snowfall, rains in cool weather	I	Desalinization, washing-out of Humus	Meadowization, forest wetting-out in depressions
	II	Desalinization, activation of solodization, swamping	Wetting-out of forests
	III	Desalinization, activation of swamping	Increase of lake surface
Precipitations are below the mean annual level and lower than evaporation; wind velocity is 0-2 m/sec; dry hot summer	I	Inconsistent, slight salinization	Steppization, drying-out of forests
	II	Intense salinization, solonetrization	Drying-out of forests, change of species composition of Meadows
	III	Activation of salinization	Degradation of lakes and swamps
Precipitations are below the mean annual level and lower than evaporation; wind velocity over processes 2 m/sec, dry hot summer	I	Desalinization	Steppization
	II	Inconsistent alternation of salinization-desalinization and solonetrization processes	Change of plant species composition in biocenoses
	III	Activation of salinization, aeral washing-out of salts with exsudation	Decrease of lake and swamps surface

of underlying rock, and of the water-salt exchange in the system of soil, rocks of the aeration zone and ground waters. The redistribution of matter and energy between soils, rocks of the aeration zone, and ground waters is the basic mechanism of matter and energy regulation in the pedo-, litho- and hydrosphere that determines the sustainability of soil properties.

5. REFERENCES

Elizarova, T.N. & Magaeva, L.A. 1994. Halogeochemical estimation criteria of ecological meliorative potential of Central Baraba territory, Siberian Journal of Ecology 3: 203-212 (In Russian).

Kovda, V.A. 1971. Soil Reclamative in the USSR, M., Nauka, 94-114 (in Russian).

Panin, P.S. 1977. Hydrochemical runoff on the territory of West Siberia and specific features of its formation // Geographical problems on agricultural development of Siberia, Novosibirsk, Nauka 66-75 (In Russian).

Shishov, L.L., Zimovets, B.A., Pankova, Ye.I. & Pyagei, E.T. 1991. Genesis and Control of Fertility of Salt-affected soils, M., 18-35.

Structure, functioning and evolution of the Baraba biogeocenoses, V. II, Novosibirsk, Nauka, 1976, 496 p. (in Russian).

Szabolcs, I. & Lesztak, J. 1969. The movements of different salt solutions in soil profiles, Water Unsatur. Zonc. Proc. Wageningen simpos. 2: 611-621.

CHAPTER 16

NATURAL, GEOGRAPHICAL, HALOGEOCHEMICAL AND SOIL FEATURES OF WESTERN SIBERIA

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1. INTRODUCTION

Soils, grounds, groundwater and superficial water of the west Siberian flat plain, in its southern part in particular, contain a great variety of salts of various compositions, such as chloride, sulphate and carbonate. Many researchers indicate that there are favorable natural conditions for contemporary salinization of soils, rocks and water, including geological, climatic, hydrological, geomorphological and biological (Bazilevich, 1965; Selyakov, 1973; Elizarova et al., 1999).

Soil salinization phenomena, as is known, are conditioned by the complex interaction of water and mineral substances within the lithosphere, ocean, hydrosphere, atmosphere, or biosphere; i.e. they occur as cyclic geochemical processes. Such phenomena have been appropriately considered in the fundamental work of B.B. Polynov, N.M. Strakhov and V.A. Kovda. The above-mentioned authors indicated that the greater part of the salts on the planet have been formed via salt-forming compounds of degasation of earth mantle, cations and crystalline rocks of the lithosphere. Salt formation in this way has continued into the present. The greater part of simple salts is concentrated in the oceans, and in the marine and continental deposits of weathering crust.

2. METHODOLOGY AND RESEARCH METHODS

The methodological basis of the conducted research is soil ecology dealing with the interrelation of soils and soil-forming factors (Volobuyev, 1973; Sokolov, 1993). This relationship occurs through mating migrational processes including halo-geochemical ones (Elizarova, 2001). Comparative geographical and comparative analytical methods have been used to reveal the distribution of

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relationships and soil, rock and water properties. Field surveys were conducted in a field course of the area under study. Analysis was conducted of the data on the territorial geological amalgamations collected by the state design institutes of water economy of western Siberia, as well as of published data.

2.1. Natural and geographical relationships

Natural factors, such as geological structure, neotectonics, relief, soil-forming rocks, climate (heat supply and moistening) and vegetation, presumably influence soil properties and halogeochemical processes.

The west-Siberian flat plain, formed by tectonic processes, was subject to a complex process of geological development, in the Cenozoic in particular. As a result of geological development, geomorphological structures have been formed, such as plateaus, flat plains, lowlands with particular elementary relief forms and two morphostructural belts as well, i.e. outer and inner. The former is relatively elevated with absolute heights of more than 150 m and active tectonic movements; the latter is relatively lower with absolute heights of over 150 m and weakly pronounced tectonic movements. This process caused the formation of two morphostructural belts, i.e. external and internal ones.

Deposits of different ages and compositions compose the soil and ground layers. In the northern part of the plain, ice marine and glacio-marine sediments are spread. In the middle part, continental glacial and fluvioglacial deposits are spread with a deep location of permafrosty rocks. In the southern part, seasonally frozen continental lacustrine alluvial, as well as subaerial covering rhythmic-bedded loess-like loams are formed. As a whole, a clear latitudinal and altitudinal zonality is observed in the genesis and composition of soil-forming rocks in which there is evidence of salinization and alkalinization.

Western Siberia serves as the catchment of the Kara Sea into which the warm, solid runoff and soluble salts are transported along with water. By virtue of its plain character, weak surface slope and wide spread of permafrosty rocks, the territory of the flat plain has tremendous capacity to hold water within its limits. Slow water runoff and perpetual water retention in swamps and peatlands are the features most specific to western Siberia.

Non-uniform heating of vast areas and non-uniform distribution of precipitation from the north to the south cause the formation of various landscapes from the far north to the desert steppes.

In spring and autumn in this area, in the subtaiga and forest steppe in particular, a collision takes place between fronts of northern and southern warm air masses that results in drastic fluctuations of air temperature, a decrease in wind energy and the most intense solid precipitation of the year (Glazovsky, 1987; Kazantsev, 1998) in the form of aeolian dust and aerosols, including water-soluble salts.

On the territory of the west-Siberian flat plain, the mean annual precipitation amounts to 1,447 cu km. A major part of this precipitation (at about of 1,100 cu km) goes to evaporation and transpiration, and about 380 cu km (26.3%) enters the river runoff of the Ob River Basin (Mezentsev & Karnatsevich, 1969). With precipitation, salts enter this region in amounts as high as 25 t. The greater part of salts transported by the wind settles in the areas closest to the areas of deflation of solonchaks and saline soils.

In tundra, forest tundra and northern taiga, along with sulphates and hydrocarbonates of alkali earths (salts of continental origin), sodium chloride, a salt of properly marine origin, composes a considerable portion of the chemical com-position of precipitation. With sprays of marine water these salts are convectionally transported into the atmosphere. As a consequence of the flat plainy character of western Siberia, they were transferred for considerable distances, where they entered the soil surface. In the Altai Mountains, sulphates prevail in precipitation, because here the rock weathering products predominate in the composition of aerosols. Sulfates may also have been transferred by wind from Kazakhstan or in industrial wastes. In the middle and southern taiga, hydro-carbonates of alkali earths prevail in meteoric waters, as in the southern forest steppe and steppe, and magnesium and sodium sulphates are prevalent. Here chlorides of alkali metals appear. Most likely their source of entry into the atmosphere is via the saline lakes of the flat areas. Hence as the climate continentality increases, the proportion of sulphates in the chemical composition of precipitation increases as well.

At the expense of the flow of the Ob River, about of 37,7 t of leached salts are removed beyond the limits of the west-Siberian flat plain (Panin, 1977). Salt amount and composition of the removed salts are variable in individual parts of the basin and natural belts. The present-day state of salt balance of the territory is characterized by predominance of salt removal over salt arrival in tundra, forest tundra and northern taiga. In the middle and southern taiga salt arrival and salt removal are in relative equilibrium in the subtaiga and the north forest steppe. As for the subtaiga, forest steppe and steppe, salt arrival prevails over salt removal (Panin, 1977; Kazantsev, 1998).

In the vertical geological section one can expect to observe the alternation of thick, highly water-permeable rocks and practically impermeable rocks. Water-impermeable rocks give rise to layers that have a rather constant area. These layers form regionally stable retainers that separate soil and ground water from pressure subterranean waters. However, a link between waters is established in discharge zones. The discharge zones themselves represent the location of the exchange of retainers of adjacent stratigraphical layers or are the locations of the erosional section. In the peripherical part of the flat plain the role of regional retainer is played by crystallic rocks of the Paleozoic and Mesozoic, and in the central part, by the Paleogene and Neogene clays. (Uglanov, 1981).

Soil and ground waters of exogenic crackings and quarternary deposits are fed on the whole area by precipitation and pressure subterranean waters in the discharge zones. On the greater part of the territory, the groundwaters are formed under conditions of weak and notably weak natural drainage. They are characterized by the prevalence of the processes of evaporative concentrating and carbon-acid leaching of sodium from soils, grounds and water-holding rocks. This results in a wide zonal and azonal diversity of groundwater (by mineralization and composition). The direction of flow of groundwaters and salts is entirely controlled by the lake hollows and rivers that drain them. Salt removal beyond the limits of the territory is effected by the waters of the Ob, Irtysh, Ishym, and Tobol rivers and their tributaries. Mean annual volume of runoff of the territory of south-western Siberia amounts in total to 96 cu km (Uglanov, 1981). According to the data of the Salekhard hydrological station, the total runoff of the catchment basin of the Ob river accounts for 384 cu km (158 mm) (Panin, 1977).

The feeding area of the pressure subterranean waters is mainly associated with the extremal parts of the flat plain. The direction of the runoff is from the north-west to the north and north-east, i.e. toward central regions. The pressure subterranean waters form several water-bearing horizons and complexes, which are by convention subdivided into two zones – lower and upper. In the lower zone of immersion in the Jura and Lower Carbonic deposits, the water exchange of fresh and weakly saline waters (presumably sodium-calcium hydrocarbonaceous) has been hampered; they are saturated with sodium chloride. Water mineralization makes up 15-20 g per cu dm: in immersed parts, it makes up more than 20-30 g per cu dm. The local sites of discharge of subterranean waters in the zone of fracture are the hollows of the lakes of Teke, Zhimangu, and Kyzyl-kak, as well as the Tobol river valley above the town of Kustanai where subterranean waters are the main source of salts. These hollows cut through the first retainer from the surface (Uglanov, 1981).

Pressure subterranean waters of the Eozene-Oligozene and Neogene are found to belong in the upper zone. The conditions of water exchange are better here than in the lower zone. Fresh and weakly saline water prevail here; their mineralization amounts to 3-5 g per cu dm. Under conditions of maximum immersion of water-bearing horizons and a decrease in water permeability of water-holding rocks one can observe an increase in mineralization and complication of the chemical composition of the waters. Some water-bearing horizons are higher than the floor of the principal rivers (Ishym, Tobol, Irtysh) and have clearly-pronounced discharge zones within the limits of their valleys. Subterranean waters from the Lower-Kochkovsky member are discharged into the rivers of the enclosed basins of Central Baraba and the eastern part of the Kulunda.

The data presented provide evidence that subterranean waters themselves represent an essential source of salt arrival and redistribution; on the territory under study several recharge areas are being formed from the lower hydrochemical zone. Quantitative estimation of the removed salts is difficult; however, the most significant salt removal seems to occur in the transfer of salts into lake hollows and the Ishym river valley and from the deposits of the Lower-Kochkovsky member into the region of the Chanovskaya depression and the Kulunda flat plain. A less significant portion is removed through their transfer into the valley of the Tobol River and a minimum through their transfer into the Irtysh

River valley (Uglanov, 1981). It should be noted that in some regions of the territory under study the deep subterranean flow is of no essential geochemical importance. This is true in regard to the regions where thick clay layers are buried in the upper part of the section. Such layers hinder the recharge or discharge of water in the deep water-bearing horizons. This is also true in regard to mountainous regions where the greater part of formed fracture waters is discharged into deep valleys, and in regard to the regions where the levels of ground and deep waters are the same with no notable recharge or discharge of deep waters.

2.2. Soil and halogeochemical relationships

Within the limits of western Siberia, the specific zonality of natural conditions and soil cover is formed. In tundra and forest tundra, soils are formed on the marine accumulative low plain. Low evaporation and permafrost favor a high degree of over-moistening of soil. Permafrosty rocks thaw up to 1 m. On the surface, the water-bearing horizon is formed where the salt content (HCO_3-Ca) accounts for 0.5-1.5 g per cu dm.

Soil cover is formed by arctic tundra soils with a shallow humus horizon. Gleyzation is weakly pronounced here. Low peaty gleysols and peaty tundra soils with a peaty layer at about 2 m are widely spread.

Taiga soils are characterized by over-moistening. The degree of drainage of the territory is medium. By general natural and geographical features, the taiga belt is classified into northern, medium and southern sub-belts.

In the northern taiga one can note insular depositions of the permafrosty rocks. Sands and peat-sandy grounds are widely spread. The groundwater table (HCO_3-Ca-Na waters) reaches depths as low as 1.0-2.0 m and water mineralization is no higher than 1 g per 1 cu dm. At swampy plots, groundwaters are very near the surface.

The soils are presumably gley podzolic with a complex of tundra gleysoils. As a rule, flat watershed areas are occupied by upper peat swamp soils.

The middle taiga is mainly characterized by deep deposition of permafrosty rocks. Sandy and clay rocks with extensive peat inclusions are spread here. The groundwater table (HCO_3-Ca-Na waters) is not deep: from 1.0 to 2.0 m at watersheds to up to 10 m in valleys; water mineralization is no higher than 1 g per cu dm. In swampy plots, groundwaters are very near the surface. The soils are spread as follows: gley podzolic, iron-illuvial and humus-illuvial podzols, and upper peat swamp.

The southern taiga, like the middle taiga, is notable for deep deposition of permafrosty rocks. Clay rocks with intensive inclusions of peat material are spread here. The groundwater table (HCO_3-Ca-Na, Mg waters) is insignificant: from 0-5 m at the watersheds up to 5-10 m on the slopes, water mineralization does not exceed 1.0-1.5 m per 1 cu dm. On swampy plots, groundwaters are very near the surface.

As for the soils, iron-illuvial and dry peaty podzols, sod-podzolic, sod-gley and upper peat swamp soils are most common. In the extreme southern part of the belt, gleyed and gley gray forest soils are spread.

The feature specific to the subtaiga, forest steppe and steppes is the excess of evaporation over precipitation that favors salt accumulation in soils, rocks and waters. The degree of salinity of the territory of the flat plain is weak or medium; that of flat plains of foot-mountains is strong. The forest steppe and steppe include sub-belts, such as the northern forest steppe, the southern forest steppe, the typical steppes, and the dry desert steppes.

In the subtaiga, one can observe deep permafrosty rocks. Clay rocks with extensive inclusions of peat material are spread. The groundwater table (HCO_3-Ca-Na; HCO_3-SO_4-Na waters) varies from 0.5-3.0 m on the watersheds and slopes, up to 10 m on terrace rims; water mineralization is not higher than 1-3 g per cu dm. The soils are as follows: sod-podzolic, gray forest, meadow chernozemic, soloths, upper and low peat swampy.

In the northern and southern forest steppe, the depth of seasonal freezing is up to 2.5 m. The rocks are presumably clay and loess like rhythmite. The groundwater table (water of variable chemical composition) ranges from 5-7 m on mane-like elevations up to 0.5 m in depressions; water mineralization varies from 1 to 10-50 g per 1 cu dm respectively.

The soils are as follows: gray forest, chernozems leached, sands of pine forests, meadow soils, soloths, solonetzes, solonchaks and meadow swampy soils.

In the typical, dry desert steppes, the depth of seasonal freezing varies from 1.5 to 2.0 m. The rocks are for the most part sands and loess-like rhythmic loams. The groundwater table (waters of variable composition) ranges from 5-7 m on mane-like elevations to 0.5 m in depressions, and water mineralization varies from 1 to 30-50 g per 1 cu dm.

Soils are mainly represented by southern solonetzic chernozems and chestnut soils. Semihydromorphic and hydromorphic soils are saline to a variable degree.

The presented soil and halogeochemical characteristics of the territory under study allow us to conclude that the main sources of salts in the soils of western Siberia constitute three principal categories of salt accumulations:

1. Salts of the oceans and seas transported onto the continent through precipitation.
2. Salts of open salt accumulations of dried-out lakes, such as Kara-Bogaz-Gol, and solonchakous shores of inner reservoirs in arid regions subjected to deflation. From the surfaces of these shores the salts are transported by aerial masses for a long distance from arid regions into humid ones.
3. Salts of the past geological epoch accumulated in sedimentary deposits. They are soluble and transported with superficial, ground and subterranean waters into depressions. A part of these salts enters the rival net and is removed into the ocean, inner seas and lakes; the other part enters soils through groundwater.

