TASKS FOR VEGETATION SCIENCE – 46

Sabkha Ecosystems

Volume III: Africa and Southern Europe

edited by

M. Öztürk, B. Böer, H.-J. Barth, S.-W. Breckle, M. Clüsener-Godt and M.A. Khan




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Tasks for Vegetation Science 46

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Foreword

Africa is one of UNESCO's priorities. This has a lot to do with the availability of critical resources that are absolutely essential for the daily livelihood, or shall we say, survival of families, such as drinking water, fuel and food. It has also to do with the availability and accessibility of scientific knowledge as well as education, both of which are critical factors for empowering people to enhance their living standards and escape the trap of poverty.

The Sabkha Ecosystem series deals with the globally important scientific problem of how to utilise abundant saline soils and water for fodder and food production, and is consistent with science-based ecosystem management.

Sabkha – the Arabic term for flat salt deserts, a term which has been accepted by multi-disciplinary scientists – occur globally in abundance, especially in the northern and southern dry desert belts. These areas are hundreds of thousands of square kilometres in size, and people make little use of them for agricultural production due in part to their excessive salinity. On the one hand this is good, because it allows for these geologically interesting ecosystems to remain largely untouched. They do actually have an ecosystem function and biodiversity value, even though they may appear on first sight as just barren wastelands. They also have a scientific, education, and heritage value. At the same time, there is evidence that biosaline agriculture in coastal sub-tropical and tropical dry desert sabkhat can make use of abundant seawater for the irrigation of halophyte cash crops, such as mangroves, seagrasses, algae, and other types of plants. The editors have demonstrated this clearly in Volumes I and II, as well as during the "1st International Symposium on Sabkha Ecosystems" which was co-organised by UNESCO in Tunis in 2006.

Using seawater for biosaline agriculture is certainly most challenging. Highly complex questions arise on issues such as practicability, marketing, corrosion, soil salinisation, irrigation techniques, drainage, seed ecology, root systems, element concentration analyses of soil, water, and biota, and this ranges all the way to salinity conversion tables, and soil fertility, nutrients, as well as farmers' cultural acceptance of science-based innovations, and finally to investment, and profit.

This means biosaline agriculture using high-saline, and even full-strength seawater, as an irrigation source is not an easy task. However, it offers multiple promising prospects. Herbivorous seacows, and various species of marine turtles and fish for example, use seagrasses as their staple food supply. The feeding ecology of terrestrial livestock however, does not allow them to graze on those valuable plants under the seawater surface. Is it possible then to produce them in land-based coastal systems, similar to rice-fields, harvest them, rinse the salt off, and use them as a cash fodder crop for camels, sheep, goats, and cattle?

There are many scientific questions that need to be addressed and experiments that need to be conducted, in order to provide answers to these questions. Mangrove leaves and seeds can provide good fodder for camels. Certain other halophytes from among the more than 2,000 known salt-tolerant plant species have huge economic potential. This can be of benefit for African Members States that suffer from a lack of freshwater resources, as well as for other countries.

It is with the above thoughts in mind that I encourage the stakeholders in biosaline agriculture development as well as in nature conservation and environmental management related to salt deserts to read and study the contributions from this new volume on sabkha ecosystems. It is a small, yet significant science-based contribution to find an answer to an old question: How can we use saline water, and salty soils for agricultural productivity?

Prof. Dr. Walter Erdelen
UNESCO Assistant Director-General for Natural Sciences

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P M E

Preface

We, as the people of the world, are facing real environmental challenges today which must be taken seriously. These challenges are numerous and can no longer be ignored. Some of the most pressing challenges are freshwater scarcity, groundwater depletion and salinization, climate change, loss of biodiversity and fertile soils, and food supply in competition with biofuels. This is not science-fiction – this is real and present danger to us, and to our children.

UNESCO has already produced two volumes on Sabkha Ecosystems, dealing with the sabkhas of the Arabian Peninsula and adjacent countries, as well as West and Central Asia. This is a laudable effort, trying to make scientific information available on various aspects of sabkhas including how to utilize sabkhas for biosaline productivity, and describing the educational, heritage, and ecosystem value of sabkhas.

Sabkhas belong naturally to many dry areas in the world, including the dry zones of Africa and Southern Europe, and their agricultural potential is considered quite low. However, with research and development in saline irrigation and good drainage it is possible to convert at least coastal sabkhas into agro-systems with mangrove, seagrass, and algal biomass. This can contribute to land-based fish and shrimp production, livestock fodder, carbon sequestration, and production of charcoal and biofuels on currently non-productive soils. It would also provide jobs and income in dryland agriculture using high-saline irrigation and drainage, assisted by a non-corrosive irrigation system and solar energy for seawater pumps.

There are examples and success stories with biosaline productivity. However, more needs to be done to obtain knowledge on seawater-based seagrass productivity in coastal seagrass-terraces, as well as mangrove and salt marsh crops as livestock fodder. It is therefore important to continue research and experiments into this field since it can potentially make hundreds of thousands of square kilometers of salt-deserts green using saline soils and seawater for the production of cash-crop-halophytes.

In this context, sabkha development can make a significant contribution to reduce dependency and wastage of freshwater in agriculture, which is globally the highest freshwater consumer.

I highly welcome this new volume entitled "*Sabkha Ecosystems Vol III: Africa and Southern Europe*", and encourage further studies into this subject, with a particular view towards enhancing professional environmental management, and impact assessments.

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Sabkha Regions of Tropical East Africa

Shahina A. Ghazanfar and Henk J. Beentje

Abstract Sabkhat in the region of tropical East Africa (treated here as Uganda, Kenya and Tanzania) are comparatively small in area and limited mostly to lake basins in the Eastern Rift and a few coastal areas. A relatively large inland sabkha lies in North Kenya, west of Lake Turkana, associated with the Chalbi Desert (a former lake). The chief plants of saline flats that surround the saline lakes in Kenya and Uganda include *Cyperus laevigatus*, *Sporobolus spicatus* and *Dactyloctenium* spp. The coastal sabkhat, flooded only at spring tides, are occupied by monospecific stands of stunted *Avicennia marina*. At the more open parts of the *Avicennia* fringe *Arthrocnemum indicum*, *Paspalum vaginatum*, *Sesuvium portulacastrum*, *Sporobolus virginicus*, *S. spicatus*, *S. kentrophyllus*, *Pedalium murex* and *Suaeda monoica* form the main associates. In the inland sabkhat low rainfall and high potential evaporation have resulted in an arid and saline landscape dominated by grasses *Aristida adscensionis*, *A. mutabilis*, *Drake-Brockmania somalensis*, *Sporobolus consimilis*, *S. virginicus and Psilolemma jaegeri*, and the subshrubs *Duosperma eremophilum* and *Indigofera spinosa*. *Lagenantha nogalensis* occurs on gypsophilous soils and *Dasysphaera prostrata* on saline soils at the edges of Lake Turkana and the Chalbi Desert. Stunted woody vegetation is dominated by *Acacia reficiens* and in drainage channels by *Salvadora persica*. Floristically the coastal sabkhat of tropical East Africa fall in the Zanzibar-Inhambane regional mosaic and the inland sabkhat in the Somalia-Masai regional centre of endemism. There are no endemic genera in the coastal sabkhat, but all of the nine East African mangrove species occur in Kenya, Tanzania and Mozambique. In the inland sabkhat, the Somalia-Masai regional centre of endemism includes the endemic genera *Drake-Brockmania* and *Dasysphaera*. There is no arid-zone agriculture in the inland sabkhat region and nomadic pastoralists, depending on their livestock for subsistence, are the main occupants; *Duosperma* and *Indigofera* are amongst some of the important food plants of livestock (camels). Salt deposits are harvested from the extensive flats surrounding the saline and soda lakes, and the mangrove is an important economic resource as a nursery for fish and crustaceans, as well as a source of poles, timber and firewood. Over-harvesting of wood and conversion to saltpans and aquaculture, housing and industry is a threat to many parts of the mangrove area. There are no strict nature reserves in the inland sabkhat of tropical East Africa designated for the protection of arid landscapes and its flora; however the Mount Kulal Biosphere Reserve in northern Kenya covers the salt desert and lake ecosystems; Lake Manyara and Amboseli Biosphere Reserves also partly cover the saline and alkaline ecosystems. Mangrove areas are included in Watamu Marine National Park, Kiunga National Marine Reserve and Ras Tenewi Marine National Park in Kenya, and in Mafia Island Marine Park, Jozani National Park and Sadaani Game Reserve in Tanzania. Other areas of East African mangrove are included in forest reserves, with varying degrees of protection.

1 Introduction

Sabkhat in the region of tropical East Africa (treated here as Uganda, Kenya and Tanzania) are comparatively

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small in area when compared to the extensive arid and saline areas of the Sahara desert and the Karoo-Namib region in southern Africa. In tropical East Africa sabkhat are limited mostly to lake basins in the Eastern Rift (mainly in the Kenyan Rift Valley) and a few coastal areas. A relatively large inland sabkha lies in north Kenya, west of Lake Turkana, associated with the Chalbi Desert (a former lake) (Fig. 1).

Lakes in the Eastern Rift were created by tectonic and volcanic activity associated with the formation of the Rift Valley (±2 myBP). Most of these are fed by springs and surface drainage and are thus rich in solutes; as most of these are closed lakes and water loss is only through evaporation, they are saline or alkaline and fluctuate seasonally in their solute concentration and water levels. Soda lakes in the eastern Rift valley are among the most biologically productive ecosystems in the world (Melack 1996) with phytoplankton and cyanobacteria attracting flocks of flamingos and other avifauna. The monospecific blooms of *Spirulina platensis* characteristic of soda lakes forms the primary graze for flamingos; it has also been a diet item for the people of Chad for many years (Léonard and Compère 1967)

The distribution of saline soils in East Africa is mainly determined by salt deposits in lake basins and valleys where the mean annual rainfall is between 250 and 1,000 mm. Some areas may not be sufficiently saline to have halophytic vegetation, such as the sodium soils created by rocks containing soda feldspar perthite, nevertheless they support a distinct vegetation. In this chapter we will describe the vegetation, the main plant communities and associated species, their local uses and economic importance, and conservation

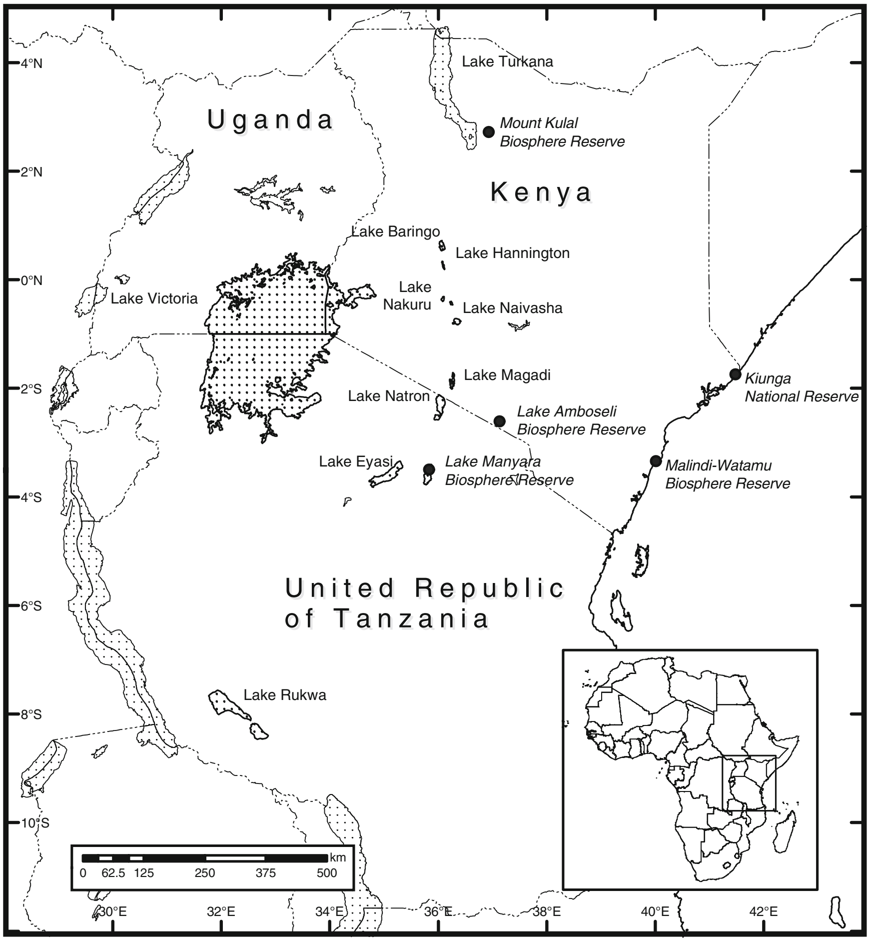

Fig. 1 Tropical East Africa, showing the location of the lakes and the Biosphere Reserves

status of coastal, true saline (soluble salts 0.2–0.3%) and alkaline (pH 8.0–9.6) ecosystems in tropical East Africa.

2 Inland Sabkhat

2.1 Saline Sabkhat

In tropical East Africa, the inland saline sabkhat are not extensive and occupy relatively small areas. A large area in northern Kenya in the Marsabit District, the Chalbi Desert and its immediate surrounding plains can be classified as an inland sabkhat.

The Chalbi desert is composed of saline and alkaline sediments and stabilised sand dunes associated with the old bed of Lake Chalbi. During the Pleistocene (1.8 mya to 10,000 years BP) this lake drained the volcanoes at Marsabit, but has since dried up to form the extensive Chalbi desert. The area lies in a depression between 430 and 500 m above sea level surrounding a large central plain. Precipitation is low with an average of between 100 and 250 mm a year for the region, occurring between March–May and October–December. Much of the drainage from the surrounding mountains (Mt Marsabit, Hurri Hills, Mt Kulal, Mt Nyiru, Ol Doinyo Mara and Ndotos) is lost by evaporation and never reaches the Chalbi Desert.

2.2 Vegetation

The vegetation of the inland sabkhat in tropical East Africa (northern Kenya) falls under the Somalia-Masai regional centre of endemism which includes NE Uganda (Karamoja), most of Kenya in the North and between the Highlands and the coastal belt, and the dry lowlands of north and central Tanzania; the region is characterised by an *Acacia-Commiphora* deciduous bushland and thicket and secondary and wooded grassland. Two genera, *Drake-Brockmania* and *Dasysphaera* that are found in the inland sabkhat, are endemic to this floristic region.

The major part of the Chalbi desert itself is barren except for at the edges where there is subsurface water flow from springs from the surrounding mountains. Due to extensive evaporation the area is hyper-arid, and after seasonal rains and flood, the soil becomes highly saline supporting a few halophytic grasses. These too grow only near runnels and water outlets. In the surrounding plains and parts of the Chalbi Desert the most extensive vegetation type is the semi-desert annual grassland. Second to this is the semi-desert dwarf shrubland which occupies the stabilized sand dunes (White 1983). The main halophytic grass which grows in these locations is *Drake-Brockmania somalensis.* This is a mat-forming annual, spreading by stolons and rooting at nodes, and with leaves covered with stiff hairs. It occupies seasonally flooded places in silty and saline soils. *Drake-Brockmania somalensis* is distributed from Tanzania through to NE Africa (Sudan, Somalia, Ethiopia; excluding Uganda); it is also found on the Farasan Island (Saudi Arabia) in the Red Sea (Phillips 1997).

By far the most common and widespread in the desert and semi-desert are the annual grasses, *Aristida adscensionis* and *A. mutabilis.* They occupy the driest areas, extending up to elevations of 1,000 m on the drier parts of the surrounding hills. They occur on poor, shallow soils and during periods of drought may be absent for as long as the drought lasts (White 1983). Associated with these are a few species of subshrubs which form the perennial woody components of the sabkhat. Dominant amongst these are *Duosperma eremophilum* (Family Acanthaceae) and *Indigofera spinosa* (Family Leguminosae); the former found on relatively moister soils, and the latter on the drier soils. *Indigofera spinosa* is a small intricate subshrub found throughout the semi-desert grassland in East Africa and is distributed through Sudan, Somalia and Ethiopia to Arabia. It is also present in the dry *Acacia-Commiphora* deciduous bushland (Gillett et al. 1971). In northern Kenya, around settlements where there is heavy utilisation of vegetation through grazing and where soils are degraded, *Indigofera spinosa* is the main species. Its cover is 8.5% (Lusigi et al. 1986), and it forms the main graze for livestock.

Amongst other shrubs, *Lagenantha nogalensis* (Family Chenopodiaceae) a succulent that is tolerant of gypsophilous soils, forms almost pure stands on white calcareous soils of the old Chalbi Lake bed; *Dasysphaera prostrata* (Family Amaranthaceae) occurs on saline or alkaline soils at the margins of Lake Turkana and at the edges of the Chalbi Desert (White 1983).

There are a few annuals which come up after rain but are grazed out as soon as they appear. These form a very low cover (0–1%) and constitute only a few species such as *Cenchrus ciliaris*, *Dactyloctenium aegyptium*, *Psilolemma jaegeri*, *Sporobolus consimilis*, *S. virginicus*, *Gisekia pharnaceoides*, *Hermannia* sp. and *Limeum praetermissum*.

Only a few trees or large shrubs are associated with arid and saline soils. These are usually stunted, with *Acacia reficiens* as the dominant species; other species include *A. seyal*, *A. tortilis*, *A. horrida*, *A. senegal* and *Commiphora* spp. In areas degraded by intense grazing pressure the unpalatable *Calotropis procera* is widespread and *Salvadora persica* occurs on saline soils associated with the Chalbi drainage system.

2.3 Alkaline Sabkhat

The alkaline sabkhat are associated with lakes of the Rift Valley. Except for Lakes Baringo and Naivasha, the others on the Eastern Rift (Lake Bogoria, Nakuru, Elementeita, Magadi, Natron, Manyara, Eyasi and Rukwa) are highly alkaline and show salt deposits around their shores. Several are centres for the commercial harvesting of soda ash (Lind and Morrison 1974).

The main species around the saline lakes in Kenya and Uganda are *Cyperus laevigatus*, *Sporobolus spicatus* and *Dactyloctenium* spp. The vegetation of the grassland on the flats close to Kiboko river is described by Bogdan (1958) which shows different dominant species inhabiting soils with different concentrations of salts: thus in slightly alkaline conditions the grass cover is mainly *Cenchrus ciliaris*, but as alkalinity increases *Chloris gayana* becomes dominant. With increasing moisture and alkalinity *Sporobolus consimilis* becomes the dominant species and where soils are shallow, *Cynodon dactylon* appears, and in highly alkaline soils that are waterlogged in the rainy season, *Sporobolus spicatus* takes over and forms dense growth. In the flat valleys in the drier parts of Tanzania, such as the Pangani River valley, where the waters are saline, the flood plains are dominated by grasses *Sporobolus consimilis*, and shrubs such as *Suaeda monoica*, *Sesbania sesban*, *Salvadora persica* and *Triplocephalum holstii*.

The vegetation of the Lake Rukwa basin in Tanzania, which is chiefly grassland has been described by Vesey-FitzGerald (1963); this is summarised here: the vegetation can be divided into three zones from the fringe of the lake to the lake bed itself. The edges of the lake are occupied by almost pure stands of *Sporobolus consimilis*. This species does not grow in water, but colonizes the alkaline soils on the beach of the lake. The shallowly flooded alkaline swamp present on the extensive flat lake bed is vegetated by the grass *Diplachne fusca*. This is a rhizomatous perennial rooting and branching from the lower nodes forming dense mats over large areas. *Diplachne fusca* is found throughout East Africa and is distributed right through the tropics and subtropics of the Old World including Australia (Clayton et al. 1974). On the lake bed, the alkaline flats are occupied by two species: when the lake is dry *Sporobolus spicatus* grows associated with *Psilolemma jaegeri*; when the flats are flooded with the highly alkaline water, *Psilolemma jaegeri* takes over and replaces *Sporobolus*.

Other saline and alkaline patches of vegetation exists around Lake Amboseli in Kenya, where the major vegetation type is the *Commiphora-Acacia* bushland, and the saline and alkaline plains are dominated by *Suaeda monoica* and *Salvadora persica*. Alkaline grassland dominated by *Sporobolus spicatus* is also present around Lake Manyara.

3 Coastal Sabkhat

The coastal plain consists of deposits of corals and sands with occasional dune formations (Lind and Morrison 1974). The climate is controlled by the monsoonal currents of the Indian Ocean, with long rains from April to June and short rains from October or November to January. Annual rainfall in the coastal strip decreases from ±1,425 mm in the South of Tanzania to ±1,075 mm in northern coastal Kenya. The mean annual temperature is 25°C and does not vary much (Dahdouh-Guebas et al. 2004).

Floristically the coastal sabkhat of tropical East Africa fall in the Zanzibar-Inhambane regional mosaic. There are no endemic genera in the coastal sabkha, but all of the nine East African mangrove species occur in Kenya and Tanzania: *Avicennia marina*, *Bruguiera gymnorhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Pemphis acidula*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum* (Beentje and Bandeira 2007).

The mangrove is an important economic resource as a nursery for fish and crustaceans, as well as a source of poles, timber and firewood. Both mangrove trees and mangrove vegetation are decreasing in East Africa, particularly around urban areas and large villages. This is due to increasing populations and continuing poverty, leading to more tree cutting for fuelwood, building material and urban development; large mangrove areas are also converted into salt-pans or to agricultural land, and to a lesser extent for aquaculture purposes (oyster, shrimp and fish ponds). Coastal developments further threaten mangrove areas, and the main reasons are those of infrastructure and tourism; increased population has led to increasing pollution from industry and agriculture (e.g. crude oil, heavy metals, pesticides) (Semesi 1998).

3.1 Vegetation

Along the coast fringing coral reef is more or less continuous, and where it is lacking, mangroves occur. Much of the rocky coral shore is overlaid with sand (Lind and Morrison 1974). Mangrove forest is found in suitable sites all along the East African coast, from Egypt to South Africa, but in East Africa it reaches relatively high diversity, with the mouth of the Rufiji River in Tanzania among the richest mangroves in Africa.

The true mangrove is flooded regularly, but an area inland of the mangrove is flooded only twice a year (during the equinoctal spring tides), and the salt content of the sandy soil is so high through evaporation that often vegetation is almost absent. During the rainy season the salt is leached out, and so even halophytes have to struggle to cope with this changing habitat. The vegetation cover is usually low, in the region of 10% on the edge of the mangrove, just about the High Water Mark (HWM), to virtually absent in the area only flooded by the spring tides (Walter and Steiner 1936; Knapp 1973; White 1983; Table 1).

Diversity is low, with twelve species reported (see the list below). *Avicennia marina* and *Lumnitzera racemosa* both are mangrove trees, but extend into the sabkha zone, becoming more stunted as the salt concentration in the soil increases. *Avicennia* extends into the sabkha zone thanks to its capacity to withstand high salt concentrations; McCusker (1977) reports that the upper limit of soil osmotic potential for other East African mangrove trees is between 38.8 and 50.1 atm, but that of *Avicennia* is up to 97.8 atm. The pneumatophores of *Avicennia* are colonized by red algae (*Bostrychia* sp.). *Suaeda monoica* may form large stands on the edge of the barren sand flats, while *Arthrocnemum indicum*, *Sporobolus virginicus* and *Suaeda monoica* grow on slightly elevated soil between the HWM and the barren zone. *Salicornia pachystachya* may form carpets in summer.

Table 1 List of coastal salt marsh halophytes (Data from Walter and Steiner 1936; Knapp 1973; White 1983)

Chenopodiaceae	
Suaeda monoica J.F.Gmel	Between the stunted Avicennia zone and the vegetation-free sandflats, about the HWM
Arthrocnemum indicum (Willd.) Moq.	On slightly raised parts just above HWM
Salicornia pachystachya Ungern.-Sternb.	On slightly raised parts just above HWM
Gramineae	
Sporobolus spicatus (Vahl) Kunth	No detail
Sporobolus kentrophyllus (K.Schum.) W.D.Clayton	On slightly raised parts just above HWM
Sporobolus virginicus (L.) Kunth	No detail
Paspalum vaginatum Sw.	No detail
Dactyloctenium geminatum Hack.	No detail
Pedaliaceae	
Pedalium murex L.	No detail
Aizoaceae	
Sesuvium portulacastrum (L.)L.	About HWM, in moister sites
Verbenaceae/(Avincenniaceae)	
Avicennia marina (Forssk.)Vierh.	Next to mangrove,the more inland ones becoming more stunted
Combretaceae	
Lumnitzera racemosa Willd.	Next to mangrove in slightly moister sites, the more inland ones becoming more stunted

4 Utilisation and Economic Importance

There is no arid-zone agriculture in the inland sabkhat of tropical East Africa. Nomadic pastoralists are the main occupants in this area, and the region is used as a basic grazing resource for their livestock (camels, cattle and goats). *Duosperma* and *Indigofera* are amongst some of the important food plants, and wood from the larger shrubs is used as a source of fuelwood and materials for livestock fencing. The Range Resource Assessment and Management Strategies for South-Western Marsabit, Northern Kenya (Lusigi et al. 1986) showed that the rangelands were heavily utilised, well beyond their carrying capacity leaving the soil barren and encouraging erosion. The annuals provide little cover, but are grazed very soon after they come up.

Harvesting of salt from the saline and soda lakes is an important industry in tropical East Africa. In western Uganda, Lake Katwe, a closed crater lake fed by brine springs is an important source of salt and revenue. Soda ash, harvested from Lake Magadi in Kenya is also of much economic importance to the country.

Uses of plants of coastal regions are minimal, apart from some casual grazing or fodder collecting (reported for *Avicennia marina*) and use as vegetables (reported for *Pedalium murex*, *Sesuvium portulacastrum*); plus some firewood collection. Hence, economic importance is virtually nil.

5 Conservation and Designated Protected Areas

There are no strict designated protected areas in the inland sabkhat of tropical east Africa for the protection of the flora per se. However several Biosphere Reserves are designated as part of the UNESCO Man and the Biosphere Programme which are essentially aimed at the conservation and sustainable development of terrestrial and coastal ecosystems and are recognised within the framework of UNESCO (Clüsener-Godt 2002). Amongst these is The Mount Kulal Biosphere Reserve in northern Kenya, established in 1978 and situated on the eastern side and southern end of Lake Turkana, with Mount Kulal in its centre. The area comprises a variety of landscapes and habitats, including brackish water at the southern end of the Lake, a volcanic landscape with lava flows, an extensive lava desert and a volcanic island within the lake, hot springs, the occasionally flooded Chalbi salt desert, sand dunes and seasonal water courses. The Amboseli Biosphere Reserve located in the south of Kenya and the Lake Manyara Biosphere Reserve in Tanzania offers protection to the saline and alkaline ecosystems (Fig. 1) (UNESCO 1977; UNEP-WCMC and the IUCN World Commission on Protected Areas (WCPA)).

There is increasing anthropogenic pressure on the coastal sabkhat ecosystems in East Africa. Fuelwood exploitation, urban development, tourism development, and conversion to saltpans and aquaculture are on the increase. Pollution from an increasing population and industry also contribute to the threats; for an overview of the various factors (see Semesi 1998). In Kenya, around 70% of the people living on the coast rely on mangrove poles for construction (Beentje and Bandeira 2007) and so access to the mangroves, which necessarily goes through the sabkha, would result in trampling and compaction.

Mangrove areas, including coastal sabkha areas, are included in Watamu Marine National Park, Kiunga National Marine Reserve and Ras Tenewi Marine National Park in Kenya, and on Mafia Island Marine Park, Jozani National Park and Sadaani Game Reserve in Tanzania. The Malindi-Watumu Biosphere Reserve (IUCN Management Category II, VI, IX: National Park, Resource Reserve, Biosphere Reserve) located south of Malindi was established in 1981. This includes intertidal rocks, sand and mud flats and sublittoral areas; the Mida Creek mud flats with fringing mangrove swamps with *Rhizophora mucronata, Bruguiera gymnorrhiza* and *Ceriops spp.* are also included. It also offers protection to the nesting grounds for the roseate tern, *Sterna dougalii* and the bridled tern, *S. anaethetus*. Several species of shore birds and crabs, and sea grasses *Thallasia chemprechii, Syringodium* spp., *Cymodocea* spp., and *Halodule wrightii* on the intertidal sand and mud are also included in the Reserve (UNEP WCMC, Protected Areas Programme). Other areas of East African mangrove are included in forest reserves, with varying degrees of protection.

6 Conclusions

The sabkhat regions of tropical East Africa are few and limited in overall area, nevertheless constitute an important ecosystem that provides habitats for a number of plants and animal species, and contributes to the economy of the region. As most arid regions in Africa, the sabkhat are also over-utilized and are in need of management and protection. This is especially relevant for the coastal sabkhat, which are constantly subject to damage due to coastal development and over-use of coastal resources. The conservation and the sustainable use of coastal sabkhat should be a priority for any conservation and management plan for a country with setting up more Biosphere Reserves essential for the protection and proper management of coastal regions. Programmes on establishing living halophytic collections and genetic material for restoration, and undertaking research projects to understand the dynamics of coastal and inland sabkhat ecosystems are also necessary to preserve these important ecosystems.

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A Review of Fauna and Flora Associated with Coastal and Inland Saline Flats from Namibia with Special Reference to the Etosha Pan

Peter L. Cunningham and Willem Jankowitz

Abstract Coastal saline flats are often frequented by a plethora of migratory birds, mainly waders, and mammals such as the elusive Brown Hyaena (*Hyaena brunnea*) and Black-backed Jackal (*Canis mesomelas*). Inland saline flats, particularly Etosha Pan, which is fringed by broad- and fine-leafed arid savanna woodlands, teem with a variety of game. Greater Flamingo (*Phoenicopterus ruber*) and Lesser Flamingo (*Phoeniconaias minor*) also occasionally breed on the Etosha Pan depending on local rainfall. Only vegetation adapted to halophytic conditions occur in association with saline systems in Namibia. Grasses such as *Sporobolus salsu* and *Sporobolus spicatus* may occasionally occur on the Etosha Pan while the succulent-like perennial herbs such as *Salicornia natalensis* and *Anthrocnemum africanum* may grow in the coastal saline conditions. Although no fauna and flora are exclusively known to be associated with saline flats in Namibia, these habitats are important for wildlife mainly due to the vegetation (i.e. source of food and shelter) surrounding these flats, fountains (i.e. source of water) often associated with these flats and breeding/feeding/resting sites for migrant waders and other birds.

1 Introduction

Saline flats are widely distributed throughout Namibia with numerous relatively small flats located between "dune streets" or in open dry woodland areas from the Kalahari Desert, in the east, to coastal saline flats to one of the largest and most well known flats such as the Etosha Pan in the central north of Namibia.

1.1 *Etosha Pan*

The Etosha Pan is a flat saline depression approximately 120 km long × 55 km wide and covers an area of 6,133 km² at an altitude of 1,100 m (Berry 1972) and one of the most remarkable geomorphological landforms in the world (Buch 1997). The pan is situated in the north of Namibia (Lat. 19°S, Long. 16°E) mostly within the Etosha National Park which covers a total area of 22,270 km² and is the largest protected saline wetland in Africa (Lindeque and Archibald 1991). The Etosha Pan is classified as a wetland of international importance and listed as a Ramsar site (Kolberg).

The Etosha Pan forms part of the Cuvlai drainage system that drains the Sierra Encoco Mountains – some 300 km inside Angola – and eventually ends up in the Etosha Pan under exceptional flood years. The saline wetlands of the Etosha Pan are ephemeral in nature (Berry 1972; Clarke 1998; Lindeque and Archibald 1991; Lowery 2001), holding water for several months after extensive flooding although usually rarely more than a month. The pan holds large sheets of shallow water, usually not exceeding 1 m in depth and when dry the area is a hostile stretch of salt-crusted wasteland. Flooding of the lower reaches of the pan seldom occurs while the main inlet on the eastern side of the pan – Fishers Pan – is flooded almost every year although the amount of water received and the duration of the wetland varies annually. Water entering the pan turns brackish towards the end of the rainy season through

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evaporation and contact with previous evaporites with a suspected salinity gradient increasing from north to south (Lindeque and Archibald 1991).