An extensive literature is available on the geochemical regioning of the territories (Volobuyev, 1973; Pankova, 1992), which was first elaborated by A.E. Fersman. The proposed halogeochemical regionalization of the territory is based on analysis of the processes of salt transfer and accumulation, which are effected by atmospheric, rival, lacustrine and subterranean waters. The basin of runoff that is formed within the limits of large geological structures with a general development history and unified water and salt runoff is accepted as the largest taxonomic unit. The basin of runoff is defined as a large unit of regioning. It is formed within the limits of large geological structures with a general history of development. The basin of runoff is a completed system of hypergenic migration of salts and qualitative and quantitative transformations of salt accumulations from the area of recharge of runoff to its discharge. Furthermore, the morphostructures that occupy the run-off basin differ by genesis, regime of sediment accumulation and neotectonic development, giving the runoff basin a complicated inner structure. In line with the taxonomic units of ecological and reclamative regionalization (Elizarova et al., 1999), this enables us to classify in their own rights the units of halogeochemical regionalization such as formations, provinces, regions, subregions, groups of districts and districts (Table 1).

The west-Siberian flat plain is a unified runoff basin with a specific spectrum of soil-geochemical conditions (Figure 1). Two halogeochemical formations (outer and inner) and five complexes (outer arctic, outer forest-swampy, outer forest-steppe, inner arctic and inner forest-swampy) are classified. This permits us to evaluate here the intensity of recharge and discharge of subterranean waters. It also permits us to evaluate the direction and intensity of their movement under the different landscape conditions that influence the total volume of ionic runoff and its qualitative peculiarities.

Table 1. *System of taxonomic units of halogeochemical regioning of the flat plain territory of western Siberia.*

Regioning units	*Factors determining halogeochemical processes*
Basin	Geological structure; main direction of moisture and salt runoff
Formation	Revealing of tectonic movements; character of feeding of subterranean waters
Province	Frost, climate, intensity of regional water and salt exchange; resources of fresh natural waters
Region, subregion	Specific features of climate, relief, vegetation, degree of drainage of the territory; groundwater table, mineralization of and chemical composition of groundwater; stage of hypergenic salt migration
Complex	Revealing of tectonic movements, characteristics of landscapes, character of feeding of subterranean waters;
Group of districts, district	Genesis of relief, rocks, soils, characteristics of landscapes; specific features of pedohalogenesis

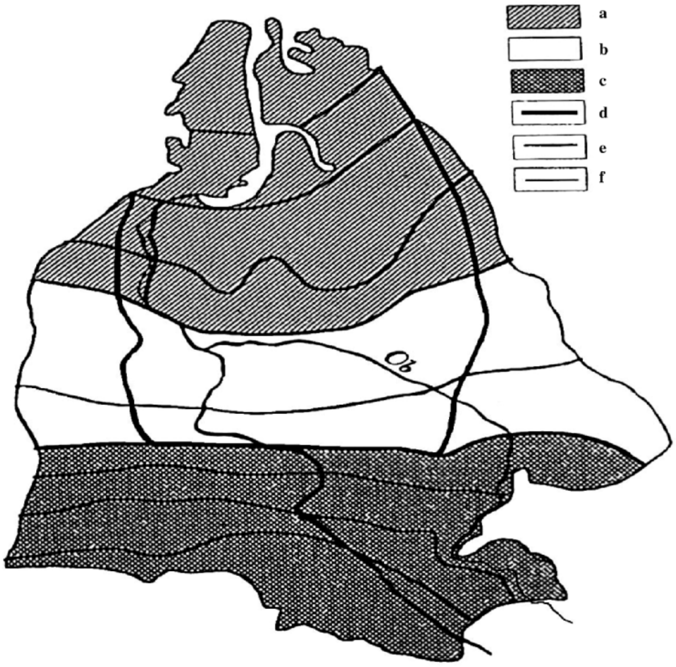

Figure 1. *Diagram of ecology and reclamative soil regioning of Western Siberia Provinces of:*

a -low activity of water and salt exchange with predominance of salt removal over salt delivery (arctic and subarctic tundra, forest tundra and northern taiga).
b -active water and salt exchange with an approximate balance of salt delivery and removal (middle and southern taiga).
c -active water and salt exchange with a predominance of salt delivery over salt removal (subtaiga, northern and southern forest steppe, typical and dry deserted steppe).
Borders of:
d -formations, e - complex, f - region and subregion.

In the direction from north to south, depending on the activity of regional water and salt exchange and the propagation of permafrosty rocks, the basin is subdivided into three halogeochemical provinces (Elizarova, 2001). Depending on the chemical composition of precipitation and the type of salt transfer (chloride and sulphate, or sulphate and sodium carbonate, or sodium carbonate and sulphate) as well as on the prevailing type of salt accumulation, the basin is subdivided into regions and subregions. Respectively, the following regions (tundra, forest-swampy, forest-steppe) and subregions (arctic and subarctic tundra; forest tundra; northern, middle and southern taiga; subtaiga; northern, southern forest steppe; typical, dry deserted steppes) are subdivided. Eventually, the study of nature-geographical and soil-halogeochemical features of the territory allowed us to reveal the zonal and azonal specific effects of soil-forming factors on the formation of a diversity of properties of soil cover and to obtain the most exhaustive characteristics of salt accumulation type for the territory under study.

Tectonic activity of the territory and wide spreading of permafrosty rocks complicate the processes of moisture and salt exchange. In the south of the territory under study, the salts are mainly accumulated by aerial means, and alkalinization of soils and rocks is developed. The reason is that the sloping, rival and subterranean waters are deficient.

3. REFERENCES

Bazilevich, N.I. 1965. Geochemistry of soils of sodium carbonate salinization. M.: Nauka, 351 pp. (In Russian).

Elizarova, T.N., Kazantsev, V.A., Magaeva, L.A. & Ustinov, M.T. 1999. Ecological and reclamative potential of soil cover of western Siberia. Novosibirsk: Siberian Publisher «Nauka» of RAS, 226 pp. (In Russian).

Elizarova, T.N. 2001. Balance estimation of pedohalogeochemical processes // Siberian ecological Journal 271-275 pp. (In Russian).

Glazovsky, N.F. 1987. Contemporary salt accumulation in arid areas. M.: Nauka, 192 pp. (In Russian).

Kazantsev, V.A. 1998. Problems of pedohalogenesis (in the example of the Barabinsk flat plain). Novosibirsk: Publisher «Nauka» of SB RAS, 192 pp. (In Russian).

Mezentsev, V.S. & Karnatsevich, I.V. 1969. Degree of moistening of the west-Siberian flat plain. Leningrad, 368 pp. (In Russian).

Panin, P.S. 1977. Hydrochemical runoff in the territory of west Siberia and specific features of its formation // Geographical problems in agricultural development of Siberia. Novosibirsk, 66-75 pp. (In Russian).

Pankova, Ye.I. 1992. The genesis of salinization of soils of the deserts. M., 136 pp. (In Russian).

Selyakov, S.N. 1973. Historic outlines of the study of saline soil of the Ob-Irtish interfluve // Results of an investigation of living nature/Proceedings of Biol. Institute. Novosibirsk, 272-284 pp. (In Russian).

Sokolov, I.A. 1993. Theoretical problems of genetic soil science. Novosibirsk: Publisher «Nauka» of SB RAS, 232 pp. (In Russian).

Uglanov, I.N. 1981. Reclamated layer of soils and rocks of the south of Western Siberia. Novosibirsk: Publisher «Nauka» of SB RAS, 193 pp. (In Russian).

Volobuyev, V.R. 1973. Soil system of the world. Baku: Elm, 308 pp. (In Russian).

CHAPTER 17

SABKHAT REGIONS OF IRAQ

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1. INTRODUCTION

The territory of Iraq lies between longitudes 38°42′ E and 48°23′ E, and between latitudes 29°27′ N and 37°23′ N. of a total land area of approximately 444,500 km^2, over half is desert. These vast deserts of Iraq lie mainly in the western and southern parts of the country, rise gradually and meet the high plateaus of the Syrian Desert in the west and the Arabian Desert in the south. The desert region is bound to the north and northwest by the upper plains and foothills and to the east and southeast by the right bank of the Euphrates River. The western, southwestern and southern boundaries of the desert region are Iraq's frontiers with Syria, Jordan, Saudi Arabia and Kuwait (Figure 1).

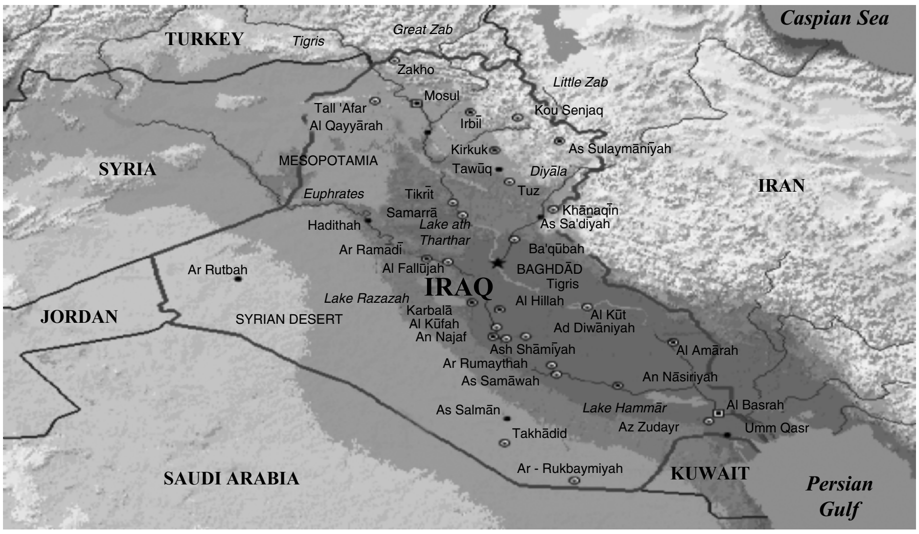

Figure 1. *Physical map of Iraq*.

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Most of the desert region of Iraq lies below 200 m on the lower plains, rising westwards to a maximum elevation of about 900 m (Jabal Anaiza), near the border to Saudi Arabia and Jordan. Geologically this region consists of undisturbed limestone with some shale of Cretaceous (135 MYBP), Eocene (60 MYBP), Miocene (25 MYBP) and Pliocene (11 MYBP) origin. This is a part of the Arabian Shield, which forms the western part of the Arabian Peninsula. The oldest (Cretaceous) part of this shield in Iraq is at the southwest corner (Rutba District) surrounded by Eocene limestone and marls. The only extensive zone of sand dunes in Iraq stretching over 270 km lies from south of Najaf in the south to west of Basra in the southeast, forming a belt of dunes 15 to 20 km wide.

The desert soils of Iraq are calcareous, usually gypsiferous, often with a cover of recent unsorted material as a result of wind erosion, and contain a low organic content (generally below 0.5%) (Guest, 1966). The soils are often covered with a thin layer of gravel, or with a gypsum or limestone crust. The subsoil starts at a depth of a few centimetres, and has high lime content. The desert soils (gypsum and limestone) occupy the greater part of the desert plateau region of Iraq (the Jazira, the Western Desert, and the Southern Desert). Many saline marshy depressions may be found in these deserts, especially near Karbala (central Iraq) around the two large salt lakes, Bahr al Milh and Lake Abu Dibbis.

1.1. Climate

The climate of the desert regions of Iraq is characterized by long hot summers and comparatively short cool winters. Lower Iraq, where the desert and sabkhat are present, is divided into two well-marked seasons with short transitional periods in between. The climate diagrams produced by Lieth (1999) show that May to October marks the summer with high temperatures and low rainfall, and the comparatively short winter lasts from December to February (Figure 2). The coldest month in the year in all parts is January when mean daily minimum and maximum temperatures on the plains range from 2°C–15°C, and the hottest months are July and August when mean daily minimum and maximum temperatures range from 24°C–43°C. The prevailing winds are all northwest, but during the winter months strong southeasterly winds occur accompanied by rain. Mists are common but rarely last a few hours beyond sunrise.

1.2. Vegetation

The description of the desert and sabkha vegetation given here is taken predominantly from Guest (1966) who edited and contributed to the introductory volume of the Flora of Iraq (Townsend & Guest, 1966). Other literature is cited as used in the text. Apart from these literature sources, not much published information is available on the desert regions of Iraq, and recent studies on plant ecology are sadly lacking or unavailable.

As for most arid regions, the flora of the sabkhat of Iraq is poor in species. Low soil coverage and high soil salinity as a result of low rainfall and high temperatures have resulted in a desert flora of about 200–300 species (Zohary, 1941, 1946; Rechinger, 1964). The majority of these species is spread over a large area; for example, of all the species found in the desert area of southwest Iraq, about 10% are absent from the deserts of the Arabian Peninsula. There are only a few species of trees, the vegetation being dominated by small shrubs and perennial herbs.

The typical natural vegetation of the desert in Iraq consists of "…more or less scattered perennial shrublets (e.g. *Haloxylon salicornicum, Artemesia herba-alba, Achillea fragrantissima, Rhanterium epapposum*) practically nowhere completely closed and often very open, and including barren tracts of edaphic desert and secondary desert. In the spring the open places between the bushes are generally occupied by a relatively sparse crop of annuals. In depressions and other favourable habitats the cover of vegetation may approach almost luxuriant during its short-lived spring growing and flowering season. Where the bushy perennials have been destroyed the sparse ground vegetation is usually dominated by *Stipa capensis*, this being everywhere a sign of degradation. Within the sub-desert zone there are many smaller or larger tracts of secondary desert where vegetation may be almost lacking – sometimes for a dozen kilometres; other barren stretches – some quite extensive, fall into the category of edaphic desert, such as the highly saline soils which inhibit the growth of all plants except an occasional extreme halophyte, or the flat hard impervious soil from which rain evaporates before it has time to percolate through to the substratum…" (Guest, 1966).

The majority of the perennial plants of the sabkha regions of Iraq are succulents, principally of the Chenopodiaceae family; annual plants that are common to most desert and saline areas constitute about 60% of the desert species (Al Rawi, 1964).

1.3. Plant communities

The most characteristic plant communities are as follows:

1. *Haloxyletum ammodendri.* The main component of this association is *Haloxylon ammodendron* (=*H. aphylla*) (Arabic: ghada), and is found only in the sandy desert with unstabilized sand dunes, and is prevalent in southern Palestine and northern Arabia. In Iraq this community stretches along the Euphrates sand-belt. It is evident that this community was once much more widely spread and close than it is perhaps in recent times due to degradation from fuel gatherers who use it for making charcoal.

The dominant species is *Haloxylon ammodendron*, which is a woody shrub or small tree, up to 3 m tall. *Panicum turgidum* (Arabic: thummām) and *Calligonum comosum* are often associated with it; other members of this community include species such as *Haloxylon salicornicum*, *Salsola* spp., *Aristida plumosa*, *Seidlitzia*

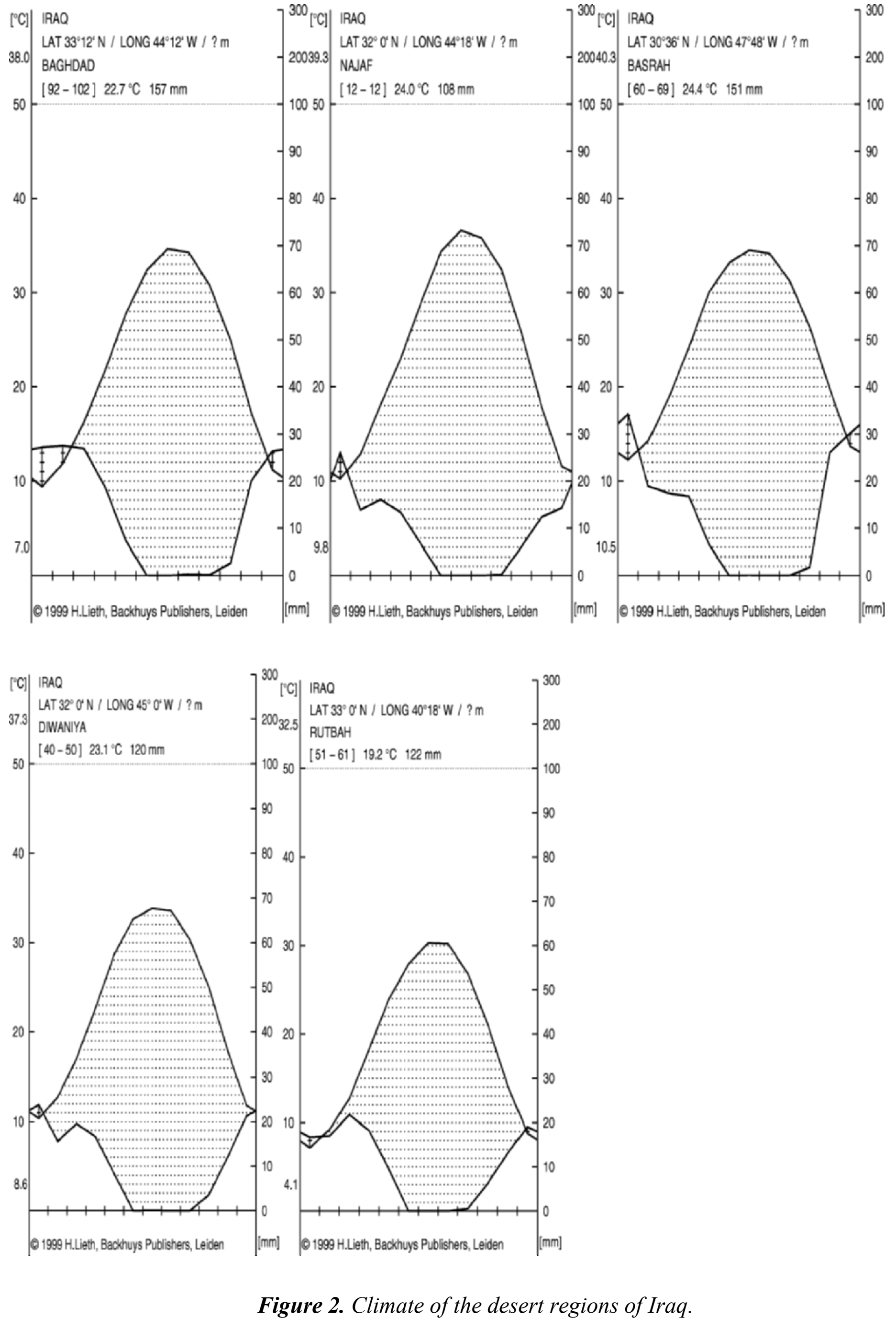

Figure 2. *Climate of the desert regions of Iraq.*

rosmarinus, *Moltkiopsis ciliata*, *Neurada procumbens*, *Plantago* spp., *Cyperus conglomeratus*, *Silene villosa*, *Anisosciadium lanatum*, *Eremobium aegyptiacum*, *Cutandia memphitica*, *Bassia muricata* and *Astragalus gyzensis*. *Cistanche* is parasitic on the saline shrubs especially *Haloxylon* and is conspicuous in spring when it is in flower.