The climate is semi-arid and harsh with highly unpredictable rainfall mainly between October and April varying from 300 mm in the west to 500 mm in the east (Berry 1972; Clarke 1998; Mendelsohn et al. 2000). The average maximum temperature for December is 39°C and the lowest mean temperature of 6°C occurs during July (Baker 1996). Mendelsohn et al. (2000) states that September to December have the highest maximum temperatures followed by slightly cooler months associated with greater cloud cover and rain. Evaporation is high as Mendelsohn et al. (2000) and Wellington (1938) measured annual evaporation of between 2,500 mm and 2,700 mm per year, respectively, while wind speeds of up to 30 knots have been measured on the pan.

The vegetation associated with the Etosha Pan is broadly classified as Saline Desert with a Dwarf Shrub Savannah fringe (Giess 1971) and surrounded by salt-tolerant shrubs and spiny grasses (Strohbach 1996).

The wetlands in northern Namibia are most important in terms of supporting human populations and biodiversity as approximately 60% of Namibia's total population lives in this area of which 75% live alongside the perennial and/or ephemeral wetlands (Hines and Kolberg 1996). About 44% of the people living adjacent to the wetland system live within the Cuvelai drainage system, where a mixed economy is dependant on the flood regime for water, grazing and food – mainly in the form of fish. The Etosha Pan is also important as a tourist destination as the Etosha National Park is the most visited conservation area in Namibia (Baker 1996) with more than 140,000 visitors recorded annually (Berry 1997). The starkness of the Etosha Pan during the dry season(s) does not decrease the importance of the area as wildlife habitat and tourist attraction.

1.2 Coastal Flats

Namibia is well endowed with coastal saline flats along its entire coast from the Orange River mouth (bordering South Africa) in the south to the Kunene River mouth (bordering Angola) in the north. These flats vary in size from approximately 10,000 m^2 to 60 km^2 (Grűnert 2000) with most of the flats occurring close to the sea. The Namibian coastline is extremely arid (Namib Desert), however the shallow, brackish or saline wetlands make a major contribution to the ecology of the coastal zone. Three of these sites (Walvis Bay lagoon, Sandwich Harbour and mouth of the Orange River) have been registered as wetlands of international importance under the Ramsar Convention (Kolberg n.d.). The Namib Desert is one of the oldest deserts with most of the area protected by either the Namib-Naukluft Park or the Skeleton Coast Park (Baker 1996). The Desert biome is an extreme desert with highly irregular precipitation – mean annual varying between 5 and 85 mm annually – while fog is experienced throughout the year and a crucial life-support system (Lovegrove 1993). The region is generally cold and windy with a mean annual temperature of 16.3°C (Baker 1996). The vegetation is characterized by a dominance of therophytes and lichens (Lovegrove 1993). Very little work has been conducted on the fauna and flora associated with these coastal and inland saline flats within Namibia. This paper attempts to collate the known information on this subject.

2 Methods

An extensive literature survey was conducted on the fauna and flora associated with saline flats – with special reference to the Etosha Pan as an inland saline system as well as coastal flats – from Namibia. Personal observations as a result of numerous field excursions throughout the country over a number of years added to this information, as did anecdotal information gathered from people currently living and working in close proximity to the saline flats.

3 Results and Discussion

3.1 Fauna

3.1.1 Etosha Pan

3.1.1.1 Mammals

No mammal species are specifically associated and/or unique to the Etosha Pan system although a wide variety of species make use of the pan in some or other way. Etosha National Park – which includes the largest portion of the Etosha Pan system – has 114 mammal species (Baker 1996) with most of these (especially the water dependant species) congregating at waterholes at the edge of the pan during the dry season, which usually extends from May to September. Mendelsohn et al. (2000) states that the grass and dwarf-shrub plains surrounding the Etosha Pan are favoured by grazing antelope and zebra with high densities of wildlife generally found to the east, south and west of the pan. Mammals utilize the pan in the following ways:

- Obtain water at natural seepage's associated with the edge of the pan
- Source of food
- Movement and migration routes
- Shelter and resting
- Natural licks

Ungulate species that frequent these natural waterholes (seepage) include most of the herd forming "plains game" such as Blue Wildebeest (*Connochaetes taurinus*), Burchell's Zebra (*Equus zebra burchelli*), Oryx (*Oryx gazella*) and Springbok (*Antidorcas marsupialis*) (C. Brain Pers. comm., B. Kötting Pers. comm. and W. Versveld Pers. comm.). Elephant (*Loxodonta africana*) also frequent this seepage at the edge of the pan. Predator species such as Lion (*Panthera leo*) use these waterholes as ambush sites especially during the dry season. Although many species are water independent they do utilize water when available and are subsequently attracted to the waterholes at the edge of the pan. According to Griffin and Grobler (1991) the following mammal species – all water dependant i.e. require permanent drinking water – are associated with the seasonal wetlands of Owambo and Etosha: Elephant, Black Rhino (*Diceros bicornis*), Burchell's Zebra, Blue Wildebeest, Black-faced Impala (*Aepyerus melampus petersi*), Kudu (*Tragelaphus strepsiceros*) with the Serval (*Felis serval*) not verified, but expected. Buffalo (*Syncerus caffer*) also used to occur on the eastern fringes of the pan during the 1950s although currently do not occur in the region (Berry et al. 1997).

When stands of *Sporobolus salsus*, a short-lived micro-perennial grass, occur on the pan after good rains, grazers converge on the pan to feed on these grasses (Berry et al. 1997). A small island aptly named "Haas Eilande" (Hare Island) refers to Scrub Hare (*Lepus saxatilis*) that are found on these grassy shrubland islands located in the pan (Berry et al. 1997). Few predatory animals venture far out into the pan (Berry 1972). Other than waterholes used as ambush sites, predators such as Black-backed Jackal (*Canis mesomelas*) and Spotted Hyena (*Crocuta crocuta*) venture out onto the pan to feed on Greater Flamingo (*Phoenicopterus ruber*) and Lesser Flamingo (*Phoeniconaias minor*) chicks and eggs (Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.). Flamingo breeding does not however occur on an annual basis, but rather only in years of good rainfall. Lion have also been known to venture out onto the pan to prey on ungulates that utilize grass growing at the edge of the pan, especially after good rains. A spring on the western tip of a peninsula named "Leeunes" (Lion Den) is due to lions using a copse of *Salvadora persica* as an ambush site (Berry et al. 1997).

Animal footpaths are often located out on the pan often as far as a few hundred meters from the edge of the pan. It would seem that these footpaths are used as a result of predator pressure close to the edge of the pan (e.g. predators lying up in denser vegetation at the edge of the pan) and/or easier walking (Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.). Ungulate species known to utilize these footpaths include Blue Wildebeest, Burchell's Zebra, Oryx and occasionally Giraffe (*Giraffa cemelopardalis*). Elephant often cross the pan following age old migration routes especially across some peninsula's although they also cross the pan during the wet season when the pan may be flooded (Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.). Giraffe are also known to cross the pan regularly in certain areas.

Many animals use the pan as a lying up place due to the precise nature of the area – i.e. makes the approach of predators obvious. Species known to utilize the pan as a resting-place include Blue Wildebeest, Burchell's Zebra, Oryx and Springbok. Oryx even go so far as to leave their young (predator avoidance) on their own – often several hundred meters from the edge of the pan – whilst foraging in the area. This even occurs during the hottest part of the day during summer (Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.). Predators such as lion and cheetah (*Acinonyx jubatus*) are also known to hide their young in the sparse vegetation at the pan's edge whilst the adults are away foraging. The saline clays associated with the pan is often used by ungulates as a natural lick to supplement their salt requirements (Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.).

3.1.1.2 Birds

According to Baker (1996) 340 bird species are in the Etosha National Park area although not all are associated with the pan. Although no bird species are specifically associated and/or unique to the Etosha Pan system, birds frequent the pan after the rains. Birds utilize the pan in the following ways:

- Breeding
- Feeding
- Migratory stopover

The Etosha Pan is the only known breeding reservoir of Greater and Lesser Flamingo in Southern Africa (Berry 1972). Up to a million or more birds have been known to congregate at the pan when sufficient water allows for breeding. Berry (1972) supplies a detailed report on the breeding of flamingo's at the Etosha Pan including a rescue operation conducted to save some of the chicks when the water dried up prior to them fledging. Interesting enough it has been determined that flamingos migrate between the coastal saline flats on the west coast of Namibia and the Etosha Pan depending on water availability in the latter location. The largest island on the pan (2.5 km × 700 m in size) is named Pelican Island due to White Pelicans (*Pelecanus onocrotalus*) occasionally breeding on this island and foraging in the vicinity after good rains (Berry et al. 1997).

Other species known to breed at the pan, often in association with flamingos, include Grey-headed Gulls (*Larus cirrocephalus*), Grey Heron (*Ardea cinerea*), Sacred Ibis (*Threskiornis aethiopicus*) and Glossy Ibis (*Plegadis falcinellus*). Spoonbill (*Platalea alba*) has also been documented as breeding on a small island on the pan albeit away from the flamingo colony. A variety of duck species and Dabchick (*Tachybaptus ruficollis*) have been documented as breeding on the pan depending on the water level (Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.). According to Williams (1991) it is probable that species such as the Whiskered Tern (*Chlidonas hybridus*) and Openbilled stork (*Anastomas lamelligerus*), which breed in seasonally flooded wetlands in Bushmanland (eastern Namibia), also breed in the seasonally flooded wetlands in Owamboland (includes Etosha Pan). It is expected that some of the smaller waders (e.g. plovers and sandpipers, etc.) also nest in the vicinity of the pan. Globally near-threatened species that occur at Etosha Pan include the Slaty Egret (*Egretta vinaceigula*), Lesser Kestrel (*Falco naumanni*), Wattled Crane (*Bugeranus carunculatus*) and Blue Crane (*Anthropoides paradiseus*) (Simmons et al. 1998).

A species that breeds on the pan, but not necessarily dependant on water to do so is the Ostrich (*Struthio camelus*) (Berry 1972; Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.). Berry (1972) even mentions an Ostrich nest as far as 10 km from the edge of the pan on raised ground surrounded by water. Vulture species are also known to breed in trees on the vegetated islands in the pan (Brain Pers. comm., Kötting Pers. comm. and Versveld Pers. comm.).

Wetland associated birds (to numerous to mention here) including the species breeding at the site migrate to the Etosha Pan after good rains to feed on aquatic invertebrates. Predatory and scavenger avian species – usually associated with the flamingo breeding attempts – such as Tawny Eagle (*Aquila rapax*), Grey-headed Gull, Pied Crow (*Corvus alba*), Black Crow (*Corvus corvus*) and Lappet-faced Vulture (*Torgos tracheliotus*) have been known to prey on flamingo nestling and eggs (Berry 1972).

A wetland such as Etosha Pan – albeit temporary of nature – would serve as a stopover for migratory bird species. This has been documented for flamingos (Berry 1972) and would be expected for any other aquatic migratory species, of which many different species visit Namibia annually.

3.1.1.3 Herpetofauna

According to Baker (1996) 110 reptile species and 16 amphibian species are in the Etosha National Park area although not all are associated with the pan. According to Griffin and Channing (1991) relatively few (only eight species) Namibian reptiles are dependent on wetlands due to the country being primarily arid and semiarid in nature. Furthermore Griffin and Channing (1991) state that 12 species (verified) and 4 species (not verified, but expected) of reptiles and amphibians are associated with the seasonal wetlands of Owambo and the Etosha Pan area. Of these, six (verified) and three (not verified, but expected) belong to the

Bufonidae and Ranidae (Amphibians). Jurgens (1979) states that of the 127 anuran species found in Southern Africa only 10 are found within the boundaries of the Etosha National Park. This scarcity of anuran species is probably as a result of the low number of different habitats and also the chemical composition of the water (pH levels vary from 8.92 to 10.3 in Etosha with high concentrations of dissolved chemicals making the water unsuitable for anuran use) (Jurgens 1979).

A Namibian endemic, *Agama etoshae* (Etosha Agama), occurs in sandy areas in the Etosha National Park area although not specifically associated with the pan. A Botswana endemic, *Agama makarikarica* (Makgadikadi Spiny Agama), on the other hand is restricted to the Nata and Makgadikadi salt flats in northeastern Botswana (Branch 1998). Other than the occasional *Psammophis* (Sand Snake) species crossing the pan no retiles are specifically associated with the pan itself (M. Griffin Pers. comm.).

3.1.1.4 Fish

According to Baker (1996) only one fish species occurs in the Etosha National Park area. Bethune and Robberts (1991) state that at least 49 species of fish are present – albeit temporarily after flooding episodes – in the Owambo and Etosha area. Fish of these temporary pans in northern Namibia are dominated by the genera *Barbus*, *Clarias* and *Oreochromis* (Van der Waal 1991). Fish species that do enter the Etosha Pan under flood conditions are usually located in the Ekuma area (north central part of the pan) which is the major inlet from the Cuvelai drainage system further north and usually consist of *Barbus* species (Brain Pers.comm., Kötting Pers.comm. and Versveld Pers.comm.). According to S. Bethune (Pers. Comm.) only the hardiest species survive the "migration" during occasional flooding episodes into the Etosha Pan and don't survive for long either due to the temporary nature of the pan.

3.1.2 Coastal Saline Flats

3.1.2.1 Mammals

Mammals are not common along Namibia's extremely arid coastal areas more commonly known as the Namib Desert, including the northern section aptly termed the "Skeleton Coast". Rainfall is irregular with as little as 15–100 mm precipitating annually (Baker 1996). Mammals that do occur and that undoubtedly utilize the saline flats whilst foraging include predators such as the Black-backed Jackal, Brown Hyaena (*Hyaena brunnea*) and occasionally Lion – in the far northern reaches of the Namibian coast (Baker 1996; Lovegrove 1993; O'Toole 1996). Cape Fur Seals (*Arctocephalus pusillus*) have breeding colonies at Sandwich Harbour and Cape Cross (both areas well endowed with saline flats) and consequently support high densities of Black-backed Jackal and Brown Hyaena. Black-backed Jackal's are masters at foraging for beached prey originating from the sea and very rarely rely on the desert for food (Lovegrove 1993). Oryx and Springbok are two ungulate species also often seen along the inhospitable Namibian coast and obtain their water at springs emerging close to the coast at the mouth of some of the westward flowing ephemeral rivers. The authors personally observed tracks of the above-mentioned species crossing coastal flats probably in search of food or moving from one area to another.

3.1.2.2 Birds

The combination of nutrient rich ocean waters, tidal shoreline and coastal wetlands along the Namibian coast provides a habitat and feeding ground for many species of seabirds and waders, that congregate in very large numbers at certain times of the year (Lowery 2001). The coastal region south of Swakopmund, including Walvis Bay and Sandwich Harbour (both including saline estuaries and flats situated in the central western part of Namibia's coastline), offers sanctuary to hundreds of thousands of wading birds (Baker 1996). Of the 21 sites identified as important for birds in Namibia, 10 are along the Namibian coast and all someway associated with the saline flats systems (Simmons et al. 1998). The Greater and Lesser Flamingos – which occasionally migrate to and breed at the Etosha Pan – extensively use these coastal wetlands for feeding (Berry 1972). It has been estimated that the Swakopmund coastal salt flats support at least 1% of the Southern African population of the aforementioned two species and up to 250,000 pairs of Cape Cormorants (*Phalacrocorax capensis*) (Lowery 2001). The artificial saltworks (salt extracted by means of evaporation of seawater) at Swakopmund supports more than 20,000 shore-birds (Williams 1988). Globally near-threatened species that occur at the Swakopmund saltworks include the Lesser Flamingo, Damara Tern (*Sterna balaenarum*) and African Black Oystercatcher (*Haematopus moquini*) (Simmons et al. 1998).

Overall populations of wetland birds range between 37, 500 and 78,200 (peak counts up to 150,000) at the Walvis Bay saline flats (Noli-Peard and Williams 1991). Globally near-threatened species that occur at the Walvis Bay saline flats include the Lesser Flamingo, Damara Tern, African Black Oystercatcher and Bank Cormorant (*Phalacrocorax neglectus*) (Simmons et al. 1998).

Sandwich Harbour seasonally supports up to 25% of the estimated world population of the Chestnutbanded Plover (*Charadrius pallidus*) and >3% of the sucontinental populations of the Blacknecked Grebe (*Podiceps nigricollis*) (Noli-Peard and Williams 1991). Globally near-threatened species that occur at Sandwich Harbour saline flats include the Lesser Flamingo, Damara Tern, African Black Oystercatcher and Bank Cormorant (Simmons et al. 1998).

There is also a rich variety of waders in the Cape Cross Seal Reserve further north (saline flats are common throughout this area) with the endemic and rare Damara Tern breeding in the vicinity (Baker 1996) as well as other localities along the Namibian coast, often in conjunction and/or close to saline flats (Clinning 1978) although more commonly on gravel plains (Frost 1976). Williams (1991) shows that the Cape Cross saline lagoons support between 6–16% of the non-breeding populations of the endemic Southern African race of the Blacknecked Grebe (*Podiceps nigricollis gurneyi*) and between 3,000 and 7,500 birds of any 30 species at any time. Globally near-threatened species that occur at the Cape Cross saline flats include the Lesser Flamingo and Damara Tern (Simmons et al. 1998).

The Namibian feeding grounds are essential to the survival of a large variety of Palearctic migrants, which include species such as the Ruff (*Phylomachus pugnax*) and the Curlew Sandpiper (*Calidris ferruginea*) (Lowery 2001).

3.1.2.3 Herpetofauna

The herpetofauna associated with coastal saline flats is extremely limited at best with few reptiles specifically associated with any type of wetland from Namibia (Griffin and Channing 1991). The mouth of the Cunene River (river separating Angola from Namibia in the north western part of the country) is of particular interest due to it being the southernmost (disjunct) range of the Nile Softshelled Turtle (*Trionyx triunguis*) (Branch 1998; Griffin and Channing 1991). Green turtles (*Chelonia midas*) and even the Nile Crocodile (*Crocodylus niloticus*) have been reported in this same vicinity (Branch 1998; Griffin and Channing 1991) although not exclusively associated with the saline flats abounding in the area. A roadkill of a *Psammophis* (Sand Snake) species (unconfirmed) in the vicinity of Cape Cross, adjacent to coastal saline flats in the area, suggests that other reptiles do occur there although not necessarily specifically associated with these areas (Pers. obs.). Amphibians would generally not be expected in these saline areas due to them not typically being suited morphologically to inhabit saline areas (Loughland and Cunningham 2002).

3.1.2.4 Fish

Although no fish species are exclusively associated with coastal saline flats in Namibia, the larger saline estuaries and flats occasionally inundated during high tides may hold fish temporarily. Bethune and Robberts (1991) have documented 36 estuarine and marine fish species occurring in coastal wetlands along the Namibian coast.

3.2 Flora

3.2.1 Etosha Pan

The high sodium content of most of the pans results in vegetation being non-existent or very rare with few species adapted to cope with halophytic soil conditions. According to Le Roux (1980) the Etosha Pan is largely without any vegetation due to the high sodium content. The whitish clay soils have a sodium contents in excess of 30,000 ppm and the pH varies between 8.8 and 10.2, which is also very high. In good rain years some grass species such as *Sporobolus salsus* and *Sporobolus spicatus* may occur on the pan (Berry et al. 1997; Le Roux 1980; Mendelsohn et al. 2000).

Along the pan margins the dominant perennial grasses are *Odyssea paucinervis*, *Sporobolus spicatus*, *S. ioclados*, *S. tenellus* and the sedge *Cyperus marginatus* (Mendelsohn et al. 2000). Woody species are generally absent but salt-loving woody dwarf-shrubs such as *Suaeda articulata* and *Sporobolus salsus* can be found on sand hummocks, which occur as little "islands" in the pan and on the pan margins (Le Roux 1980; Mendelsohn et al. 2000). *Salvadora persica* is occasionally found on some of the larger islands (Berry et al. 1997).

Several different vegetation types, in most cases well adapted to halophytic conditions, occur at the very edge of the pan. These vegetation types are classified by Le Roux (1980) as follows.

The **Andoni Veld** vegetation type is situated to the north east of the Etosha Pan. The vegetation in this vegetation type is dominated by an almost mono-specific stand of the perennial course grass species *Sporobolus spicatus*. Other prominent grass species in this vegetation type include *Crassipedorachis sarmentoasa*, *Digitaria setrivalva*, *Eragrostis sabine* and *Odyssea paucinervis*. Shrubs such as *Dichrostachys cinerea* are currently encroaching into this vegetation type.

To the southwest and south of the Etosha Pan, sweet grasses are associated with lime soils and classified as the **Sweet grass veld**. The vegetation in this area can generally be described as treeless plains although three tree species that do however occur in this area include *Acacia mellifera*, *Acacia nebrownii* and *Acacia reficiens*. *Albizia anthelmintica* may also be present in certain areas. Thickets of *A. nebrownii* occur on the southern side near the edge of the pan.

To the west of the pan small shrubs, such as *Monechma tonsum*, *Monechma qenistifolium* and *Petalidium enqelerianum* dominate the vegetation. Closer to the edge of the pan *Salsola* species such as *Salsola aphylla* and *Suaeda articulata* are found on the halophytic soils. Some perennial grass species such as *Cenchrus ciliaris* and *Stipagrostis hochstetteriana* may occur, but more common grasses such *Aristida adensionis*, *Enneapogon cenchroides*, *Enneapogon desvauxii* and *Eragrostis nindensis* are more typical for this vegetation type.

On the western side of the Etosha Pan shrubs such as *Leucosphera bainesii* and *Salsola tuberculatec* dominate the vegetation type known as **Ondeka Duneveld** and grow right up to the edge of the pan. Some of the important grasses are *Enneapogon desvauxii*, *Eragrostis sabinea* and *Eragrostis porosa*. Herbs such as *Monechma dwaricatum*, *Herpicium gazansoides* and *Zygophyllum simplex* also occur in this vegetation type.

On the northern side of the pan a geographic feature known as Poachers Peninsula – peninsula extending southwards into the pan – is dominated by shrubs such as *Catophraetes alexanderii* and *Dichrostachys cinerea* while the grass layer is dominated by *Stipagrostis uniplumis*.

To the east of Poachers Peninsula a relative small vegetation type known as the **Ekuma grass lands** extends down to the edge of the pan from the north. The vegetation can be described as a tall grass veld with palatable grasses such as *Anthephora pubescens*, *Cenchrus ciliaris*, *Schmidtia pappophoroides* and *Stipagrostis uniplumis*. The most important shrub in this area is *Leucosphera bainesii*.

On the northeastern side of the pan the vegetation is characterized by a **Sandveld vegetation type**. The vegetation in this area is dominated by tree species such as *Acacia erioloba*, *Acacia mellifera*, *Philenoptera nelsii*, *Terminalia sericea* and *Terminalia prunioides*. Several *Grewia* species for example *Grewia flava* are typical of the shrub components that occur in this area. The grass layer is poorly developed with *Schmidtia kalaharienses* as the most prominent species.

Clarke (1998) describes the vegetation associated with saline pools and flats slightly to the north of the Etosha Pan, but still in the Cuvelai drainage basin, as sparse and poorly vegetated. Species that are characteristic of saline pools in this area include the small grass *Sporobolus coromandelianus* and large clumps of *Sporobolus ioclados*. Sandy edges support *Odyssea paucinervis* and *Sporobolus spicatus*. Trees are absent possibly due to the waterlogged and saline soils in this area.

3.2.2 Coastal Saline Flats

The coastal saline flats are devoid of vegetation (except for some algae species) except on the edges of the flats. Similar to the Etosha Pan, only vegetation adapted to halophytic conditions occurs around these flats. In general the density of vegetation is low in the coastal areas, but does increase further away from the flats.

Species such as *Anthrocnemum africanum* and *Sarcornia natalensis* are succulent-like perennial herbs (small ±30 cm in height) that succeed in growing in these very saline conditions. Small shrubs such as *Galenia papulasa*, *Lycium cinereum*, *Salsola* species, *Suaeda* species, *Psilocaulon* species, *Tamarix usineoides* and *Zygophyllum* species occur slightly further away (i.e. inland). Members of the grass family that succeeded in establishing themselves in this area are *Odyssea paucinervis*, *Sporobolus nebulosus* and the well-known reed, *Phragmites australis*, which occur in these halophytic conditions especially near an area called "Jakkalsputs" north of Swakopmund. The salt marsh and adjacent brackish waters at Sandwich Harbour support four communities – *Sarcocornia natalensis* var. a*ffinis*, *Sporobolus virginicus*, *Typha capensis* and the *Odyssea paucinervis* communities, whose distribution is determined by the salinity gradient between the fresh water seepage and the marine system (Robinson 1976).

In many cases the vegetation grows on sand hummocks created by the wind. On the gravel/gypsum plains the most prominent plant is a perennial shrub (±30–40 cm high) known as *Arthraerua leubnitzii*. A large number of endemic lichens are also found on these gravel plains. These plants are a symbiosis between fungi and algae and are dependent on the fog-regime along the coast for their moisture requirements.

4 Conclusion

As far as could be determined no specific fauna (mammals, birds, reptiles and fish) and flora are specifically associated with inland and coastal saline flats in Namibia. This however, should not detract from the immense importance such systems have in terms of supporting a wide variety of life especially in an arid country such as Namibia. Not only are the saline flats important from a national perspective such as the tourism potential of Etosha National Park, Cape Cross Seal Reserve, Walvis Bay lagoon, etc., but also from an international perspective. The fact that these saline flats especially the coastal flats host Palearctic waders, underscores its international importance.

The ecological importance of saline flats in Namibia is often overlooked and certainly not well understood and usually deemed worthless from a farming and tourism perspective. Secondary benefits of these saline flats such as the importance for migratory waders that in their turn attract tourists (birders) should be encouraged. The importance of these saline flats should not be underestimated and it is suggested that an awareness campaign, similar to the awareness campaigns regarding lichens and Damara Terns, should be initiated in Namibia. Further research into the saline flats system(s) from Namibia is warranted especially regarding the invertebrates, which form the basis of the food chain for migratory birds. This little understood and unique landform deserves further attention.

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Introducing the Namib Desert Playas

Frank D. Eckardt and N. Drake

Abstract The hyper arid Central Namib gravel plains to the north of the Kuiseb River feature a series of playa clusters which are nested in shallow drainage channels. The playas form primarily as the result of groundwater water ponding at bedrock obstructions which produces surface salts such as halite and gypsum on top of thin stream sediments. They differ considerable in size, shape and composition when compared with playas elsewhere in the region such as the Kalahari and Karoo.

1 Introduction

The Namib Desert is mainly associated with dunes, inselbergs, escarpments, gravel plains and coastal sabkhas. This paper aims to add desert playas to the list of landforms of the coastal region. The pans occur in a number clusters, in particular in the central region between the Ugab and Kuiseb Rivers on the broad, 120 km wide, shallow gradient (1%) gravel plains below the escarpment (Fig. 1).

The playas or pans are nowhere near as well known, as the Etosha pan complex or their counterparts in the Kalahari but deserve attention for a number of reasons. The pans produce some of the most saline waters in southern Africa (Day 1993). Furthermore, while currently occupying less than 5% of the Namib gravel plains, given the age of the desert, the pans must have played an important role in the denudation of the inselberg landscape. The aggressive salt weathering environment in the Namib (Goudie et al. 1997; Goudie and Parker 1998) may be amplified by salt deflation from pans and the high relative humidity and fog advection for which the region is known. The deflation of gypsum dust from the pans may also have created the widespread pedogenic gypsum crusts (Eckardt et al. 2001; Eckardt and Spiro 1999). Many of the sites described here feature small salty springs. Most of the pans described here have no name. Some names given here are not official but refer to nearby place names which are used as a means to distinguish between the different systems.

The environment and geomorphology of the Namib Desert has been described previously (Meigs 1966; Logan 1969). Rainfall gradually decreases from the semi-arid environment found in the highlands (250 mm), towards the Pro Namib Desert (70 mm) and on to the hyper arid coast, which receives less than 20 mm of rainfall per annum. The Namib Desert is considered to have been hyper-arid for the last 5 million years (Ward et al. 1983).

The playas are found on the gravel plains, which exhibit an extensive but subdued and poorly developed drainage system. This dentritic drainage network provides a conduit for sparse Pro Namib rain towards the hyper-arid Atlantic coast. Playas occur at numerous locations, clusters have been identified in Landsat Thematic Mapper imagery and aerial photography. The ones visited in the field were to the northeast of Swakopmund, on the Welwitschia Flats and towards the east of the Okahandja Lineament and will be described in turn. In addition to some basic field validation and XRD analyses of salts, water was collected and analysed for its chemical composition. About ten pans have been visited throughout the area and are considered representative of what can be expected in the coastal region.

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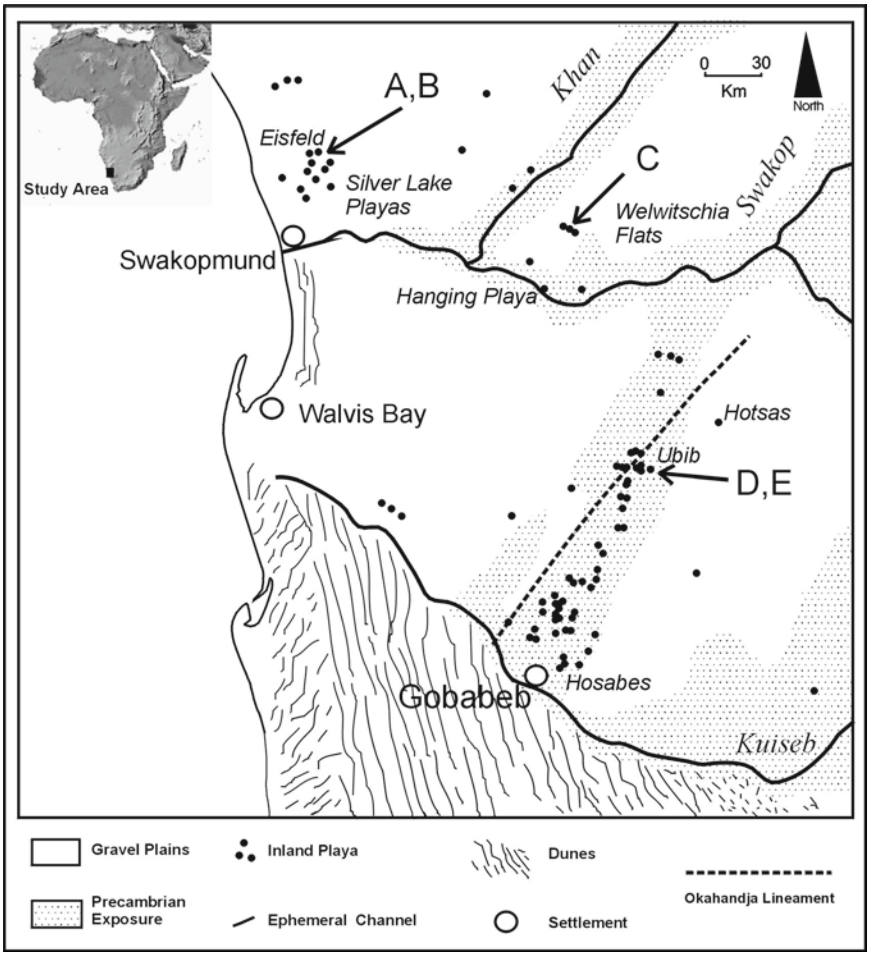

Fig. 1 Map of Study Area and major pans in the Central Namib (A, B, C, D, E Locations of Sections in Figure 3)

2 Results

2.1 The Silver Lake Playas

The playas are found 10 km to the NE of Swakopmund and form part of the Silver Lake Pans (Roper undated; Table 1, Fig. 2). Here Ehrhorn's playa has briefly been mined for halite in the 1930s, while Eisfeld, Kaliman and Kalifrau seem to have been subjected to some initial prospecting (Gevers and Van der Westhuyzen 1931; Schneider and Genis 1992; Table 1). Judging by the rusty diggers left at those pans, salt mining has been abandoned a long time ago. Salt production has entirely shifted to the nearby coastal lagoons where marine water is evaporated in a series of shallow ponds such as Walvis Bay and Swakopmund. These are among the largest salt productions sites in Africa.

Two short soil profiles have been obtained at Eisfeld which reveal halite, gypsum and moist, clay rich sediments, superimposed onto a shallow Precambrian bedrock (Fig. 3a, b). The pans form due to relatively impermeable dolerite outcrops traversing drainage channels that appear to carry groundwater, as is suggested by spring discharge at a number of points. This results in groundwater ponding behind the dense network of dolerite dyke outcrops which results in the rise of the water table and which promotes evaporation (Plate 1).

2.2 The Welwitschia Flats Playas

A second and less pronounced cluster of playas exists on the Welwitschia Flats (Table 2). Again these are the result of groundwater ponding. While these pans are

Table 1 Silver Lake Playas as identified in Landsat Thematic Mapper image

Playa	Size (ha)	Latitude	Longitude
1	21	22° 26′ 09″	14° 35′ 09″
2	69	22° 28′ 22″	14° 34′ 33″
3 Eisfeld	76	22° 31′ 12″	14° 32′ 56″
4 Ehrhorn	63	22° 32′ 24″	14° 34′ 19″
5	43	22° 33′ 28″	14° 37′ 37″
6	20	22° 29′ 17″	14° 37′ 16″
7	25	22° 28′ 01″	14° 37′ 22″
8	19	22° 27′ 09″	14° 38′ 43″
10 Kaliman	10	22° 35′ 09″	14° 33′ 00″
11 Kalifrau	16	22° 34′ 21″	14° 32′ 39″

comparable in terms of size to the Silver Lake playas, they appear to form due to Precambrian marble obstructions rather than Karoo dolerite dykes. The morphology of the playas is comparable to the Silver Lake pans at Swakopmund and features thin, moist sediment overlying Precambrian rocks (Fig. 3c).

An unusually perched hanging playa can be found at the nearby Swakop Canyon rim, upstream from the Swakop/Khan confluence (Lat 22° 42′ 34″ S, Lon 14° 59′ 09″ E). This has created a massive contemporary pan-type salt deposit 50 m high, covering a length of nearly 200 m on the north side of the steep the Canyon

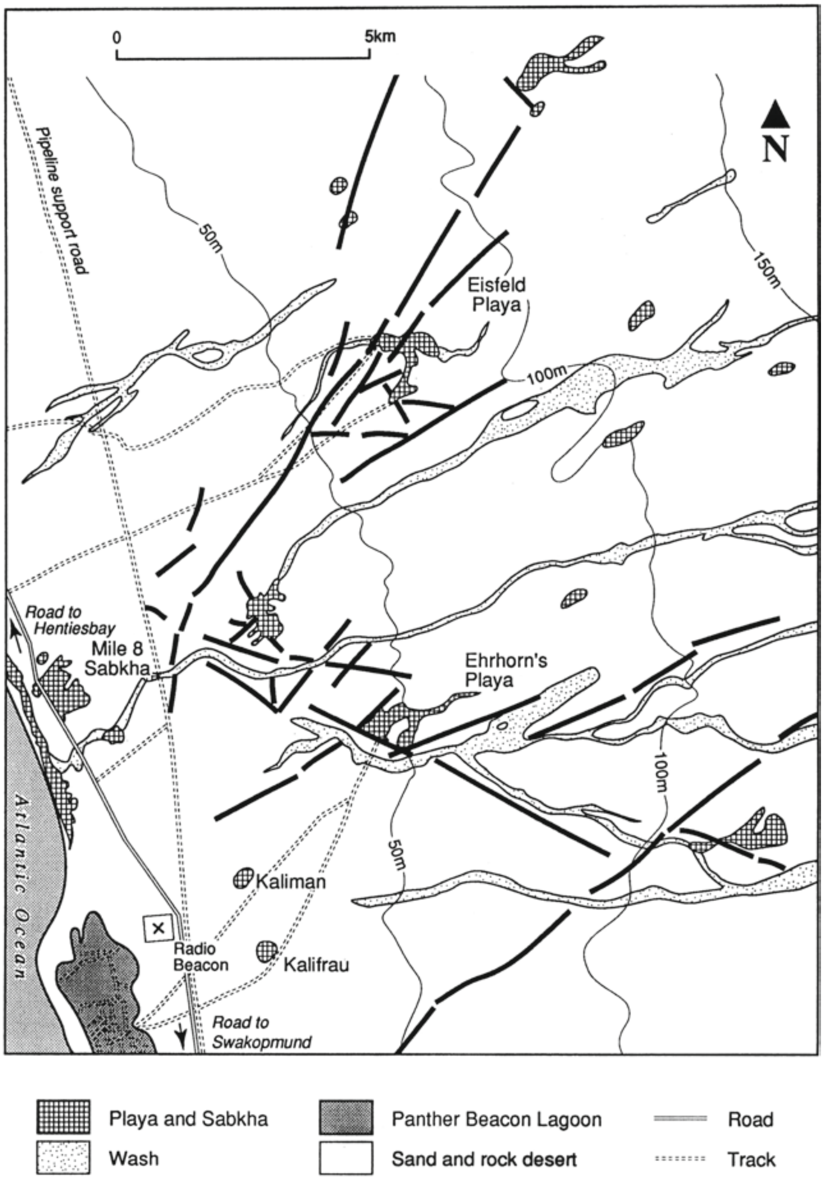

Fig. 2 Map of Silver Lake Playas and dolerite ridges near Swakopmund

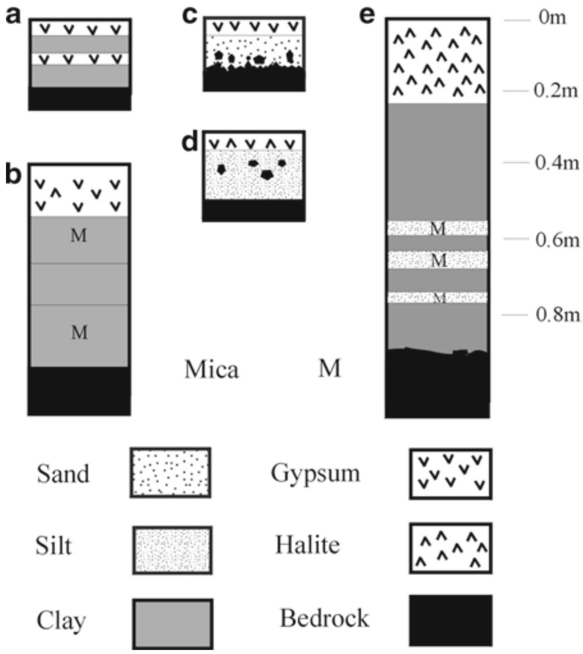

Fig. 3 Section of playas taken in the Namib. (**a**, **b**) Eisfeld, (**c**) Welwitschia Flats, (**d**, **e**) Ubib

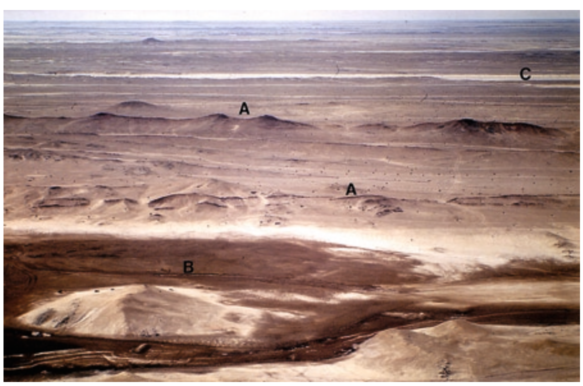

Plate 1 Low level aerial photo of Eisfeld playa surrounded by gravel plains. (**A**) Dolerite Ridges, (**B**) Pan Surface, (**C**) Wash (note tyre tracks for scale)

Table 2 Playas on the Welwitschia Flats as identified in LandsatThematic Mapper image

	Size (ha)	Latitude	Longitude
1	31	22° 38′ 46″	15° 03′ 59″
2	32	22° 39′ 17″	15° 04′ 04″
3	40	22° 37′ 43″	15° 06′ 41″

wall. Halite stalactites and stalagmites have coated material such as ostrich feathers and other detritus on the dry river bed.

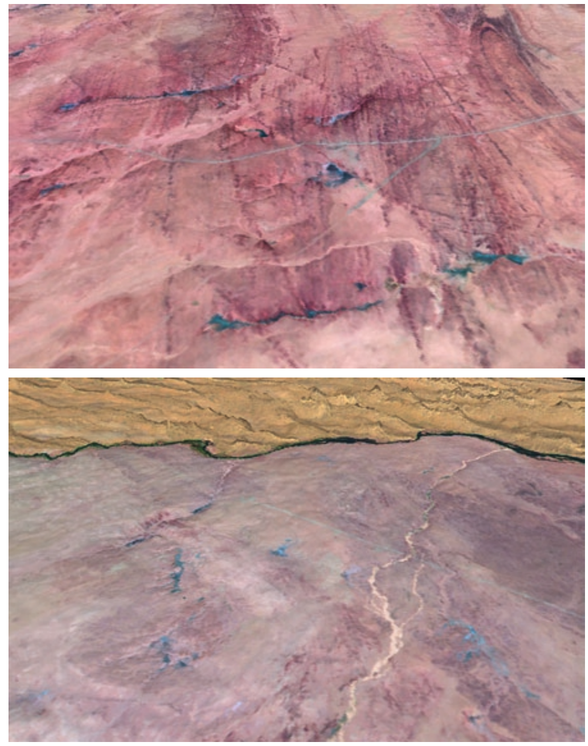

Plate 2 Three dimensional terrain Visualisation. Landsat Enhanced Thematic Mapper image (Display: *Red, Green, Blue, Bands 7,4,2*) draped of Shuttle Radar Topography Mission data depicting playas at Okahandja Lineament. Salt and gypsum appear as dark patches. (top) Playas at Ubib, note gravel road network. (bottom) Playas at Hosabes, note Kuiseb River and dunes to the south

2.3 The Okahandja Lineament Playas

The third and largest accumulation of playas can be established through the careful examination of aerial photography, which highlights the presence of between 50–60 small playas (<5 ha). Pans are found within the gravel plain drainage and can be identified on aerial photography by their dark appearance, caused by the presence of silt and clays, polygonal thrust faults and phreatophyte mounds. It appears that these playas are usually the result of Damara bedrock outcrops associated with the Tinkas schists and the Salem granites in the vicinity of the Okahandja lineament (Fig. 1) and fault lines to its east (Plate 2). They form a pronounced belt which runs from Hosabes playa near Gobabeb on to Ubib Spring and terminates to the west of Hotsas water hole which approximately coincides with the eastern margin of appreciable gypsum occurrences in the Central Namib Desert.

The presence of clay, silt and some sand sized material in most of the playas suggests surface water input to take place. This is likely to occur during sporadic high magnitude rain events, which will cause surface run-off and erode material from inselbergs and the gravel plain into playa depressions. The deepest profile (Fig. 3d, e) is found in a playa, which does not have an outflow but instead two distinct inflows, with different types of source materials from different sized catchments producing alternating layers in its profile. Other playas, which are positioned in more pronounced drainage channels, promote coarser and thinner profiles.

2.4 Water Chemistry

Water can be found at most Namib playas (Table 3). Some feature permanent springs and some water holes may be maintained by frequenting gemsboks and springboks. In some cases water may only be assessed by digging a shallow pit.

3 Discussion

The Namib playas feature thin halite (NaCl) and gypsum crusts ($CaSO_4 \cdot 2H_2O$) have phreatophyte mounds, thrust polygon surfaces or other irregular microtopagraphy. The playas form, as sporadic surface water and sparse groundwater traverse the 150 km wide desert from east to west. The water is subject to evaporative concentration in particular when the porous tertiary colluvium of the plains is punctuated by impermeable bedrock such as dolerite, marble or granite. All playas presented here occupy drainage channels and depression, which have accumulated sediments that are often less than 1 m deep. The crusts are replenished by capillary rise of shallow groundwater stored in moist, fine-grained clays and silt. Permanent surface water is present at a few small pools where it reaches extreme salinities in an environment of very high potential evaporation rates and moderate flow rates.

The small surface water pools appears perennial as they were present in 1994 and 1995, and some had even been sampled in the 1980s (Day 1993). The salinity changes at Welwitschia Playa (−18%), the Hanging Playa (−11%) and Eisfeld (+3%) are noted to be minimal, suggesting that evaporation, inflow and crystallisation have attained equilibrium. Hosabes samples show considerable temporal variability (+72%), which could be controlled by a number of factors, including sampling distance from discharge point as well as mixing of stratified bottom and surface water.

The hypersaline spring at Hosabes was investigated in detail by Day and Seely (1988) revealing flow rate maxima at 0.023 m/s with discharge ranging from 0.22 to 0.75 Conductivity was observed to double over a flow length of 80 m, with concentration being controlled by channel depth and distance from source.

Other evaporates such as sylvite (KCl) and humberstonite ($K_3Na_7Mg_2(SO_4)6(NO_3)2 \cdot H_2O$) have also been identified at Hosabes (Lat 23° 30′ 15″ S, Lon 15° 03′ 11″ E). Humberstonite is a rare hydrous sulphate-nitrate of potassium, sodium and magnesium, which has for the first time been found outside the Atacama Desert (Mrose et al. 1970).

The composition of Namib Playas is comparable to the coast parallel sabkhas, which stretch from Angola into South Africa. More than 20 well-established sabkhas with a cumulative area of 300 km^2 are known. The coast

Table 3 Playa water samples obtained in 1994 and 1995 (all figures in ppm)

Water Samples	date	pH	TDS	SO_4	Cl	Na	Ca	Mg	K	HCO_3
Ubib playa east	23.5.94	8.1	11,213	800	4,800	2,850	330	885	270	176
Ubib playa east	2.10.95	7.8	16,104	12	7,400	3,900	387	1,153	330	178
Eisfeld playa	23.5.94	7.4	46,728	3,000	26,000	15,300	3,496	3,089	215	170
Eisfeld playa	10.10.95	7.6	48,444	19	34,600	18,200	4,545	3,377	460	286
Hosabes playa	24.5.24	8.1	111,203	10,000	46,000	32,500	190	4,859	580	200
Hosabes playa	10.10.95	8.1	192,060	25,200	96,000	67,000	55	7,659	1,940	226
Hanging playa	23.5.94	7.7	20,328	2,040	11,400	5,000	2,597	1,977	194	148
Hanging playa	10.10.95	7.6	18,216	2,120	10,400	5,500	2,447	1,771	185	104
Welwitschia playa	17.5.94	7.7	26,994	2,000	13,600	7,050	3,646	2,553	185	112
Welwitschia playa	10.10.95	7.9	22,242	2,420	13,100	6,800	3196	2,059	280	108

Table 4 Playas identified in the Central Namib, Keetmanshoop District and Owamboland

Playa	Location	Size (ha)	Evaporites
Central Namib Desert			
Reserve 0, 1, 2, 3	Henties Bay area	25	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Rottraut	Henties Bay area	60	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Marko	Hentiesbaai area	50	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Eisfeld	17 km north east of Swakopmund	20	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Kaliman	2 km east of Panther Beacon	8	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Kalifrau	2 km east of Panther Beacon	11	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Ehrhorn	16 km north-northeast of Swakopmund	30	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Arandis	13 km north of Arandis	11	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Tsondab Vlei	Namib Naukluft Park Tsondab River (size obtained from Landsat Thematic Mapper imagery)	660	Magnesium calcite (MgCa), Dolomite ($CaMg(CO_3)2$) Aragonite ($CaCO_3$), Halite (NaCl)
Soutrivier	Namib Naukluft Park, Central Namib	3–4	Halite (NaCl) Gypsum ($CaSO_4 \cdot 2H_2O$)
Keetmanshoop District			
Keetmanshoop District Pans	Keetmanshoop District		Glauber salt (Na_2SO_4)
Verwall Pan	15 km east of Koes	550	Epsom salt ($MgSO_4$)
	Keetmanshoop district		Halite (NaCl) Thenardite (Na_2SO_4) Sylvite (KCl)
Owamboland			
Odangwa Pan	Owamboland Etosha (Aminius)	2,100	Halite (NaCl) Thenardite (Na_2SO_4) Sylvite (KCl) Anhydrite ($CaSO_4$) Calcium carbonate ($CaCO_3$) Magnesium chloride ($MgCl_2$)
Otjivalundu Pans No. 1 and 2	Owamboland Etosha	40 and 400	Thenardite (Na_2SO_4) Trona ($NaH(CO_3)_2 \cdot 11H_2O$) Sulphohalite ($2Na_2SO_4 \cdot NaCl \cdot NaF$) Pirssonite ($CaCO_3 \cdot NaCO_3 \cdot 2H_2O$)

Source: Forshag 1933; Teller and Last 1990; Schneider and Genis 1992.

parallel, flat, salt encrusted surfaces, often less than a meter above mean sea level, are found near the high water mark between the Kunene and Orange Rivers. Some are well documented (Schneider and Genis 1992) and have been described already in the 1930s. Gypsum and halite exists at Swakopmund, Cape Cross (Gevers and Van der Westhuyzen 1931), Conception Bay (Kaiser and Neumaier (1932) and Torra Bay (Torien 1964).

These playas and sabkhas in the hyper arid Namib differ significantly from those found elsewhere in

Namibia (Forshag 1933; Schneider and Genis 1992). The well-known scenic Vleis or lake deposits associated with the Namib Sand Sea such as Sossus, Koichab and Tsondab Vlei are recharge points in the permeable sand sea. Shortlived highland floods terminate in the dunes where they produce temporary lakes and leave behind fine calcified sediments and shorelines (Teller and Last 1990). In the Kalahari and Etosha area, playas hold Epsom salts ($MgSO_4$), halite (NaCl), thenardite (Na_2SO_4), anhydrite ($CaSO_4$), calcium carbonate ($CaCO_3$), magnesium chloride ($MgCl_2$), and sylvite (KCl). The playas of the Etosha Pan in northern Namibia hold, thenardite (Na_2SO_4), trona ($NaH(CO_3)_2 \cdot 11H_2O$), sulphohalite ($2Na_2SO_4 \cdot NaCl{\cdot}NaF$), and pirssonite ($CaCO_3{\cdot}NaCO_3 \cdot 2H_2O$; Table 4.

4 Conclusion

There are numerous playas throughout the Central Namib which precipitate halite and gypsum on the gently sloping drainage of the gravel plains. The playas are best developed in areas where bedrock obstructions run perpendicular to the drainage pattern and groundwater flow. Ground water appears to be present all year round despite conditions of hyper aridity. In most cases playas have a distinct in and outflow channel and do not appear to produce major aeolian features such as lunette dunes. In that regard they differ considerably from playas in the Kalahari and the Karoo region. Their main role in shaping the landscape of the Namib would be enhanced denudation by salt weathering. Their contribution to the regional ecology still needs to be determined.

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Quantitative Eolian Transport of Evaporite Salts from the Makgadikgadi Depression (Ntwetwe and Sua Pans) in Northeastern Botswana: Implications for Regional Ground-Water Quality

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Abstract Eolian salts from the evaporite-covered Makgadikgadi Depression in Botswana were observed in the soil as far as 150 km downwind from the depression. Over three million metric tons of chloride, sodium, and bicarbonate are transported each year from the basin to the adjacent land. Infiltering soil water mobilizes and transports these soluble salts to the ground water, where they degrade the water quality. A relation between the size of the evaporative floor area and the length of the downwind salt "footprint" on the soil was established. This permits use of readily available topographic maps to estimate the area and length of potential degradation of ground water without extensive field sampling. Significant mass of naturally-occurring radioactive 226-radium is present in the eolian-transported salts that may have deleterious health consequences for individuals residing in the downwind area.

1 Introduction

Solute concentrations of ground water in many arid and semi-arid regions are so elevated and spatially variable that they inhibit development for many domestic, livestock, irrigation, or industrial uses. In a significant number of these regions, the concentration of ground-water solutes appears to be impacted by eolian transport of evaporite salts from local or regional saline pans (Wood and Sanford 1995). Salts from these pans are transported tens of kilometers by wind, where they fall to the ground and are dissolved in recharge water to become part of the ground-water system. The resulting affect on ground water is a plume of high-solute water that reflects a combination of source, dominant wind, and ground-water flow directions.

Eolian-transport processes in arid and semi-arid areas are well documented in the geologic record by the presence of dunes, loess, volcanic ash, and other features (Péwé 1981). The observation that dust can travel great distances has been shown by detection of dust from Asia in the atmosphere over Alaska (Rahn et al. 1981) and of dust from the Sahara over the North Atlantic (Schütz et al. 1981). Eolian transport of sea aerosols on the continents also is well established (Jung and Werby 1958; Mandel and Shiftean 1981; Hingston and Gailitis 1976), as are the effects on surface water and soils (Person and Fisher 1971; Dethier 1979; Eisenreich 1980; Wiman and Agren 1985; Wiman et al. 1990). The presence of ^{3}H, ^{14}C, and ^{36}Cl isotopes from above-ground nuclear testing in many water-table aquifers worldwide clearly demonstrates the existence of eolian transport of aerosols on a global scale. However, specific contributions of solutes to ground water by eolian processes, other than the isotopes indicated above, have received relatively little attention in the literature.

Heim and Giuliana (1988) showed that radioactive material from the Chernobyl accident has contaminated the ground water regionally; Lehman and Hansen (1988) documented uranium derived from smoke-stack

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release in the ground water in parts of Ohio; and Robertson et al. (1989) demonstrated that eolian transport of sulfur from smelters in Sudbury, Ontario resulted in high sulfate levels in aquifers hundreds of kilometers from the source. Brown and Sharp (1992) summarized much of the previous work and developed a generic numerical model to simulate mass transport from a point source at the surface, through the unsaturated zone, and into the ground water.

Eolian transport of soluble evaporite minerals from a small 4.7-km^2 pan in western Texas (Double Lake) created a "footprint" of soluble salts that could be identified in the soil as far as 35 km downwind from the pan (Wood and Sanford 1995), negatively impacting the quality of ground water. For efficient water management, it is important to develop a methodology to identify and quantify these eolian inputs to the ground water. It was hypothesized that the length of the soluble footprint derived from a pan is a function of the size of the source area. That is, the length of the solute footprint is limited by the mass of the evaporite minerals, if all other factors remain the same. If this "size/length of footprint" hypothesis can be demonstrated to be true, existing maps of pans coupled with prevailing wind directions could then be used to estimate the area of eolian salt influence on regional ground-water quality. This knowledge would be useful in ground-water resource evaluation by helping to minimize drilling and sampling necessary for water-quality characterization as current maps generally define the locations and area of these saline pans.

The experimental design used to test the "size/length of solute footprint" hypothesis was to evaluate the concentration of various soluble salts from soil samples collected at known distances from a pan and compare these concentrations with similar distance/area relations developed for the western Texas pan. The Makgadikgadi Depression in northeastern Botswana (Fig. 1) was identified as a possible site to test the hypothesis. The Makgadikgadi Depression exhibits wind and precipitation patterns similar to those in the western Texas study area. Both sites exhibit significant ground-water evaporation that contributes solutes to the pan. It was assumed that both sodium sulfate (western Texas) and sodium carbonate (Makgadikgadi Depression) evaporative salts would form similar sized eolian particles with similar density and thus have similar transport properties.

1.1 Hydrogeology

An estimated 8,000 pans cover Botswana, which is at the heart of the Kalahari basin. The Makgadikgadi Depression represents by far the largest pan system in the country, occupying more than 30,000 km^2. The Makgadikgadi consists of several dozen connected pans, but it is dominated by the Ntwetwe Pan to the west and Sua Pan to the east. The Ntwetwe Pan is fed by surface water from the Boteti River, an overflow of the Okavango Delta, but surface water from this source has failed to reach the pan since 1991 (Personal communication, Botswana Department of Water Affairs). The Sua Pan receives surface water mainly from the Nata River, which drains the wetter eastern regions of Botswana and Zimbabwe. The Nata River discharges seasonally but is subject to a considerable degree of flood variability. The Sua Pan represents the lowest point of the southern African inland basin, at 890 m above sea level. Because of its low altitude, the Makgadikgadi is the natural discharge point for regional ground-water flow. The water table is typically less than a meter below the surface, permitting evaporative discharge from the capillary fringe.

The eastern sides of the pans feature elevated terrain. Here, the metamorphic basement of Achaean and Precambrian material forms the so-called hardveld. The south of the pan system is home to a 100-m sandstone escarpment, part of the Carboniferous-Jurassic Karoo sequence (Thomas and Shaw 1991). To the west and north, the pans open to the Kalahari sandveld. Bedrock exposure on the surface is limited due to the extensive cover of Tertiary Kalahari beds. These eolian and fluvial sands are poorly stratified and are cemented by calcrete and silcrete, particularly along drainage lines and pans (Thomas and Shaw 1991). This terrain features limited surface-flow input and is dominated by numerous shorelines, indicative of past lake levels between the 912- and 945-m contours. Western pan margins have preserved sand ridges (lunettes) produced by prevailing winds and past wave action. The hardveld is home to tree savanna, while the remaining sandveld, which dominates Botswana, consists largely of open shrub savanna. The Makgadikgadi pans themselves lack vegetation because they are covered with evaporative salts. Grasslands extend beyond the perimeters of the pans.

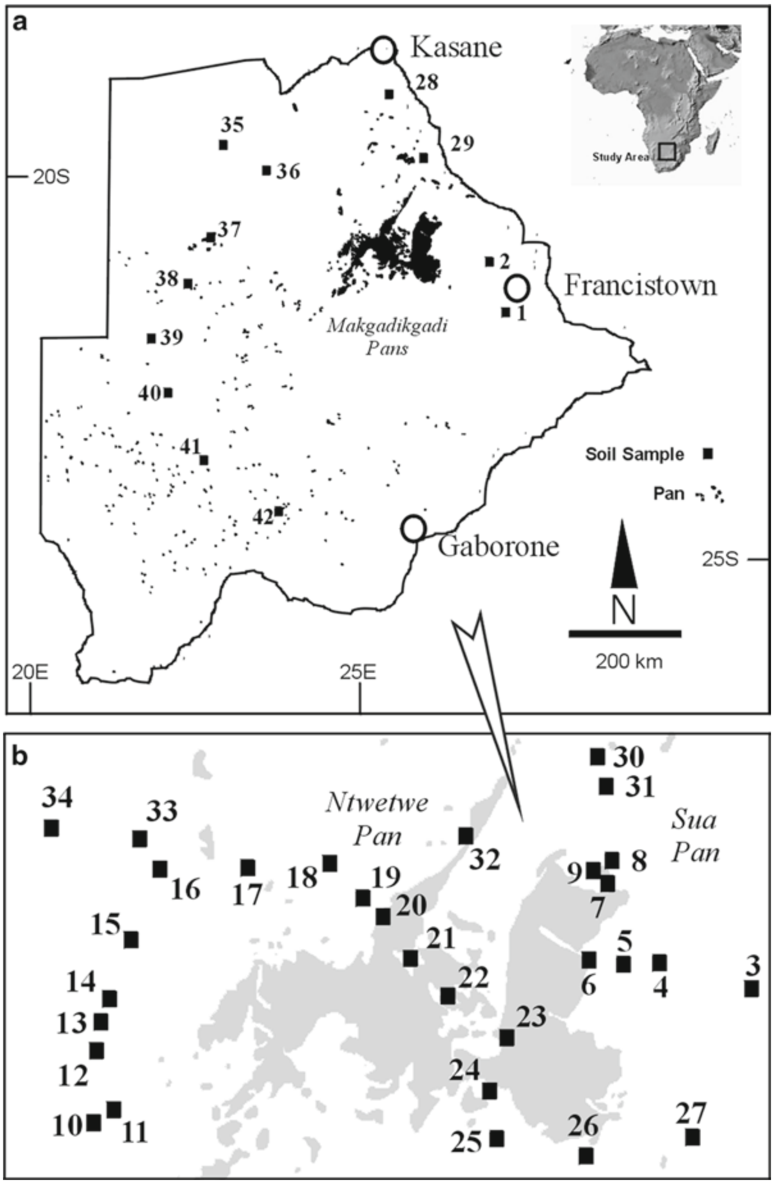
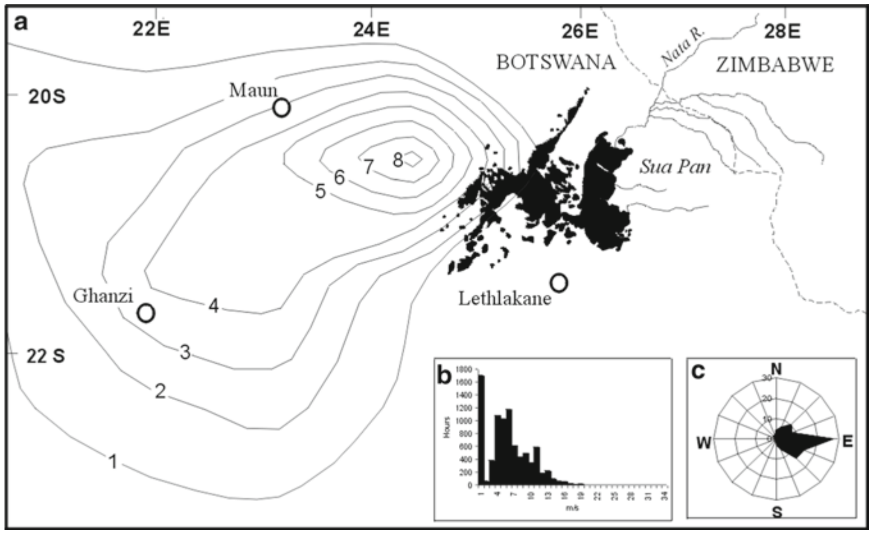


Fig. 1 Map showing location of Makgadikgadi Depression (**b**) and soil sampling in Botswana (**a**)

The climate in the study area is semi-arid and subject to considerable annual and inter-annual rainfall variability. Generally, most of the rainfall occurs between the months of November and March, while April through October are dry (Thomas and Shaw 1991). Rainfall gradient in Botswana ranges from 600 mm/year in the northeast to 250 mm/year in the southwest (Thomas and Shaw 1991), with between 400 and 450 mm/year at the Makgadikgadi Depression**.** Winds are dominated by the Eastern Trade Winds that have an average speed of 5.9 m/s, with maximum gusts to 33 m/s (Fig. 2) recorded just south of the pan complex. The input of eolian salts, rainfall, and wind direction in the Makgadikgadi Depression appears to have been relatively constant over the last several hundreds of years, representing a steady-state condition of soluble salts in the soil comparable to those documented for western Texas (Wood and Sanford 1995). Steady-state concentration of soluble salts in the soil is directly related to solute flux entering the ground-water table. This concentration can be calculated if the ground-water recharge rate and soil moisture content are known.

Fig. 2 Map showing wind direction associated with a map of contours of Aerosol Index (optical opaqueness) in the atmosphere. Aerosol Index data from the TOMS (Total Ozone Mapping Spectrometer)



2 Methods

Under an assumption of steady-state soluble salt and rainfall input, surface soil samples represent the concentration profile in the unsaturated zone (Wood and Sanford 1995). Thus, soil samples were collected at varying horizontal distances from the pan (Fig. 1). Approximately 500 g of soil were collected at each site by excavating shallow pits (10–20 cm). Samples were selected to represent natural, un-farmed conditions and both up- and downwind locations. Each soil sample collection site was documented using a hand-held Global Position Satellite receiver. Distances of the collection sites from the nearest basin floor (defined by the presence of evaporites on the surface) were determined from an enlargement of Fig. 1 as follows: Samples falling between the northern and southern latitude boundary of the basin floor were measured directly east or west to the floor margins (Samples 2–25, plus samples 27, 37, and 38, Fig. 1). Distances of samples north or south of the bounding latitudes (1, 39, and 40, Fig. 1) were measured to the nearest floor margin of the pan.