2. *Haloxyletum salicornici*. This is the most characteristic and important community of the desert region of Iraq and is widespread throughout the deserts of the Arabian Peninsula (Ghazanfar, 2002; Zohary, 1941). This community is found on calcareous substrates with a gypsophilous underlying substrate. The dominant species of this community is *Haloxylon salicornicum* (Arabic: rimth), which usually grows in small mounds made from aeolain sand. It has been estimated that the average ground cover with this community may vary between 10–30% (Zohary, 1941). Major associates of *Haloxylon salicornicum* are *Anabasis setifera* (Arabic: sha'ran), *Salsola jordanicola*, *Seidlitzia rosmarinus*, *Cornulaca aucheri*, *Cymbopogon olivieri*, *Aristida plumosa*, and *Annothamnus gibbous*. *Seidlitzia rosmarinus* is found on higher ground at the edges of saline mud flats as apposed to the halophyte *Halopeplis perfoliata* found in the sabkhas of the Sultanate of Oman (Ghazanfar, 1995). Other associates are *Heliotropium ramosissimum*, *Farsetia aegytiaca*, *Plantago ciliata*, *Teucrium oliverianum* and *Neurada procumbens*.

3. *Zygophylletum coccinei*. This community is usually found on sandy soil overlying saline flats. The shrub, *Zygophyllum coccineum*, grows on small hummocks made from windblown sand. In Iraq often found in the southern desert, this species often occurs near the sea in Kuwait and southern Arabia.

4. *Seidlitzietum rosmarini*. This is another halophytic or semi-halophytic community often found on fringes of saline or brackish water pools. *Salsola* species are often associated with *Seidlitzia rosmarinus* in this community.

5. *Halocnemum strobilacei*. This is the most characteristic community of sabkha areas and is prevalent on the saline mud flats in south western Iraq. *Halocnemum strobilaceum* is the dominant species, with occasional associates of *Aeluropus lagopoides* and *Cressa cretica*. The average cover is usually less than 5%, though at times can be as high as 30% with the associated species.

6. *Bienertietum cyclopterae*. This community consisting of a single species, *Bienertia cycloptera*, is found on margins of small saline depressions in sandy areas. Associated with it in some areas, such as at the margins of Bahr al Milh in the western desert, are *Frankenia pulverulenta* and *Aleuropus lagopoides*.

In addition to these communities, scattered plants of *Tamarix passerinoides*, and *Peganum harmala* are often found in saline habitats. In particular *Peganum harmala* is present often on disturbed and waste ground where there is a high level of soil nitrates. *Ziziphus nummularia* is a constant species of sandy depressions.

1.4. Endemism and conservation

The desert region of Iraq is not rich in biological diversity. Much of the arid desert has already been degraded by livestock grazing and motorized hunting. Satellite surveys show that only 0.2 percent of the country's total land area is covered in forest, much of which has been heavily exploited for fuel and grazing needs.

There are no recent data available on the number of endemic species in the desert and sabkhat of Iraq. As the region of lower Iraq falls within the Saharo-Sindian phytochorion, a few species, such as *Haloxylon salicornicum* and *Suaeda aegyptiaca*, are endemic to this phytochorion. Other than these two, Zohary (1946) estimated that nine other species were endemic to Iraq in this phytochorion.

There are no recent studies available on any aspect of conservation in the sabkhat regions of Iraq, and as far as I know there are no projects underway by the Internal Union for the Conservation of Nature (IUCN) (Parakatil, pers. comm., 2003) or other NGO’s for the conservation or conservation assessment of the natural vegetation and other sustainable resources.

1.5. Plants of economic importance

As in other arid zones, one of the main economic uses of plants in Iraq is as forage for livestock, and fuel for human use. Chakravarty (1976) gives a comprehensive account of cultivated and non-cultivated plants in use and those of potential economic importance in Iraq. Houérou (1985) gives a summary of the forage and fuel plants of North Africa, and the near and Middle East, drawing data from species or groups of species of particular interest. In arid zones browse species include those belonging to the Chenopodiaceae and Leguminosae. Again most of the examples in Houérou (1985) are from arid regions other than those of Iraq, but species such as *Haloxylon ammodendron*, Calligonum spp., and *Atriplex* spp. supply a good perennial browse, and annuals such as species of *Astragalus* and *Lotus* are utilized seasonally.

2. SUMMARY AND RECOMMENDATIONS

Little is known or available on the ecology of the sabkhat regions of Iraq. The information that is at hand is obsolete, thus making it difficult to asses the present state of the vegetation and the conservation status of the fragile ecosystem that sabkhat represent. In arid-zone countries, desert rangelands make up a very important part of an ecosystem that is fully utilized for livestock food and production, firewood, and hunting, thus providing an essential part of the livelihood of its inhabitants. It is therefore important that comprehensive research and studies are conducted in Iraq in order to understand the dynamics of such ecosystems in the country, and to apply the knowledge for the sustainable utilization of its desert ecosystems. This is of utmost relevance to the sustainability of human development.

3. REFERENCES

Al Rawi, A. 1964. Wild plants of Iraq with their distribution. Government Press, Baghdad. 220 pp.

Chakravarty, H.L. 1976. Plant Wealth of Iraq, Vol. 1. Ministry of Agriculture and Agrarian Reforms. Baghdad. 506 pp.

Ghazanfar, S.A. 1995. Coastal sabkhas: an analysis of the vegetation of Barr al Hikman. pp. 277-283 In: M.A. Khan & I.A. Ungar (eds.), The Biology of Salt Tolerant Plants. Department of Botany, University of Karachi, Pakistan.

Ghazanfar, S.A. 2002. The Sabkha vegetation of Oman. In: Sabkha ecosystems. Volume 1, The Arabian Peninsula and adjacent countries (eds Barth, G.H. & Böer, B.), pp. 99-107. Kluwer Academic, Dordrecht, The Netherlands.

Guest, E. (ed.) 1966. Flora of Iraq, Vol. 1: Introduction. Ministry of Agriculture and Agrarian Reforms. Baghdad. 213 pp.

Le Houerou, H.N. 1985. Forage and fuel plants in the arid zone of North Africa, the Near and Middle East. In: Plants for arid lands (ed. G.E. Wickens, J.R. Goodin & D.V. Field), pp. 117-141. Royal Botanic Gardens, Kew.

Lieth, H., Berlekamp, J., Fuest, S. & Riediger, S. 1999. Climate Diagram World Atlas: CD-ROM 1, Climate and Biosphere. Backhuys Publishers, Leiden.

Rechinger, K.H. 1964. Flora of Lowland Iraq. J. Cramer, Weinheim. 746 pp.

Townsend, C. & Guest, E. 1966. Flora of Iraq. vol. 1, 2 (1966), vol. 3 (1974), vol. 4, parts 1 & 2 (1980), vol. 8 (1985), vol. 9 (1968). Ministry of Agriculture and Agrarian Reforms. Baghdad. Incomplete.

Zohary, M. 1941. The flora of the desert to the south and west of Basra, Mesopotamia. Proc. Linn. Soc. ser. 1: 98-107.

Zohary, M. 1946. The Flora of Iraq and its Phytogeographical Subdivision. Department of Agriculture, Baghdad. 200 pp.

CHAPTER 18

THE DYNAMICS OF HALOPHYTE ECOSYSTEMS IN THE ZONE OF IMPACT OF KAPCHAGAI RESERVOIR (KAZAKHSTAN)

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Abstract. The article summarizes the dynamics of the ecosystems of the zone influenced by the Kapchagai reservoir. It also describes changes in hydrological regime and hydrogeological conditions (depth of underground waters, their mineralization and chemical composition). The article also considers changes in soil (salt content and types of soils) and vegetation cover (in composition, in structure and types of vegetation).

1. INTRODUCTION

The setting up of reservoirs and hydroelectric stations enables more efficient use of water and soil resources. Irrigated land improves water supply for large enterprises and settlements; resorts and recreational facilities are set up. The filling up of reservoirs, however, also provokes major changes in the environment. Increases in the level of underground waters, flooding, paludification, and salinization of valuable agricultural lands occur. Unfavourable conditions for spawning arise. Climatic and sanitary – technical conditions change. Transformations of the climate and underground water regime cause changes in edaphic conditions and vegetation cover. Hydro-technical infrastructure not only transforms the environment on the flooded territory and narrow coastline; influence on the surrounding territory sometimes spreads to dozens of kilometers away from the reservoir.

The primary goal of the investigations was to evaluate the appropriateness of ecosystem formation on the coasts of the reservoirs of the desert zone, while examining the hydrological regime, hydrogeological and edaphic conditions, and vegetation cover. The secondary goal was to investigate changes in vegetation and in the peculiarities of degradative-demutative successions in conditions of periodical flooding and underflooding of the territory. The investigations of

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halophyte ecosystems were conducted in southeastern Kazakhstan on the southern coast of the Kapchagai reservoir in 1976-1986.

1.1. Physical and geographic conditions

The Kapchagai reservoir is situated in southeastern Kazakhstan. The reservoir was set up in the western part of the inter-mountain Ilyiskaja hollow. The hollow is limited by the Altynemel mountain ridge to the north and by the Zailyiski Alatau to the south (Figure 1).

The reservoir is about 200 kilometers long and 15-20 kilometers wide. Its volume, according to the project, is 28.1 kilometers cubed. The zone of impact of the reservoir includes the northern part of the Chilik, Enbekshi Kazakh, Talgar and Ily regions of the Almaty province. The territory is well developed economically. Cereals, watermelon, vegetables, fruit, technical crops, and grapes are cultivated on large areas. Stockbreedineg is well developed in the foothills and on the coast of the reservoir. The filling of the reservoir began in 1970.

The territory examined was the foothill plain of the Zailyiski Alatau mountain ridge. The ridge consists of a belt of cones of traces edges with northern spurs. They merge in a united proluvial train and create a wavy, strongly sloped plain with a surface inclination of 0.02-0.05° in the hypsometric range of 600-1,200 meters above sea level. The foothill plain extends in the meridian direction by 12-20 kilometers. A gently sloped plain extends to the north to the coast of the reservoir. The surface of the plain is straight with an inclination that does not exceed 1-3°.

A high level of dryness and continentality characterizes the climate of the territory. The average annual air temperature is 6.4-8.7 degrees centigrade. The coldest month of the year is January with an absolute minimum of –44 degrees centigrade. The hottest month of the year is July with an absolute maximum of

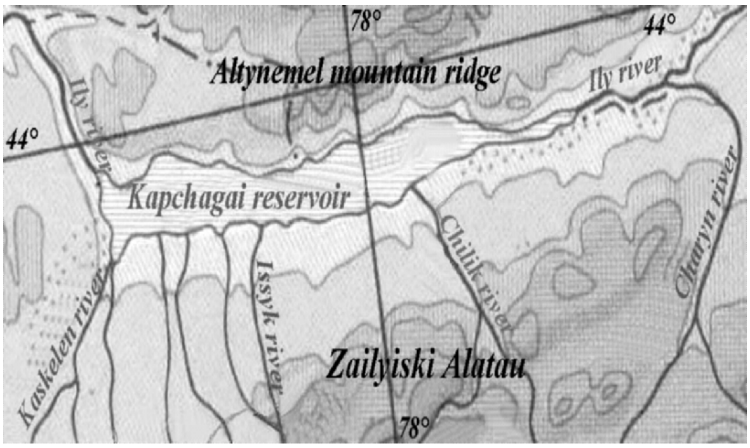

Figure 1. *Location of the Kapchagai reservoir.*

+43 degrees centigrade. The sum of effective temperatures reaches 3,090-3,770 degrees centigrade. Average annual quantity of precipitation does not exceed 150-250 millimeters; capacity of snow-cover is 10-20 centimeters. The predominant wind direction is northeast. Wind speed exceeds 18 meters per second. Breezes conditioned by differences in the air and land temperatures of the reservoir are typical on its coast.

Medium quaternary alluvial-proluvial sediments compose the foothill plain. They form over flood land terraces in the Ily river valley. Different granular sands predominate in the lithological composition, which contains gravel and pebbles. The capacity of the sediments varies until 100-500 meters.

The upper quaternary alluvial-proluvial sediments of the gently inclining plain are sediments of small rivers and temporary flows of the foothills. These sediments form the first over flood-land terrace in the Ily river valley, and their capacity reaches 30-40 meters. Loess ground composes the main part of the soil profile.

The sediments of the modern epoch are represented by a wide complex of genetic types. Layers of sands, sandy loams, loams and clay mainly compose the western part of the foothill plain. At depths between 62 and 200 meters, capacity of the sediments varies. Horizons of sandy loams, loams and different granular sands stratify in the central part. Their capacity does not exceed 3-5 meters and rarely reaches 10 meters. The eastern part of the foothill plain is characterized by multiple stratifying of sandy loams and sandy layers. Its capacity does not exceed 2-3 meters.

The hydrogeological conditions of the territory are quite complicated. The territory belongs to the central part of large many-tier artesian basins. The areas of water supplement are surrounded by mountain ridges (Shapiro and Vinnikova, 1980). The placement of underground waters (ground and pressure) is connected with the presence of coarse quaternary sediments of a different age. The depth of underground waters is 0.3-0.5 meters in the outlying part of the cones of traces. An increase in underground water depth to 4-5 meters is marked further north towards the Ily river on the foothill plane. The level of underground waters increases to 1.0-1.5 meters from the surface on the border of the Ily river valley (at a distance of 12-15 kilometers from the river) and decreases to 2-5 meters in the valley. Since the start of the filling of the Kapchagai reservoir (1970), the normal projective horizon of the reservoir has conditioned the regime of the level of underground waters on the coast.

The hydrographical network of the region of the investigations worked out well. It is the basin of the Ily River. The area of the basin is 140 thousand square kilometers. The Ily River has glacial and snow supply. The volume of outflow by average perennial data is 14.8 cube kilometers in urochishe Kapchagai. Flows of the Ily River (the Kaskelen, the Big and Small Almatinka, the Issyk, the Turgen, the Charyn, and the Chilik) are rough and well watered in the limits of the mountains. They lose up to 50-60% of outflow for infiltration, irrigation, and water supply on the cones of traces. The regime of water supply of the flows is closely connected with the intensity of the melting of glacier and high mountain snows. Rivers of the plain type begin in outlying cones of traces in the zone of wedging of underground waters. The sources of water supply for the rivers are ground waters and rainfall.

Zonal soils of the region of the investigations are light serozem and grey-brown. The following types of soils were identified on the foothill plain (in the left-bank): meadow serozem, meadow (of varying degrees of salinization and solonetzic), meadow, and ordinary solonchaks. Light serozems (loamy and sandy loamy) and grey-brown soils are spread on the northern coast of the reservoir. Boggy meadow, meadow boggy and boggy soils develop in the flood lands of the rivers.

Sagebrush desert with *Achnatherum splendens* and halophyte saltwort represent the vegetation of the inclined plain of the southern coast of the reservoir. However, the main part of the territory is ploughed up. Zonal dwarf semishrub (of *Artemisia terrae-albae* and of *Camphorosma monspeliaca*) communities (com.) remained on small areas only. Com. of *Artemisia terrae-albae* with *Climacoptera brachiata* and com. of *Artemisia terrae-albae* with *Alhagi pseudalhagi,* and *Vexibia alopecuroides* are found more frequently. The composition of the vegetation represents stages of pasture digression of sagebrush communities. Com. of *Camphorosma monspeliaca* with *Puccinellia tenuiflora* and ephemers (*Poa bulbosa, Alyssum turkestanicum*) develop on prairie grey solonchakous-solonetzic soils. Annual saltwort (*Climacoptera brachiata, C. obtusifolia*) and sagebrush (*Artemisia schrenkiana*) communities are found on prairie grey saline soils.