Samples were transported to the U.S. Geological Survey in Reston, Virginia where they were disagraded and dried at 50°C for 24 h. 50 g of the dried soil were placed into 100 ml of high-purity distilled water. This suspension was gently stirred for 24 h and after decanting, filtered through a 0.45-μm filter. The resulting solutions were analyzed for soluble ions utilizing the methods of Fishman and Friedman (1989). Major ions are reported as micrograms/gram dry weight (PPM) (Table 1). Radium was analyzed by gamma-ray spectrometry based on the emission from the soil of the 186-Kev gamma ray from 226-radium. A weighted sample of dried soil was placed in a metal ointment can and sealed with clear tape. The can was then placed on a high-purity germanium detector for counting for periods of from one to five days. The detector was previously calibrated by analyzing a NIST river sediment standard of known radium activity (National Bureau of Standards 4350). Results are reported as disintegrations per minute per gram (dpm/g) of dried soil (Table 2). Trace elements were determined by ICPMS (inductively coupled plasma mass spectrometry) using the U.S.E.P.A. method 200.8 (U.S. Environmental Protection Agency 1994). Data for the trace elements are reported in nanograms/gram (PPB) (Table 3).

3 Results

Samples 7, 20, 21, 23, and Sua Pan crust were assumed to represent input conditions, suggesting that the dominant ions available for eolian transport are sodium, bicarbonate, and chloride (Table 1). The logarithmic concentration of these ions as a function of logarithm

Table 1 Chemical analysis of major ions (micrograms/gram dried weight) derived from a distilled-water leach of soil samples

Sample ID and Map number	South	East	Distance Km	Ca μg/g	Mg μg/g	Na μg/g	K μg/g	Sr μg/g	Si μg/g	HCO_3 μg/g	Cl μg/g	SO_4 μg/g	Br μg/g	NO_3 μg/g	PO_4 μg/g
B-12/7/99-1	21.6150	27.3684	140	14	2.7	2.3	12	0.11	11	52	15	1.2	0.07	0.00	3.7
B-12/7/99-2	21.0691	27.4188	115	4.0	1.5	1.5	35	0.04	9.5	43	15	1.4	0.00	0.00	0.00
B-12/7/99-3	20.7198	26.8315	58	68	9.6	1.1	41	0.16	11.8	285	17	2.4	0.00	0.00	0.00
B-12/7/99-4	20.5198	26.4077	26	46	10	2.3	25	0.21	13	205	17	0.0	0.30	0.00	0.00
B-12/7/99-5	20.5531	26.1543	16	72	7.3	38	29	0.66	34	343	25	10	0.00	0.00	0.00
B-12/7/99-6	20.5525	26.2816	2	3.8	2.3	1.6	11	0.06	16	30	14	0	0.00	0.00	0.00
B-12/7/99-7	20.3486	26.2433	0	3300	68	84200	4200	48	87	14100	126400	10200	99	0.00	0.00
B-12/7/99-9	20.3238	26.2362	9	7.7	0.1	63	211	0.15	51	180	0.0	400	8.5	0.00	9.7
B-12/7/99-10	21.0890	24.2978	44	17	3.0	7.2	8.1	0.12	19	67	16	0	0.00	0.00	0.00
B-12/7/99-11	21.0864	24.3503	35	44	3.6	10	18	0.33	25	175	16	0	0.00	0.00	0.00
B-13/7/99-12	20.9981	24.3600	56	67	8.9	11	16	0.63	27	275	18	1	0.00	0.00	0.00
B-13/7/99-13	20.8481	24.3603	39	47	4.3	6.8	17	0.32	27	175	16	0	0.00	0.00	0.00
B-13/7/99-14	20.6303	24.4142	39	19	2.9	2.0	11	0.19	9.9	69	15	0	0.00	0.00	0.00
B-13/7/99-15	20.4509	24.5175	88	17	3.9	2.2	14	0.22	9.4	69	15	0	0.06	0.00	0.00
B-13/7/99-16	20.2131	24.5942	105	13	1.2	0.7	3.0	0.14	8.5	46	14	0	0.00	0.00	0.00
B-13/7/99-17	20.2350	24.9215	74	12	3.1	4.3	21	0.11	8.7	130	15	5	0.00	0.00	8.6
B-13/7/99-18	20.1950	25.2239	44	6.7	1.5	3.2	4.5	0.08	10	34	17	0	0.00	0.00	0.00
B-14/7/99-19	20.4201	25.3533	9	42	4.6	33	68	1.1	38	265	30	3	0.00	3.1	0.00
B-14/7/99-20	20.4556	25.3819	0	10	1.2	62100	1350	0.90	81	20000	67700	13200	110	0.00	0.00
B-14/7/99-21	20.5711	25.5108	0.3	42	0.7	680	118	0.63	220	610	550	210	3.4	88	0.00
B-14/7/99-22	20.6886	25.6067	4	48	4.9	58	23	0.52	48	315	30	1.9	0.00	0.00	0.00
B-14/7/99-23	20.8886	25.8289	0	5.0	0.1	38800	2100	0.27	375	8200	54400	5800	47	1900	0.00
B-14/7/99-24	21.0787	25.6497	9	37	5.2	23	34	0.37	31	160	54	2	0.00	0.00	0.00
B-14/7/99-25	21.3094	25.5706	23	52	7.5	8.1	28	0.35	24	215	16	1	0.00	0.00	0.00
B-14/7/99-26	21.3248	26.0449	9	40	2.3	11	16	0.11	14	140	21	0	0.00	0.00	0.00
B-14/7/99-27	21.1850	26.5831	39	28	1.9	1.7	11	0.06	18	105	14	0	0.00	0.00	0.00
B-16/7/99-29	19.1656	25.7686	105	3.4	1.5	1.1	8.4	0.01	1.6	9.3	14	0	0.00	0.00	0.00
B-16/7/99-30	19.9172	26.1456	49	2.4	0.5	0.4	3.2	0.02	1.5	6.6	13	0	0.00	0.00	0.00
B-16/7/99-31	19.9494	26.1542	38	92	4.7	11	19	0.93	32	330	15	0	0.00	0.00	0.00
B-16/7/99-32	20.1417	25.7111	26	26	2.0	20	14	0.21	22	120	24	0	0.00	0.00	0.00
B-16/7/99-33	20.1861	24.3231	114	35	3.4	0.7	6.6	0.24	10	120	15	0	0.00	0.00	0.00
B-16/7/99-34	20.1639	23.7717	158	26	3.3	2.7	10	0.20	15	72	15	0	0.00	11	0.00
B-18/7/99-36	19.8078	23.6317	150	22	5.9	0.4	39	0.22	15	99	13	0	0.00	0.48	22
B-18/7/99-37	20.6216	22.7417	220	3.6	0.6	0.6	13	0.02	6.0	16	13	0	0.00	0.55	0.00
B-18/7/99-38	21.0597	22.4011	260	13	3.8	1.7	25	0.13	7.0	30	15	5	0.00	25	0.00
B-19/7/99-39	22.0081	21.3739	370	1.8	0.6	0.6	13	0.08	9.1	14	16	0	0.01	0.00	0.00
B-19/7/99-40	22.9911	22.1764	400	1.4	0.3	0.2	4.7	0.00	3.1	4.2	14	0	0.00	0.00	0.00
Sua Pan Crust			0	3600	60	61800	2850	51	170	15300	108000	0	0.00	0.00	0.00

Table 2 Analysis of 226-radium and 238-uranium, in dpm/g of dried weight

Map No.	238-uranium	226-radium
1	4.41	4.88
2	1.4	0.48
3	–	0.36
4	1.23	0.43
5	0.41	1.48
6	1.28	0.26
9	1.09	2.13
10	0.71	0.57
11	0.96	1.29
12	1.56	1.12
13	0.47	0.35
14	0.14	0.11
15	0.14	0.24
16	0.32	0.24
17	0.55	0.36
18	0.63	0.36
19	2.98	1.67
21	1.93	3.76
22	3.25	3.31
24	0.42	1.62
25	1.58	0.63
26	–	0.82
27	2.23	0.87
28	–	0.53
29	0.34	0.49
30	0.24	0.34
31	1.17	1.71
32	0.49	0.54
33	0.37	0.39
34	0.05	0.48
36	0.27	0.24
37	0.32	–
38	0.49	0.74
39	1.22	0.76
40	0.7	0.74

of distance from the source is shown in Figs. 3–5. The activity of radioactive element 226-radium (Fig. 6; Table 2) is plotted arithmetically as a function of the logarithm of the distance. Trace elements concentrations (Table 3) failed to yield a significant correlation with distance. Samples 3, 4, 5, 6, 27, 30, and 31 were considered upwind and not plotted in Figs. 3–7. Samples 1 and 2 were used as background for the major ions. Background for 226-radium was assumed to be the lowest values observed. Extrapolation of the lines in Figs. 3–6 to the background values suggests a solute influence distance of approximately 125 km downwind. The length is consistent with data from Total Ozone Mapping Spectrometer (TOMS), 2003 (Fig. 2). The data in Fig. 2 are contoured as Aerosol Index, which is a measure of optical opaqueness. October–February, corresponding to the driest period, are the months of the largest index values and hence, highest aerosol concentration.

The hypothesis that the solute footprint would extend farther downwind in a regular fashion as a function of the larger area of the source is consistence with these observations. In this case, the larger area led to a significant increase in the length of the solute footprint over that observed in western Texas (35 km), suggesting that eolian transport of evaporative salts is proportional to the amount of salt available, all other factors remaining constant. The relation between the two locations is shown in Fig. 7 and is expressed as:

$$x = 27.94y^{0.145}, \quad (1)$$

where x is the length of the footprint in km, and y is the area of the pan in km^2. Thus, a pan with an area of 1,000 km^2 would be expected to yield a solute footprint approximately 76 km long, given the same wind conditions and mineral source. Systems dominated by halite (sodium chloride) would likely have a smaller eolian footprint than those dominated by sodium sulfate or sodium carbonate. Halite tends to form in interlocking grains that create "ice-like" surfaces compared to the fine, "fluffy," more easily mobilized texture of sodium sulfate and sodium carbonate minerals.

Average concentrations over distance downwind from the source were used to provide estimates of bulk-deposited amounts of sodium, bicarbonate, chloride, and 226-radium. These concentrations were determined by first establishing a linear regressed relationship between the sample concentrations and the distance from the source (Figs. 3–6). The form of the equation for sodium, bicarbonate, and chloride is:

$$y = a\,x^{b}, \quad (2)$$

where x is the distance from source, in km, and y is the concentration, a is the intercept, and b is the slope (Table 4). The expression for calculating the distance vs. concentration relation for 226-radium is of the form:

$$y = b\ln x + a, \quad (3)$$

Table 3 Chemical analysis of trace ions (nanograms/gram dried weight) derivedfrom a distilled-water leach of soil samples

Co (ng/g)	Cr (ng/g)	Cs (ng/g)	Cu (ng/g)	Dy (ng/g)	Er (ng/g)	Eu (ng/g)	Fe (ng/g)	Ga (ng/g)	Gd (ng/g)	Ge (ng/g)	Hf (ng/g)	Hg (ng/g)	Ho (ng/g)	I (ng/g)	In (ng/g)	Ir (ng/g)	La (ng/g)	Li (ng/g)	Lu (ng/g)	Mn (ng/g)
2	1	0	17	0	0	0	35	0	0	0	0	0	0	5	0	0	0	2	0	97
6	6	0	8	0	0	0	45	0	0	0	0	0	0	1	0	0	0	0	0	900
0	0	0	0	0	0	0	38960	0	0	0	0	0	0	0	0	0	0	7670	0	0
5	17	0	32	0	0	0	0	0	0	0	0	0	0	9	0	0	6	16	0	5
1	2	0	3	0	0	0	38	0	0	0	0	0	0	1	0	0	0	2	0	62
0	0	0	0	0	0	0	25450	0	0	0	0	0	0	0	0	0	0	9930	0	0
0	5	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	11	0	2
0	3	0	8	0	0	0	3	0	0	0	0	0	0	2	0	0	0	0	0	11
1	31	0	5	0	0	0	115	0	0	0	0	0	0	0	0	0	0	0	0	36
1	0	0	2	0	0	0	75	0	0	0	0	0	0	0	0	0	0	1	0	57
0	1	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	4
0	2	0	4	0	0	0	17	0	0	0	0	0	0	0	0	0	0	1	0	1
0	1	0	3	0	0	0	30	0	0	0	0	0	0	1	0	0	0	5	0	18
0	0	0	0	0	0	0	34590	0	0	0	0	0	0	0	0	0	0	12630	0	0

Re (ng/g)	Rh (ng/g)	Ru (ng/g)	Sb (ng/g)	Sc (ng/g)	Se (ng/g)	Sm (ng/g)	Sn (ng/g)	Ta (ng/g)	Tb (ng/g)	Te (ng/g)	Th (ng/g)	Ti (ng/g)	Tl (ng/g)	Tm (ng/g)	U (ng/g)	V (ng/g)	W (ng/g)	Y (ng/g)	Yb (ng/g)	Zn (ng/g)	Zr (ng/g)
0	0	0	0	0	5	0	3	0	0	0	0	0	0	0	0	23	0	1	0	5	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	1	0	14	0
0	0	0	0	0	2710	0	0	0	0	0	0	0	0	0	1680	4210	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	330	8	3	0	4	0
0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4	0	0	0	18	0
0	0	0	0	0	1860	0	0	0	0	0	0	0	0	0	4250	0	0	0	0	0	0
0	0	0	3	0	3	0	1	0	0	0	0	0	0	0	1	4	0	0	0	4	0
0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	6	0	0	0	6	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	10	0	2	0	4	3
0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	8	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	3	0
0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18350	0

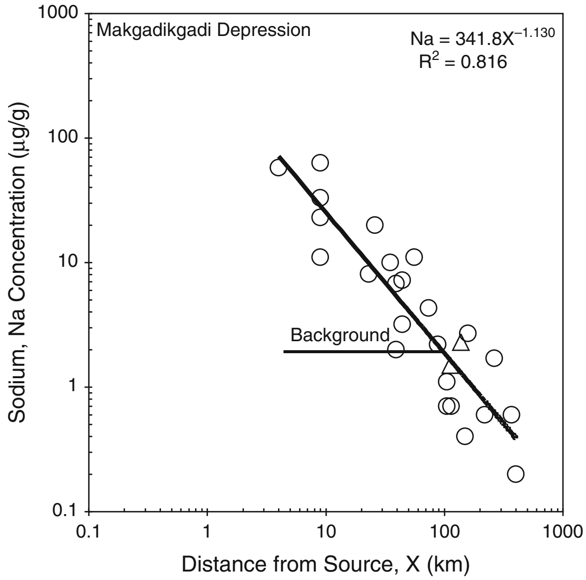


Fig. 3 Graph showing soluble sodium concentration in the soil as a function of distance from the edge of the Makgadikgadi Depression

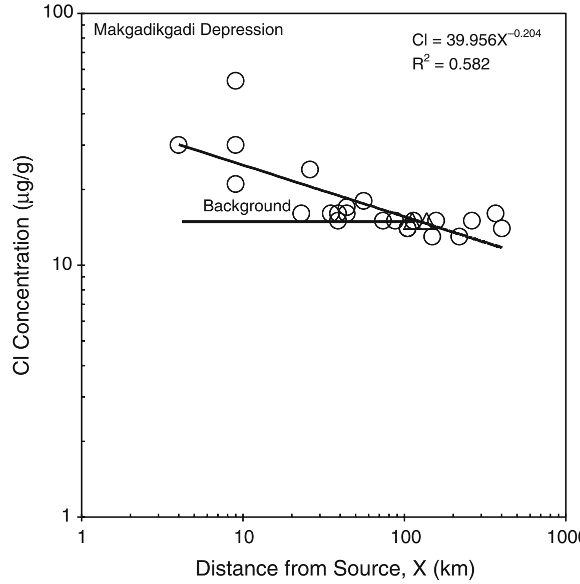


Fig. 5 Graph showing soluble chloride concentration in the soil as a function of distance from the edge of the Makgadikgadi Depression

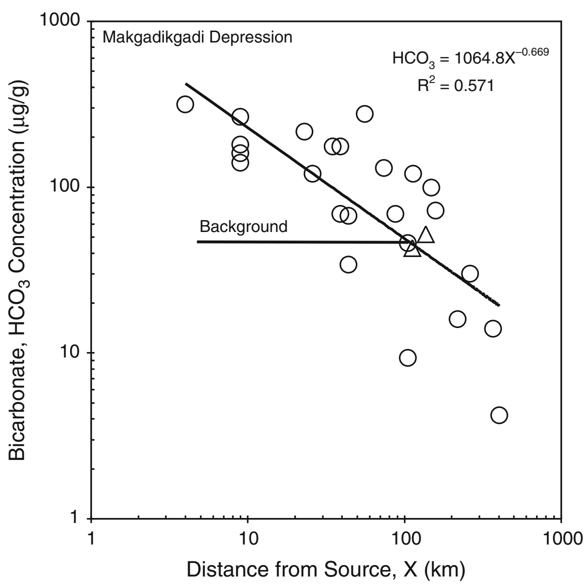


Fig. 4 Graph showing soluble bicarbonate concentration in the soil as a function of distance from the edge of the Makgadikgadi Depression

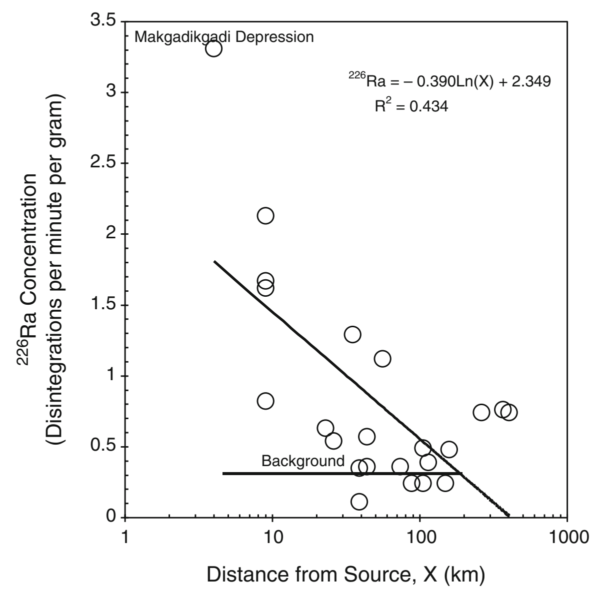


Fig. 6 Graph showing total radium activity in the soil as a function of distance from the edge of the Makgadikgadi Depression

where y is activity of the ion of interest, and ln is the natural logarithm of the distance x; other parameters are defined above (Table 4).

The linear regressed parameters were determined by ordinary least squares and are listed in Table 4. Lilliefors tests (Wilks 1995) at the 20% level strongly indicate that all these variables can be described by lognormal distributions. However, the distribution for chloride was found not to follow any type of theoretical distribution. The distribution for sodium is given in Figs. 8 and 9.

The idealized area receiving eolian input is assumed to be a rectangular area 140 by 125 km. That is, the N/S dimension of the Makgadikgadi Depression is approximately 140 km, and the downwind distance for solutes is approximately 125 km. Thus, the total area receiving soluble eolian input is approximately 17,500 km^2. Because of the complex shape of the shoreline of the Makgadikgadi Depression, the wind dispersion addition used in the study of the west Texas pan, where the shoreline is regular, was ignored. The area beneath the curves (Figs. 3–6) was determined by integration from the closest site at 4 km to approximately 125 km downwind. The distance where the sampled concentrations reached a background value was identified as the upper integration limit. Average concentrations for sodium, bicarbonate, chloride, and 226-radium were obtained by dividing the area underneath the curve by the effective distance of transport (125 km), they are listed in Table 4. The background concentrations were then subtracted from these average concentrations before any bulk estimates were calculated. Assuming soil moisture content remains at steady state with a recharge flux of 4 mm/year, similar to that of western Texas, estimates in metric tons/year are sodium 309,905; bicarbonate 2,737,266; chloride 176,615; and 226-radium 0.0154 (Table 4). The aerosol chloride flux in the small western Texas pan represented 450 metric tons/year of chloride.

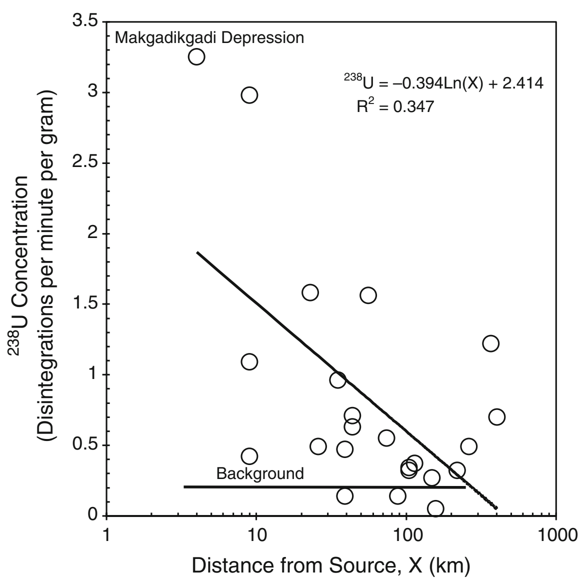


Fig. 7 Graph showing total 238-uranium activity in the soil as a function of distance from the edge of the Makgadikgadi Depression

It is suspected that the regional topography may play a role in eolian transport of particles. The wind is down the topographic gradient in the western Texas site, while the dominant wind in the Makgadikgadi Depression site is up the topographic gradient. This condition tends to minimize the length of the Makgadikgadi footprint. Because the wind direction (east to west) is opposite the regional ground-water flow direction (west to east), the amount of ground water impacted by degraded quality is lower than it would be if the gradients were the same. Further, it is clear that because of the opposing gradients, much of the solute mass is recycled back into the depression.

An additional assumption is that flux calculation assumed that the ground-water recharge is the same in both the Botswana and western Texas systems. This assumption has no observational basis. The only similarities are the amount of annual rainfall and seasonal deposition. Thus, values could be significantly different if actual values of ground-water recharge were used. Another assumption is that the estimates of radium in the calculations are based on the total amount of 226-radium in a sample above a background level (based on the lowest values seen in the data set) rather

Table 4 Mass of salts, in metric tons/annum, deposited on the surface down wind of the Makgadikgadi depression

Solute	a	b	R^2	RMSE	Area under curve	Background concentration	Average concentration over 125km	4 mm/year or 4 L/m^2 year of recharge bulk amount deposited metric tons/year
Sodium	341.8	−1.1305	0.816	0.285	790,902	1.9	4,427	310,000
Bicarbonate	1064.8	−0.6687	0.571	0.309	10825,476	47.5	39,104	2,740,000
Chloride	39.956	−0.2042	0.582	0.089	2190,206	15	2,522	177,000
226-Radium	2.3491	−0.3895	0.434	1.757	98,452	0.3	0,488	0.0154
238-Uranium	2.4142	−0.3939	0.347	1.848	104,230	0.275	0,559	52,000

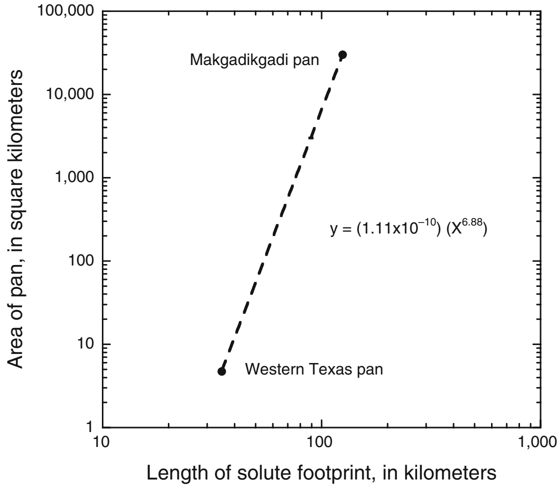


Fig. 8 Graph showing relation between length of solute footprint and evaporite covered area of the contributing pan

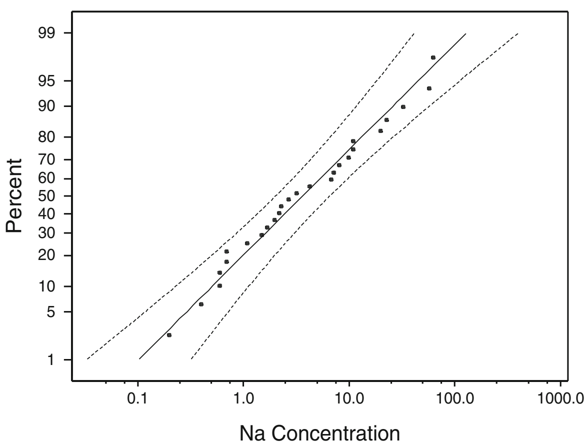


Fig. 9 Probability of non-exceedence of sodium concentration. The solid straight line represents the lognormal distribution with the same mean and standard deviation as the data; the dashed limes are the 95% confidence interval

than a soluble leach extract, as was done for the other components examined. This was done because the relative instrumental insensitivity of the technique used for quantification (gamma ray spectroscopy) would not have produced measurable responses from leach solutions used for the other analytes. Even though the radium value exhibits the same general trends as the other constituents and are consistent with the described hypothesis, it must be recognized that there is the possibility that different processes of concentration in the solute footprint of the soils may be operative for this element, which may affect the interpretation of the total quantity transported to the ground-water system. An explicit assumption in this analysis is that the flux of salts generated is the same in similar settings; thus, the total mass available for eolian transport is a function of the area of the pan. In this approach, the area of the pan is used as a surrogate for the mass of evaporite salts available, as annual mass generation is difficult to calculate.

4 Conclusions

Eolian salts from the evaporite-covered Makgadikgadi Depression in Botswana were observed in the soil between 125 and 150 km downwind from the basin. This salt input is almost certain to have an adverse affect on the underlying ground-water quality. Over three million metric tons of chloride, sodium, and bicarbonate are transported each year from the basin to adjacent land, where these soluble salts are dissolved and transported to the ground water. The relation between the size of the evaporative floor area and the length of the salt footprint on the soil was established. This relation permits use of readily available maps depicting areas of an evaporite-covered depression to estimate the area of potential degradation of ground water. This relation minimizes the amount of field sampling necessary to define the area of potential degradation. It is clear that similar eolian transport processes are occurring in the Makgadikgadi Depression and the western Texas pan and that significant eolian transport of soluble salts to the water table is likely to occur. These data should be considered in water-quality management decisions. Additional work on different basins is necessary to improve this relation and to add more control to area vs. length of the solute footprint (Fig.7). Significant mass of radioactive 226-radium is present in the eolian-transported salts and may have deleterious health consequences for individuals residing in the downwind area.

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Palaeo-Ecological Aspects of Farafra Oasis (Egyptian Sabkha) During the Mid-Neolithic Period (7130–6190 BP): A Multivariate Analysis

Ahmed Gamal-El-Din Fahmy and Monier M. Abd El-Ghani

Abstract Studies have been carried out on carbonized plant macro-remains recovered from the Hidden Valley, a Neolithic settlement located on ancient playa shoreline deposits near Farafra Oasis, Egypt. Site contexts have been radiocarbon-dated to 7130–6190 BP. A total of 63 soil samples were collected the total volume of these samples is 81 l collected in two seasons (1996 and 1997), during which a total area of 61 m^2 was excavated. Soil samples were processed by dry-screening, Recovered plant macroremains were dominated by grains of wild grasses. Multivariate and correspondence analyses were employed to explore the temporal distribution of plant macro-remains and their relationship to archaeological features, including hearths, milling stones, and pot-holes. Two-Ways Indicator Species Analysis (TWINSPAN) of a data matrix of 40 samples × 36 taxa using density values resulted in the recognition of seven floristic groups. Canonical Correspondence Analysis (CCA) was used to examine the relationships between floristic groups and 18 archaeological variables. The highest densities of plant macro-remains characterised sections of the site that had been occupied by human Neolithic inhabitants for longer periods of time (horizons 1 and 2). The highest species diversity indices were that of pot holes, while sediments collected near milling stones had the lowest values. The study indicated that the playa deposition on the archaeological site provided a unique opportunity to preserve the botanical remains underneath. Reconstruction of the past vegetation around the Hidden Valley settlement increased our knowledge on palaeoecological aspects of the Farafra Oasis during the Mid-Neolithic period.

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1 Introduction

Early Neolithic human populations of the Eastern Sahara are known to have inhabited the shorelines of ancient playa lakes as early as 8,000 years ago (Wendorf and Schild 1980). Previous macro botanical studies in Nabta playa by Wasylikowa et al. (1995) have shed the light on their significance for palaeo-environmental studies in the Western Desert of Egypt. Remnants of these settlements are preserved today in playa deposits, such as those found at the site of the Hidden Valley located 65 km north of Farafra Oasis. Excavations conducted at this locality in 1996 and 1997 by Prof. Barbara Barich (University of Rome "La Sapienza") have produced the remains of a permanent or semi-permanent Neolithic human settlement preserved in playa shoreline deposits. Long-term continuous occupation of this site is indicated by a deep stratigraphy (1 m), which revealed a clear succession of occupation floors containing many hearths. According to Barich (1996) radiocarbon determinations for the site have been done in Silesian Technical University, Gliwice, Poland, they are: 7030 BP (Gd-1170)/6910 BP (Gd- 9629) and 7130 BP (Gd-10505)/6710 (Gd-7820). Carbon dating was followed by radiocarbon laboratory number between practice for documentation. Also, she recognizes three horizons of occupation, all of which have produced notable traces of human activity, including rock-lined hearths, small pot holes, and milling stones. In 1996, 38 m^2 were excavated using a 10 × 10 m grid, and the work concentrated on the archaeological sectors 96 E

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and 96 F/1. In 1997, excavations were extended further east to cover sectors 97 E and 97 F trench, and a total area of 23 m^2 was uncovered. A corridor was cut in order to connect the eastern sector with the central area of the settlement, which contained circular structures used by Neolithic inhabitants as dwellings.

At present, the climate of this region is extremely arid. Precipitation records from 1969 to 1989 indicate a mean of 2 mm/year consequently the area around the Hidden Valley is completely devoid of plant cover. The present study aims at finding correlation between the distribution of the recovered plant macro-remains and the excavated archaeological features including hearths, milling stones and pot holes using multivariate analysis techniques. Another goal of the study is to reconstruct past vegetation around the site in question.

2 Materials and Methods

A total of 63 soil samples amounting to 81 l was collected from hearths, pot-holes, milling stone and living floors in 1996–1997. Hearths are spherical holes, about 40 cm in diameter and 20 cm in depth. The inhabitants used these features as primitive ovens. Pot holes are small depressions in which vessels containing food are placed for cooking by piling hot ash around them (Mitka and Wasylikowa 1995). Milling stones are rounded, concave, stony artefacts used to grind grains of wild grasses.

Quantities of individual soil samples ranged from 0.75 to 4.00 l. Ashy layers were targeted for the recovery of plant macro remains including, seeds, grains and culm fragments. All samples were dry-screened in the field using a 3 mm mesh to separate stones, potsherds, and charcoal fragments, after which they were transported in plastic bags to the laboratory. Although samples collected in 1997 were entirely examined, those excavated in 1996 were sub-sampled in 100 ml units using a 5 ml spatula. Each sample (or sub-sample) was sieved through 1.0 and 0.5 mm mesh sieves and preliminary sorting was completed using a binocular objective magnification (8–25 X). Plant macro-remains were examined in more detail using a Wild stereoscopic microscope with a range of magnification from 20 to 50 X. Identifications were made using descriptions and illustrations in publications concerned with the flora of Egypt (Täckholm 1974; Boulos 1999; Cope and Hosni 1991).

Some illustrations in these contributions are provided with drawings of spikelets, grains and seeds of living plants, which have been used by the first author to narrow the scope of identification into definite species or genera. On the other hand, illustrations, photos and descriptions of plant macro-remains from the Nabta playa by Wasylikowa (1992, 1997) and Wasylikowa and Kubiak-Martens (1995). According to Wasylikowa (1997), identification categories include the qualification "type" following plant name, which means that morphological resemblance to a taxon named but without excluding the possibility that similar fruits, seeds may be found in other taxa which were not examined by the first author. On the other hand, the abbreviation "cf" means closer identification than type. Identifications were confirmed through comparison with modern reference collections of Egyptian plants housed at the Department of Botany, University of Helwan, Cairo.

Two-Way Indicator Species Analysis (TWINSPAN; Hill 1980) a polythetic divisive classification method; was applied on a data matrix comprising 40 samples × 36 taxa using their density values. Here, density is the number of plant macro remains per liter of soil sediment retrieved from the archaeological site in question TWINSPAN program was run using the default options, with the exception of the pseudospecies cut levels which were altered to: 0, 5, 10, 20, 40, 60 and 80. The computer program CANOCO 3.12 (ter Braak 1991) is used for all ordinations, and plots were drawn using CANODRAW 3.0 (Smilauer 1993).