Brushwood of reed grass (*Phragmites australis*) and reed mace (*Typha angustifolia*) on boggy soils constitute the intrazonal meadow vegetation of the flood lands of the small rivers. Com. of *Heleocharis acicularis* and com. of *Xanthium strumarium* occur on the meadow boggy soils. Mesophyte communities, grassy (*Festuca orientalis, Calamagrostis epigeios, Elytrigia repens*) and forb-grass (*E. repens, Euphorbia soongarica, Althaea officinalis*), develop on the meadow soils. Com. of *Aeluropus littoralis, Puccinellia tenuiflora* and annual saltwort (*Climacoptera brachiata, Petrosimonia brachiata*) communities are typical for meadow solonchaks. Halophyte dwarf semishrub (*Nanophyton erinaceum*, *Anabasis ramosissima, A. elatior, Atriplex cana*) and annual saltwort (*Climacoptera obtusifolia, C. brachiata*) communities with participation of shrubs (*Suaeda physophora, Kalidium caspicum*) are widespread on ordinary solonchaks.

Ephemeral-undershrub (*Hulthemia persica, Ceratoides papposa, Anisantha tectorum, Poa bulbosa)* with grasses (*Stipa hohenackeriana*) and ephemeral-sagebrush (*Artemisia terrae-albae, Secale sylvestre*) communities are found on the grey-brown soils of the left coast of the reservoir. Shrub-dwarf semishrub (*Ceratoides papposa, Calligonum aphyllum, Kochia prostrata*) and ephemeral-sagebrush (*Artemisia terrae-albae, Alyssum turkestanicum, Poa bulbosa*) communities develop on desert sandy soils of small hilly sands.

Thus, we examined the physical and geographic conditions of the inter-mountain Ilyiskaja hollow. The Kapchagai reservoir was set up in the axis part of the hollow.

1.2. The dynamics of halophyte ecosystems in the zone of impact of the kapchagai reservoir

The setting up of the Kapchagai reservoir has changed the natural hydrological regime and hydrogeological situation of the adjoining territory. The following transformations are occurring: flooding of the adjoining territories, rising of the groundwater level, and changes in the soil and vegetation cover.

The influence of reservoirs of the desert zone on adjoining territories has distinctive peculiarities. The influence of the reservoirs is conditioned both by the natural conditions of desert regions and by the character of the economic usage of the reservoirs. In contrast to areas of surplus moistening and strong filtration, a rapid increase in the level of underground waters occurred here after the setting up of the reservoirs. In connection to this, the main part of the water on the coast of the artificial reservoirs evaporated. Because of evaporation, a strong flow of water towards the surface appears in the soil because of continuous filtration from the reservoir. Water brings dissolved salts, which stay in the soil and provoke salinization of the soil profile.

Besides being used for electricity, the reservoirs of the desert zone have been used for irrigation. Significant water volume has been used for the irrigation of agricultural lands. Water loss from the reservoir occurs in March-August. Because of seasonal and perennial variance of the water level down to its mortal stock, significant territory vacates from the water. The territory is shoal for a long period (from several months till several years). This constitutes the zone of periodical flooding (the zone of «working up» of the reservoir). An increase in the level of underground waters on the territory adjoining the "water cut off" of the reservoir occurs in the process of filling the reservoir. This is zone of backwater of underground waters (Figure 2).

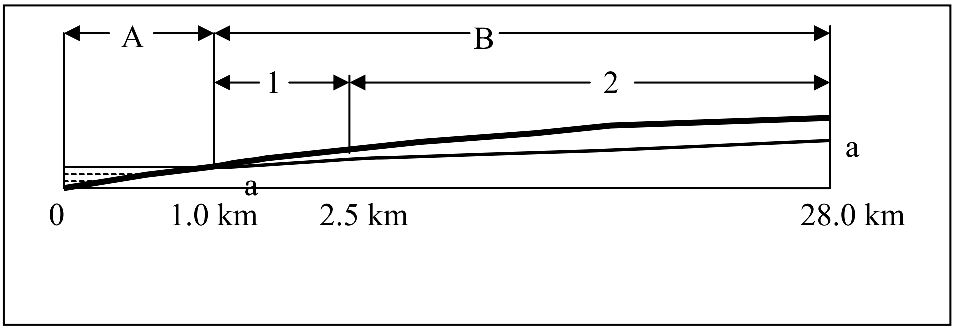

Figure 2. *Diagram of the subdivision of the territory adjoining the reservoir A - zone of periodic flooding; B- zone of backwater of underground waters: 1- subzone of underflooding; 2- subzone of hydrogeological influence. a-a - level of underground waters.*

We will use investigations in the central part of the south coast of the Kapchagai reservoir to illustrate the dynamics of halophyte ecosystems in the zone of influence of the reservoir. The territory is located in the country between the Issyk and Chilik rivers (Figure 1). Heavily and extremely heavily salinized ecosystems occupy about 80-90% of the territory of the foothill plain. The area of investigation is the over-flood land terrace of the Ily river valley. It is a gently sloping plain. A brief description of the main natural ecosystems of the country between the Issyk and Chilik rivers in existence before the setting-up of the reservoir is presented in Table 1.

The zone of periodic flooding developed on the coast of the reservoir because of water escape after the setting up of the reservoir. The width of the zone fluctuates from several dozens of meters to one kilometer and more depending on the volume of water escape. The relief of the territory has been impacted even by the waves. The main factor of development of ecosystems in the zone of periodic flooding is hydrological regime (length and depth of flood of the territory). Lixiviation of salts from soil occurs in conditions of long-term flooding. Flooded soils desalinate until a depth of 30-50 cm. Degree of desalination decreases at depths lower than 50-70 cm. Restoration of salinization of the soils after vocation from water occurs over one vegetation period. The main reason for this is accumulation of sodium chloride. Initial soils – ordinary solonchaks – transform into meadow crust solonchaks. Salt crust forms on the soil surface. The salt sum

Table 1. *Brief description of the main natural ecosystems of the country between the Issyk and Chilik rivers in existence before the setting up of the reservoir.*

Components of the ecosystems		*Description of the components of the ecosystems*
Underground Waters	Level, m	3-5
	Mineralization, gr./liter	10.1-41.5
	Type of salinization	Chloride-sodium, occasionally with heightened content of ions of calcium
Soils	Type	Ordinary solonchaks
	Salt composition	Chloride-sodium, occasionally with heightened content of ions of calcium
Vegetation	Widely-distributed communities	Annual saltwort (*Climacoptera brachiata, C. obtusifolia*) with participation of *Suaeda physophora* and *Kalidium foliatum*, annual saltwort-dwarf semishrub (*Nanophyton erinaceum, Anabasis ramosissima, A. elatior, Climacoptera obtusifolia, C. brachiata*), orach (*Atriplex cana*), dwarf-semishrub (*Nanophyton erinaceum, Anabasis ramosissima*).

along the whole profile reaches 1-2% and more (Starodubtcev, 1984). The dynamics of ecosystems in the zone of periodic flooding in the country between the Issyk and Chilik rivers are presented in Table 2.

Analysis of the data of the table shows a radical change in the development of ecosystems of the considered territory. Single individuals and open aggregations of halophytes and halomesophytes on meadow crust solonchaks have replaced initial xerohalophyte dwarf semishrub communities with the participation of semishrubs on ordinary solonchaks. The halohydroseries consists of the following stages: com. of *Nanophyton erinaceum* with participation of semishrubs (*Suaeda physophora, Kalidium caspicum*) → *nanophyton-annual-saltwort* (*Suaeda prostrata, Atriplex tatarica, Nanophyton erinaceum*) → aggregations with participation of *Suaeda physophora* and *Kalidium foliatum* → herb annual saltwort (*Atriplex tatarica, Salicornia europaea, Suaeda prostrata, Rumex marshallianus, Galatella fastigiiformis*) aggregations → rarefied annual saltwort (*Salicornia europaea, Chenopodium rubrum, Climacoptera obtusifolia*) aggregations → single individuals of *Puccinellia diffusa, Atriplex tatarica, Salicornia europaea* → single individuals of hyperhalophytes (*Halostachys caspica, Halocnemum strobilaceum, Nitraria sibirica*).

Replacement of xerohalophyte dwarf semishrub com. of *Nanophyton erinaceum* by halomesophyte and haloxeromesophyte annual saltwort lasts 4-6 years. *Nanophyton erinaceum* sustains six year surface flooding. The considered territory showed signs of an extremal ecological situation (ecocide): underground waters had a high level of mineralization and chloride-sodium salt composition, and heavily saline, meadow crust solonchaks appeared along the whole profile. Because of these conditions, higher plants assimilate less than 5% of the territory. The territory became unsuitable for pasturing because of vegetation degradation in the process of the filling of the reservoir.

The zone of backwater of underground waters has not yet developed on the southern coast of the Kapchagai reservoir. The filling of the reservoir continues. According to the hydrogeological prognosis (Shapiro and Vinnikova, 1980), the impact of the backwater of the underground waters will spread to 22 kilometers in the western part of the southern coast and to 28 kilometers in the eastern part (water levels: 480 and 485 meters). The area of the territory is 100 thousand hectares under a stationary regime of water level in the reservoir.

We should distinguish the hydrogeological impact of the reservoir (backwater of underground waters) from the more sophisticated physical and geographic process of underflooding. The process of underflooding occurs when the under backwater of underground waters or the capillary border of the under back water reaches the root layer. An increase in the level of underground waters provokes transformations in the water-salt regime of soils and in the development of vegetation cover. Therefore, we subdivide the zone of backwater of underground waters into two subzones: underflooding and hydrogeological influence (Figure 2).

The width of the underflooding subzone reaches 1.5 (1.7) kilometers. Because of strong backwater of underground waters from the reservoir side, underground waters rose from 3.5-4.5 to 0.7-1.0 meters from the soil surface. The waters are brines by salt content. Their type of salt composition is chloride-sodium and sulphate-chloride-sodium. Ordinary solonchaks transformed into meadow plump solonchaks in conditions of strong backwater of underground waters. At the end of summer and in autumn, wind disperses plump forms on the soil surface. Content of salts in surface soil horizons reaches 2-4% and more. The content remains high (1-5%) along the whole profile until the level of underground waters. The type of salt composition by anion is sulphate-chloride with participation of soda, by cation – mainly sodium, and mixed in lower horizons.

Total alkalinity was heightened in the upper half-meter layer, and alkalinity of normal carbonates was found until 1.0-1.5 meters. Significant participation of chlorine in the composition of anions is evidence of the activation of the process of salinization under the influence of the underground water prop from the reservoir side (Starodubtcev, 1986).

Table 3 presents the dynamics of ecosystems in the subzone of underflooding on the southern coast of the reservoir (in the country between the Issyk and Chilik rivers). The data of the table show that because of a strong rise in the level of underground waters, a transformation in the development of ecosystems occurs. Communities and aggregations of halomesophytes on meadow plump solonchaks replace initial xerohalophyte dwarf semishrub communities with participation of semishrubs on ordinary solonchaks. Shrubs-hyperhalophytes appear. In a summarized view, the following stages represent the halohydroseries: dwarf semishrub (*Nanophyton erinaceum, Salsola orientalis, Anabasis ramosissima*) communities with participation of semishrubs (*Kalidium caspicum, K. foliatum*) → dwarf semishrub-annual saltwort (*Climacoptera brachiata, C. obtusifolia, Nanophyton erinaceum, Salsola orientalis, Anabasis ramosissima*) with participation of *Kalidium caspicum, K. foliatum,* and *Suaeda physophora* → annual saltwort (*Suaeda prostrata, Salicornia europaea*) → single individuals of shrubs (*Nitraria sibirica, Halostachys caspica*). Duration of this halohydroseries is 6-8 years.

The considered territory showed signs of an extremal ecological situation (ecocide): underground waters had a high level of mineralization and sulphate-chloride-sodium and chloride-sodium salt composition, and meadow plump solonchaks were heavily saline along the whole profile. Therefore, higher plants do not assimilate significant part of the territory. Rarefied aggregations of annual saltwort low in productivity and insignificant as fodder develop on the greater part of the territory. The territory has become unsuitable for pasturing.

The subzone of hydrogeological influence of the reservoir (Figure 2) is characterized by weak backwater of underground waters, an insignificant rise in underground waters, strengthening of intra-soil evaporation and vertical water exchange. Nevertheless, these processes do not significantly influence the root layer and vegetation cover development. The subzone of hydrogeological influence of the reservoir has not yet developed because the filling up of the reservoir has not been completed.

Table 2. *The dynamics of halophyte ecosystems in the zone of periodic flooding on the southern coast of the Kapchagai reservoir (the country between the Issyk and Chilik rivers).*

Hydrological regime	Underground waters			Soils		Vegetation
	Depth, m	Mineralization, g/l	Salt composition	Type	Salt composition	
					1976	
Six month flooding	0.3-0.8	77.0-88.0	Chloride-sodium	Sulphate-chloride-sodium	Sulphate-chloride-sodium	Higher plants did not assimilate 20% of the territory (line 60-120 meters wide from water "cutoff"). Numerous aggregations of annual saltwort (*Suaeda prostrata, S. crassifolia, Salicornia europaea, Chenopodium rubrum*), halomespohyte herbs (*Galatella fastigiiformis, Rumex marschallianus, Polygonum hydropiper*), and halomesophyte cereals (*Aeluropus littoralis, Puccinellia distans, Phragmites austrails) occupy* 80% of the territory.
					1983	
Three year flooding	0.7-0.9	44.3-51.1	Chloride-sodium	Meadow crust solonchak	Chloride-sodium	Single individuals of *Salicornia europaea, Suaeda prostrata, Phragmites australis*
					1984	
Seven month flooding	0.8-1.1	40.0-56.6	Chloride-sodium with heightened content of magnesium	Meadow crust solonchak	Chloride-sodium	Higher plants did not assimilate 80% of the territory. Rarefied aggregations with a predominance of *Kalidium foliatum, Puccinellia diffusa*, and *Tamarix hispida* occupy 20% of the territory.
					1985	
Eight month flooding	0.8-0.85	61.1-70.0	Sulphate-chloride-sodium with heightened content of magnesium	Meadow crust solonchak	Sulphate-chloride and chloride-sodium	Higher plants did not assimilate 95% of the territory. Single individuals of *Salicornia europaea, Suaeda prostrata,*and *Puccinellia diffusa* occupy 5% of the territory. Hyperhalophytes-shrubs (*Halostachys caspica, Nitraria sibirica*) and dwarf semishrubs (*Halocnemum strobilaceum*) appeared for the first time.

Table 3. *Dynamics of halophyte ecosystems in the subzone of underflooding on the southern coast of the reservoir (in the country between the Issyk and Chilik rivers).*

Underground waters			Soils		Vegetation
Depth, m	Mineralization, g/l	Salt composition	Type	Salt composition	
				1976	
1.1-1.5	76.8-87.6	Sulphate-chloride-sodium	Meadow plump solonchak	Sulphate-chloride-sodium with participation of soda	Xerohalophyte communities of dwarf semishrubs (*Nanophyton erinaceum, Salsola orientalis, Anabasis ramosissima, Atriplex cana*) with participation of semishrubs (*Kalidium caspicum, K. foliatum, Suaeda physophora*) and annual saltwort (*Climacoptera obtusifolia, C. brachiata*).
				1982	
0.83-0.92	51.9-55.7	Sulphate-chloride-sodium	Meadow plump solonchak	Sulphate-chloride-sodium with participation of soda	Communities of annual haloxerophyte (*Climacoptera brachiata, C. obtusifolia*) and haloxeromesophyte (*Suaeda prostrata, Salicornia europaea*) saltwort occupy 60% of the territory. Single individuals of *Tamarix hispida, Aeluropus littoralis,* and *Salicornia europaea* occupy 30% of the territory. Initial xerohalophyte (*Nanophyton erinaceum, Salsola orientalis, Anabasis ramosissima, Atriplex cana*) communities with participation of semishrubs (*Kalidium caspicum, K. foliatum, Suaeda physophora*) remained on 10% of the territory.
				1986	
0.63-0.80	35.1-61.2	Chloride-sodium	Meadow plump solonchak	Chloride-sulphate-sodium with participation of soda	Higher plants did not assimilate 15% of the territory. Rarefied aggregations of annual halomesophyte saltwort (*Suaeda prostrata, Salicornia europaea*) occupy 55% of the territory. Communities of annual saltwort (*Climacoptera brachiata, C. obtusifolia, Suaeda prostrata*) with participation of shrubs (*Tamarix hispida*) and semishrubs (*Kalidium foliatum*) occupy 30% of the territory. Initial species – xerohalophytes (*Nanophyton erinaceum, Salsola orientalis, Anabasis ramosissima*) – have died. New for the territory, species of hyperhalophyte shrubs (*Nitraria sibirica, Halostachys caspica*) have appeared.

Table 4. *Dynamics of halophyte ecosystems in the subzone of hydrogeological influence of the reservoir on the southern coast of the Kapchagai reservoir (in the country between the Issyk and Chilik rivers).*

Year of investigations	Distance from water "cut off"	Underground waters			Soils		Vegetation
		Depth, m	Mineralization g/l	Salt composition	Type	Salt composition	
In the peripheral part of the subzone of hydrogeological influence of the reservoir							
1976	3,780	2.98	12.6	Sulphate-chloride magnesium-sodium	Ordinary solonchak	Chloride-sulphate sodium	Sea-lavender-saltwort-annual saltwort (*Climacoptera brachi-ata, Anabasis ramosissima, Limonium otolepis*) communities with sea blite (*Suaeda physophora*).
1982	2,970	3.65	12.7	Sulphate-chloride magnesium-sodium	Ordinary solonchak	Sulphate-chloride sodium	Annual saltwort-sea-lavender-saltwort (*Anabasis ramosissima, Limonium otolepis, Climacoptera brachiata*) communities
1985	3,500	4.38	14.8	Sulphate-chloride magnesium-sodium	Ordinary solonchak	Sulphate-chloride sodium	Saltwort-annual saltwort (*Climacoptera brachiata, Anabasis ramosissima*) communities with sea blite (*Suaeda physophora*).
In the central part of the subzone of hydrogeological influence of the reservoir							
1976	8,280	3.5	10.0	Sulphate-chloride magnesium-sodium	Ordinary solonchak with signs of solonetz-like soils	Sulphate sodium	Annual saltwort (*Climacoptera obtusifolia, C. brachiata,*) communities with tamarisk (*Tamarix hispida*) and saltwort (*Anabasis ramosissima*).
1982	8,470	3.7	10.4	Sulphate-chloride magnesium-sodium	Ordinary solonchak with signs of solonetz-like soils	Sulphate sodium	Ephemeral-saltwort-annual saltwort (*Climacoptera obtusifolia, Anabasis ramosissima, Eremopyrum orientale*) communities with *Tamarix hispida.*
1985.	8,000	4.27	11.1	Sulphate-chloride magnesium-sodium	Ordinary solonchak with signs of solonetz-like soils	Sulphate sodium	Saltwort-annual saltwort (*Climacoptera brachiata, C. obtusifolia, Anabasis ramosissima*) communities with *Artemisia schrenkiana* and *Tamarix hispida.*

The territory under consideration is a gently sloped plain. Halophyte ecosystems occupy the greater part of the territory. The regime of underground waters has been established and is cyclic. Inflow from mountains and expenditure towards the aeration zone determine the regime of underground waters. There is insignificant outflow towards the reservoir side. The level of underground waters reaches 2.75-3.25 meters in spring and 3.5-4.5 in autumn. Average amplitude of seasonal fluctuations is 70-80 centimeters. Mineralization of underground waters reaches 10-30 gram per liter. Salt composition is sulphate-chloride, magnesium-sodium. Soils are ordinary solonchaks. Salinization of soils is heavy along the whole profile (until a depth of 2.5-3.0 m). The sum of salts reaches 1-3%. The greatest salinity exists in soil layers of heavy soil texture. Salt composition is mainly sulphate-sodium and rarely chloride-sulphate-sodium. There is a heightened total alkalinity and alkalinity of normal carbonates (Starodubtcev, 1981, 1986). Numerous haloxerophyte communities represent the vegetation. Dwarf semishrubs with participation of annual saltwort, semishrubs, and shrubs constitute the communities.

Analysis of the data of the table shows that fluctuating ecosystems develop on the considered territory. The underground waters and capillary border do not reach the root layer. Types of soils and their salt composition do not change. Specie composition of vegetation does not differ from the initial state. There is the same composition of dominating and accompanying species. Ecotope fluctuations represent the dynamics of the vegetation: in the change of total coverage of the communities and in the occasional abundant development of annual saltwort and ephemers. However, these changes are conditioned by meteorological conditions, not by backwater of underground waters. Regime of economic use of vegetation for pasturing did not change.

2. SUMMARY

The reservoirs provoke significant changes in the environment of the surrounding territory. Changes of ecosystems of the zone of influence of the reservoirs are sharper than in humid regions. Insufficient moisture and high temperatures in the arid zone promote wide development of salinization processes The salinization process becomes one of the main factors in the development of ecosystems of the zone of influence of the reservoir. Critical transformation of ecosystems of the zone of periodical flooding is occurring: the hydrological regime and hydrogeological conditions are changing. Hydromorphity and halomorphity of initial soils are strengthening: ordinary solonchaks are transforming into meadow crust solonchaks. Aggregations of halomesophyte annual saltwort and halophyte shrubs are replacing haloxerophyte dwarf semishrub communities with participation of semishrubs. Replacement of types of ecosystems occurs over 4-6 years.

Peculiarities of hydrogeological and edaphic conditions and duration of flooding condition the direction, character, and rates of successions of vegetation

Hyperhalophytes (according to N.I. Akzhigitova classification, 1982), *Salicornia europaea, Climacoptera brachiata, Halostachys caspica, Kalidium foliatum*, are pioneers of assimilation of the territory in conditions of heavy sulphate-chloride and chloride-sodium salinization of underground waters and soils. Since 1982, diapauses in halohydroseries in the zone of periodical flooding have ensued: a heathland with single individuals of the plants has developed.

A rise in the level of underground waters in the subzone of underflooding is provoking transformation of initial ordinary solonchaks into meadow plump solonchaks. Dense salt "plump" appears on the soil surface. Stocks of salts in the root layer are increasing significantly. Oppression and disappearance of initial species (dwarf semishrubs and semishrubs) is occurring. Communities of halomesophyte annual saltwort are replacing haloxerophyte dwarf semishrub communities with participation of semishrubs over 6-8 years. Single individuals of shrubs-hyperhalophytes are appearing. These changes represent the halohydroseries of the ecsodynamic succession. A heathland with single individuals of hyperhalophytes is developing on the greater part of the subzone of flooding.

The underground waters and capillary border do not reach the root layer in the subzone of hydrogeological influence of the reservoir. Fluctuating ecosystems develop here. Ecotope fluctuations represent the dynamics of the vegetation: through the change in the componential composition of communities, occasionally through an increase in the abundance of the annual saltwort, and through the appearance of ephemers.

3. REFERENCES

Akzhigitova, N.I. 1982. Halophyte vegetation of Central Asia and its indication properties. Tashkent: Pub. house of BAS of Uzbek SSR, 189 pp.

Shapiro, S.M. & Vinnikova, T.N. 1980. Hydrogeological forecasts in zone of Kapchagai reservoir. Alma-Ata: Nauka Kaz. SSR, 106 pp.

Starodubtcev, V.M. 1981. Impact of reservoirs on soils of the coast Izvestija AS of Kaz. SSR. Biol., 57-62 pp.

Starodubtcev, V.M. 1984. Processes of salt exchange on the coast of Kapchagai reservoir Problems of desert assimilation, 39-48 pp.

Starodubtcev, V.M. 1986. Impact of reservoirs on soils. Alma-Ata: Nauka of Kaz. SSR, 295 pp.

CHAPTER 19

LANDSCAPE ECOLOGY AND CARTOGRAPHICAL ANALYSIS OF NATURAL SALT COMPLEXES IN THE SOUTH WEST SIBERIA BASINS OF LAKE CHANY AND LAKE KULUNDINSKOYE

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1. INTRODUCTION

The largest salt lands in southwest Siberia are situated between the Ob and the Irtysh rivers. Natural salt complexes on these territories are associated mainly with the evolution of large lake systems once occupying vast areas and now represented by a number of smaller lake systems. This is evident from the alluvial-lake sediments of the last epochs, the general topography of the region, the landscape and the evolution of the lakes.

Climatic fluctuations in the quaternary influenced the formation of the inland water bodies in the country between the Ob and the Irtysh rivers. In humid periods, most of the water bodies were fresh and abundant in water, while in dry periods the lakes became shallow, decreased in size and gradually became salty, particularly in the southern regions. Coastal topography shows signs of level shift in the lake terraces. At present, these geosystems should be more properly considered as lake-basin incorporating the two subsystems – "lake" and "basin". The first includes the present areas of water of one or several communicating lakes as well as narrow riversides of a width not exceeding one kilometer. The second incorporates the basins with constant and temporary runoff entering the lakes.

The integrity of lake-basin systems is due to the important functional-dynamic factors of the landscape, i.e. flow and moisture.

The main specific features of some lake-basin systems depend on the zonal position of the lake subsystem, the area and the landscape structure of the basin and anthropogenic activity.

M. Ajmal Khan et al. (eds.), Sabkha Ecosystems. Volume II: West and Central Asia, 233-247.

Among numerous lake-basin systems in southwest Siberia, the two largest are the Kulundinskaya lake subsystem situated in the subzone of the Kulunda dry steppe (Figure 1), and the Chanovskaya lake subsystem situated in the subzone of the Baraba south forest-steppe (Figure 2).

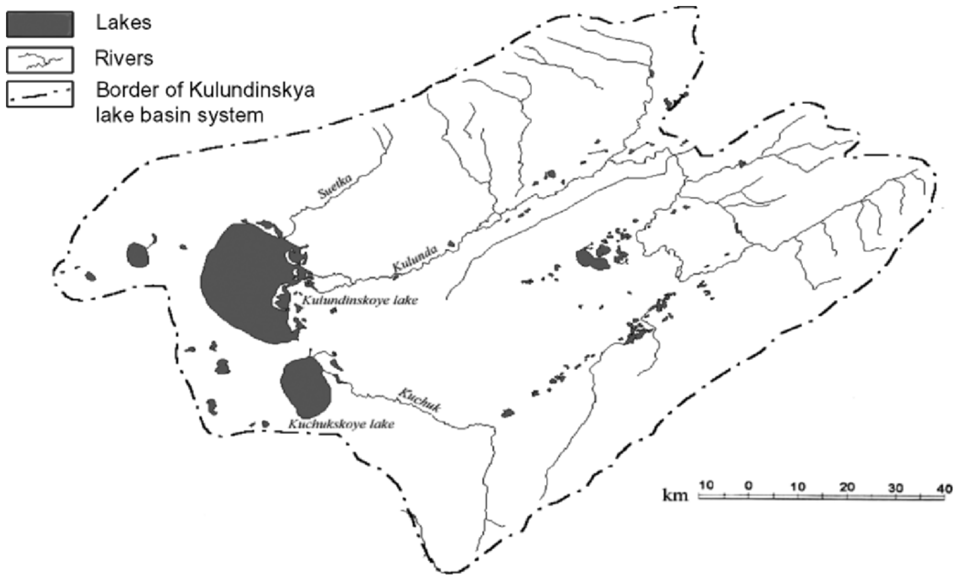

Figure 1. *Kulundinskaya lake-basin system.*

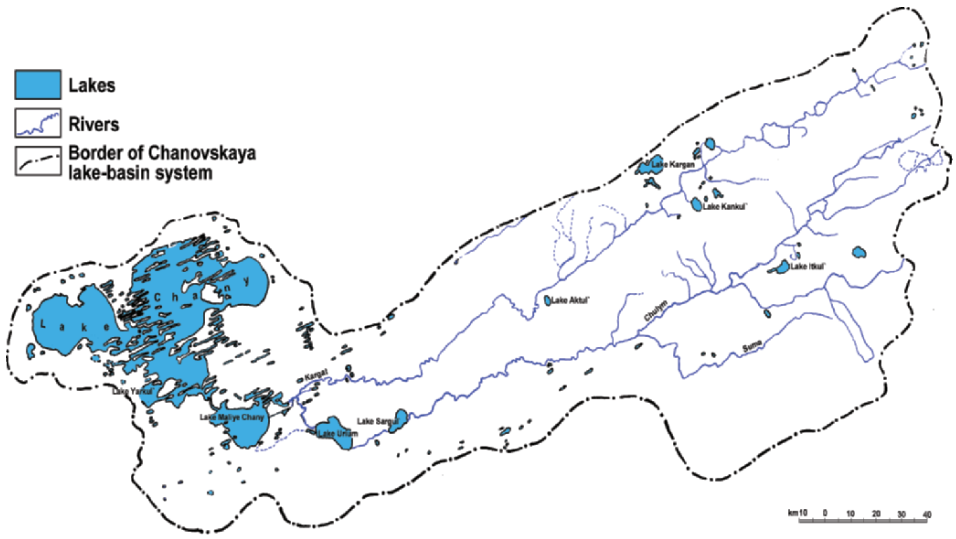

Figure 2. *Chanovskaya lake-basin system.*

These lake-basin systems are located within a young epihercynian, west-Siberian platform consisting of two layers, the lower of which is a folded compound base and the upper a horizontal mesocenozoic cover. Composed of sandstone, tufa, siltstone and claystone, the base has been lowered for hundreds and even thousands of years on its northern part. The structure of the base mantle in the lower part is represented by upper chalk and neogenic deposits. These are clays of the lake mesomiocene complex and sands and clays of the lake and lake-alluvial upper miocene-mesopliocene complex (Kulundinskaya and Kochkovskaya sedimentary complexes). They are covered by lower mesoquarternary alluvial sediments (Chanovskaya, Krasnodubrovskaya and Fedosovskaya sedimentary complexes); meso-upper-quarternary, alluvial-lacustrine sediments (Karasukskaya sedimentary complex); upper quarternary alluvial, subaerial and aeoline sediments; and by modern lake, boggy, lake-boggy, and dealluvial-boggy, combined alluvial deposits.

Most chemical elements enter water bodies via surface and underground inflows. Most salt in the lake is due to the solution of the bottom salts composing the lake depressions. Some elements, mainly gases, enter water bodies from the atmosphere. However, the different zonal positions of these lakes result in a variety of landscape structures, with varying involvement of natural salt complexes. At the same time, variations caused by azonal factors due to the geological structure of the substrate, relief, morphometry, neotectonic movement and intensive plowing up of land are observed. These variations are found in the zonal backgrounds of substances accumulation in the lakes. Sometimes salt rocks due to marine sediments govern the formation of the mineral composition of the lake water. The lakes of the Chanovskaya system are examples of azonal salinization.

The dynamics of water content in the south of the country between the Ob and Irtysh rivers exhibit inter-decadal cycles of 45 years alongside shorter 10-11 and 2-4 year fluctuations. The dynamics of water content reflect the long-term dynamics of the hydrochemical and hydrobiological features of lakes and the landscape transformation. However, a shift of water inter-decadal maxima is observed between the southern and northern parts of the territory. In Baraba, the highest maximum was recorded in the late 1940s; in Kulunda, it was recorded from the 50s until the 60s (Doganovsky, 1978; Pon'ko, 1985) (Figure 3).

1.1. Kulundinskaya laske-basin system

The Kulundinskaya lake-basin system includes lakes Kulundinskoye, Kuchukskoye, Selitryanoye and Kulunda, the Kuchuk and Suetka rivers along with other water bodies and currents. The total area of the lake-basin system is 24,100 km^2.

The lake-basin system is situated between two regional morphostructures: the Kulundinskaya planoconcave low plain in the lake subsystem and the more elevated and dissected Priobskoye plateau, where a major part of the Kulunda, Kuchuk and Suetka rivers basins are situated.

Figure 3. *Dried surface of Lake Kulundinskoye.*

The climate of the lakes and catchment area varies. The lake subsystem is located in the dry steppe subzone, while a large part of the basin is situated in the arid steppe and south forest-steppe.

The climate in Kulunda is continental and dry: winter is cold with few clouds and summer is hot. The abundance of warmth and high light intensity during summer compensates for the short photoperiod and accelerates the plants' growth. About 230-250 mm of precipitation (150-180 mm in summer) fall every year (1962; 1978). The region shows a high frequency of strong winds of over 15 m/sec (35 days a year) and dust storms (43-54 days a year) (Slyadnev, 1958). In Kulunda, in dry warm periods dust storms occur with wind speeds of more than 6 m/s. In winter, this wind causes snow storms. Because of the thin blanket of snow that is usually blown away from the flat ground, the frost penetration in soil reaches 2.5 m. In summer, dust storms blow away the upper layer of soil resulting in redeposition of a large quantity of soil particles in different relief depressions. More frequent dust storms were observed after the ploughing up of virgin and unused lands in the 1950s and 60s.

The geomorphology of the territory of the lake subsystem is characterized by a system of terraces (Figure 4) placed at different levels in relation to Lakes Kulundinskoye and Kuchukskoye. We can infer that these terraces were formed by a large, gradually lowering water basin.

Lake Kulundinskoye is shallow and has a well-defined depression. The main morphometric characteristics of the lake are given in Table 1. The north and west coasts of the lake are steep and range in height from 5 to 6 m; the east coast is gently sloping and is indented by bays with many islands, shoals, spits, and delta floodplains.

The present high content of salts in Lake Kulundinskoye has resulted in a lack of fish.

The landscape structure of the territory adjacent to lakes Kulundinskoye and Kuchukskoye (Figure 5) reflects the history of the territory's formation and

Figure 4. *The surface of the lake terrace of Lake Kulundinskoye.*

Table 1. *Morphometric features and salinity of Lake Kulundinskoye (1962).*

Absolute watermark, M	*Length, km*	*Average width, km*	*S of water surface, km²*	*Average depth, m*	*Maximal depth at the highest level, m*	*Salinity in summer low water, g/kg*
980	368	265	728	32	49	30-40

current climatic, hydrological and sedimentation conditions. Recent drainage of the surface results in hydromorphism in natural complexes of all high-altitude levels.

Lake depressions are the collectors of readily soluble salts. Shallow lakes and small lowland rivers (Kulunda and Suetka) are usually overgrown with water-boggy vegetation. Large lakes are separated from dry valleys by boggy and saline-meadow communities. The borders of aquatic systems as well as flood-lands, delta sites, low terraces of river valleys and lake depressions are covered by osier-bed, woody-and-shrubby flood-plain forests, and soggy, fluffy and meadow alkali soil (Figure 6). Saline meadows, meadow solonetz and saline meadow-steppe complexes are found on the high lake terraces. The main part of the lower terraces is occupied by semihydromorphic aspen-birch groves covered by thick grass. The soil of the lower terraces is characterized by soda-sulfate salinity and the soil of the upper terraces is characterized by chloride-sulfate salinity.