Preliminary analyses were made by applying Detrended Correspondence Analysis (DCA) to check the magnitude of change in species composition along the first ordination axis (i.e., gradient length in standard deviation units). All default settings were used for CCA, except the samples scores that are the weighted averages of species scores. The variables in the CCA biplots are represented by arrows pointing in the direction of maximum variation, with their length proportional to the rate of change (ter Braak 1986) Each arrow determines an axis on which the species points can be projected (ter Braak and Prentice 1988). In general, these projection points estimate the optima of species distribution for each archaeological variable. Intra-set correlations were used to assess the importance of the archaeological variables. All data variables were assessed for normality prior to the CCA analysis (Berk 1994), and appropriate transformations were performed when necessary to improve normality according to (Zar 1984) In total 18 archaeological variables were used: 4 archaeological artefacts (AF), including hearths (H), pot holes (PH), milling stones (MS) and corridors (C); and 13 depths below surface (D), including D_1 (10 cm), D_2 (15 cm), D_3 (20 cm), D_4 (25 cm), D_5 (30 cm), D_6 (35 cm), D_7 (40 cm), D_8 (45 cm), D_9 (50 cm), D_{10} (55 cm), D_{11} (60 cm), D_{12} (65 cm), D_{13} (70 cm), D_{14} (75 cm) and D_{15} (80 cm). We checked all archaeological variables for multicollinearity problems, and two depths: D_{10} and D_{15} are removed from the analysis. Monte Carlo permutation tests (99 permutations) were performed to test the significance of the first canonical axis.

The species diversity within each recognized floristic group was assessed using two indices expressing species richness and relative evenness of species abundance. Species richness was expressed as the average number of species per sample, while relative evenness was calculated using the Shannon–Wiener index ($H` = -\sum pi \log pi$) where p*i* is the relative density of the *i*-th species (Pielou 1975).

3 Results

Seven floristic groups (A–G) were recognized after the application of TWINSPAN technique. Group A includes three samples dominated by *Sorghum* grains, and represent the corridor in sectors 97 E corridor and 97 F trench as well as a hearth in sector 97 E. It is. Group B comprised seven samples dominated by *Echinochloa* and *Setaria* grains belonging to sectors 97 E, 97 E corridor, 96 E and 96 F/1, and were all retrieved from hearths. Group C includes 13 samples, nine of which are dominated by *Setaria* while *Echinochloa* prevailed in four. Specimens originated from hearths and pot holes from sectors 97 E, 97 E corridor, 96 E and 96 F/1. Group D includes samples dominated by seed fragments of *Acacia* type, recovered from sectors 97 E, 97 E corridor and 97 F. Group E includes six samples dominated by grains of *Panicum* and *Sorghum*, and collected from hearths at 97 E, 97 F corridor and 96 E. Group F includes one sample that had fruits (siliqua) of *Coronopus* which was recovered from a hearth in sector 96 F/1. Group G had four samples clustered in this group, dominated by Leguminosae type-seeds. The sediments were excavated near a milling stone and from hearths in sector 96 F/1 and sector 97 E. The highest densities of plant macro remains occur in sectors 96 E and 96 F/1, both of which were inhabited for longer periods than sectors 97 E, 97 E corridor and 97 F trench.

4 Discussion

The present study shows that plant macro-remains appear in higher concentrations in the stratigraphic levels 10, 25, 35, and 40 cm below surface. In particular, the remains of *Echinochloa*, *Setaria*, and *Brachiaria* appear to cluster at a depth of 40 cm (D_7). Stratigraphic levels 10–40 cm correspond to the first and second horizons of occupation recognized through artifactual evidence by Barich (1996). Consequently, densities of plant macro-remains appear to support the archaeological interpretation that the first and second horizons were occupied for a longer periods than others, perhaps due to the prevalence of favourable environmental conditions, such as summer rainfall associated with low temperatures.

The associations of macro-remains with archaeological features including hearths, pot holes, milling stones, and corridors. Grains of *Digitaria* and *Sorghum* are clearly associated with hearths at 10 cm below the surface (D_1). Perhaps these grains were deposited in the hearths as the result of cooking accidents. In addition, there is a high correspondence between the seeds of Cruciferae-type and *Schouwia* with recovered pot holes (AF_2). This pattern could suggest that these vessels were used to prepare foodstuffs, which included wild grasses and *Schouwia* seeds. There is another possibility that parts of these seeds could have been introduced into the deposits via being burned as ash for fuel.

The results of DCA indicate a reasonable segregation among groups along the ordination plane of axes 1 and 2. The eigenvalue for the first DCA axis 1 was relatively high ($\lambda = 0.675$), indicating that it captured the greater proportion of the variation in the taxa composition among the floristic groups. Statistical analysis of the samples under study reveal that wild grasses are highly represented in most of the studied samples. The 289 caryopses identified are attributed to 8 taxa: *Digitaria* type, *Sorghum*, *Echinochloa* cf. *colona*, *Setaria*, *Stipagrostis* type, *Brachiaria*, *Panicum* cf. *turgidum*, and *Cenchrus* type. In particular, *Sorghum* grains show a highly significant p value (0.001), indicating that this taxon must have been a common plant in the area during the various periods of habitation.

Canonical correspondence analysis (CCA) was performed on 40 samples, 34 taxa and 16 archaeological variables. The eigenvalues for the first two CCA axes (1 = 0.395 and 2 = 0.350) indicate acceptable levels of separation of sample scores along the measured archaeological variables. The successive eigenvalues of the first three axes (1 = 0.395, 2 = 0.350 and 3 = 0.330) of the CCA decrease rapidly, suggesting a well-structured data set. In general, intra-set correlations are low.

Although medicinal uses of *Schouwia* species have considerable antiquity (Fahmy 1995), based on this evidence alone, it is not possible to argue convincingly that this species was used as a medicine during the Neolithic occupation of Hidden Valley. Indeterminate grains and milling stones (AF_3) are highly correlated (results not shown). This pattern could be attributed to the fact that grains are destroyed in the grinding process, making them difficult to identify to definite taxonomic categories.

The highest species diversity indices are recorded from pot holes while sediments recovered near milling stones show the lowest. Because of their association with cooking (Mitka and Wasylikowa 1995), it is not surprising that pot holes produced highest species diversity values. Possible sources of seeds in these features are foods lost during cooking as well as plant materials in the ashes used to heat the pots. The ash layer surrounding the pot holes would have provided a gentle charring environment where grains could fall into the hot ashes surrounding the vessels. In case of hearths, grains are more apt to fall directly into fire resulting in their destruction. This could explain the high number of taxa recorded from pot holes compared to hearths. The low species diversity indices of milling stones are attributed to the fact that grinding results in the deposition of fragmentary grains, making them difficult to identify. The relatively high number of species recorded from the corridor is probably related to the large quantities of soil samples (17 l) examined from this context.

5 Palaeo-Economic Interpretations

The recovery of several wild grasses from hearths, pot holes, and milling stones strongly suggests that Neolithic inhabitants of the Hidden Valley gathered them for food consumption. The eight wild grasses identified in site deposits are: *Brachiaria*, *Cenchrus* type, *Digitaria* type, *Echinochloa colona*, *Panicum turgidum*, *Setaria*, *Sorghum*, and *Stipagrostis* type. Many of these taxa have been identified at other Saharan sites, and this, in addition to ethnohistoric evidence, further indicates the widespread use of these species by Saharan populations from ancient to recent times (Barakat and Fahmy 1999) *Sorghum* represents 41.5% of the total number of grasses identified in the Hidden Valley samples. The caryopses are well preserved by carbonization. They are dorsally flattened, obovate to oval elongate in outline, and some are still enclosed by coriaceous glumes. Morphologically, these *Sorghum* grains compare very well with those recovered from Nabta Playa (8,000 BP), Wasylikowa and Kubiak-Martens (1995), Wasylikowa et al. (1995) and Wasylikowa (1997) attribute the Nabta remains to *Sorghum bicolor* (L.) Moench. subsp. *arundinaceum* (Desv.) De Wet and Harlan, a species whose distribution extends across the African savanna (Wendorf and Schild 1980; De Wet 1978). Further investigations are underway to more precisely identify the Hidden Valley *Sorghum* grains. Neolithic inhabitants may have intensively collected its panicles for food due to its big grains in comparison to the associated wild grasses.

From an ecological point of view, the dominance of *Sorghum* during the Neolithic period is expected, as this grass is characterized by wide ecological amplitude due to its remarkable physiological features. *Sorghum* can cope with hot and dry conditions, and it is a high salt tolerance. Furthermore, it can withstand high rainfall, and even temporary water-logging. Its penetrating multi-branched roots are very useful to compete for water with other plants at different depths of the soil (National Research Council 1996).

The macro-remains of eight wild species are represented at Hidden Valley in relatively low frequencies: *Acacia*, *Coronopus niloticus*, *Juncus*, *Phragmites*, *Tamarix aphylla*, *Typha*, *Carex*, and *Cyperaceae* type. This assemblage of plants probably formed part of the natural vegetation in the vicinity of the site during the mid-Holocene. Although many of these wild plant remains have not yet been identified to the species level, some ecological inferences are possible. The relative profusion and assortment of the recovered specimens may indicate that regional plant cover was rich in species and that compared to modern times, a much wetter environment was in existence during the Neolithic. Rainfall is estimated to have been between 100 and 250 mm annually during the wet phases of the early and middle Holocene (Neumann 1989). Also it is very interesting to note that the assemablage of wild grasses identified from the Hidden Valley are recorded in studies on recent vegetation of North and Central parts of the Sudan (Schulz 1988; Wilson 1978). These areas of the Eastern Sahara enjoys precipitation ranges between 100 and 250 mm (Walter 1979).

The present data indicate that two types of vegetation existed in the vicinity of the playa, one dominated by reeds and the other by thorny vegetation. Reed vegetation probably existed along the playa margins and may have experienced some fluctuation in water levels, but for the most part remained waterlogged throughout the year. *Typha* and *Phragmites* dominated this vegetation type. The wet fringes around the playa probably provided a favorable habitat for the growth of associated species, such as *Tamarix* and *Juncus*, as well as water loving species such as *Carex* and *Coronopus niloticus*. This reconstruction is based on modern vegetation analysis around water bodies (e.g. springs) in the oases of the Western Desert (Zahran and Willis 1992). Thorny vegetation probably occurred on the plain surrounding the playa. Trees of *Acacia* grew on the upstream sections of water runnels that dissected the plateau towards the playa. Several wild grasses including, *Digitaria sanguinalis*, *Sorghum*, *Echinochloa cf. colona*, *Setaria*, *Stipagrostis type*, *Brachiaria*, *Panicum cf. turgidum*, *and Cenchrus* type would have dominated the herb layer.

6 Conclusions and Recommendations

The present study provides archaeobotanical evidence on the relationship between man and their Neolithic environment in the Egyptian Sahara. Also, it increases our knowledge regarding economy and ecology of settelements, where, the settlers lived close to sabkhas collecting wild grasses and herding animals.

Results obtained from Nabta and the Hidden Valley (Fahmy 2001; Barakat and Fahmy 1999) add important dimension to the sabkha ecosystem research. Understanding the subsistence strategy of these early groups of people can be achieved only through archaeological and archaeobotanical studies.

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Overview of Halophytic Plants of the Sudanese Red Sea Salt Marsh

Omyma Osman Karrar

Abstract Halophytes of the Sudanese Red Sea coast are considered to be one of the important key habitats in the region providing many important ecological functions and useful services. At present, these communities are exposed to coastal disturbances and wide spread degradation due to combination of factors. To this effect, this review was organized in order to illustrate the extent and magnitude of these effects if exists .The results of the effects on the status of these communities have been enlisted followed by discussion leading to conclusions and recommendations that are hoped to contribute towards future conservation and management.

1 Introduction

Sudan is the largest country in the African continent with a total gross area of 2.505,800 sq km including deserts and water-bodies. It lies between 4–22ºNC and 22–36ºE. This location has given Sudan distinctive characteristic reflected in variety of environments and hence variety of flora and fauna. Ecologically Sudan is divided into six zones. These are the desert zone constituting 29% of the total land area, semi-desert zone covering 20%, low rain Savanna on sand and low rainfall Savanna on clay constituting 13% and 14% of the total arid area respectively; and the heavy rainfall Savanna of a total area of 13.8%.The sixth zone is comprised of what is known as Special habitats. This includes the Erkawit plateau 900 meters above the sea in the Red Sea Hills in the eastern part of the country, Imatong and Dongotoren mountains in the south. Special habitat zones are characterised by unique botanical composition (Kassas 1957).

The river Nile is the most significant feature in the country forming a prominent incision in the terrain. The Red Sea is the second dominant water body. Sudanese Red Sea extends for 750 km including embayments and inlets. It constitutes a unique ecosystem with high biological diversity and its natural resources provide substantial economic support for the region (Schoreder 1982). The climate along the coast is very dry with annual rainfall around 111 mm varying from 39 mm at Haliab (Northern Sudanese Red Sea coast) and 164 mm at Suakin harbour (southern coast). The Sudanese coast lies in the intermediate region of the Red Sea which is characterized by a definite wind regime between the North–north west at the northern half and the south east winds. This area is characterized by relatively low pressure and temperatures which shows progressive increase in southward direction. Fundamental movement of surface waters follows the winds pattern. (Sheppard et al. 1992). Salinity varies from39% to 41% and surface water temperature ranges from 26°C to30.5°C and it may be higher in shallow and enclosed areas.

2 Study Area

2.1 *Red Sea State*

The most important land forms of the Red Sea state are the coastal strip, The Red Sea hills and the plateau stretching west of the hills with an elevation of up to 1,000 m. The most dominant topographical feature is the rocky hills which are intersected by the seasonal

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water courses draining east into the Sea and west into the Nile. The region is characterized by a number of varying habitats, these are:

The Wadis or water courses (local name denoting the presence of ridges and elevations with low lying runnels).

The mist, low temperature oasis of Erkawait.

Inland river deltas.

Salt marshes along The Red Sea.

All these features are reflected in the structure and composition of flora and fauna of the region which is classified as the semi-desert grass and shrubs.

2.1.1 Basic data

The Red Sea state, as the name implies borders the Red Sea, yet few people earn a living from the sea. The population of the state live at the centres located on the coast including Port-Sudan, Suakin, Toker and the Sinkat sub-region. The population consists of rural nomadic, rural settles and urban people who represent 48%, 26% and 26% of the total population respectively. People to the north of Port-Sudan are generally classified as being more dependent upon the sea and those to the south on nomadic pastoralism and small scale seasonal agriculture in the Toker Delta. Port-Sudan is the major sea port for Sudan. The city has a population of about 30,0000 which is approximately 30% of the estimated population for the Red Sea (CIDA 1995). Most of the industrial and economic activities are concentrated in Port-Sudan. The nearest populated centre is Port Suakin 57 km south of Port Sudan. It is the second largest sea port on the Sudanese coast. It handles mostly passenger vessels and small vessels. Most of the newly planned socio-economic projects are located within Suakin and Port-Sudan.

Coastal and marine habitats of Sudan include sandy, muddy and rocky beaches, salt marshes, sub-tidal soft bottom areas and extensive coral reefs. A typical feature of the 720 km coastline are "Mersas" which are sheltered embayments often fringed with mangroves. Significant mangrove areas are located south of Port-Sudan and Suakin with great number of species and habitat diversity (Krupp et al. 1994).

However based on recent studies, it is reported that the range of plant species have declined greatly due to the increasing pressure from the surrounding region during the recent recurrent drought and the unfriendly human activities. At present there is a great concern about the rapidly deteriorating conditions along the coast from various hazards resulting from coastal activities. (Suga 1999; Khider 2000; Bashir 2001).

3 Objectives

To provide a review of the current status of halophytic communities of the coastal region.

To identify possible threats to these resources.

To provide some suggestions for conservation programmes.

4 Literature Review

This review has prompted the need for consultation of literature on the subject matter with reference to topics of relevance. However biology and taxonomy of the Sudanese Red Sea marine and coastal habitats have been investigated by relatively few scientists. Andrews (Andrews 1948, 1950; 1952; 1956) gave a passing reference on the taxonomy of the halophytes of the Red Sea region. His outstanding pioneer work gave merit to his work as a leading accomplishment. Kassas (1957) and Kassas and Zahrah (1967) provided detailed description of these natural communities which stand out beyond any other in the region at that time. The references for the last three decades include SMSD (1950–1980); Chapman (1974); Mohamed (1984); UNDP, UNESCO (1986); Eltom (1989); Sheppard et al. (1992); Abdel Latif (1993a); Krupp et al. (1994); FNC (1994); CIDA (1995); UNEP/PERSGAA (1997); Elhag and Abdel Gadir (1998); Suga (1999); Abu Gideiri (1990); Ali et al. (2000); Khider (2000); Bashir (2001); Karrar (2003). It is worth mentioning that Bashir (2001) in Sudan Country Study on Biodiversity dedicated many parts to this topic and contains more information on the subject that has been accumulated in any subsequent publication.

5 Methodology

The assessment consisted of inventory of all related elements on the main subject matter. These include information on the main habitats and their characteristics, species composition, environmental threats and pressures to which they are currently subjected. Sources of information consulted include published literature, departmental reports and results of previous questionnaires and field surveys of selected sites of the study area by the author, in addition to discussions with the staff of the ministry of agriculture-Red Sea State and community leaders.

6 Results

The following brief summaries together with tables and diagrams describe the current status of salt marsh communities in terms of species distribution, diversity and related threats and environmental impacts. The data obtained are assessed and utilized in the overall assessment of the current status as basis for the prediction of the future.

The sea salt marsh covers approximately 7 km in width, it consists of shallow waters interrupted by wide bays, lagoons and drainage extremities of seasonal streams originating at the Red Sea Hills and mainly covered by salt tolerant grasses and shrubs.

6.1 Floristic Composition

The flouristic composition of the Sudanese salt marsh constitutes 11 major families with a varying number of representative species (Table 1). Families Chenopodiaceae and Gramineae are represented by a wide range of species while the rest are represented by fewer species; two to three species at most. The distribution of the Halophytic communities along the different zones of the Salt Marsh is shown in Table 2.

The halophytic communities dominate three Marsa or gulf habitats, namely Heidub, Ata and Arus. In these habitats halophytic communities exhibit clear and distinct zonation according to soil type and salinity gradient.

Marsa Heidub is rich Red Sea Mangrove; halophytic communities include *Arthrocnemum glaucum, Halopoplis perfoliata, Suaeda fruticosa* and *Suaeda monoiaca.*

Marsa Ata is an open bay protected by coral islets. Its location is a typical representative of salt marsh sector. Most dominant halophytes are *Artrocnemum glaucum, Halopoplis perfoliata. Acluropus lagopoides, Suaeda fruticosa and Suaeda vermiculata.*

Table 1 Floristic composition of the Red Sea Salt Marsh

Family	Species
Chenopodiaceae	*Arthrocnemum glaucum, Atriple farinose, Halopolis perfoliata, Salicornia fruticosa, Salsola baryosma, Suaeda fruticosa, S. monaica, S. vermiculata, Acluropus lagopoides*
Gramineae	*Aristida adscensionis, Conchrus setigrus, Cyperus glomeratus, C. rotundus, Dactylotenium aegyptiun, D. scindicum, Echinochola colonum, Juncus arabicus, Lasiurus hirsutus, Panicum turgidum, Sporobolus spicatus, Targus beteronianus*
Mimosaceae	*Acacia tortilis, Prospis chillensis, Limonium axillare*
Resedaceae	*Ochradenus baccatus*
Rhamnaceae	*Ziziphus spina-christi*
Salvadorceae	*Salvadora persica*
Solanaceae	*Datura stramonium, Soanum dubium*
Tamariacea	*Tamarixx aphylla*
Tiliacea	*Corochorus depressus*
Verbenaceae	*Avicennia marina*
Zygophyllaceae	*Tribulus terrestris, Zygophyllum album and Z. simplex*

After Bashir (2001)

Table 2 Distribution of Halophytes in the Sudanese Red Sea Salt Marsh

Location	Species
Marsa Heidub	*Avicennia mania, Arthrocnemum glaucum, Halopoplis perfoliata, Suaeda fruticosa, suaeda monoica*
Marsa Ata	*Avicennia mania, Arthrocnemum glaucum*
	Halopoplis perfoliata, Acluropus lagopoides, Suaeda fruticosa, Suaeda vermiculata
Marsa Arus	*Limonim axillare*
	Salicornia fruticosa, Artiplex farinose
Khour Arus	*Suaeda monoica*
Transition zone	*Jatropha aceroidesAcacia Trotilis, Tamarix aplylla, Calotropis procera.Zygophyllum album,Limonium axillare,Sporobolus spicatus,Aeluropus*

Marsa Arus represents the salt marsh in the North with varying habitat from the southern part due to the presence of the water edge which in direct contact with the coral reefs. It is characterized by hard calcareous soils and consequently different halophytic species such as *Limonium axillare, Salicornia fruticosa and Atriplex farinosa.*

Khor Arus is characterized by salinity gradient that decreases from the water edge towards the upper reaches of the Khor and consequently it supports different types of vegetation. Halophytes are dominated by *Suaeda monoica* which thins out at the upper reaches of the Khor where the semi desert plants prevail. These include *Jatropha aceroides, Calotropis procera, Acacia trotilis and Tamarix aphylla.*

Other halophytic communities include patches dominated by *Zygophylum album, Limonium axillare, Sporobolus spicatus* and *Aeluropus lagopoides.*

Mangroves: are the most conspicuous of the coastal vegetation. Thirteen mangrove sites are recorded along the Sudanese southern coastline south of Port-Sudan and Suakin Harbours mainly fringing coastal lagoons. Three of the four mangrove species known to occur in the Red Sea are found in the Sudanese coastline. These are *Avicenia marina, Rhizophora muncronata, Bruguiera gymnorhiza. Avicenia* is the most porominant while *Rhizophora* is restricted to few locations in the southern coast. *Bruguiera* is the least prevalent mangrove and mainly found in the northern part of the coast. Apart from the above mentioned localities, other important mangrove stands include Kilo-Tammania south of Port-Sudan, Klianeeb and Heidub south of Suakin.

7 Potential Threats

The coastal vegetation is subjected to various environmental threats which are expected to augment as further coastal development occurs. These are summarized in Table 3. One of the most significant environmental problems is related to coastal land use and human activities. These include filling and dredging which is usually carried out in shallow inter-tidal waters resulting in the destruction of a number of biologically important habitats including halophytes and mangroves through removal or accumulation of silt. Another threat is the pollution from various sources of the marine and

Table 3 Threats to halophytic communities; impacts and causes

Issue	Impacts	causes
Habitat destruction		
Coastal development	Dredging and filling (siltation and burial), destruction of mangroves	Urban, Industrial and port development
Waste disposal	Pollution of coastal areas around Port Sudan and Suakin harbors	Improper disposal facilities
Coastal tourism	Disturbance to vegetation	Treading, collection of shells
Salt pans	Damage of mangroves and associated flora and fauna	Construction and consequent removal of vegetation cover
Sedimentation	Mobilization of sand	Deforestation grazing of livestock-fuel wood collection
Urban development		
Coastal construction	Damage to coastal and marine biota	Infrastructure development
Discharge of untreated or insufficient treated sewage and solid wastes	Eutrophication and alteration of coastal environment	Lack of sewage treatment plants, lack of maintenance of existing ones and improper disposal facilities
Industrial activities		
Industrial pollution	Decline in water quality	Chemical pollution, organic pollution and thermal pollution
Maritime risks		
Marine vessel sewage and discharges of solid wastes	Localized marine and beach pollution	Discharges from ships
Petroleum development and transport		
Oil spills	Beach contamination, damage to coastal and marine biota	Discharges from terminals accidents, ballasts and bilge water

coastal environment. Pollution is becoming a problem of growing magnitude especially along the coasts of Port-Sudan and Suakin harbours. This includes oil and thermal pollution, industrial effluents, chemicals, pesticides and solid wastes from industrial and domestic sources (Elhag and Abdel Gadir 1998). Coastal tourism if uncontrolled is expected to result in disturbance to vegetation. Another concern is related to planned socio-economic development of the coastal region which includes a number of projects and activities, each with a different set of requirements and impacts. A major threat is attributed to one of the oldest and major activity along the Sudanese coast i.e. salt pans construction. Construction results in the removal of halophytic plants including well established mangroves.

8 Discussion

The Red Sea Coast is an area of intense activity, an area of interchange within and between physical, biological, social and economic processes. Its shallow coastal area have traditionally supported high productive ecosystems from which resources are harvested, in addition to natural protective and defensive fluctuations against coastal erosion and flooding. Red Sea marine coastal habitats are potentially subject to various interactions, not only physical interactions but also with regard to human population inhabiting the area with wide variety of activities leading to certain changes in coastal environment.

The combined action of the basic natural constraints and patterns of human exploitation may eventually stress coastal ecosystems that might in the future lead to complete degradation, risks to become endangered or even extinct (Karrar 2003). The expected change in climatic patterns and trends of natural deficiency seem to enhance environmental challenges to sustainability. The findings of the present review contribute supporting evidence to the above mentioned factors.

Halophytes – Saline zones include the salt marshes that fringe the land masses, coastal swamps and bays. Maritime salt marshes are relatively more spread. The dominant natural vegetation in saline habitats consists essentially of micro flora, phanerogamic herbs, some shrubs and trees. In the warm marshes there is a predominance of tropical true halophytes (Chapman 1974). These include succulents such as *Arthocnemum sp*, *Sueda spp* and *halopeplis sp*. The common salt tolerant types that are non-fleshy include *Limonium sp*, a number of *wiry grasses* such as *Sporobolus sp, Aleuropus sp* in addition to mangroves which are considered as special group of perennial halophytes (Suga 1999). Coastal areas are fragile in view of ecological hazards to which they have been subjected. These hazards include active erosion and periodical inundation of sea water leading to removal of top fertile soil and increase in salinity levels (UNDP, UNESCO 1986). Other factors include microclimatic conditions of the region (Eltom 1989).Vegetation densities and diversity are mainly governed by physiographic, edaphic and biotic factors. It is generally known that rainfall and relative humidity are higher in the southern part of the province (SMSD 1950–1980). All these factors act in a mosciac pattern creating favourable conditions for some where biological impacts such as human interference and overgrazing of more palatable species leading to destruction of some species being intense in the area (Mohamed 1984). Local administrators claim that the danger of herding domestic live-stock lies in the traditional pastoral nomads. Nomadic overgrazing of vegetation causes considerable damage to the natural plant covers and consequently inflicts barrenness of the landscape. Intermittent droughts which reflect upon the annual rainfall averages periodically limit vegetation cover to small pockets (Khider 2000; Bashir 2001). Cutting woods for domestic fuel, poses another local hazard (NEA 1983). Supplementing poor income in dry years is solved by the recent increasing demand for commercial fuel-wood, charcoal and bakery wood. This practice is likely to continue as an important source of income generation. The need for fuel wood is progressively increasing due to a clear trend of rural–urban migration and the network of fast roads to congested areas. The advancing recent aridity and excessively severe browsing of the more palatable species may account for the increasingly restricted presence of some species (FNC 1994).

Indigenous knowledge claims a strong invasion of the more competitive *Prosopis chilensis* trees being more drought tolerant and undesirable by animals.

In salt marshes where halophytes dominate in a zonal pattern of pure stands, camels are the sole animals which browse on twigs, leaves and young branches. These areas are highly degraded now (Abdel Latif 1993a; Khalil 1994). In general there is a decrease in the number of communities between the Red Sea

Coast and desert plain regarding halophytic and non-halophytic species when compared to Kassas (1957) records (Mohamed 1984; Suga 1999; Khider 2000). The present day vegetation and flora of The Red Sea Salt Marsh were reduced to poor diffuse tri-zonal assemblage of halophytes in the marginal saline habitat along the coast. The floristic composition consists of medium sized stands and shrubs in open formation. Pure stands were reduced and sporadic (Bashir 2001). Previously existing zones of halophytic communities of Marsa Ata do not exist anymore in the ecological sense. Absence of zone boundaries and overall morphological deformity is quite evident. Deterioration is a direct outcome of salt pans construction which involves the total removal of vegetation cover.

Mangroves – Mangroves are extremely important forms of coastal vegetation providing many important ecological functions in stabilizing sediments, protecting the coastline as well as providing feeding and nesting grounds for commercially important fisheries in addition to other economically valuable products. However harsh environmental conditions in the region where temperature and salinity are near upper limits of their existence make them very sensitive to disturbances and probably limits their ability to recover (UNEP/PERSGAA 1997). Most of the recent studies on Sudanese mangroves have confirmed that some stands are severely damaged. The magnitude of damage is variable from severe or moderate to light. The most affected mangroves are those of Kilo-Tammania, Shuokh and Halout (Abdel Latif (1993b); Suga 1999). Indications of mangrove destruction is also evident in Marsa Heidub which used to be typically rich Red Sea mangroves (Bashir 2001). This is quite evident when shoreline mangroves are compared with the inaccessible stands on the islands. The current condition is mainly attributed to the general degradation of the region rangeland. Mangroves offered an alternative substitute for grazing animals and important source for wood for fuel and housing construction. Some stands are heavily stressed or deteriorated. This situation is expected to intensify due to further pressure imposed by the newly planned socio-economic projects (Abu Gideiri 1990; Ali et al. 2000). Degradation of mangroves world wide is still attributed to active rehabilitation, expansion of ports, construction of new ones and human activities. The aims of reclamation are socio-economic growth in industry, urban and rural settlement. Such human manipulations have seriously threatened mangroves. Simultaneous with the above man-made destruction to extensive fragile and vulnerable ecosystems is a natural considerable degradation stress that have been observed in the last two decades.

9 Managerial Aspects

Halophytes have low priority index in the minds of the policy – makers, development planners and local administrative bodies. They are generally considered as resources with limited economic potential. The importance of halophytes is admittedly indirect and therefore their value tends to be underestimated and often limited to uses for fuel wood and sources of fodder. Halophyte ecosystems are unique whose habitat support diverse flora and fauna. They play a vital role in coastal stabilization and in maintaining the Sudanese Red Sea biodiversity heritage which would be lost if they perished. Other problems are related to data collection systems which lack proper planning and transparency, another factor is that management policies are not well defined and not based on reliable data base due to inadequate human and financial resources. Modern guidelines for responsible management is not yet part of the legal national framework. This requires an approach less focused on short term considerations and more concerned with long term sustainability of resources and the environment. Within this context, it is worth mentioning that UNESCO Regional Office-Doha is establishing a bio-saline pilot farm in the Red Sea State for the utilization of sea water to grow mangroves and other palatable halophytes as part of sustainable development of the region to address local communities basic needs as well as restoring coastal habitats.

10 Conclusions

The Sudanese Red Sea salt marsh shows signals and trends of some degree of degradation. Recent surveys revealed that halophytes belt along the Red Sea coast including mangroves are shrinking gradually under natural and man-made stress upon this unique ecosystem. Damage to coastal habitat by pollution from different sources of Port-Sudan and Suakin harbours is expanding.

It follows from the above that there is a great need for a well organized systematic monitoring programmes where research plans are well tied to development programmes. A closer interaction is required amongst different agencies in the region through a central body for the co-ordination of efforts to restore coastal habitats through integration of environmental and natural resources issues into planning and management of the region.Community participation is a must.

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A General Assessment of Marine Turtle Nesting Activity on the Libyan Saline Coast

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Abstract Marine turtle nesting sites in Libya have remained unknown until 1992/1993 for a long time due to the shortage of information with the exception of Kouf national protected area. A nesting activities survey were first conducted in 1993 between the Egyptian border and Zweetina. The first phase to assess nesting activity was conducted in 1995 between the Egyptian borders to Sirte. The Second phase was carried out in 1996 and covered the coast from Sirte to Misratah, from May to August 1996. All the tracks identified as *Caretta caretta*, and the green turtle *Chelonian mydas* was observed during this phase. The third phase was conducted in July of 1998 between the Tunisian border and Misratah, 15 crawl tracks of nesting were recorded and identified as *Caretta caretta* later in July 1999. Three beaches were resurveyed in eastern part of Libya. A general assessment of marine turtle nesting activity on the whole coast was carried out to allow us to implement a sound conservation strategy for the conservation of this endangered species.