On a relatively elevated, drained area between the two rivers, where lake sediments combine with loess-like clay, sand and loam, a moderately uniform top-soil is represented by dark chestnut and chestnut soil, which, however, very often shows evidence of solonetzicity. The humus is 25-30 cm thick, representing a very low percentage of the soil's composition at 2.2-3.5%. This low level is due to limited entry into the soil of the organic remains of the steppe vegetation, as well as to rapid mineralization, which results from the large heat demand during the

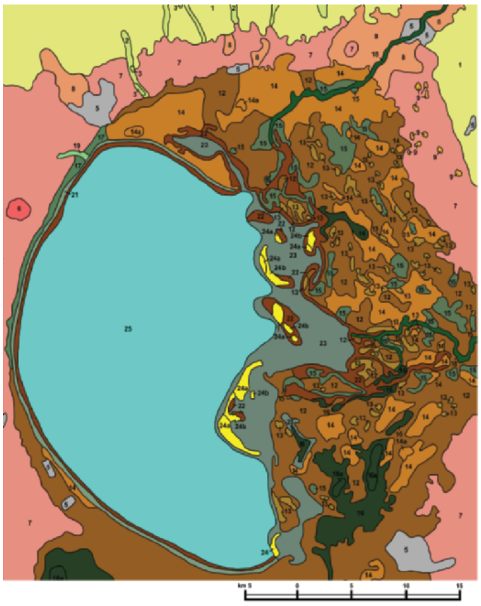

Figure 5. Landscape map of the territory of Lakes Kulundinskoye and Kuchukskoye.

Figure 6. Solonchak with halophilic vegetation at Lake Kulundinskoye.

vegetation period and deflation of the humus layer (Gerasimov, 1963). At one time the fescue-feather grass steppe prevailed here with xerophyte motley grass; shrubby bush of elm and dog rose; and halophytic fescue-wormwood communities along the sinks. An abundance of birch groves with thick mesophylic grass is found to the east of Lake Kulundinskoye where motley grass-cereal steppes are dominant on the southern, plowed-up chernozem.

Legend of the landscape map of the territory of lakes kulundinskoye and kuchukskoye

I. Gently-sloping, inclined, slightly-dissected slopes of the plateau with motley grass-cereal meadow steppes on the south and ordinary chernozems, and gully and grove birch forests on grey forest soil (largely plowed up)

1. Gently sloping, undulating, inclined surfaces with south chernozems, meadow-chernozem soil (plowed up).
2. Stretched gently sloping slightly incised depressions, plain ravines with birch groves and;
3. bushes, motley grass-cereal meadows on meadow-chernozem, grey forest soils.
4. Aspen-birch groves with grey forest soil; soil shelter forest belts of different rock composition and construction.
5. Settlements.

II. High paleo-lake terrace undulating surfaces with fescue-feather-grass steppes on south chernozems, dark chestnut soils, solonetz and meadow-chernozem soils (largely plowed up)

6. True flat with the single sink surfaces of the lake-alluvial plain with dark chestnut soil (plowed up);
7. Slightly-inclined, highly-terraced drained surfaces with wormwood-motley grass-cereal, cereal-wormwood vegetation on south chernozems, meadow-chernozem solonetz (mainly plowed up);
8. Depressed meadow-steppe, cereal-wormwood-motley grass surfaces with meadow-chernozem solonetz, meadow-chestnut and meadow chernozem soils;
9. Shallow sinks and stretched depressions with aspen-birch forests and bushes on grey forest solodized soils and solods;
10. Multi-terraced, depressed meadow-solonetz, with sometimes slightly swampy surfaces with marsh alkali soil and detrital acrids;
11. Stretched raised polygenetic surfaces with chestnut alkaline soil (plowed up).

The Chanovskaya lake-basin system includes lakes Bolshiye Chany and Maliye Chany, water bodies nearby and the entering rivers, primarily the Kargat and the Chulym.

The geosystem is situated in the south of Baraba in two geomorphological provincies: West-Barabinskaya and East-Barabinskaya.

The West-Barabinskaya denudation-accumulative low plain, with absolute levels of 95-130 m, has a flat relief with ridges and interridge depressions, sag grove sinks, and lake hollows, which is sometimes slightly dissected by small and temporary flows. The Chanovskaya lake hollow stands out in the plain as a distinct geomorphological region. It forms the basis and center of a homonymous geosystem. It is presented on the "Geomorphological map of the West-Siberia plain" as a "late quarternary lake basin". Large but shallow lake depressions with numerous islands, floodplains-shoal water, banks, bays and coastal benches dominate the relief of the region. Absolute surface levels are 105-120 m. Geodynamic processes during wet periods are caused by the flooding and swamping (obliteration) of lake hollows and interridge depressions. In summer drying and salinization of depressions take place. Marginal erosion is observed on large lakes, and wind erosion occurs when surfaces are disrupted or lack vegetation cover.

The basins of the Kargat and Chulym rivers involved in the Chanovskaya geosystem are located in the East-Barabinskaya accumulative plain. Absolute surface levels increase from the Chanovskaya hollow to the north-east from 120 up to 160 m.

III. Low-lake terraces, flat, slightly undulating, sometimes inclined and dissected by lake hollows, meadow halophytic groups, and thin forest bushes on chestnut-meadow solonetz and solonetz-alkali soil.

12. Drained true meadow (motley grass-cereal) surfaces with meadow chernozem, meadow chestnut soil (mainly plowed up);

13. Slightly expressed depressions with high grass small-leaved forests, bushes of elm, bird cherry trees, dog-rose on light grey soil and solods;

14. Low-ridged meadow, motley grass-cereal-halophyte sometimes taken over by bushes, surfaces with meadow solonetz, chestnut meadow salt soil;

15. Lake-floodplain-saline depressions with reed and halophytic meadows on saline-marsh, meadow-marsh, peaty-marsh soils;

16. Terrace lake depressions with alkali soil and detrital lakes;

17. Dissected inclined surfaces and the bench of the low-lake terrace with washed off and weakly-developed dark chestnut, meadow-chernozem, solonetzic soils;

18. Valleys of shallow flows with drying sedge-reed bottoms, alkali soil, ponds, thin xerophyte-cereal-motley grass vegetation on the edges;

19. Ravine systems, large hollows with motley grass-fescue and halophyte vegetation, swampy bottoms;

20. Depressed surfaces with solonetz halophyte meadows and thin bushes, and detrital lakes.

IV. Aquatic-coastal complexes of lakes and deltas

21. Near the terraces fine-hummocky and hilly surfaces with sandy coastal swells, flows' debris cones, saline bogs, hygrohalophyte meadows, reed bushes, detrital lakes and small sandy beaches;

22. Salt coastal muddy fine-sandy drying waste land with a thin cover of halophytes;

23. Seasonally dried sites of lake bottom with detrital shallow lakes;

24. Island meadow-bush surfaces: a) forest (with birch) and bush (willow, bird cherry tree, spirea, dog-rose) bushes with meadow-chestnut soils; b) motley grass-cereal meadows with meadow-chestnut solonetz soils;

25. The aquatic complex of salt Lake Kulundinskoye is the current lake's area of water;

26. The aquatic complex of acrid Lake Kuchukskoye is the lake's constant area of water.

The Chanovskaya geosystem is situated on the most important bioclimatic boundary from the standpoint of landscape functioning: i.e. in the transition belt where the ratio between heat and moisture exceeds 1. In this territory (the subzone of the south forest steppe), thermal belts are divided into two categories: boreal with a lack of heat supply and sufficient moisture; and subboreal with sufficient heat and deficient moisture. Lake Chany itself is a zonal-aquatic complex. Its water is salty and has a constant chloride-sodium content and mineralization of 0.8-20.0 g/l.

The dynamics and morphology of the lakes' coasts in the forest-steppe differs greatly from the coastal processes on the steppe lakes. The flatness, the swampy state and the uncertainty of the coastal line are typical only for the lakes' coasts. The complexity of the structure and configuration of the Lake Chany subsystem is stressed by its division into smaller lakes: Lake Bolshiye Chany (with the Yarkovsky, Tagano-Kazantsevsky, Chinyaikhinsky and Yudinsky pools); Lake Yarkul, which in 1911 was connected with the Chinyaikhinsky pool by two channels; and Lake Maliye Chany (Maly Chan), which is connected with the Chinyaikhovsky pool by the 7 km long Kozhurla channel. Other changes in the lake system were caused by the separation of the Yudinsky pool in 1971 and the decrease of the lake's area by 700 km^2.

The most important natural peculiarity determining the functioning of the whole system and its economic significance lies in the inter-decadal recurrence of total moistening and in the regional water levels. According to historical data in the last quarter of the 18^{th} century (the period of maximum flooding of the territory for the last periods), the area of the lakes of the Chanovskaya system reached 10-12 km^2. The system breakdown took place in the 1840s and since that time Lake Chany has not expanded beyond the modern depression, draining into the west detrital lakes only during water-level rises in inter-decadal cycles (Shnitnikov, 1976). The estimated area of water and water-mass volume of the lake are given in Table 2.

The cycling of flooding and drying periods is typical for all Baraba provinces. But if in the provinces' other parts with dominant drained sites this change does not drasticly influence the landscape structure, in the Chany system the cycle greatly influences all geosystems of the prevailing hydromorphic-halomorphic

Table 2. *Changes in Lake Chany's area and water mass volume.*

	17^{th} century	*1813-1824*	*1850-1860*	*1871*	*1880*	*1925*	*1954-1961*	*1977 (end)*
Area km^2	10	5,472	3,300	3,215	3,170	3,000	2,270	1,708
Volume km^3	21	11.5	6.9	6.8	6.7	6.3	4.8	2.3

landscape. The greatest proof against the changes in water regime is the existence of residual rocks of the high plains, as well as crests; sloping, slightly-inclined, raised surfaces covered by meadow steppes; and birch forests on automorphic soils (chernozems and grey forest soils). The Chany system's vegetation is characterized by an abundance of species and a complex multilayer structure. However, at present these landscapes have mainly been transformed into agricultural landscapes, since they make up the base stock of plough land. Developed land and industrial and agricultural infrastructure are found here.

In the contact zones of territorial and aquatic complexes, the landscape transformations are maximal due to moistening and water level fluctuations. These contact zones include: floodplains (Figure 7), banks, lake coastal zones and depressions, and capes and drying sites of the lake-hollow bottoms, the most sensitive elements. In the contact zones the most intensive exodynamic processes take place, including abrasion, silting, underflooding, swamping and salinization.

The typical process that determines the geochemistry of the modern Chanovskaya geosystem is salt accumulation due to easily soluble salts concentration (1.65-4.5 kg/m^2), flowage loss, and the introduction of salts at a rate of 3-10 t/km^2 from ambient territories. The runoff of the Chulym and Kargat rivers bringing fresh hydrocarbonate-sodium water determines the salt content in the water. Close occurrence of highly mineralized neogenic clay as well as the salinity of the soil and underground water favors an increase in water mineralization (1986).

As mentioned earlier, in 1971 the western part of the lake, the Yudinsky pool, was separated from the rest of the lake by a non-overflow dam. The curve in levels shows that the lake responds faster to changes in meteorological factors than before construction of the dam. The decrease in the lake area and water mass volume results in a "fast response", which demonstrates a loss of stability in lake functioning. This is of importance for the estimation of losses of natural potential, the optimization of nature management, ecosystems conservation and the protection of rare biological species.

Figure 7. *Reeds on Lake Bol'shiye Chany.*

During 1972-1977 the Yudinsky pool lost 41% of its area, its level decreased from 105.65 m to 104.2 m, and salinity increased to 20 g/l. In August 1991 water mineralization in the stretch was 34.3 g/l (in the eastern part it was 5.13 g/l). The reduction in water area has been occuring for over 30 years, and in 2001 one could find only a small, seasonally changing pool, 5% the size of the previous one.

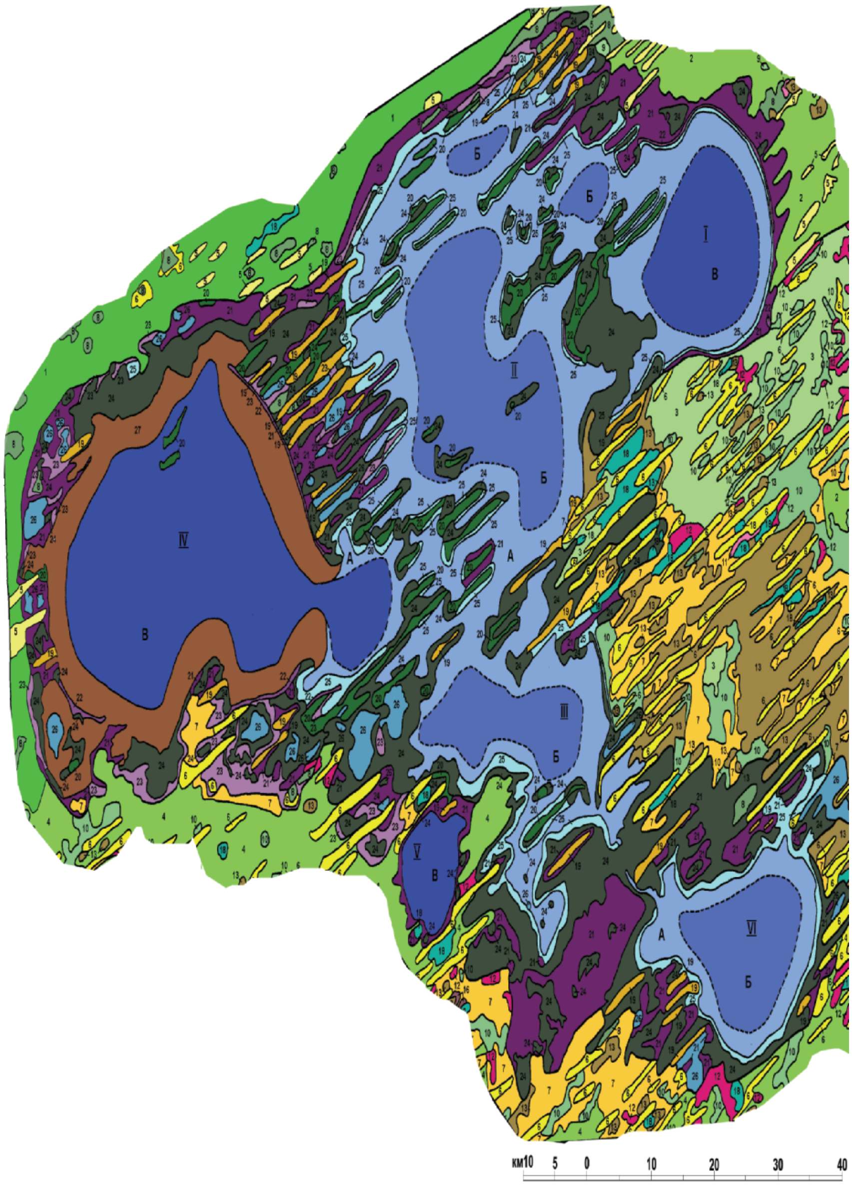

Figure 8. *Landscape map of Lake Chany.*

The motion of natural complexes is centripetal to the center of lake systems; Legend to the landscape map of lake Chanylandscapes of chanovskaya forest-steppe natural province

1. Drained denudation-accumulative forest-meadow partially plowed up surfaces with groves, cereal-motley grass and fescue-saline meadows, wormwood-fescue steppes on meadow-chernozem solonetzic soil, meadow solods;
2. Elevated with depressions and sinks drained surfaces of denudation-accumulative subaerial plain with aspen-birch groves, saline-cereal and motley grass-fescue meadows on meadow-chernozem, meadow soddy soils, solods;
3. Drained flat-sink accumulative-aeolian surfaces with motley grass-cereal and saline-reed grass meadows, agrophytocenoses, birch groves on south chernozems and meadow-chernozem solonetzic soils;
4. Elevated and interridge drained subaerial surfaces of denudation-accumulative plain with abundant motley grass-fescue steppes, aspen-birch groves on south chernozems and meadow-chernozem soils;
5. Ridges and ridge-shaped elevations of the accumulative-denudation plain with agrophytocenoses in place of halophyte-cereal meadow steppes on meadow-chernozem highly humic soils, leached and usual solonetzic chernozems;
6. Flat ridges and elevations of accumulative-denudation plain with agrophytocenoses in place of dry meadows, halophite-cereal meadow steppes on leached and south chernozems;
7. Inclined, drained, dry, partially plowed up surfaces with saline cereal-motley grass, dry meadows and wormwood-fescue steppes;
8. Depressed meadow-bog and meadow-bush surfaces, slightly salty meadows and slightly boggy sink forests on swampy peaty soils, meadow-boggy solods, meadow alkali soil;
9. Swampy sinks with sedge and sedge-reed grass everglades with the presence of bush on meadow-boggy humus, boggy lowland peaty-gleyey soils;
10. Flat depressed forest-meadow-boggy surfaces with sedge-reed grass boggy meadows, birch thin forest and bushes on meadow-boggy, swampy lowland peaty soils;
11. Slightly inclined lake depressions with motley grass-halophyte meadows, meadow solonetz, meadow steppe and boggy solonchak soils;
12. Slightly inclined salty meadow sometimes taken over by bushes, surfaces with meadow saline soils, meadow and meadow-steppe solonetz;

13. Bottoms of sinks, interridge and lake depressions with reed floodplains, and lowland boggy humus muddy soils;
14. Peaty lake hollows sometimes with detrital lakes, reed floodplains;
15. Lake meadow surfaces with halophyte-cereal dry meadows on meadow solonetz and meadow solonetzic soils;
16. Depressed saline plains and lake depressions with halophytic groups on meadow alkali soil;
17. Valley complexes of the Chulym and Kargat rivers, slightly expressed terraces and floodlands with meadows, bushes and sedge-reed brushwoods;
18. Lake depressions with fresh and salt lakes.
19. Coastal and island ridges, abraded ridges-capes and peninsulas with barley, foxtail, motley grass-halophyte meadows and agrophyto-cenoses on meadow-chernozem soils, leached chernozems, grey forest soils and solods;
20. Abraded islands-ridges meadow, taken over by bushes and forests with halomotley grass meadows, bushes, and aspen-birch shrubby forests;
21. Accumulative lake-terrace surfaces with halophyte-cereal, halophyte-motley grass dry meadows on meadow-chernozem, meadow and solonetz soils;
22. Flat abrasion-accumulative coasts of lake stretch of water with motley grass-cereal meadows and bushes on meadow-solonetzic and alkali soils;
23. Accumulative-abrasion halomorphic meadow surfaces of lowland lake terrace with halophyte meadows, halophytes and motley grass on alkali soil and meadow solonchak;
24. Coastal sedge-reed swampy depressions and floodplains on banks, boggy-humus and muddy, boggy peat-gleyey soils and muddy bottoms;
25. Seasonally dried banks of the Lake Chany area of water with thin grass and halophytic vegetation on muddy and fine-sandy bottoms;
26. Detrital lakes, depressions filled with water, pinched bays with aquatic vegetation;
27. Dried area of water of the Yudinsky pool with scattered fine-sandy and dune-like sands, motley-grass-cereal, thin-grass halophytic meadows, sandy waste ground.