1 Introduction

The current number of species of marine turtles that live in seas and oceans amounts to eight types, three of which have existence logged in the Mediterranean sea water, namely: *Caretta caretta*, *Chelonia mydes* and *Dermochelys coricea.* The existence of nests of the first two types was proved to be at the Mediterranean shores, and the studies conducted in the South Mediterranean countries proved the continuous decline for these two types due to environmental and natural causes (Kasparek 1993; Laurent 1990; Broderick et al. 2002, 2003). These studies have been conducted at the shores of Algeria, Morocco, and Egypt and the nest ratios logged in these countries do not represent any addition to the deteriorating stock of marine turtles in the Mediterranean sea, while at the northern and eastern parts of Mediterranean the activity of marine turtle nesting is concentrated on Greece, Cyprus and Turkey.

Relevant institutions and researchers in these countries gave much concern in setting certain programs to study such creatures and protect their nest locations (Demetropoulos and Hadjichristophorou 1988; Margaritoulis et al. 1992; Broderick and Godley 1996). Hazards which threaten marine turtles are outlined in the different pollution factors, and exploitation of sandy beaches in setting up tourism buildings increase and expand year by year, and which are concurrent with turtles' egg-laying on such shores.

Libya, being one of the Mediterranean States, and at the same time occupying a large space of the Mediterranean southern shore; deserves to have some studies conducted on its more significant shores as an attempt to estimate the real stock of marine turtles latent in the Mediterranean. The recent available information lacked sufficient and adequate accuracy

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and details. Part of such information was logging of existence of loggerhead marine turtles on the shores of natural protectorate at Al-Kuf Valley (Herbert 1979; Armsby 1980; Schleich 1987) as well as the information already logged about the locations of marine turtles nesting within the field visits paid in the years 1992–1993 for the shores of the eastern region (Hadoud D and Assigier 1995). As a completion for this exerted effort, a complete study was made along the Libyan coast as a part of an integrated program for determining the nesting locations of marine turtles, their species and possible dangers threatening turtles and nests. The study further included the determination of the shores that is in need for special protection programs being the most susceptible to pollution or in which predatory acts by natural hostilities are excessive. The aim of this study is a general assessment of marine turtle nesting activity on the hole Libyan coast to allow us in putting a good strategy for future conservation programs for this endangered marine organism.

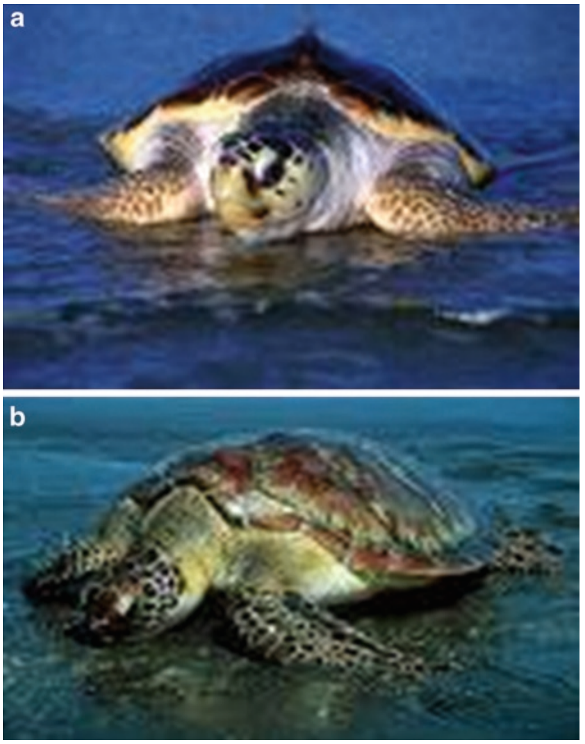

Fig. 1 (**a**) *Caretta caretta.* (**b**) *Chelonia mydas*

2 Material and Methods

This 3-year lasting study concerning of the nesting sites of marine turtle has been accomplished on three phases where the Libyan shore was subdivided into three areas (Fig. 1) such as follows:

1. Phase I: The area located between the Egyptian borders and Sirte city.
2. Phase II: The area located between Sirte and Misratah city.
3. Phase III: The area located between Misratah city and the Tunisian borders In all three phases different survey method were applied such as "walk (w), motorbike (m), vehicle (v), Quad (q)" and by such means the targeted sandy beaches were surveyed once in Phase (I) and Phase (III) and several times for some shores selected in Phase (II) in addition to re-survey of three high density nesting shores located within the boundaries of Phase (I), in Summer 1999. As with respect to classifying nesting signs applied in all phases, they were within the following five classifications: UCT, FCT, NCT, CT, N "Laurent et al. 1995".

3 Results

The total length of the Libyan coast is 1,975 km, of which a total of 1,144 km was for the sandy beaches. A large number of halophytes are distributed in the country such as the species of *Acacia, Tamarix* and *Calotropis procera.* The coastal zone vegetation strip is dominated by dunes covered by *Ammophila arenaria, Agropyron junceum, Aeluropus littoralis,* bulbous plants like *Urginea maritima* and *Pancratium maritimum*, along with scattered shrubs *Lycium europaeum*, *Rhus tripartit,* woody plants like *Limoniastrum monopetalum, Tamarix nilotica*. The seasonal mud flats include the halophytes such as *Suaeda fruticosa, Juncus maritimus, Mesembryanthemum nodiflorum* and *Cakile maritima*. *Phragmites communis, P. australis* and *Typha capensis*, together with the species of *Limonium, Salicornia, Sarcocornia, Suaeda*, and *Juncus maritimus* are scattered over the coast (Boulos 1975). There are several thousand hectares of mixed stands of *Acacia saligna*

Table 1 Loggerhead turtle nesting activity during the three phase of study

Phase of study	Coordinate of phase		Coastline (km)	Sand Beach Length (km)	Number of sites sampled	Total length of sand beach sampled (km)	Total crawl tracks (N + NC)
1995	31° 57 69′	31° 13 00′	1,195	797.7	50	141.65	342 (176)
Phase I	24° 59 28′	16° 40 00′				(17.76)	
1996	31° 13 28′	32° 12 13′	209	186.3	8	87	58 (27)
Phase II	16° 22 98′	15° 19 26′				(46.70)	
1998	32° 25 06′	33° 07 58′	407	160	23	105	15 (7)
Phase III	14° 59 62′	11° 41 15′				(65.63)	
Total			1,811	1,144	81	333.65	415(210)
						(29.17)	

Table 2 Crawl tracks survey at the east coast of Libya

	Prospected beaches				
	Coordinator		Crawl tracks		
Coastal area	Latitude	Longitude	1992/1993	1995	1999
Ayn el Ghazalah 1	32° 12 30′	23° 20 70′	24 (15/8/1992)	2 (20/6/95)	7 (23/7/99)
Ayn el Ghazalah 2	32° 12 36′	32° 20 56′	33 (23/7/1993)	11 (20/6/95)	23 (20/7/99)
Abu el Frais	32° 16 00′	23° 13 00′	18 (21/7/1993)	8 (19/6/95)	17 (23/7/99)

Table 3 Dead Turtles recorded from 1987 to1998

	1990–1992	1995 phase I	1996 phase II	1998 phase III	Total
Ayn el Ghazalah (1)	2	19	7	9	37
Ayn el Ghazalah (2)	2	2	2	–	6
Abu el Frais (3)	1	–	–	–	1

and *Atriplex canescens* found in the country. All these habitats form seclusive areas for the turtles.

Within the three phases a total of 81 shores with 333.65 km were surveyed which they represent a percentage of 29.16% of the total length of the sandy beaches along with the Libyan coast. The total crawl tracks which recorded in three phases is 415, 210 of which were tracks of turtle nests “loggerhead type”, namely the percentage of 50.60% of the total sum of tracks so logged (Table 1).

A three shores (1, 2, 3) located at the eastern part of the Libyan coast were re-surveyed in summer of 1999 these were: Ayn Al-Ghazalah (1), Ayn Al-Ghazalah (2), and Abu El Frais and the number of tracks logged were 7, 23, and 17 respectively (Table 2). The number of dead turtles logged along the Libyan coast before and within the 3 phases of survey was 44 turtles (Table 3) distributed such as follows.

Thirty seven *Caretta caretta* loggerhead, six *Chelonia mydas* (green turtle), one *Dermochelys coriacea* (leather back turtle). Two turtles of *Dermochelys coriacea* type were caught alive at Tajura shore by means of small coastal fishing gear. The length of the first turtle was 137 cm (1996), while the length of the second turtle was 1.40 cm (November 2000). The tagged turtles within the past years 1995–2002 were recoded; all being the loggerhead type. Five turtles were tagged with Phase I, one turtle was tagged in Phase II and ather most of them tagged in the sea (Table 4). The percentages of the predator nests within survey duration were 44.8%, 37.0% and 45.4% in the three phases respectively.

Table 4 Tagged Turtles *Caretta caretta* recorded from 1995 to 2002

Name of beach	Coordinates	Date	Carapace length (cm)	Number of tag
Deriana	32° 17 60′	25/6/1995	79.5 cm	F 3031
	20° 13 31′			
	31° 02 23′			
Sultan	20° 09 25′	29/6/1995	74.5 cm	F 3021
		29/6/1995	74.3 cm	F 3011
		29/6/1995	81 cm	F 3051
		29/6/1995	86.3 cm	F 3001
Al Gbiba	31° 13 28′	23/6/1996	83 cm	F 3101
	16° 22 98′			F 3121
Tajura	32° 53 73′	15/12/1996	72.5 cm	F 3022
	13° 22 54′			
North Musratha	32° 31′	20/4/2002	SCCL 74	F 3104
	15° 52′		CW 52	
North Benghazi	32° 08′	24/4/2002	CCL 71	F3172
	19° 15′		CCW 62	
North Benghazi	32° 35′	3/5/2002	CCL 90	F3123
	19° 36′			
North Benghazi	32° 51′	8/6/2002	CCL 76	F3128
	20° 10′		CCW 71	
North Bengazi	32° 27′	17/6/2002	CCL 61	F3105
	19° 51′		CCW 55	
South musratha	31° 29′	20/6/2002	CCL 68	F3106
	16° 12′		CCW 56	
North Benghazi	32° 21′	28/6/2002	CCL 62	F3114
	15° 40′		CCW 52	

4 Discussion

Based on the currently emphasized information, a number of three types of marine turtles in the Libyan waters was logged, namely: *Caretta caretta, Chelonia mydas,* and *Dermochelys coriacea.* Numerous researchers agreed upon the existence of *Caretta caretta* along the Libyan coast and with large (Laurent et al. 1995), nesting number and the findings of this comprehensive study confirms this fact and further support the already logged findings prior to this study, by other researchers during their study conducted for the natural protectorates shores at Al-Kuf Valley (Herbert 1979; Armsby 1980; Schleich 1987). The existence of, for *Chelonia mydas*, its existence in Libyan waters was emphasized for the first time, but its recorded in Ayn Al-Ghazala lagoon in the far eastern shore of Libya (Hadoud D and Assigier 1995) and the same existence was re-logged again in one of Phase (II) shores, namely: Abuwirat Al-Hasson shore (Hadoud and El Gomati 1997).

The third type "*Dermochelys coriacea*" has an existence, which was logged for the first time in the Libyan waters in years 1927, 1928 in Benghazi and Tripoli Coasts (Capra 1949). Recently two turtles of this type were suspended at Tajura area during 1996 and 2000. However, the nesting of this type at the Libyan shores has not been proved yet up to this date. Fretey (1986) presumed the existence of nesting activity of this species of turtles on the Libyan shores although there is nothing to enhance the correctness of this presumption. The density of crawl tracks in the three phases was 2.16, 0.66, and 0.113/km respectively with overall average of 1.24/km for tracks and 0.62/km as nesting density. Such ratios give intense significance to the Libyan shores and render them the most important nesting locations for Caretta caretta type worldwide.

In contrast with the logged density in the shores of the neighboring African States, it will be noticeable that in Morocco and Algeria no tracks were reported during the multiple survey made for 97.9 km. of the shores (Laurent 1990), while in Tunisia the average tracks was 0.16 km (Bradai 1993) and a calculated density of 0.039 km. witnessed by Egypt during the study conducted on the western Egyptian shores (Kasparek 1993). The large increase in the activity of marine turtles nesting on the Libyan shores in comparison with the neighboring States is the length of its sandy beaches which are still conserving their natural condition as well as the few number of turtles that subject to intentional catching and that is mainly attributed to the fact that their meat does not constitute a foodstuff as it is the case in the neighboring states. The density of the tracks logged in the three phases were not convergent, as they range from zero in some shores and frequently reach 5.8/km. in Abu El Frais shore in Phase I: (Laurent et al. 1999) and 4.4/km. In the second shore in Phase II (Hadoud and El Gomati 1997). The imperfection of density in some sandy beaches could not be perfectly interpreted rather than some probabilities would be made on the grounds of the scientific observations already logged within the study.

For instance, in phase I: that could easily be attributed to the apparent pollution in some shores with tarball, while in the shores of Phase II: interpretation of non-existence of nesting density in some shores could be made despite the fact that they are sandy beaches, with low pollution rate and far from whatever population activity. However, one fact can be taken into account, namely the concurrence of turtle nesting season with the season of egg-laying of some species of sharks which approach in large quantities towards these shores the thing which cause leaving of turtles far away from these areas. As regards to Phase III: the least nesting density area is because of the high population density and centering of the main cities of Libya within the limits of this area.

The risks that threaten the marine turtles are much diversified. For instance, turtles in the sea water are suspended in nets of fisherman, like Tunara – fisheries of tuna fish – also there are some fisheries for sharks which are gill nets called "Khanagates" in which marine turtles are suspended. What increase the number of suspended turtles in these two types of fisheries is the concurrence of tuna fishing season "June" and the shark fishing season (February – June) with the season of turtles reproduction and their approaching to the shores. And most dangerous impact of sea turtle in the Libyan coast through the season of tuna by the foreign fisheries in April to July every year many turtle catch by long line and surrounding nets. Likewise the female turtles are liable to predatory when moving out for egg-laying and the most important predators is "Jackal *Canis aurens*". As for nests, the Predatory percentages were too high and the predators reported within the study were "fox *Vulpes vulpes*, sand crab, Ocypode cursor, Jackal *Canis aurens*".

Comparing the logged percentages for marine turtle nest, predatory acts at the Libyan shores, with other shores, we will find them 44.8% in phase I (Laurent et al. 1995), 37.0% in phaseII, (Hadoud and El Gomati 1997), 45.4% in phase (3) (Laurent et al. 1999), 41.2% at Turkish Shores (Brown and Macdonald 1995) and 70% at the southern shores of Cyprus (Demetropoulos and Hadjichristophorou 1988). That will definitely make it obvious that the phenomenon of nest ravening is deemed to be a natural phenomenon of which both increase and decrease will be controlled by environmental mode of each shore and the existence or on-existence of predators. Within the past years a number of seven *Caretta caretta* were tagged while moving out to lay eggs. This process has become a routine style for data collection and clarification of some vague points concerning the biology and behavior of this animal such as study of rates of growth of this creature and migration (Carr 1967) as well as the nutritional locations and the places in which turtles spend the winter season (Margaritoulis 1988) and finally the ages of the turtles (Mrosovsky 1983).

The occupation of Libya to the longest shore southwards the Mediterranean sea enabled it to acquire a special importance and in particular after the findings obtained in this three-phase study which showed a significant nesting density in the Libyan shores and which in turn requires focusing on the intensive re-surveying specially in the high density shares in order to reach realistic findings and estimations on nesting density and the types of turtles having nesting activity in the Libyan shores. Setting a permanent protection program in some important shores such as Ayn El Ghazalah, Al-Kuf, Abu Frais shares within the limits of Phase I, and shore No. (1), within the limits of phase II as an attempt to preserve and develop the stock of this marine organism which is really threatened with extinction.

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Current Challenges and Future Opportunities for a Sustainable Utilization of Halophytes

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Abstract Increasing salinisation has significant and detrimental impacts on land, water and vegetation quality, wildlife environments, agronomy and ecosystem functioning. This is particularly true for arid and semi-arid areas where high evapo-transpiration rates expose plants to further adaptive pressure. Unlike conventional crops, halophytes are plants that survive and are able to reproduce in environments (coasts, wetlands, and inland deserts) with higher salinity levels. These species, which represent about 1% of the world's flora, have evolved complex mechanisms at different levels (whole plant, cellular, and molecular) enabling them to successfully cope with these hostile conditions. There are about a billion ha of salt-affected land world wide, which are unsuitable for agriculture and may therefore provide unique opportunities for "halo-biotechnologies". Taking into account the increasing pressure on fresh water resources and considerable diversity of potentially useful halophytes, such an approach may help in the mid- and long-term to rehabilitate these marginal zones and create sustainable production systems. Agriculture on saline soils is an alternative agriculture under a range of salinity levels in groundwater, and/or soils. A precondition for its use is the economic value added. Yet, fundamental prerequisites have to be considered to ensure that this promising approach would be cost-effective and environmentally safe. It must yield economically viable crops at yields high enough to be accepted by the farmers. This should be concomitant with the development of agronomic techniques relevant for growing saline, water-irrigated crops in a sustainable manner. Most importantly, these practices should be sustainable, ecologically well-tolerated and not lead to further damage of natural environments. If applied successfully, such an approach may lead to domestication of wild, salt-tolerant plants to be used as food, forage, oilseed crops, as well as pharmaceutical or ornamental plants. Soil desalination represents also important tasks for the so called cash crop halophytes. The successful rehabilitation of saline marginal zones by introduction of halophytes largely depends on collecting reliable data on salt-tolerance limits during life cycle of the respective candidate species. In this contribution, we present an overview of new data gained under saline conditions during the last years with respect to halophytes of interest and discuss their likely implications at applied level.

1 Introduction

Growth of the human population by 50%, from 6.1 billion in mid-2001 to 9.3 billion by 2050 (http://www.unfpa.org/swp/2001/), requires a significant and concomitant increase of crop production to ensure food security, especially in the developing countries. Recent estimations of the Food and Agriculture Organization of the United Nations (FAO) indicate that more than 850 million people are suffering from chronic malnutrition. Additionally, this problem becomes enhanced

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by the current climate change. Among the most important challenges are the increase in temperatures, desertification, and salinisation of soil and water resources. Salinity can be either natural or related to human activity (inaccurate irrigation management or fertilizer use) (Galvani 2007; Breckle 2009).

Salinity is actually an ever-present limiting factor to crop yields, notably in countries where agriculture relies on irrigation, which allows farmers to be less dependent on seasonal rainfall and the weather uncertainties (Galvani 2007). Yet, inappropriate irrigation strategies increase salinity of soils and water by depositing ions like sodium, calcium, magnesium, potassium, sulphate and chloride. In arid and semi-arid regions, solutes from irrigation water can highly accumulate, reaching levels that are harmful for the vigour and productivity of crops. According to Szabolcs (1994), 7% (1 billion hectares) of all land area is salt-effected, and about 10 million ha of agriculturally productive soils are being lost annually worldwide because of irrigation-induced salinity. Crop production is restricted by salinity on 40% of the world's irrigated land. In addition, 19.5% of the currently 230 million ha irrigated land, and ca. 5% of 1,500 million ha under dry land agriculture are salt-affected to varying degrees (Munns et al. 1999). It is estimated that salinisation of irrigated lands causes annual global income loss of about US $12 billion, severely impacting aggregate national incomes in countries affected by degradation of salt-affected land and saline water resources (Ghassemi et al. 1995). Generally, the worst salinity impacts occur where farming communities are relatively poor and face economic difficulties. In Australia, the annual expansion rate of dry land salinity is 3–5%, resulting in losses of Australian $270 million. Future projections estimate that 17 million ha of Australia's agricultural land will be significantly affected by salinity by 2050 (http://audit.ea.gov.au). The situation in Australia is even worsened by the extensive secondary salinity caused by substituting superficial rooted annual species for the deep-rooted perennial native vegetation with. As a result, rising water tables are observed that bring salt stored deep in the profiles close to the soil surface (Barrett-Lennard 2002).

Despite considerably varying in their response when salt-challenged, crop species are generally intolerant to one-third of the concentration of salts found in seawater (Flowers 2004). Several attempts to improve salt tolerance of crops through conventional breeding programs have yielded very limited success, mainly because salinity is a multifactorial problem (Koyro et al. 2008). Halophytes are plants that can complete their life cycle in soils with salinity concentrations above 200 mm NaCl (Flowers and Colmer 2008). Halophytes, which represent 1% of the world's flora, thrive in a wide range of habitats, from arid regions to coastal marshes. Several species grow in waterlogged or flooded soils, even withstanding total immersion in seawater (Munns 2008). Some halophytes require fresh water for germination and early establishment but can tolerate higher salt levels during vegetative and reproductive stages, other's may germinate at high salinities but require lower salinity for maximum growth (Debez et al. 2003, 2004; Koyro and Eisa 2008). In extreme cases (obligate or euhalophytes), increased biomass production occurs only under increased salinity. Further, some plants grow well on permanently wet areas; others grow best where the soil dries out in the summer (Galvani 2007). Mechanisms that allow such an extraordinary adaptation are still largely unknown.

Given that oceans contain most of the water on earth, the concept of sustainable agriculture using the so-called "cash crop halophytes" irrigated with saline waters up to seawater salinity is gradually emerging (Lieth et al. 1999). Although economic consideration of halophytes and other salt-tolerant plants is just beginning, they are now receiving increased attention in arid regions where intensive irrigation has led to saline soils or where water shortages are forcing use of marginal resources such as brackish underground water (O'Leary 1987; Öztürk et al. 2006, 2008). According to Yensen (2006) twenty-first century will likely be the century of halophyte agriculture expansion, as diminishing fresh water resources put pressure on civilization to utilize the vast saline soils and aquifers. While much of this land occurs in the Middle East, Central Asia, Northern Africa and Australia it seems that many other countries will face salinity issues" if steps are not taken. More recently, Galvani (2007) claimed: "To meet future agriculture needs, a solution is an environmentally friendly technique which controls salinisation, uses salt removing crops, chooses halophytes crops for direct salt water irrigation, or selects species that have high salt-removing capacity and commercial value. Some plants can be integrated into rotation programs or planted as intercrops for perennial plants to control salinisation". As hypothesized by this author, the unsuitability of sand and saline water for conventional crops may actually be advantageous when considering salt-tolerant plants, owing to the mineral composition of seawater (among the 13 mineral nutrients required by plants, 11 are present in seawater in sufficient amounts) and the texture of sandy soils, which favours the infiltration of water and prevent the harmful salt build up in the zone of root development. If applied carefully, the combination of sand, seawater, sun and salt-tolerant plants constitutes hence a valuable and realistic opportunity for many developing countries.

Several halophytes have been evaluated as potential crops for direct seawater or brackish water irrigation. Their potentialities cover a wide range of applications: the improvement of soil characteristics (desalination, heavy metal extraction), biomass production, food, fuel, fodder, fiber. Although direct consumption of halophytes by humans and animals may be limited, the seeds of many of them are being considered as new sources of grains or vegetable oils (Hinman 1984). Salt-tolerant plants can also be used to produce materials with high economical value, such as essential oils, flavours, fragrances, gums, resins, oils, pharmaceuticals, and fibers (Galvani 2007; Ksouri et al. 2007). They may also be marketed for use for ornamentation for their foliage or flowers (Messedi et al. 2004; Slama et al. 2006). Fuel-wood and building materials may also be manufactured from salt-tolerant species using land and water unsuitable for conventional crops.

The development of successful saline agriculture necessitates a better understanding of the potential of plant species to withstand ambient salinity and sodicity levels in soil and water, and also of the potential uses and markets for the agricultural products. In this contribution, we address the most recent information available with respect to the potential utilizations of halophytes in the context of halo-biotechnology, and present some practical recommendations to be considered for a economically viable and environmentally compatible sustainable biosaline agriculture.

2 Soil Bioremediation by Desalination-Efficient Halophytes

In the arid to semi-arid regions, water quality is a major factor limiting crop production (Cantero-Martínez et al. 2007). Interestingly, the natural ecosystems of the Mediterranean-climate areas are characterized by a mixture of rustic perennial shrubs and trees (mainly xerophytes and halophytes) with annual crops or fodder plants (Turner 2004). Growth activity of the annuals is governed by the rainfall regime, the rainy season extending from autumn to spring, while the slowly growing perennials are able to cope with water shortage and soil/water salinity. Variations in biomass and productivity among and within natural ecosystems may be attributed mostly to differences in water and nutrient (especially N) availability and salinity (Sherman et al. 2003). Understanding the functioning of plant saline ecosystems capable of significant productivity under salt stress is of paramount importance in perspective of improvement of soil characteristics using halophytes.

One of the most fascinating natural saline ecosystems are coastal or continental sabkhas, which are typical of the semi-arid and arid areas around the world. Because of the extreme environmental (edaphic and climatic) conditions characterizing these biotopes, they are considered as non productive wastelands. Sabkhas could actually be valorised by implementing agro-ecosystems using "alternative" cash-crop halophytes (Böer and Gliddon 1998). In Tunisia for instance, the annual fodder plant *Hordeum maritimum* (Poaceae) is commonly found in the saline depressions in close association with strict halophytes, such as *Arthrocnemum indicum* and *Halocnemum strobilaceum* (Hafsi et al. 2007). In a 2-year survey, Abdelly et al. (2006) have been monitoring the impact of halophyte-fodder species association on biomass production and soil salinity level in the inland sabkha of Enfidha (100 km south-east from Tunis), a semi-arid bioclimatic zone with moderate winters and mean annual rainfall rarely above 300 mm. The vegetation of studied area was characterized by perennial halophytes tufts in association with fodder annuals, mainly *Medicago* species, highly appreciated for their high fodder value, and ensuring most of to the ecosystem primary production in the absence of water shortage. Parallel field and laboratory investigations revealed that *Medicago* growth was restricted by salt (Abdelly et al. 1995; Abdelly et al. 1996), and nutrient (mainly nitrogen and phosphorus) deficiencies (Abdelly 1997). Halophytes displayed slow growth activity associated with poor accumulation of mineral nutrients (e.g. nitrogen, inorganic Phosphate, and Potassium) and high sodium concentrations in their shoots. On the contrary, annuals were characterized by high growth activity (up to 40% of the plant annual biomass production of the ecosystem), depending on the precipitation and sustained by a high capacity for nutrient acquirement (up to 70% of the total nutrient uptake).

The annuals were almost exclusively clustered under the halophyte tufts, or at their immediate vicinity, where soil nitrogen and inorganic phosphate levels were significantly higher, and salinity significantly lower than between the halophyte tufts. Furthermore, the shoots of the annuals growing in association with halophyte species contained relatively low Na^+ concentrations. These findings indicate that the upper horizon enclosing the halophyte tufts (where sensitive annuals grow) is fertile and contains low salt levels. This was also corroborated by the study of soil samples taken from the upper profile in the tuft centers. However, further studies are needed to support this by following the water movement in different soil horizons in different seasons. Desalination of the upper horizon by the superficial roots of halophytes may be responsible for this micro-gradient of salinity (Caldwell 1974). Further, the litter formed by halophyte fallen organs and by organic debris accumulated by the wind at the vicinity of halophyte tufts, could contribute to localized soil enrichment in N and P. Hence, the upper soil profile, where these plants grew, was fertile and contained (relatively) low salt levels, as corroborated by the results of soil analysis (upper horizon in the tuft centre was always less saline than when taken at the tuft periphery). Soil aeration near the annual glycophytes would be improved by this organic matter and by the higher soil level under the tufts, leading to better drainage capacity. Improved soil aeration is favourable for nitrification and N_2 fixation, which in turn sustains the colonization of the halophytes tufts by the *Medicago* spp. Halophytes may also play an indirect role by developing deep root systems exploiting the more saline horizons, as shown by the presence of halophyte roots at 1 m depth and by the vertical increasing salinity gradient. So, the halophytes directly contributed to maintenance of a relatively low salinity and high fertility in upper horizon, enabling the growth of annuals.

These findings were confirmed using a biological test of soil fertility. Some tufts of *Salicornia arabica* were removed for sampling soil in the upper profile (0–20 cm), where roots of annual plants developed. Other samples were taken between halophytes tufts, in zones devoid of vegetation or weakly populated. Four annual *Medicago* species (*M. ciliaris*, *M. polymorpha*, *M. truncatula* and *M. minima*) were grown on these soil samples, without mineral fertilization, in a greenhouse under controlled conditions. The plants were harvested at flowering stage. In the four species, total biomass production (dry matter per pot) was higher on soils sampled under the halophyte tufts than on soils from nude zones (Fig. 1a). Although these studies revealed that perennial halophytes improve soil characteristics by lowering salt content and by increasing nitrogen and phosphorus concentrations but further studies are needed in this connection by comparing with the salt secreating halophytes.

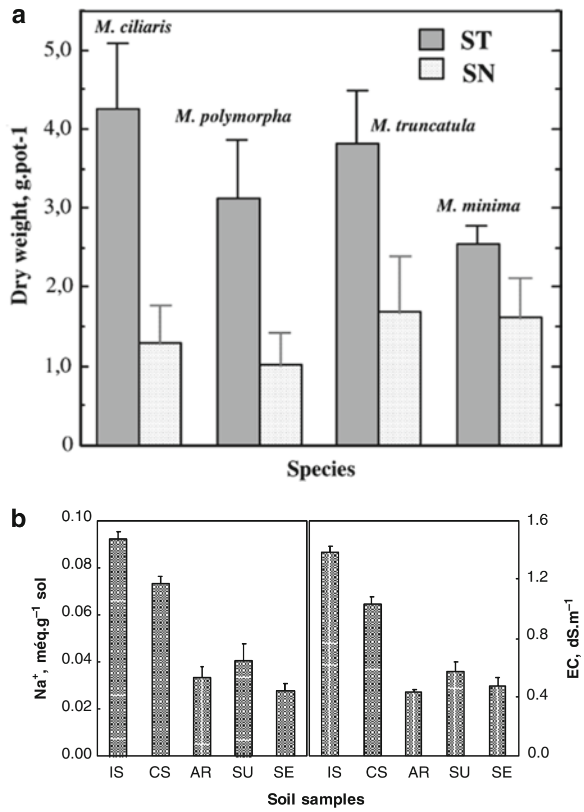

Fig. 1 Capacity of halophyte species for soil desalination. (**a**) Changes in biomass production of *Medicago ciliaris*, *M. polymorpha*, *M. truncatula*, and *M. minima* ($g.pot^{-1}$) depending on the soil origin ($n = 20 \pm$ SE at $p < 0.05$). ST: culture carried out on soil sampled under halophytes tufts, SN: cultures carried out on soil sampled in outside of halophytes tufts. (**b**) Soluble sodium content and electrical conductivity (EC) of 10% (w/w) aqueous extract of soil samples ($n = 6 \pm$ SE at $p < 0.05$) taken from the upper profile (15 cm deep) of pots (8 kg capacity), in which three halophytes: *A. indicum* (AR), *S. fruticosa* (SU), and *S. portulacastrum* L. (SE) were grown for 170 days. Plants were regularly irrigated with tap water. IS and CS stand for the initial and control (irrigated without plantation) soils respectively (adapted from Abdelly et al. 2006)

Involvement of halophytes in creation of micro-habitats favouring development of *Medicago* spp. and their micro-symbionts has been documented by Bekki (1995) who showed that *M. ciliaris* plants growing in combination with *Suaeda fruticosa*, had higher growth rates and better nodulation and nitrogen fixation potentialities than isolated ones. Several studies have highlighted the advantageous role of halophytes in soil desalination processes, especially for the most productive species, such as *Salsola salsa* (20 t · ha^{-1} among which, 3–4 t of salt exported from the soil), *Batis maritima* (3 t · ha^{-1}) (Le Houérou 1993), and the succulent *Sesuvium protulacastrum* (Pasternak and Nerd 1996). Although salt removal from soil is a common feature latter would be particularly interesting because of its high salt tolerance (growth stimulation up to 800 mM NaCl) despite accumulating high salt levels in the shoots (6 mmol · g^{-1} DW, representing ca. 35% of the whole plant biomass) (Messedi et al. 2001). In a 4-year study, Keiffer and Ungar (2002) observed a significant decline in brine-affected soils, following introduction of halophytes (*Atriplex prostrata*, *Spergularia marina*, and *Suaeda calceoliformis*), so that glycophytes could successfully establish. Recent findings of Kiliç et al. (2008) showed that purslane (*Portulaca oleracea*) may be cultivated as an intercrop all year round in one growing season, with a threshold value of salinity at 6.5 dS · m^{-1}. It removed considerable amounts of salt (up to 210 kg · ha^{-1} of Cl^- and 65 kg · ha^{-1} of Na^+) from the soil. However,it will better to use it for phyto-reclamation if efficiency is enough in comparison with total soil salinity, thus salt balance calculations are needed for this purpose, because it will take 500 years to get rid of the salt if there are 5,000 t of salt in soil per ha in the physiological and ecological sense.

The capacity of desalination of saline soil by halophytes was also evaluated in strictly controlled conditions, using *Arthrocnemum indicum, Suaeda fruticosa*, and *Sesuvium portulacastrum* (Rabhi et al. 2008). The plants, also originating from the edge of a sabkha, were cultivated for 6 months on saline soil and irrigated with tap water without losses by drainage. Salt export by plants was assessed by the difference between the amounts of Na^+ and Cl^- initially measured in the culture substrate, and those found at the end of the experiment in the soil. After 170 days, the soil electric conductivity (EC) in the pots used for the culture of the three halophytes decreased by more than 50% in average (0.6 dS · m^{-1} vs. 1.4 dS · m^{-1}) (Fig. 1b). Among the three studied species, *S. portulacastrum* was most productive and showed highest capacity of sodium extraction. It accumulated up to 26% of the original Na^+ content of the soil after 170 days, while both, *A. indicum* and *S. fruticosa* plants, accumulated 8% (Fig. 1b). Based on these findings, the calculated Na^+ export rates per ha were 2.50, 0.80 and 0.71, respectively, for *S. portulacastrum*, *A. indicum*, and *S. fruticosa* (Table 1). This study demonstrates once again that the halophyte traits displayed by *S. portulacastrum*, namely high growth rate and high capacity for salt accumulation, contribute efficiently to the soil desalination, even in short-term cultures. Hence, this species would be promising for rehabilitation of saline lands, especially those located in arid and semi-arid regions. Ravindran et al. (2007) evaluated the desalination capacity of six halophytes (*Suaeda maritima*, *S. portulacastrum*, *Clerodendron inerma*, *Ipomoea pes-caprae*, *Heliotropium curassavicum*, and the tree *Excoecaria agallocha*), in terms of fast growth rate associated with high salt accumulation. All tested species decreased the EC of the saline soil used, in concomitance with an increase of the EC of plant samples. Salt removal capacity calculated over in 4 months of time was 504, 473.9, 396.3, 359.5, 325.2 and 301.5 kg · ha^{-1} of NaCl in *Suaeda*, *Sesuvium*, *Excoecaria*, *Clerodendron*, *Ipomoea* and *Heliotropium*, respectively.

Table 1 Estimation of the capacity of soil desalination by three perennial halophytes grown during 170 days on a soil originating from a sabkha, and constantly irrigated with tap water

Species	*S. portulacastrum*	*S. fruticosa*	*A. indicum*
DW per pot (g)	30.00	9.25	10.50
Quantity of Na^+ exported per pot (g)	11.32	3.63	3.22
Quantity of Na^+ exported (t · ha^{-1})	2.50	0.80	0.71

Source: Adapted from Rabhi et al. (2008)

3 Heavy Metal Phytoextraction

Saline depressions, which are less populated, often constitute sites of accumulation of industrial and urban effluents contaminated by heavy metals. The plants from saline habitats can be evaluted to some extent in their phytoextraction potential as an environmental friendly alternative for the remediation of such contaminated areas (Cunningham and Berti 1993; Brooks 1998; Djebali et al. 2002). The first step in this direction will be to assess the potential interest in a plant species for phytoextraction and quantify, under fully-controlled conditions, the optimal level of toxic metal accumulation in relation to the growth rate (Lutts et al. 2004). Hyperaccumulators (plants able to concentrate high levels of heavy metals in their aerial parts without showing any symptom of injury) have to be identified. Plants are usually considered as hyperaccumulators if they contain more than 10,000 mg · kg^{-1} Zn or 100 mg · kg^{-1} Cd (Brooks 1998). Several studies demonstrated different tolerance mechanisms operating at the whole-plant level. For instance, salt excluding mechanisms are not always specific to sodium, so that other toxic elements such as copper, zinc, or cadmium may accumulate in salt glands, as in *Armeria maritima* and *Avicennia marina* (Lutts et al. 2004), or in trichomes, as found in *Tamarix aphylla* (Hagemeyer and Waisel 1988). Several halophyte species of the genus *Atriplex*, which are naturally salt- and drought-tolerant and mostly typical "includers" (Reimann and Breckle 1993), have been suggested as potential candidates for a phytoremediation approach (Salo et al. 1996; Glenn et al. 2001). A recent study reported that *Atriplex halimus* displayed high resistance to heavy-metals (Cd and Zn) in contaminated mining sites and that it has a strong potential for the rehabilitation of heavy metal-polluted lands (Lutts et al. 2004). This was strongly correlated to the over-accumulation of phytochelatins in combination with the induction of detoxification mechanisms, such as the co-precipitation of Cd and/or Zn with Ca in oxalate structures (oxalic acid is commonly produced in *Atriplex* species) within the stems, to prevent their toxic accumulation in the photosynthetic tissues (Karimi and Ungar 1986). Given that this species is able to produce 4–5 t of dry matter.ha^{-1} · $year^{-1}$ (Ben Ahmed et al. 1996) and that it may accumulate up to 0.083% Cd and 0.044% Zn on a dry weight basis in the shoots, the amounts expected to be removed could reach 4.15 kg · ha^{-1} Cd and 2.2 kg · ha^{-1} Zn (Lutts et al. 2004).

Halimione portulacoides was also suggested as a suitable species for the phytoremediation owing to the high translocation rates of Cd and Cu towards the aboveground tissues (Reboreda and Caçador 2007). Ghnaya et al. (2005) compared growth, cadmium accumulation and mineral nutrition in two halophytes from Aizoaceae: *S. portulacastrum* (perennial) and *Mesembryanthemum crystallinum* (annual) under the combination of mild salinity (100 mM NaCl) and Cd-stress (up to 300 µM $CdCl_2$). Cd-exposure had no impact on the growth of *S. portulacastrum*, while that of *M. crystallinum* was significantly decreased at the lowest Cd level (50 µM $CdCl_2$) (Fig. 2a). The better behavior of *S. portulacastrum* was partly ascribed to its

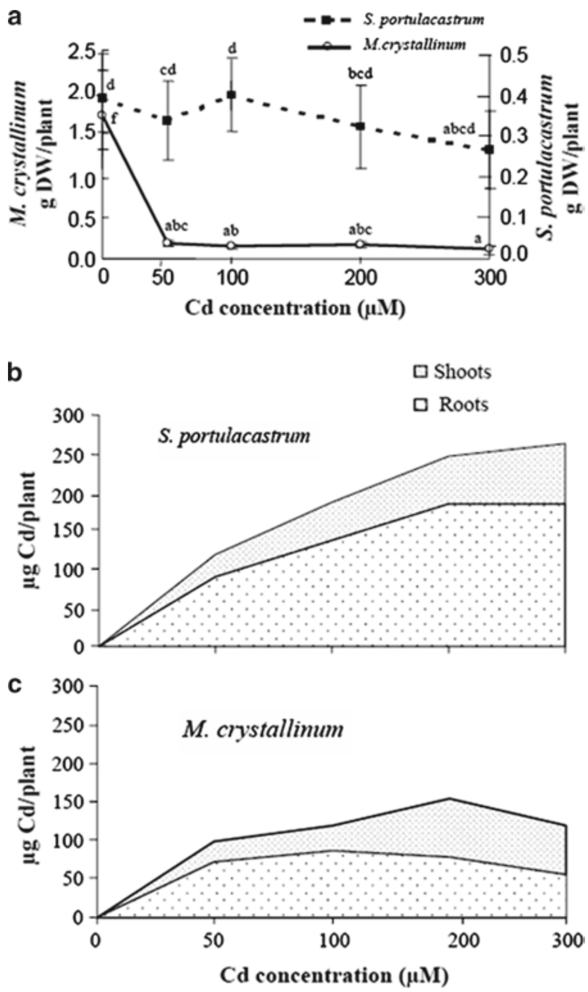

Fig. 2 Comparative heavy metal extraction capacity of the halophytes *M. crystallinum* and *S. portulacastrum*. (**a**) Changes in whole plant dry matter (g · $plant^{-1}$) produced by *M. crystallinum* and *S. portulacastrum* treated by various Cd concentrations. Means ($n = 8 \pm$ SE at $p < 0.05$) marked with same letter are not significantly different at $p < 0.05$. (**b**) Distribution of the cadmium absorbed by the whole plant (mg · $plant^{-1}$) between roots and shoots of *S. portulacastrum* and *M. crystallinum*. (adapted from Ghnaya et al. 2005)

better ability to avoid oxidative stress, when challenged with Cd (Nouairi et al. 2006). Indeed, leaves of *S. portulacastrum* showed lower decrease in their lipid content as compared to *M. crystallinum*, and cadmium treatment did not induce changes in the fatty acid composition of the total membrane lipids. Both halophytes accumulated more Cd in the roots than in the shoots. Yet, values of Cd concentrations in shoots (350–700 μg · g^{-1} DM) were characteristic of Cd hyperaccumulator plants (Fig. 2b). Hence, *S. portulacastrum* could extract up to 5950 g Cd · ha^{-1} · $year^{-1}$, this performance being even improved in the calcareous soils (Ghnaya et al. 2007).

4 Halophytes for Livestock Production

The amount of edible biomass produced is an essential aspect with respect to livestock production in biosaline agriculture. Even at high salinities a range of halophytic grasses and shrubs with appreciable crude protein and digestible fibber contents are still able to produce 0.5–5 t of edible dry matter per year. Valuable species include *Leptochloa fusca* (Ahmad et al. 1990), *Brachiaria mutica* (Kumar and Abrol 1984), *Sesbania bispinosa* (Ahmad et al. 1990), *Cynodon dactylon* (Oster et al. 1999), *Kochia scoparia* (Garduno 1993), *Echinochloa crusgalli* (Aslam et al. 1987), and *P. oleracea* (Grieve and Suarez 1997). Among the most used halophytes for grazing and forage production under both saline and non-saline conditions are the shrubs from the Chenopodiaceae family, including the saltbushes, small-leafed bluebush (*Maireana brevifolia*), *Kochia* spp., *Tamarix* spp., glassworts (*Salicornia* spp.), and *Suaeda* spp. (Le Houérou 1994; Masters et al. 2001). All these species are well known to be drought and salt tolerant. According to Le Houérou (1992), 5–10 kg · DM ha^{-1} · $year^{-1}$ of edible forage production from a range of saltbush species could be produced for each mm of rainfall in areas with low salinity. Under favorable conditions in terms of soil structure and rainfall (between 200 and 400 mm), yields of 2–4 t DM ha^{-1} · $year^{-1}$ could be reasonably attained. Regular cutting practices associated with heavy grazing of woody shrubs such as saltbush favors the regeneration of less woody and more digestible shoots. Significant attention should also be paid to the appropriate cutting height, a critical point to avoid die-off of the existing plant material. *Atriplex lentiformis*, *Batis maritima*, *Atriplex canescens*, *Salicornia bigelovii* and *Distichlis palmeri* yielded over 10 t · ha^{-1} · $year^{-1}$ following successful establishment (Glenn and O'Leary 1985), whereas *Atriplex* spp. irrigated with saline drainage water were able to yield 2.2–5.3 t DM · ha^{-1} · $year^{-1}$ of forage (Watson and O'Leary 1993). Recent studies reported that highly saline groundwater (30 dS · m^{-1}) allowed to produce much larger amounts of hay from irrigated and intensively managed inland salt grass (*Distichlis spicata*) and marine couch (*Sporobolus virginicus*) (International Center for Biosaline Agriculture 2004). Abdelly et al. (2006) investigated the salt-response of two Poaceae halophytes native to Tunisia, with fodder potential: *Aeluropus littoralis* (perennial) and *Catapodium rigidum* (annual). The latter was slightly more productive than *A. littoralis* in the absence of salt. Increasing salinity decreased the growth activity of both species, but *A. littoralis* was more tolerant than *C. rigidum* (Fig. 3a). In the salinity range not exceeding 400 mM NaCl, the relative growth rate (RGR) of both species remained between 0.04–0.06 day^{-1}. Under non saline conditions, the following data were found for other plant species: *Medicago* spp. (0.08–0.09 day^{-1}) (Abdelly 1997), *Suaeda fruticosa* (0.07–0.09 day^{-1}) (Sleimi and Abdelly 2002), *Spartina alterniflora* (0.03 day^{-1}) (Sleimi and Abdelly 2002), *Spartina anglica* and *Puccinellia maritima* (0.02–0.05 day^{-1}) (Rozema and Van Diggelen 1991).

Barhoumi et al. (2007) reported that *A. littoralis* was able to survive up to 800 mM NaCl, with only a 50% reduction in leaf water content. Salt glands were observed on both leaf sides at high density in salt-treated plants. Interestingly, these morphological structures showed to be selective for Na^+ and Cl^-, and owing to their high density, enabled the elimination of about 50% of absorbed NaCl (Fig. 3b). If the results on production, yield, and reproduction are significantly high the species can be evaluted properly. In a recent survey, Laudadio et al. (2009) assessed the nutritional value of fourteen halophytes (*Aeluropus littoralis*, *Artemisia campestris*, *Atriplex halimus*, *Frankenia thymifolia*, *Imperata cylindrica*, *Limoniastrum guyonianum*, *Nitraria retusa*, *Reaumuria vermiculata*, *Salicornia Arabica*, *Salsola tetragona*, *Salsola tetrandra*, *Suaeda mollis*, *Tamarix gallica*, and *Zygophyllum album*) naturally growing in the arid regions of Tunisia. The contents of ash, crude protein, crude lipid, structural carbohydrate and nitrogen-free extract indicated nutritional

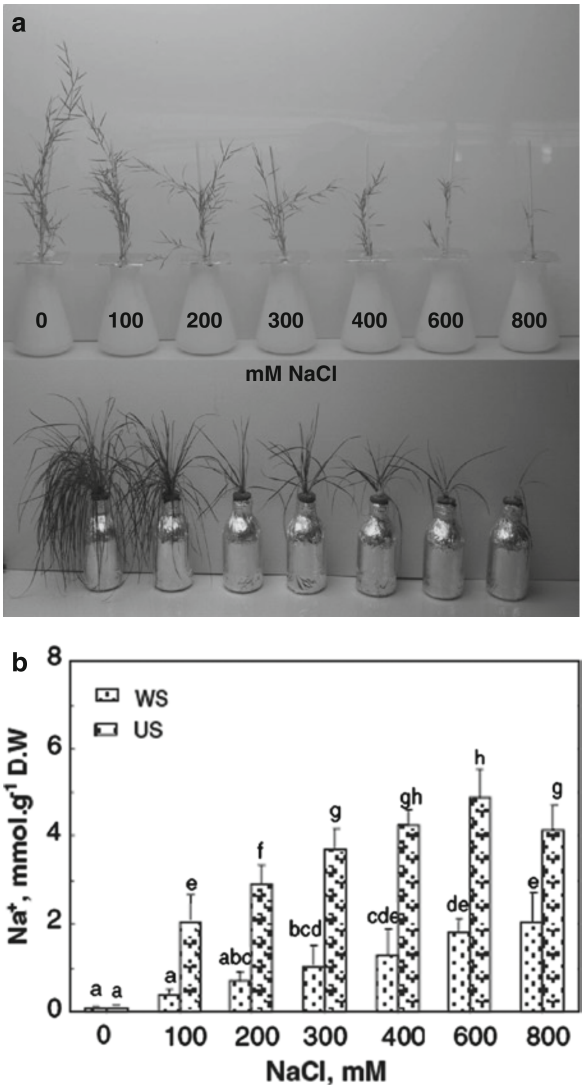

Fig. 3 (**a**) Comparative salt response of two fodder halophytes: *Aeluropus littoralis* (*above*) and *Catapodium rigidum* (below) to increasing salinity. (**b**) Importance of salt glands in salt excretion for *A. littoralis*: Na^+ contents (mmol · g^{-1} DW) mainly in washed (WS) and unwashed shoots (US) of plants exposed for 2 months to 0–800 mM NaCl NaCl. Values ($n = 7 \pm$ SE at $p < 0.05$) followed by the same letter are not significantly different at $p < 0.05$ (adapted from Barhoumi et al. 2007)

characteristics close to those found in the essence of the typical pastures of the Mediterranean region and compatible with the digestive physiology of the ruminant species.

Despite varying in both palatability and nutritive value, most halophytes contain sufficient levels of crude proteins and essential nutrients, covering the nutritional requirements of animals, particularly during the wet season (El Shaer 2006). In summer and autumn (dry season), they need to be supplemented with other feed ingredients, particularly with energy feed resources (El Shaer 1997). On the field, the mineral composition of the plants may be considerably affected by both the concentration and type of salts in the soil and/or water. For instance, sodium, potassium, chloride, calcium and magnesium may accumulate above the maximum tolerable levels for livestock (Masters et al. 2007). The high concentrations of sodium chloride in particular may decrease feed intake and under some conditions even threaten animal health. Furthermore, plants growing in saline environments often accumulate secondary compounds, which can have either beneficial (e.g., vitamin E and betaine) or toxic (oxalates, coumarins, saponines, and nitrites) impact on grazing livestock. Therefore, further investigations are essentially needed to ensure the well-tolerated application of halophytes as fodder plants.

Several treatments have been applied in order to improve the palatability and nutritive values of halophytic forage species (El Shaer and Kandil 1990). Chopping is an effective process to increase the palatability of succulent species and hence enable a more efficient utilization of whole shrubs. Appropriate conservation such as hay making and ensiling of halophytes could improve their utilization as good quality fodder and their acceptability by sheep and goats (El Shaer and Kandil 1990). This was ascribed to the effect of anaerobic fermentation during the ensiling process on some anti-nutritional factors such as tannins and other phenolic compounds. Additionally, the ash content and fibber materials are lowered. Feeding these silages to animals represents an economic alternative, feed costs being 30–50% lower in comparison with conventional diets such as berseem hay, which is of high importance in developing countries (El Shaer and Kandil 1990). The problem of preparing proper feed supply from halophytes is far from being solved. There are several reports showing mineral imbalances and shortage of essential mineral intake by animals in arid areas. It was found, for instance, that additional supply of the essential trace element Selenium may overcome nutritional constraints limiting animal productivity (see Khan et al. 2005 and citations therein).

Further combinations with other feed ingredients such as broiler litter, crushed date seeds, fodder beet and other forages could be also considered. In this way, voluntary feed intake was shown to increase by ensiling a mixture of some halophytic species, *A. halimus*, *H. strobilaceum*, *Tamarix mannifera* and *Zygophyllum album* with some agro-industrial byproducts such as ground date seeds and olive pulp (El Shaer 1997).

5 Halophytes for Oil Production

Seeds of several halophytes may contain appreciable quantities of edible oil (Weber et al. 2001). Oil extracted from the seeds (Up to 30% of seed DW) of *Salicornia bigelovii*, a highly salt tolerant annual halophyte, was found to be of good quality with unsaturation degree comparable to oils from conventional oil seeds (Glenn et al. 1991). Interestingly, *S. bigelovii* (Glenn et al. 1991) and several accessions (Mexico, Egypt, and United Arab Emirates) of the stem succulent *Salicornia europaea* appear to be highly productive, with a biomass production of 20 t · ha^{-1} among which 2 t are seeds (Goodin, et al. 1990). According to Yajun et al. (2003), *Descurainaia sophia* collected from saline soil (0.4% NaCl) contained higher amounts of linolenic acid in their seeds as compared to plants originating from non-saline soil (<0.1% salt) (53.7% and 36% linolenic acid, respectively). Weber et al. (2007) analysed the seeds of *Arthrocnemum indicum*, *Alhaji maurorum*, *Cressa cretica*, *Halopyrum mucronatum*, *Haloxylon stocksii* and *Suaeda fruticosa* to assess their potential as source of edible oil. Seed-oil content was 22–25%, and amounts of unsaturated fatty acids were high (65–74%) excepting *Alhaji maurorum*. In addition, seed lipids contained 12 unsaturated and four saturated fatty acids.

Zarrouk et al. (2003) retained *Zygophyllum album* (Zygophyllaceae), *Crithmum maritimum* (Apiaceae), and *Cakile maritima* (Brassicaceae) as potential oilseed halophytes. The dry weight of 100 seeds ranging from 133 mg in *Z. album* to 774 mg in *C. maritima*. Interestingly, the value for the latter species is nearly two times higher than that for rape (*Brassica napus*) seeds, a conventional oleaginous plant. Seeds of *C. maritima* and *C. maritimum* were rich in oil, (up to 42% and 30% of the seed FW, respectively), whereas seed-oil content was much lower in *Z. album* (ca. 6%). As for olive oil, fatty acid composition of *C. maritimum* seeds was characterised by a high level of oleic acid (81%), whereas that of *Z. album* seeds showed a high percentage of linoleic acid (64%), similar to sunflower seed-oil composition. Therefore, both species contained oil of good quality which may be used without any further modification. Erucic acid (22:1) was prominent in fatty acid spectrum (over 25% of total fatty acids) of *C. maritima* seeds, suggesting the possibility of its utilisation for industrial purposes (nylon, emollients, lubricants etc.) (Bhardwaj and Hamama 2003).

In more recent papers, the natural variability of fruit and seed oil characteristics was investigated in twelve local accessions of *C. maritima*, harvested along the Tunisian coasts, and covering different bioclimatic stages (humid to arid) (Ghars et al. 2006). Seed-oil amount was highly variable among accessions (25–39%) (Fig. 4a) and triacylglycerols (TAG) represented 80–97% of the lipid categories. Erucic acid (22:1), found only in TAG, represented 25–35% of total fatty acids. Such a variability was consistent with previous studies on Australian and Moroccan ecotypes of *C. maritima*, whose seed-oil content ranged from ca. 35–48%, respectively (Hocking 1982; Kumar and Tsunoda 1978). This intra-specific variability in the amount and the quality of the extracted oil could be ascribed to environmental factors, such as precipitation (Rana and Ahmed 1981; Pannelli et al. 1994), temperature (Champolivier and Merrien 1996), and salinity (Zarrouk and Cherif 1983). Fruit morphology and NaCl accumulation also were accession-dependent. Furthermore, the repartition pattern of Na^+ and Cl^- between the plant tissues (stems, siliques, and seeds) suggested that some protective mechanisms prevent excessive salt accumulation in reproductive organs, which is essential for the establishment and survival of *C. maritima* in saline biotopes. The successful rehabilitation of saline marginal zones by introduction of halophytes for the creation of sustainable production systems largely depends on the germination capacity at each site as stressed by Debez et al. (2004, 2006a, 2008) (Fig. 4b) and Ben Amor et al.(2006) and Ksouri et al.(2007).

At fructification stage, the number of seeds per plant was also significantly augmented at salt concentrations optimal for plant growth (50–100 mM) (Debez et al. 2004). Concentrations exceeding 200 mM NaCl strongly reduced both seed mass and seed viability, likely owing to salt-induced restriction of seed nutrition and filling. While seed-oil content was only slightly increased at the extreme salt levels (25%), qualitative changes of seed-oil were more obvious: erucic acid (C22:1) was the major fatty acid (29%) in seed-oil of plants grown at NaCl above 200 mM to the detriment

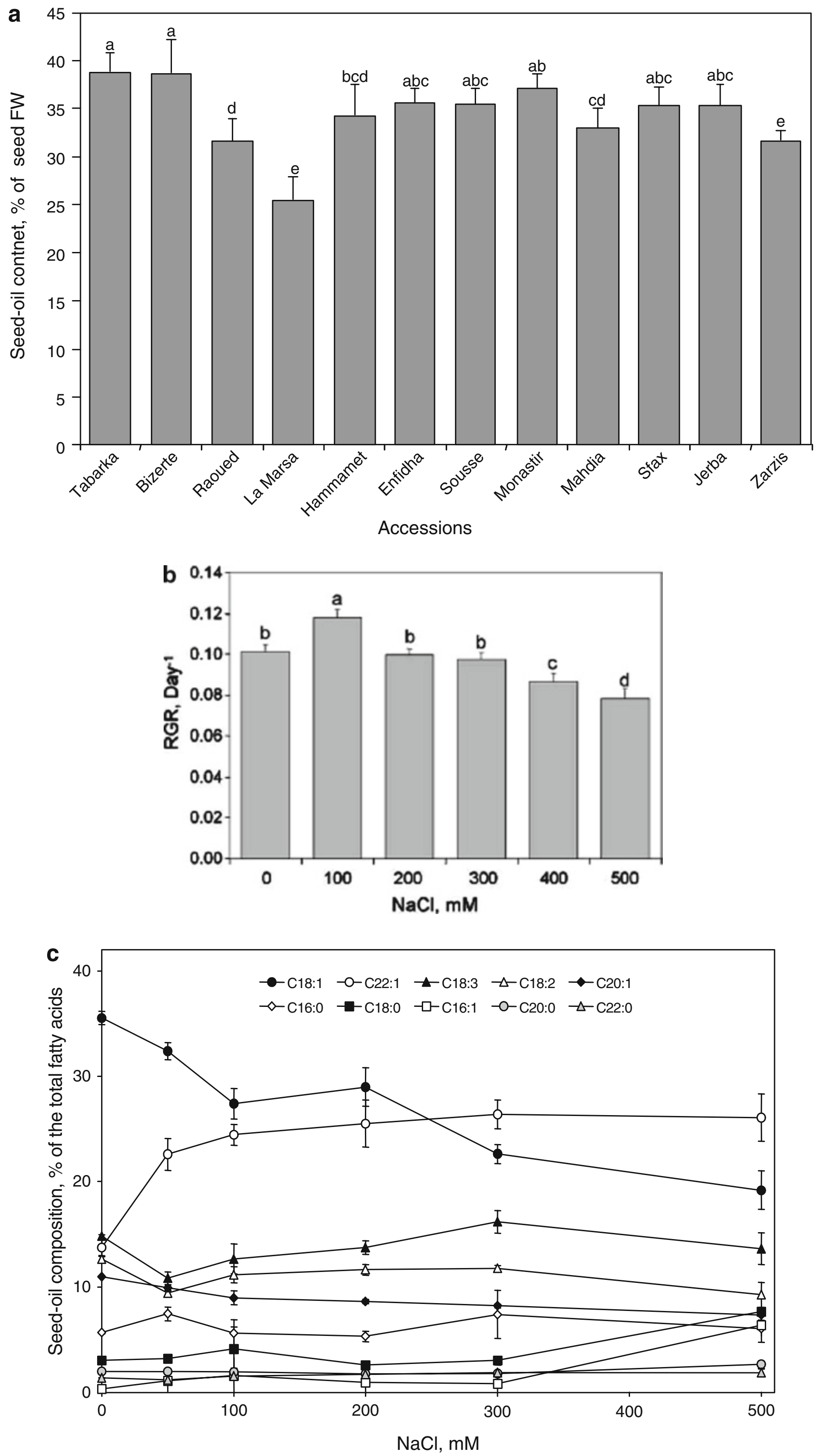

Fig. 4 Seed-oil characteristics and salt-responses of the halophyte *C. maritima* (**a**) Variability of seed-oil content in seeds of *C. maritima* Tunisian accessions. Means ($n = 3 \pm$ SE at $p < 0.05$) followed by at least one same letter are not significantly different between the accessions at $p < 0.05$ (adapted from Ghars et al. 2006). (**b**) Changes in relative growth rate (RGR) of plants exposed for 6 weeks to 0–500 mM NaCl salinities ($n = 10 \pm$ SE at $p < 0.05$) (adapted from Debez et al. 2006). (**c**) Effect of increasing NaCl on the seed-oil composition ($n = 3 \pm$ SE at $p < 0.05$)

of oleic acid (C18:1), which was prominent in the control (36%) (Debez et al. 2006b). Such a trend likely mediated elongases, which are known to catalyze the formation of long fatty acids (such as erucic acid), using oleic acid as initial substrate (Katavic et al. 2002). The search for accessions with a better match between salt concentrations optimal for seed production, seed oil content, and erucic acid concentration, is therefore of high interest. Seed-oil content seemed also to be unaffected by salinity in the oleaginous halophyte *Lesquerella fendleri* (Dierig et al. 2003).

Another promising oilseed halophyte is *Kosteletzkya virginica*, native to the American salt marsh. This species was introduced into China as a candidate species to improve tideland and develop ecologically sound saline agriculture Ruan et al. (2008). A 10 year-long field study revealed that *K. virginica* was flooding-tolerant, displaying multiple eco-benefits, such as landscape beautification, revegetation, and representing a food source for migratory birds. Besides, seed yields of unselected mixed and bred lines were 621 kg · ha^{-1} and 957 kg · ha^{-1}, respectively. Oil contents in the seeds of the unselected mixed and bred lines were 18% and 21%, respectively. Gallagher (1985) reported that seed yield of *K. virginica* in the USA was 800–1,500 kg · ha^{-1} with a seed-oil content of 20–30%. Unsaturated fatty acids (70%) in the seed oil predominated over saturated ones (30%). Oil content in the seeds of *K. virginica* was equivalent to the soybean, whose oil content was about 5%–20% (Yang et al. 2000). The content of unsaturated fatty acids was slightly less than soybean (85%), peanut (82%) and gingili (86%). All these indicated that seed of *K. virginica* has a high potential to become a oil resource at saline sites.

6 Halophytes with Medicinal Potential and for Cosmetics

The use of medicinal plants is common in many developing countries. In addition, there is a renewed interest in developed countries in using medicinal plants to treat humans, pets and livestock. In the late 1990s, the world market for herbal remedies was estimated at US $19.4 billion (Qadir et al. 2008). Environmental stresses (salinity, drought, heat/cold, luminosity and other hostile conditions) often trigger in plants a significant oxidative stress, generating the formation of ROS, leading to cellular damage, metabolic disorders, and senescence processes (Wang et al. 2004). Increasing ROS concentrations eventually affect biological molecules, such as DNA, proteins, or lipids, resulting in mutations and membrane damage, and finally lead to cell and tissue injuries (Abdil and Ali 1999). Enhanced synthesis of protective secondary metabolites under stressful conditions is believed to save the cellular structures from oxidative effects (Buchanan et al. 2000). Halophyte ability to withstand salt-triggered oxidative stress is governed by multiple biochemical mechanisms that facilitate retention and/or acquisition of water, protect chloroplast functioning, and maintain ion homeostasis. Most essential ones include the synthesis of osmotically active metabolites, specific proteins, and antioxidant compounds (Ksouri et al. 2008). This might explain (i) the utilization of some halophytes as traditional medicinal plants and (ii) the increasing interest for their potential for industrial applications (e.g. agro-food, cosmetic and medicine). Natural antioxidants occur in all plant parts, and the typical compounds that exhibit antioxidant activities include phenols, carotenoids and vitamins (Chanwitheesuk et al. 2005). Among various kinds of natural antioxidants, polyphenols constitute the main powerful compound. Accordingly they are widely applied in food industry, cosmetic, pharmaceutical and medicinal materials (Maisuthisakul et al. 2007). In plants, polyphenol synthesis and accumulation is generally stimulated in response to biotic/abiotic stresses (Naczk and Shahidi 2004), such as salinity (Navarro et al. 2006). In addition to their role as antioxidant, these compounds exhibit a wide spectrum of physiological properties, such as anti-allergic, anti-arthero-genic, anti-inflammatory, anti-microbial, anti-thrombotic, cardio-protective and vasodilatory effects (Balasundram et al. 2006).