Coastal and aquatic-territorial landscapes
Pools of the Lake Chany area of water

I – Yarkovsky	II – Tagano-Kazantsevsky
III – Chinyaikhinsky	IV – Yudinsky (drying since 1970)
V – Lake Yarkul	VI – Lake M. Chany

Zones of hydrodynamic activity

A – shallow coastal zones;
B – shallow (up to 4 m) areas of water;
C – deep (more than 4 m) areas of water.

2. CONCLUSION

The landscape structure of the lake-basin systems in the south between the Ob and the Irtysh rivers reflects the general regional conditions, the territory's evolution as well as the specific combinations of landscape formation factors complicating regional zonal-azonal conditions. The main factors of salinization are the arid climate, the close deposition of mineral underground water, hydromorphic or paleohydromorphic conditions of the soil profile, and the pulsating water-salt regime of the soil under alkalinization.

Among the general peculiarities of the spatial and functional organization of the landscapes, the most typical are the following:

– the adolescence of the majority of natural complexes;

– the close relationship between landscape transformations and climatic and hydroclimatic changes;

– the high complexity of the landscape structure;

– the prevailing of natural complexes with the features of hydromorphism resulting in the reserved character of their zonal features;

– conjugate development of hydromorphic and halomorphic series of natural complexes transformation. Under these circumstances (in one case at deficient moistening, in the other when the hydrothermal coefficient is close to 1, and total salinity of sediments occurs) the division of these series appears inexpedient.

2. REFERENCES

Atlas of Altai Territory/Exec. 1978. Editor A.M.Ryabchikov – Moscow-Barnaul: Department of geodesy and cartography.Vol. 1, 222 pp.

Doganovsky, A.M. 1978. Regularities of long-term fluctuations of Lake Kulundinskoye levels// Water resources of Altai Territory, their rational use and conservation. Barnaul, 109-112 pp.

Ecology of Lake Chany. 1986. Novosibirsk: Nauka.

Gerasimov, I.P. 1963. Originality of genetic types of soil in Siberia//Siberian geographical collection. M: Publishing House of AS USSR, Issue 2, 7-27 pp.

Pon'ko, V.A. 1985. On the superlong-term forecast of the levels of inland seas and lakes in the middle region. Natural conditions of West Siberia and transfer of rivers runoff to Central Asia. Novosibirsk: "Nauka", Siberian Branch, 113-123 pp.

Resources of surface water in the regions of virgin and long-fallow lands development/1962. Edited by V.A. Uryvaev. Leningrad: Gidrometeoizdat, – Issue VI. Flat regions of the Altai Territory and the southern part of Novosibirsk oblast. 978 pp.

Shnitnikov, A.V. 1976. Large lakes of Central Asia and West Siberia. Reports at annual readings in memory of L. Berg,

Slyadnev, A.P. 1958. Sketches on the climate of the Altai Territory. Barnaul, 138 pp.

The Chany pulsating lakes. 1982. L: Nauka,

CHAPTER 20

SALINITY OF IRRIGATED LANDS OF UZBEKISTAN: CAUSES AND PRESENT STATE

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1. INTRODUCTION

Most irrigated lands of the Republic of Uzbekistan are subject to salinity, due to the country's arid climate, and the geological and the hydrogeological conditions of its irrigated areas.

The primary climatic features that determine the rate and tendency of salt accumulation in soils and underlying depositions are abundance of warmth, moisture deficit, and the country's long hot and dry summers, and short relatively warm winters. The radiation aridity index *R* (Averjanov, 1964) varies between 2.5 and 12. This index measures the relationship between energetic, water and salt regimes, and determines the set of environment-forming factors. Also important are the aridity coefficient (Budiko, 1977, – Ka <0.12 – 0.3) and the continentality coefficient (Chembarisov et al., 1989, – Kk = 220-290). Under the conditions of a hydromorphous regime, these indices influence the level of soil salinity (Fedorov, 1953).

Irrigated agriculture has been developing in the first and second terraces and deltas of the river valley since the beginning of mass land-reclamation dating from the middle of last century. Choice of this location was due to its technical capacity for off taking of water and its peculiar hydro-geological properties. Only the outlying districts of the so-called river debris' cone and delta sites of ancient irrigation underwent surface salting.

In the Central Asian plain territory, most soils are naturally salted and potentially dangerous in their secondary salinity development. The Aral Sea area's lowland is a region of ancient and contemporary salt-accumulation. Active mountain-forming processes on the area contiguous with the lowland are accompanied by a continual carrying-out of soil-forming, material-inclusive salts and their accumulation on the plains. Surface and underground flows were formed

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on the Central Asian territory in the Cretaceous and Tertiary periods and continue today. The flows carry salts out of strata that are being eroded and in the course of their movement are enriched with salts of ancient salt-containing deposits. In the course of their movement, the flows change their chemical contents and mineralizations. Streams running from mountains partly discharge into rivers and dips, and carry their water as far as zones of finite accumulation. As a result, thick layers of the depositions that composed the lowlands during geological epochs underwent salt accumulation dependent on eluvial, transit and accumulative processes (Fedorov, 1953, 1964; Ivanov, 1948; Kats, 1976; Khasanov, 1964).

The second source of salts in the region is in deep-laid ascending brines. Though the brines have a rather local development at a number of deep dips, they nevertheless play an important role in forming adverse alkali soils, from the surface of which salts are carried away to long distances through aeolian transfer.

At littoral zones of the Aral Sea, the third source of salinization is seawater. During the drying-out of coasts, alkali soils form along the seaboard, mainly chloride in type, but including sulphate-magnesium and natrium salts. Soils forming at sea depositions are originally salted. Ancient sea depositions are “suppliers” of salts, which are carried away by wind to surrounding plains.

In the conditions of an arid climate, the fourth source of soil salinization, particularly in irrigated soils, comes from quick soluble salts in Central Asian river water. Use of surface flow of rivers for irrigation increases salt accumulation in soils and underlying depositions. Since the expansion of irrigation to sub-mountain plains and steppes, the area of lands (non-salted in the upper layer, but with a considerable relict salt reserve) potentially subjected to salting has abruptly increased (Fedorov, 1964).

As irrigated agriculture developed, knowledge of formation of groundwater flows and their use in transporting salts developed, for the success of reclamation on newly reclaimed lands depends to a great extent on the forming of groundwater flows.

Depending on the hydrogeological features of a territory, hydrogeologists and specialists in land-reclamation distinguished the following (Ivanov, 1948; Kats, 1976; Khasanov, 1964; Khodjibaev, 1964; Krilov, 1977):

- zones of submersion and transit of groundwater flow passing through well permeable depositions, generally fresh, of the hydrocarbonate chemism type;
- zones of pinching out of fresh and slightly salted waters serving as a source of formation of lime and gypseous layers, and of alkali soils where the permeability of strata transporting underground water slumps;
- zones of secondary submersion (or rather dispersion), where groundwater is generally highly mineralized with a greater prevalence of chlorides when the groundwater’s external inflow becomes negligibly small, and groundwater level is determined only by precipitation and evapotranspiration (Figure 1).
- melkozem, low permeable depositions
- large-fragmental, gravelly, well permeable depositions
- regional waterbed

- groundwater level
- zones of submersion and transit of groundwater flow
- zones of pinching out of fresh and slightly salted waters
- zones of dispersion
- precipitation

While moving away from the mountains, flows of groundwater, both natural and formed artificially through irrigation, naturally change their chemism from hydrocarbonate to sulphate to chloride-sulphate and chloride (Fedorov, 1964; Lobova, 1977; Morozov, 2000).

It is noted (Fedorov, 1964) as significant that two kinds of landscape are distinguished in the region. The two landscapes differ greatly in their soil salting processes:

- The first landscape consists of automorphic soils, with relict salinity predominating.
- The second landscape consists of hydromorphic soils with contemporary salinization. Excluding irrigated soils, this landscape occupies less than 10% of the territory.

Soils of river valleys within a mountain territory are generally not salted on the surface, for in these areas, precipitation falls in amounts sufficient for a leaching regime, and groundwater has very low mineralization. However, even in valleys in the mountain area, zones of thick gypsum and lime horizon formation occur in the subsoil layer. So called “shokh” and “arzyk” salts ride the gypsum and lime out of the relatively cold groundwater and enter warm horizons due to the reduction of these salts’ solubility as the temperature rises. In the river valleys, though seldomly, zones of highly mineralized groundwater discharge are also found, the salt source of which are relict fields.

Figure 1. *Salt-marshes on irrigated soils.*

The main massifs of salted soils in Uzbekistan's natural conditions occur only in regional zones of pinching groundwater, despite these zones' comparatively low mineralization of 2-5 g/l, as well as in river delta sites and local lowlands. Only in these areas did alkali soils form of the variety known in local dialect as "shory" or "sory" and in literature on salted soils, as "sebkhy".

A typical example of a zone of alkali soil formation in Uzbekistan occurs on the outskirts of sub-mountain plains, affecting a sufficiently extensive area on the intersection of the Djizak region and the Golodnaya Steppe. Zones of spread of alkali soils at delta sites of large and small rivers are exemplified by the deltas of the Zarafshan river (the Karakul oasis) and the Amudarya river (the Khorezm oasis and Karakalpakstan). Among the most typical lowlands in steppe and desert zones that have large areas of alkali soils are the Shuruzyakskoe and Arnasayskoe lowlands in the Golodnaya Steppe, the Charagylzsloe and Denghizkulskoe in the Karshy steppe, and the Tudakulskoe, Shorsayskoe and Shorkulskoe in the Bukhara oasis.

Locations of salt accumulation include micro-highlands on regularly irrigated lands, which are a consequence of poor leveling of fields, as well as adjacent non-irrigated areas and lowlands, which receive a permanent inflow of groundwater from neighboring irrigated areas (Figure 3). In literature this phenomenon is often referred to as "dry drainage". "Dry drainage" on compactly irrigated lands ensures an outflow of salts from the irrigated fields, provided that at least 20-40% of the lands are not irrigated. This phenomenon has become most apparent in the Khorezm oasis, is not apparent on the Karakalpakstan territory.

According to estimates, more than half of soils irrigated or suitable for irrigation in Uzbekistan is salted to a high extent. The classical process of salt transportation under natural conditions is changing dramatically on both a local and regional level under the influence of intensive irrigation and drainage (Fedorov, 1953). Irrigation essentially intensifies the natural processes in soils. Figure 2 charts groundwater motion under natural and irrigation conditions on various local reliefs. Under conditions of artificial irrigation, soils' salinity and evolution depend for the most part on economic activity, since irrigated agriculture radically changes the hydrological regime of soils and hydrogeological processes on the irrigated areas. Irrigation canals of reclamation systems form sources of concentrated supply for groundwater (Panin, 1968; Pankova et al., 1996).

Intensive irrigation and drainage lead to localization of sufficiently global hydrogeological and hydrochemical processes in existence before irrigation and intensify by many times the salt transfer processes by which salts are carried out to the sources. These impacts occur because pressure gradients between inflow and outflow elements on irrigated areas increase several times in comparison with pre-existing gradients under natural conditions.

Irrespective of climate aridity, the salt accumulation process in a soil is defined by the direction of net moisture flow in the soil layer over a long period of time (Parfenova & Reshetkina, 1995). In an arid zone, where a relatively large amount

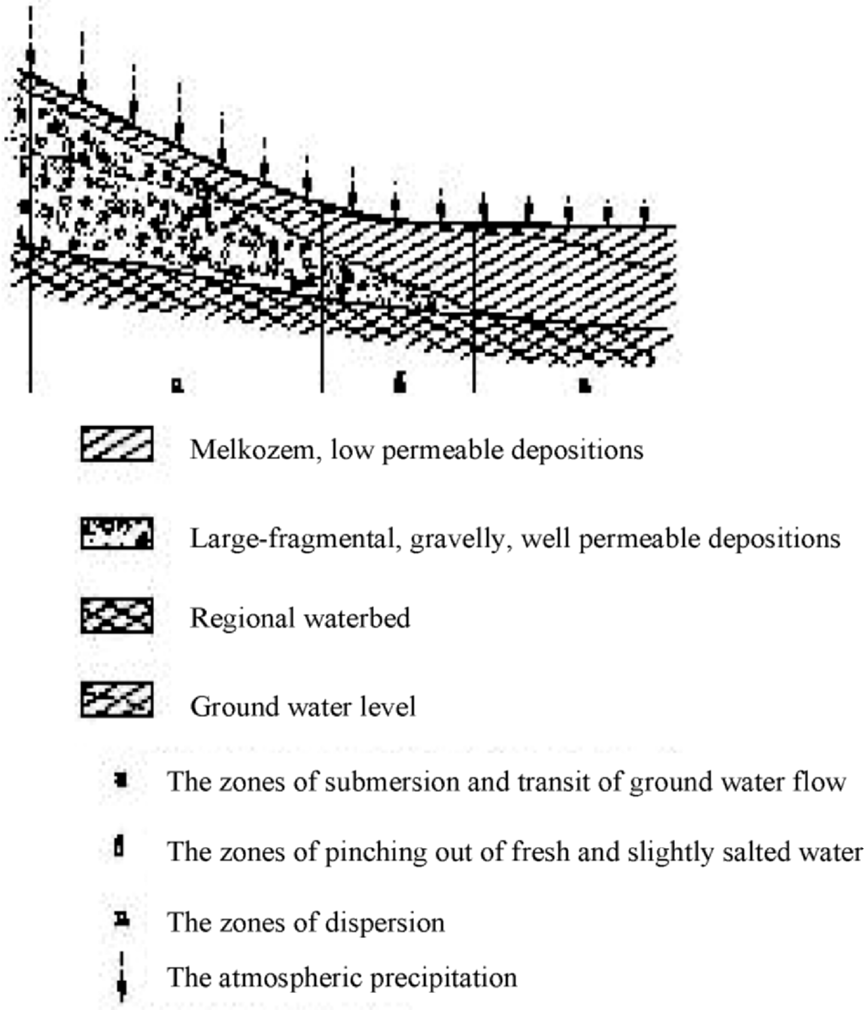

Figure 2. *Motion of groundwater under natural conditions and under irrigation.*

of water is evaporated and transpired, these processes accelerate greatly, and formation of the water-salt regime of the soil depends heavily on the source of salinization and the means of salt transfer.

It is obvious that a crop's yield depends on how far and how evenly over the field the agrotechnical requirements of the crop are spread. In accordance with numerous data, the root layer determining the vital functions of plants of any sort (from herbs to wood growth) extends no more than 1 meter (Rubinova et al., 1975).

Field irrigation influences salt transfer in soils. When irrigation water in the Central Asian rivers reaches mineralization levels of 0.2 to 0.3 g/l at mountains exits or 0.1 g/l and higher at lower situated areas, it becomes a strong source of salts to soils, since about 80% of the water undergoes evapotranspiration. The economic well-being and ecological state of the irrigated lands depends on how irrigation is carried out, the extent to which it counteracts the natural moisture deficiency in the arid zone, and its not being rendered useless by by-passing the field surface and feeding groundwater (Fedorov, 1953; Shreder, 1973).

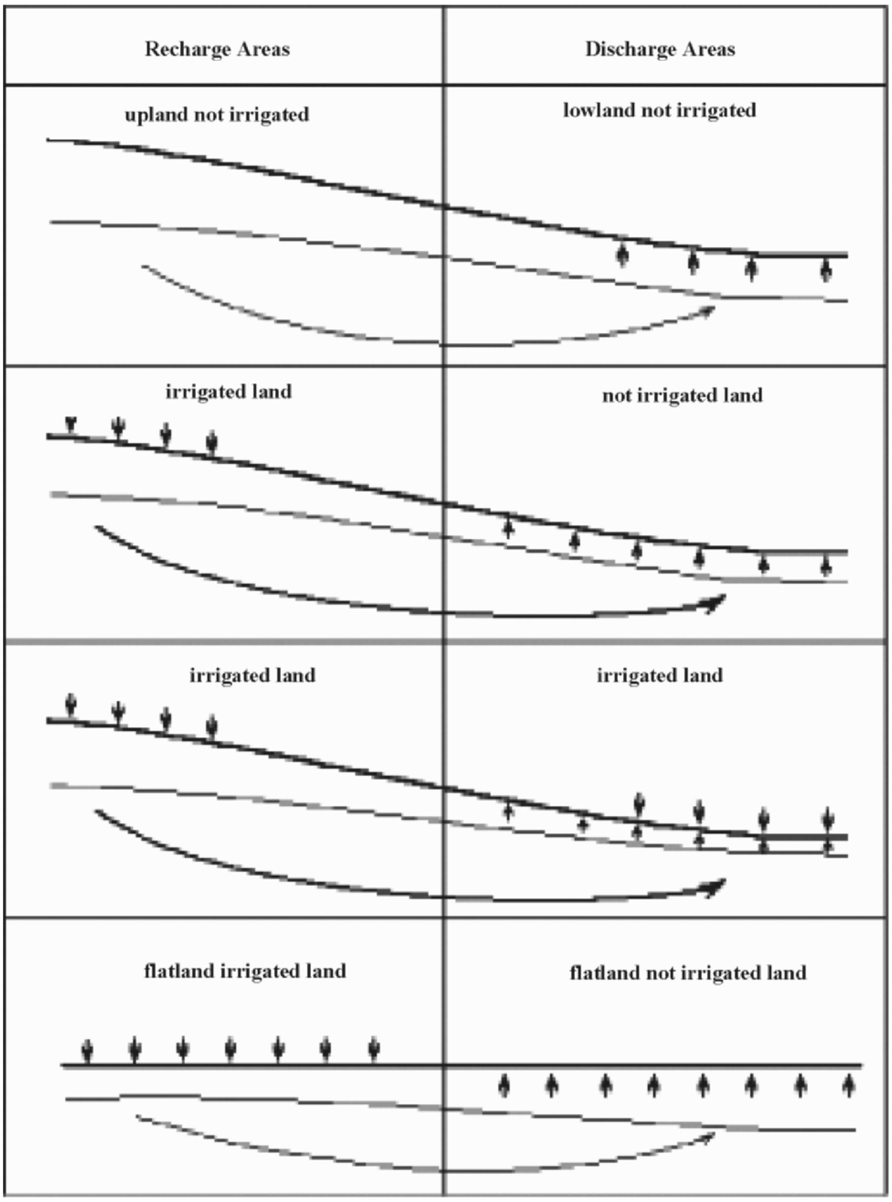

Figure 3. *Diagram of groundwater flows and salt transfer under irrigation conditions.*

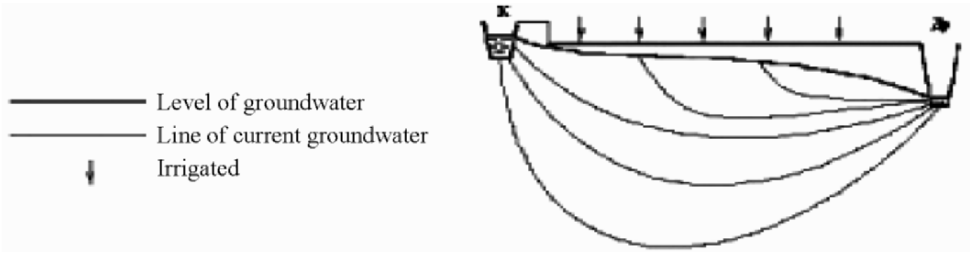

Figure 4. *Shows how prevailing flows of groundwater and their local pressures form under these conditions.*

Figure 5 shows a diagram of the formation of the soil water-salt regime of a field in identical vertical and horizontal scales.

The figure shows how thin the soil layer is and how accurately and evenly over the field irrigation water should be allocated in order to create the required water and (particularly) salt regime in the root layer. Poor consideration of water allocation results, to a considerable extent, in the problems that are being observed on irrigated lands subject to salinity in the Aral Sea basin.

Historically, it has been established that only one link has been missed by engineers and reclamation specialists in the movement of moisture towards plants in the soil layer, namely the water distribution technique on fields that allows, according to reclamation experts, for transfer of water from a free flow state to one of soil moisture.

Perfect irrigation technique can solve a number of problems. It can save up to 40% of irrigation water on the field; it forms a water-salt regime that increases

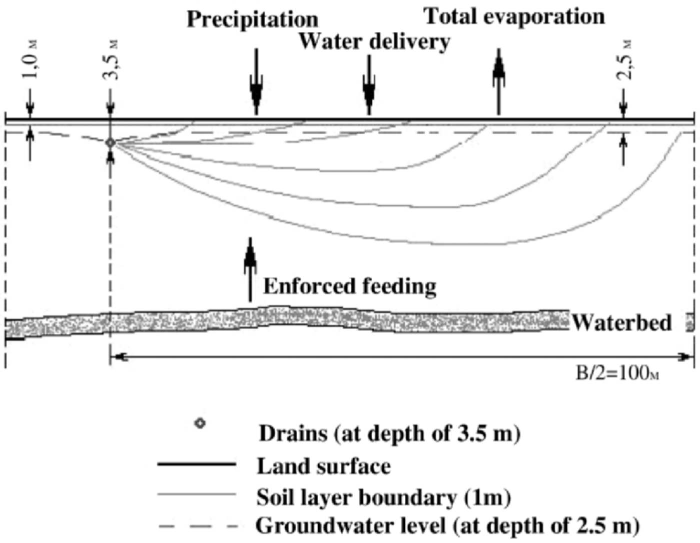

Figure 5. *Diagram of movement of water flows and salts at subsoil horizons on irrigated lands.*

crop capacity as much as twofold; it meets the required agrotechnical demands for growing crops; it prevents deep and surface water discharge; and it provides high evenness of water distribution over the field area, thus at the same time resolving problems of the land reclamation state.

The current state of irrigated lands relating to salinity, according to data of the Reclamation Service of the Ministry of Agriculture and Water Resources, is displayed on Figure 6.

Figure 7 Extension of salted lands on irrigated areas (according to autumn soil observations by the Monitoring Service of the Ministry of Agriculture and Water Resources of the Republic).

Figure 6. The figure shows the general understanding of the location of salinized irrigated lands in Uzbekistan.

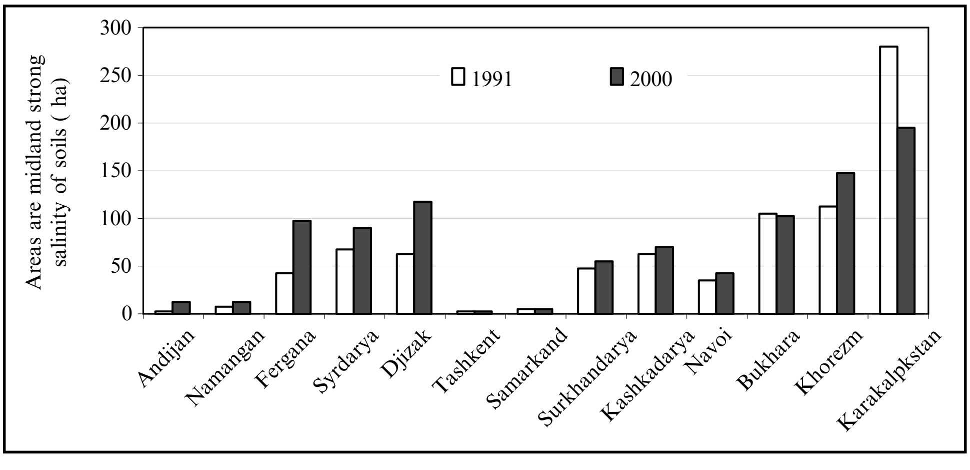

***Figure 7.** Shows the allocation of irrigated lands in Uzbekistan's regions comparing the years 1991 and 2000. Within that period areas of irrigated land have considerably increased, especially in egions where large tracts of land potentially subject to salinization were relatively recently reclaimed.*

The extent of anthropogenic impact is even more visible in cosmic pictures. In Figure 8, a fragment of a cosmic picture of irrigated lands on the Golodnaya Steppe shows that an area's salinity depends on economic activity.

Results of regime observations, shown below as examples (Figure 9), are indicative of the extent and dynamicity of salinity on individual fields within sufficiently short periods.

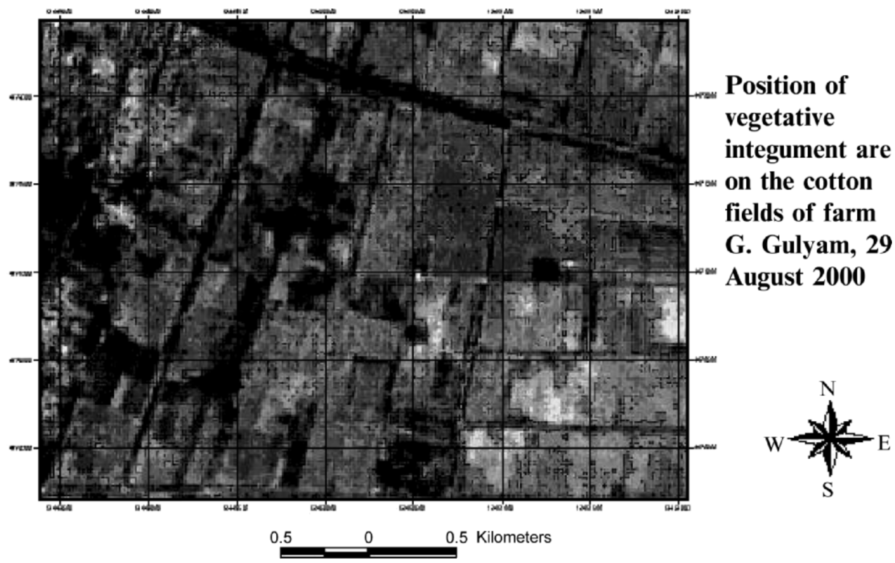

Figure 8. *Fragment of an irrigated area of the Golodnaya Steppe.*

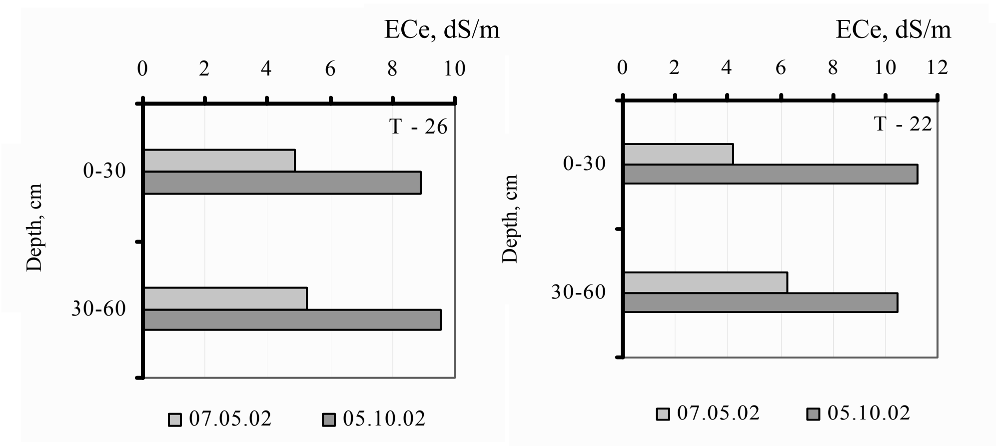

Figure 9. *Seasonal salt accumulation in a soil layer with a thickness of 0-60 cm on the test site of the farm after Syddikov in the Syrdarya region.*

In today's situation, seasonal salinization of irrigated lands occurs more as a result of the tightening of salts dissolved in groundwater due to violation of the irrigation regime than as a result of irrigation water quality. Salts enter the root layer more often through evaporation of groundwater than through irrigation, even when irrigation water is mineralized.

Approximate balance calculations performed for individual fields (according to actual observations of the WUFMAS project of 1996-1999) have shown that about the same amount of salts enters the soil layer from the top as from the bottom. Irrigation water delivers 7-8 thousand m^3/ha with a mineralization of 1.5 g/l, with a depth of groundwater around 2 m and groundwater mineralization of 5-7 g/l. In conditions of insufficient water supply to the surface from irrigation, even with irrigation drainage water of 3-4 g/l, most salt enters the soil from groundwater because of its high mineralization (18-20 g/l).

Data from investigations in recent years on irrigation water composition and mineralization of the Aral Sea basin's main rivers testify to their increasing mineralization in comparison with previous years' data. As noted above, these waters are becoming increasingly dangerous in the salt accumulation processes, because of their important role in the salinization processes of irrigated lands.

This article only touches on the principal issues of irrigated soils subject to salinity. Little research exists on salt transfer processes in soils and their control, and little analysis has been conducted on the economical and ecological consequences of technical decisions that impact salinization processes. The Aral Sea crisis, connected mainly with the exhaustion of basin water resources, has become particularly critical in the region at the current technical state of hydro-reclamation systems. For day-to-day control, it is above all necessary to strengthen monitoring of potentially dangerous irrigated areas undergoing repeated salinization. Such monitoring can be improved via the application of remote mapping technology in conjunction with GIS methods. There is also a need for simpler on the ground techniques to monitor soil salinity on individual fields during vegetation.

2. REFERENCES

Averjanov, S.F. 1964. Control of irrigated lands salinization. M., "Kolos", 288 pp.

Budiko, M.I. 1977. Global ecology. Moscow, "Mysl", 318 pp.

Chembarisov, E.I. & Bakhritdinov, B.A. 1989. Hydro-chemistry of river and drainage waters of Central Asia. Tashkent, "Ukituvci", 132 pp.

Fedorov, B.V. 1953. Agro-reclamation zoning of Central Asian irrigation area. Tashkent, the USSR Academy of Science's publishing house. 150 pp.

Fedorov, B.V. 1964. Principles of building a reclamation system for prevention and liquidation of irrigated lands salinity. Influence of irrigation upon repeated salinization, chemical structure and regime of underground water. M., "Nauka", 49-53 pp.

Ivanov, N.N. 1948. Landscape-climatic zones of the globe // Notes of the World Geographical Society, M.-L., the USSR Academy of Science's publishing house, 224 pp.

Kats, D.M. 1976. Influence of irrigation upon groundwater. M., "Kolos".

Khasanov, A.S. 1964. Features of forming sub-surface water chemical contents and groundwater regime. M., "Nauka", 106-110 pp.

Khodjibaev, N.N. 1964. Large irrigation canals as pressure-water systems, and their influence on reclamation state of lands. Influence of irrigation upon repeated salinization, chemical structure and regime of underground water. M., “Nauka”, 162-166 pp.
Krilov, M.M. 1977. Basics of reclamation hydro-geology of Uzbekistan. Tashkent, “Fan” publishing house, 248 pp.
Lobova, E.V., Ostrovskiy, I.M. & Khabarov, A.V. 1977. On determination of dryness of arid regions of the world. // Deserts development problems. 31-40 pp.
Morozov, A.N. 2000. Systems approach to determination of development strategy of hydro-reclamations. Report at the research conference “Present-day problems of reclamation and water economy, and ways of their settlement” dedicated to SANIIRI 75th anniversary. Jubilee research articles of SANIIRI, Tashkent, 6 pp.
Panin, P.S. 1968. Salt delivery processes in soil strata being leached. Novosibirsk, “Nauka”, 303 pp.
Pankova, E.I., Aydarov, I.P., Yamnova, A.M., Novikova, A.F. & Blagovolin, N.S. 1996. Natural zoning of salted soils of the Aral Sea basin (geography, genesis, evolution), 180 pp.
Parfenova, N.I. & Reshetkina, N. 1995. Ecological principles of hydrogeological regime regulation of irrigated lands. Saint Petersburg, “Hydrometeoizdat”. 360 pp.
Rubinova, F.E., Ghetkher, M.I. & Kuropatka, L.M. 1975. About change of general water mineralization in the Syrdaryar. due to conducting irrigation in its basin. // SANIGMI transactions, issue 23 (104). 43-58 pp.
Shreder, V.R. 1973. Soil-reclamation zoning and calculation regimes of irrigation. Report on the totality of works that had been performed, presented in competition for the academic degree of PhD in agriculture. Tashkent, 29 pp.
Stankov, N.Z. 1964. Root system of field crops. “Kolos”, 280 pp.
Vladimorov, A.G. 1961. Reclamation hydrogeology. M., “Gosgeoltechizdat”.

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