The nonhalophytic species like medicinally important *Catharanthus roseus* can perform successfully at 10 dS · m^{-1} salinity without showing substantial decline in biomass production (Anwar et al. 1988). *Lycium barbarum* (Solanaceae) is a perennial halophytic species, which is important in traditional medicine in arid and semi-arid areas of China. It has been widely used as health-giving food for about 2,300 years (Cui and Xing 1999). Furthermore, *L. barbarum* fruits are used owing to their nourishing virtues for the kidney, liver, and for brightening eyes (Peng and Tian 2001). Wei et al. (2006) reported that moderate salinity (100 mM NaCl) was optimal for the plant biomass production (+30% as compared to the plants cultivated in non-saline conditions). This was associated with higher shoot succulence, significant accumulation of osmotically active compounds (i.e., betaine and sugar) and the absence of depressive effect on chlorophyll content, gas exchanges (CO_2 assimilation rate and stomatal conductance) and maximum quantum efficiency of photosystem II. Recent findings of Meot-Duros et al. (2008) confirmed the multiple potential of halophytes as natural food (or cosmetic) preservatives. The authors assessed both antioxidant and antimicrobial activities (against 12 bacterial and yeast strains) of three halophytes (*Eryngium maritimum*, *C. maritimum*, and *C. maritima*) collected from the Brittany (France) shoreline. The chloroformic and methanolic extracts were tested for their antimicrobial activities. Interestingly, all bacterial strains were inhibited by plant extracts with exception of *Listeria monocytogenes*. Both phenol content and the antioxidant activity were variable among the tested extracts, *E. maritimum* showing the lowest phenolic level as well as the lowest radical scavenging activity. On the contrary, *C. maritimum* exhibited the highest total phenol content and ABTS (2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid)) radical scavenging activity. Total antioxidant capacity was strong and ranged from 32 mg · g^{-1} DW in *E. maritimum* to 48 mg · g^{-1} DW in *C. maritima*. Antimicrobial activity of the apolar fraction was appreciable in the three investigated species, as most of the extracts showed a MIC (minimum inhibitory concentrations) of 100 μg · ml^{-1}, being even active at 1 μg · ml^{-1} in some cases. Polar fraction was effective as well. *E. maritimum* showed a strong antibacterial activity against *Pseudomonas aeruginosa* and *P. fluorescens*, while *C. maritima* was very effective against *Salmonella arizonae*. A good antimicrobial activity was found in *C. maritimum* against *Pseudomonas aeruginosa* and *Candida albicans*.

Besides its potential as oilseed, *C. maritima* could be of interest for production of secondary metabolites and antioxidant compounds. A comparative survey of two Tunisian accessions (Jerba and Tabarka, respectively, sampled from arid and humid bioclimatic stages) of this halophyte highlighted the presence of an accession-dependent capacity to induce antioxidant mechanisms in response to salt (up to 400 mM NaCl). This may result in a corresponding variability for growth sustainability (Ksouri et al. 2007). Indeed, Tabarka growth (shoot biomass, leaf expansion) was significantly restricted by increasing salinity whereas Jerba growth increased at 100 mM NaCl before declining at 400 mM NaCl. The better behaviour of Jerba was closely related to higher polyphenol content (+56% and 30% of the control values at 100 and 400 mM NaCl, respectively) and better antioxidant activity (lower IC_{50} values for both 1,1-diphenyl-2-picrylhydrazyl and superoxide scavenging), associated with lower leaf MDA (malonyldialdehyde) accumulation (*ca.* –66% of the control at 100 mM NaCl) (Table 2). The parallel stimulations of shoot biomass and polyphenol concentration in tissues in Jerba at 100 mM NaCl hence support the assumption that stress-tolerant plants (such as halophytes) are potentially interesting systems for production of secondary metabolites useful for food and medicinal applications. A similar trend was documented by Falleh et al. (2008) in *Cynara cardunculus*, (Asteraceae). Moderate salinity (25–50 mM NaCl) had no significant impact on leaf growth (biomass, length and number), but these parameters showed a severe reduction at 150 mM NaCl (–30% to –90% as compared to the control). Leaf phenolic content was significantly higher at 25–50 mM NaCl, before declining at 150 mM NaCl. The superoxide anion scavenging capacity of leaf extracts was proportional to the external NaCl concentration. *C. cardunculus* occurs mainly in Mediterranean arid regions, characterized by high

Table 2 MDA and total polyphenol and contents and antioxidant activities (IC_{50} values) in leaves of two *C. maritima* accessions irrigated for 28 days with a nutrient solution containing 0, 100, or 400 mM NaCl

NaCl (mM)	MDA (nmol · g^{-1} FW)		Total polyphenol (mg of GAE · g^{-1} DW)		DPPH· scavenging activity IC_{50} (μg · ml^{-1})		Superoxide scavenging activity IC_{50} (μg · ml^{-1})	
	Jerba	Tabarka	Jerba	Tabarka	Jerba	Tabarka	Jerba	Tabarka
0	4.30 ± 0.2e	4.64 ± 0d	43.02 ± 4c	42.84 ± 8c	0.67 ± 0.1c	0.62 ± 0.2c	3.10 ± 0.1bc	3.57 ± 0.9bc
100	1.48 ± 0.2f	7.48 ± 0.2b	66.93 ± 4a	37.73 ± 8c	0.76 ± 0.0c	1.34 ± 0.2b	1.70 ± 0.3c	5.10 ± 1.1b
400	5.61 ± 0.1c	12.03 ± 0.0a	56.04 ± 1b	31.58 ± 8c	0.89 ± 0.5c	1.95 ± 0.1a	3.90 ± 0.1bc	14.90 ± 3.0a

Source: Adapted from Ksouri et al. (2007)
Values ($n = 8$ ± SE at $p < 0.05$) of each parameter followed by at least one same letter are not significantly different at $p < 0.05$

temperature, elevated salinity and drought in summer (Gominho et al. 2000). It is noteworthy that *C. cardunculus* flowers are used for cheese preparation (Valentao et al. 2002), while leaves are traditionally known for their therapeutic virtues as diuretic, antidiabetic, and antimicrobial agent (Fratianni et al. 2007).

Saïdana et al. (2008) focused on the chemical composition of the essential oil and the antibacterial and antifungal activities from the flowering parts of *Suaeda fruticosa* (Chenopodiaceae) and *Limonium echioides* (Plumbaginaceae) sampled from the Sahel region in Tunisia, where semi-arid Mediterranean climate prevails. The first species is known for its hypoglycaemic action, while *Limonium* spp. is known as an antioxidant medicinal herb. 65 compounds were identified in *L. echioides* among which 48 were common with *S. fruticosa*. The main components in *L. echioides* were hexacosane (10.7%), palmitic acid (9.8%), nonacosane (8.4%), (E,E)-farnesyl acetate (7.0%) and vanillin (6.5%). Palmitic acid (15.2%) was also prominent in *S. fruticosa*, followed by methyl linoleate (10.8%), phytyl acetate (8.8%), hexacosane (7.4%) and methyl decanoate (7.0%). Oil of both species was effective against bacteria such as *Staphylococcus aureus*, *S. epidermidis*, *Micrococcus luteus*, *Escherichia coli*, and *Salmonella typhimurium*, but no antifungal activity was detected, presumably because of the low concentrations used in this study.

Recently, more exhaustive studies revealed large variability in total polyphenol contents and antioxidant activities (DPPH and superoxide radicals scavenging activities, and iron chelating and reducing powers) of several halophytes (*C. maritima*, *Limoniastrum monopetalum*, *Mesembryanthemum crystallinum*, *M. edule*, *Salsola kali*, and *Tamarix gallica*), depending on biological (species, organ and developmental stage), environmental (original habitat), and technical (extraction solvent) factors (Ksouri et al. 2008; Ksouri et al. 2009; Falleh et al. 2009). Such a variability might be of great importance in the perspective of valorising these halophytes as a source of naturally secondary metabolites.

7 Agroforestry Ecwosystems and Carbon Sequestration

Implementing salt-tolerant tree plantations while utilising saline drainage or groundwater represents a promising alternative of using abandoned lands. Of the most promising species are *Prosopis juliflora*, *Acacia nilotica*, *Casuarina equisetifolia*, and *Eucalyptus camaldulensis* (Qadir et al. 2008). Widely used *Acacia* species in agroforestry on saline soils include *A. stenophylla*, *A. nilotica*, *A. ampliceps*, *A. tortilis*, *A. maconochieana*, and *A. cyclops*. Although most *Acacia* species are not halophytes but some are highly salt-tolerant and at the same time sensitive to waterlogging (Craig et al. 1990). *Casuarina*, a fast-growing evergreen tree native to Asia and Australia, was successfully used in the coastal regions of Africa due to its ability to cope with extreme environmental conditions. Marcar et al. (2000) reported a 77% survival rate in *C. cunninghamiana* growing in soils with 11.5 $dS \cdot m^{-1}$ EC for 30 months and 55% for more than 7 years. The evergreen tree *E. camaldulensis* is a medium to tall (20–45 m) tree native to Australia with several uses, such as essential oil and paper production, landscaping, sand dune stabilization, and to lower high water tables of saline environments. In a mid-term (4-year) field study, Oster et al. (1999) found significant restriction of both growth rate and water use of *Eucalyptus* when irrigated with saline-sodic waters (20–22 $dS \cdot m^{-1}$ salinities in the root zone). Whereas a long-term (9 year-long) investigation with 31 tree species challenged with saline water at 8.5–10.0 $dS \cdot m^{-1}$ EC showed that *Tamarix articulata*, *A. nilotica*, *P. juliflora*, *E. tereticornis*, *A. tortilis* and *Cassia siamea* were performing best (Tomar et al. 2002).

The process of carbon sequestration, or flux of carbon, into soils forms part of the global carbon cycle. Movement of carbon between the soil and the above ground environment is bidirectional and consequently carbon storage in soils reflects the balance between the opposing processes of accumulation and loss. Carbon in soils comes from CO_2 in the atmosphere, which is captured by plants *via* photosynthesis, and ultimately stored to soil by direct decomposition of plant material. Halophytic plants adapted to saline dry lands offer potential for sequestering carbon in this hostile ecosystems. Investment in anti-desertification measures in the world's drylands appears to be an economical method to offset CO_2 build-up in the atmosphere while accomplishing a major international objective of re-vegetating drylands. This alternative relies on the assumption that salinity of a halophyte agro-ecosystem may slow the processes of residue decay, and thereby increases the potential for sequestering halophyte carbon. According to Glenn et al. (1993), 0.6–1.2 Gt $C \cdot year^{-1}$ could be assimilated by halophytes, among which 50% of C might enter long-term storage in soil (Glenn et al.

1993). Taking into account the irrigation requirements (based on the irrigation demand which is related to the plant biomass production), the authors consider the rate of 22.5–30% as realistic. Yet, this assumption needs to be corroborated by further field surveys, as the potential for storing organic carbon in agronomic soils depends on the type of organic material in the system. Goodfriend et al. (1998) addressed the decomposition of three promising halophytic crops (*S. bigelovii*, *Suaeda* sp., and *B. maritima*) in order to assess their potential for carbon storage in a coastal desert agro-ecosystem, near Sonora (Mexico). Several parameters including decay rates, incorporation of residues into the soil, microbial decomposition activity, the abundance of bacteria, fungi were determined. Results showed that after 1 year, the rate of halophyte residue decay and the number of microbial decomposers associated with the residues are similar to those of fresh water systems. There appears to be no advantage in storing carbon as plant residue in this saline agricultural system.

Mangroves are woody tress or shrubs located at the interface between land and sea, presently occupying ca. 181,000 km^2 of tropical and subtropical coastline. Over the past 50 years, approximately one-third of the world's mangrove forests have been lost, mostly because of urban development, aquaculture, mining and overexploitation for timber, fish, crustaceans and shellfish (Alongi 2002). Mangroves grow in sheltered shores, penetrating into the estuaries of rivers, tidal creeks, backwaters, salt marshes and coastal mudflats. They are open systems since they are constantly subject to tidal flow and seasonal flooding. As halophytes, mangroves thrive well in saline waters but require fresh water to a certain extent in order to maintain an optimum salinity balance and to get nutrients. Mangrove ecosystems contribute to stabilize sediments and may augment local sediment accumulation and enrich soil with nitrogen, phosphorus and sulphur (Hussain and Badola 2008). They not only create a living buffer between neighbouring river, marine and terrestrial communities, but also play an important role in supporting the productivity of the coastal environments. Among the most common species there are *Avicennia officinalis*, *A. alba*, *Aegiceras majus*, *Aegialitis rotundifolia*, *Acanthus ilicifolius*, *Kandelia rheedii*, *Bruguiera caryophylloides*, *Sonneratia griffithii*, *Laguncularia racemosa* and *Carapa obovata*. Ecophysiological (salt-tolerant, highly efficient nutrient retention) and morphological features (respiratory aerial roots, viviparous embryos, absence of growth rings, wood with narrow densely distributed vessels rings) make mangroves structurally and functionally unique (Alongi 2002).

Because mangroves fix and store significant amounts of carbon, their loss may drastically affect global carbon budgets. Cebrian (2002) calculated that a loss of about 35% of the world's mangroves led to a net loss of $3.8 \cdot 10^{14}$ g · C stored as mangrove biomass. The ecological significance of mangroves in protecting the coastal areas was recently highlighted by Danielsen et al. (2005) who showed that mangroves and *Casuarina* plantations attenuated the tsunami-induced waves and protected shorelines against damage: indeed, villages located within the *Casuarina* plantations remained undamaged except for rows of 5–10 trees nearest to the shore, which were uprooted. In addition, based on analytical models, mangrove plantations at 30 trees per 100 m^2 in a 100-m wide belt may reduce the maximum tsunami flow pressure by more than 90%. Measurement of wave forces and modeling of fluid dynamics suggested that tree vegetation may protect coastlines from tsunami damage by reducing wave amplitude and energy.

8 Conclusions and Perspectives

Crop diversification and production systems based on halophytes are likely to be the key to both socially and economically rehabilitate, and thereby valorise, the salt-affected-regions. Such an approach will be particularly relevant for developing arid and semi-arid countries, where most farmers exploiting these marginal lands are resource-limited and communities face severe unemployment, poverty, and population migration (Qadir et al. 2008). Revolutions in agriculture rely on empirical approaches. Looking towards the future, sometimes means taking a step to the past, in order to discover guided by an open mind thousands of possibilities hidden by nature, and enlarged by cultural evolution (Galvani 2007). Historical evidence suggests that farmers always shift from more sensitive to more tolerant crops as salinity in their fields rises (Flowers 2004). Ending this infernal series could be achieved by the sustainable use of the wide range of halophytes available, whose large potential as crops is still under-explored (Koyro and Huchzermeyer 2004). The use of salt-affected land and saline water resources by crop diversification could also be an alternative to move from subsistence farming to higher income-generating ventures.

The emerging data supporting the feasibility of successfully cultivating salt-tolerant plants in saline agro-ecosystems offer unexpected opportunities for researchers, farm advisors, and farmers to identify the most appropriate cash crop halophytes and their combinations to optimize the input/output ratios. Besides, since salt-affected soils and ground waters cross national boundaries, co-operation and coordination at regional and global levels is of high importance to elaborate and apply effective salinity strategies. With this respect, it is crucial to initially involve politicians, institutions, select farmers, water user associations, and other potential beneficiaries, so that (when the critical time for expansion comes) all parties will be familiar with their role. (Yensen 2006). This means changing the general opinion of the affected farming communities and policy makers about the questionability of using salt-affected soils.

Preliminary assessments suggest that there are 26 salt-tolerant plant species capable of producing 13 products (or services) of value to agriculture in Australia (Barrett-Lennard 2002). As suggested by Koyro et al. (2006), once the selection of halophytic species suitable for a particular climate and for a particular utilization has been achieved, a progressive realization of the following steps may bring to establish useful cash-crop halophytes:

(a) Performing greenhouse experiments at the local substrates (and climatic conditions) to select and propagate promising sites (Fig. 5)
(b) Using Lysimeters on the field to gather reliable and long-term data about the water consumption and ion movements
(c) Developing a sustainable production system in plantations at coastal areas or at inland sites (for example for economical use)
(d) Assessing the plant yield and the financial outcome for the farmers
(e) Evaluating the economic acceptance of the product The development of successful industries for salt-land will require pertinent information regarding the capabilities of land and water, plants and animals, and markets
(f) Protecting the environment by using appropriate culture and irrigation practices and finally
(g) A major task is the need to change perception in the community of biosaline agriculture

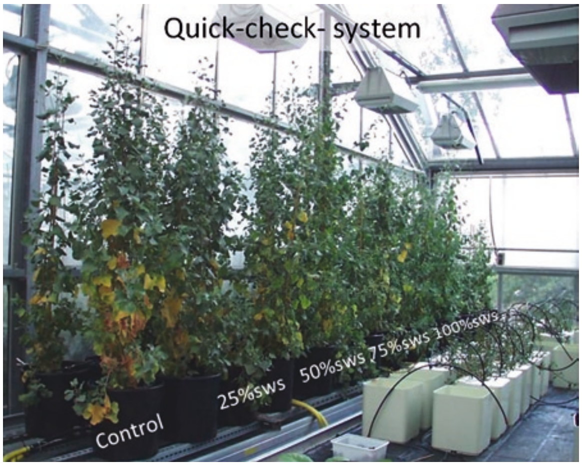

Fig. 5 On the left side gravel/hydroponic quick check system (QCS) with automatic drip irrigation under photoperiodic conditions in a growth cabinet (plant species: *Atriplex nummularia*) and on the right side hydroponic culture of *Sesuvium portulacastrum*. Controls are visible in the foreground, the sea water salinisation treatment (100% sws ≅ 500 mol * m^{-3} NaCl) in the background

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The Salt Marsh (Sabkha) in the Western Part of Libya

M.O. El-Magsodi and Daw A. Haddoud

Abstract The total coastline of Libya is about 1975 km long. Numerous salt marshes bordered by sabkhas occur along the coast. These sabkhas cover some a very large area on the coast line and most of them are completely dry during the summer season. One of the larger sabkhas is located in the western part of Libya and is called "the Abu Kammash salt marsh (Abu Kammash subkha)" and it is found along the coastal Libyan-Tunisian highway about 150 km west of Tripoli in the Abu Kammash area near the Tunisian border, at an altitude of 2.5–4.0 m below sea level. This is a typical salt marsh of coastal Mediterranean region. It is generally a flat sabkha with a total area of about 50 km^2. There are 38 wells in the sabkha, from which brine water is pumped through pipelines to Abu Kammash factory (chemical plant) which was established on the area near the seashore for the mass production of pure salt and bleaching agents. The saline ponds and pools are formed when such low land area floods in rainy winters, and 12 km long and 4 km wide small seasonal lake is formed. In summer, however, most of these lakes dry up. The high salinity and evaporation lead to precipitation of a thick layer of salt on the sabkha floor.The phytoplankton density is quite low. The sabkha has been identified as a natural biotope for brine shrimp (*Artemia*). Next to the *Artemia* comes the birds which are also found in moderate number. Majority of the birds are migratory, as such the sabkha may serve as good refuge for such birds provided certain measures are taken. There is a very poor vegetation cover composed mainly of halophytes and desert plant taxa around the sabkha due to coarse sand texture and prevailing semiarid conditions.

1 Introduction

Libya has a total area of 1,759,540 km^2 and a coast line over 1,975 km long. Numerous salt marshes (sabkhas) occur along the coast. These sabkhas cover an area of hundreds of square kilometer all along the coast and most dry up during the summer season. The huge areas of isolated marsh lands are unique habitats of great significance. Therefore an evaluation of their biodiversity will be highly fruitful. The biodiversity inhabiting such habitst plays important role in this type of ecosystem and human population living around these areas depend on them for food. They are also a source of industrial raw materials such as salt, chemicals and *Artemia.* One of the main marshes among these is Abu Kammash salt marsh "Abu Kammash sabkha" extending from the western coast from the Tunisian border to Musratha. It shows natural topographical structure all along the Libyan-Tunisian coastal highway lying about 150 km west of Tripoli in the Abu Kammash area close to the Tunisian border. Major part of the sabkha is located in the middle of coast from Musratha to Benghazi. The coves and marine lagoons are found in the eastern part of this coast from Benghazi upto the Egyptian border. These are Ain Ziyana, Bumba and Ain Gazala lagoon. The Farwa lagoon is found on the western part near Libyan-Tunisian boarder (Kerambrun 1986; Haddoud 1999; Gashout and Haddoud 2001). Several experimental trials have been done to use some of these lagoons and sabkhas in aquaculture activities

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especially in Farwa, Ain Gazala, but no progress has been acheived due to several reasons (Gashout and Haddoud 2001).

2 Material and Methods

2.1 Study Area

The Abu Kammash subkha (salt marsh) is located c. 33° 48' 00' N, 1 1° 36' 00' E, approximately 150 km west of Tripoli, along Tripoli–Tunisia coastal highway close to the Tunisian border (Fig. 1). The sabkha has an elongated basin extending from west to east with an axial length of c. 12 km, a maximum width of 4 km, and a total area of c. 50 km^2. The depth of the lagoon varies from 10 to more than 80 cm. The actual basin (Abu Kammash sabkha) is separated from the sea by a narrow sand bar of c. 3 km width. It is a typical salt marsh of coastal Mediterranean region, generally a flat with an altitude varying between 2.5 and 4.0 m below sea level. The floods in rainy winters form saline ponds and pools on such low land areas and a small seasonal lake is formed. In summer however, most of these lakes dry up.

The Abu Kammash area is characterized mainly by semiarid climate, coarse sand and poor vegetation cover made up mostly of halophytes and desert plants. The climate of the area is mostly maritime which does not differ from that on the nearest mainland. The temperature of the Abu Kammash area reaches a maximum of 43°C in summer and a minimum of 13°C during winter. The relative humidity ranges from 64–88% (x = 73.6%).

In 2001, a pilote workplan was proposed by MBRC to study Libyan sabkhas and wetlands covering; biological, chemical and socio-economic features and use of each site. The information was gathered by using a questionaire prepared for this purpose. The scientific information was collected from different sites by using portable instruments. The results from previous studies were also taken into consideration during the evaluation.

Artemia cysts (eggs) were collected in summer 2001, when the pond was completely dry, together with debris and dry muddy-sand which formed a dark gray thin layer at the edges of the dried pond. All samples were processed at the *Artemia* Reference Center (Belgium). Cysts were cleaned by means of the bi-flotation technique as described by Sorgeloos et al. (1978). The lake samples produced only limited amount of full cysts because of considerable amounts of salt and impurities. The diameters of hydrated non-decapsulated, hydrated decapsulated cysts, length of instar-I nauplii and the thickness of chorion were measured according to the technique of Vanhaecke and Sorgeloos (1980). The incubation of cysts for collection instar-I nauplii and the decapsulation of cysts were performed according to Sorgeloos et al. (1986). The cyst diameters and the length of nauplii were measured using a light microscope equiped with a micrometer eyepiece previously calibrated with a stage graticule. A random sample of 100 cysts and nauplii was evaluated.

Artemia sibling species were defined for Abu Kammash brine shrimp in cross-breeding tests performed following procedures outlined by with *Artemia* from Sanfrancisco Bay (California-USA) and Lamaca Lake (Cyprus) were used as reference material for *A, franciscana* (Bowen et al. 1978) and *A. salına* (*tunisiana*) respectively.

In November 2001 the same sabkha was rain flooded forming a pond of about 12 km length and a maximum 4 km width, and four study trips were organized to collect samples and scientific information from the area. During these study trips the *Artemia* biomass was collected by using a standard plankton net of 200 µm mesh size, with mouth diameter of 0.25 m for further analysis. Also, samples of water were collected and brought to the laboratory for chemical analysis. Moreover, glass jars were used to collect water samples for salinity, oxygen and pH determination. Jars were also used to skim water and top soil layer for analysis of microscopic flora. Temperature and humidity were recorded in all study trips, by using the following equipments: Maximum and minimum thermometer, wet and dry bulb hygrometer and whirling hygrometer.

The sediment samples for sediment analysis were collected from pond periphery and near its center. These samples were analyzed for the determination of soil texture. The technique adapted and used in the analysis was that described by Folk (1974).

Samples of the plant cover in the area arround the sabkha were collected and identified following Tackholm (1956) and Keith (1965).

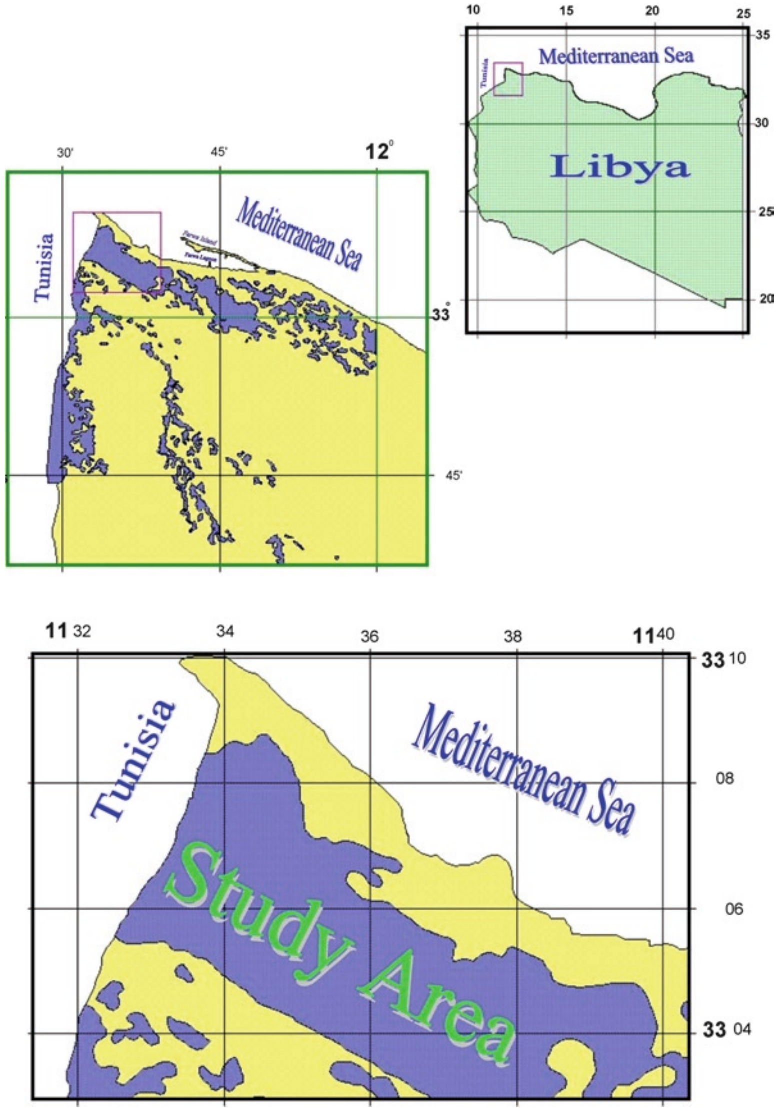

Fig. 1 A map showing location of the study area (Abu-Kammash subka)

Birds were mainly observed and identified by field glasses (Binoculars). Also we followed Heinzel et al. (1972), Bundy (1976) and Hollom et al. (1988) for identification of bird fauna on the area.

3 Results

Phytoplanktons: Planktonic organisms found in the water and top soil surfaces of the pond are listed in Table 1. There are seven genera and ten species of diatoms, one genus of dinoflagellates and one genus and one species of blue green algae. The analyses of the sabkha substrate indicated that it has sandy texture; composed of coarse, medium and very fine sand. The silt and clay were around 35% in most samples. Fine sediment covered the largest area of the sabkha especially near the edge, while the area around it shows mainly coarse sand texture.

Table 1 List of phytoplanktons in pond water and soil samples

A. Diatoms: *Amphora coffeaeformis* (C. Agardh) Kutzing , *A. coffeaeformis* var. *perpmilla* Grunow., *A. lineolata* Ehrenberg, *A. cstata* W. Smith, *Nitzschia vivax* W, Smith, *Navicula minuscitlata Grunow*, *Fragilaria* sp., *Mefosira* sp., *Synedra* sp., and *Surirella* sp.

B. Blue green algae: *Phormidium fragile* (Menegh) Gomont

C. Dinoflagellates: *Gymnodinium* sp.

Table 2 Summary of biometrical measurements

Sample	Biometrical measurements	Sample size	Mean (μm)	Standard deviation
Libyan cysts (ARC code number 1437)	Non decapsulated cysts	100	256.8	13.7
	Decapsulated cysts	100	227.8	11.2
	Instar-I nauplin	100	478.0	21.0
	Chorion thicknes	–	14.5	–

Table 3 Temperature, salinity, oxygen content and (pH) recorded during the four study trips in 2001 and 2002

Field trip dates	Temprature (°C)		Salinity (o/oo)	Oxygen content (parts per million)	pH
	Air	Water			
August 2001	43	ND	ND	ND	ND
November 2001	19	18	312.4	2.2	6.83
January 2002	13	12	302.0	3,6	7.72
April	28	25	317.4	1.63	7.31

ND No data recorded due to the drying of the sabkha

Table 4 Summary of the average values of the individual constituent of salts

Chemicals composition	Concentration in g/1 during (summer)	Concentration in g/1 during (winter)
NaCl	237.0	287.6
$MgCl_2$	31.0	5.6
$MgSO_4$	23.5	9.4
KCL	11.0	4.7
Br	0.4	0.1
$CaSO_4$	1.7	2.8

Artemia: The results obtained for the measurement of hydrated non-decapsulated and decapsulated cyst diameters and instar-I naupliar length are presented in Table 2. Although the cross-breeding tests between Abu Kammash *Artemia* and Larnaca (Cyprus) brine shrimp yielded viable fl offsprings, the Abu Kammash and San Francisco Bay matings were sterile. Abu Kammash *Artemia* can be classified within the *A. salina* (*Tunisiana*) sibling species complex. The *Artemia* biomass was found to be the predominant member of the plankton. It was present in such prolific abundance as to impart red colour to the surface of water of the sabkhas.

Physical and chemical parameters: The results of physical and chemical parameters of the Abu Kammash sabkha waters revealed that during the four study trips temperature, salinity, oxygen content and pH varied between; 17–33°C, 302–317‰, 1.63–3.6 part per million and 6.83–7.72 (pH) respectively (Table 3). The results of brine analysis during summer and winter seasons are presented in Table 4.

Birds: A large number of birds were observed to visit the area. Out of these 65% were migratory and 35% were resident species. Most of the birds observed are passerines. The details are given in Table 5.

Plant diversity: The vegetation comprises of xerophytes and halophytes with few date palms, the rest being coarse sand. Most of the plants in the area (arround the sabkha) are halophytes and desert species. These are not favoured by animals. The dominant species are *Salicornia fruticosa* and *Halimione porlulacoides*. There is no great variation between the flora of the mainland (area around the sabkha) and that of the nearest island (Farwa island) (Annajar and Hussain 1984).

4 Discussion

Salt evaporating ponds of varying sizes can be found along the coastal deserts in "many parts of the world. Such areas are traditionally used by man for salt production. The production of food in these salterns could be an important by-product. The natural productivity of these ponds per unit surface area was reported to approach that of the open sea, even though the ponds are only 30–50 cm deep.

The results of present work indicate that ponds formed during rainy seasons in sabkha and marshes along the north-western coast of Libya contain a number of diatoms and other microscopic algae that can thrive and grow to support food availability to newly hatched larvae (nauplii) and adults of *Artemia.* The soil texture of such ponds may provide more aeration for these microscopic organisms. Also, the nature of the substrata seem to be a suitable habitat for both soil diatoms and *Artemia* cysts (Fig. 2a–c).

The brine shrimp (*Artemia salina*) was found to be the predominant member of the plankton. It was present in such prolific abundance as to impart red colour

Table 5 List of birds observed on the sabkhas

Species	Common name	Habitat	Status
Sterna hirundo	Common tern	A	B
Sterna anaethetus	Bridded tern	A	B
Tringa totanus	Red shank	A	B
Pholacrocorax carbo	Cormorant	A	M
Ardea cinerea	Grey heron	A	M
Egretta garzetta	Little egert	A	M
Fulica atra	Coot	A	M
Larus argentatus	Herring gull	A	M
Alceda atthis	King fisher	A	M
Luscinia megarhynchos	Nightingale	T	M
Erithacus rebecula	Robin	T	M
Apus melba	Alpine swift	T	M
Motacilla alba	White wagtail	T	M
Ficedula hypoleuca	Pied fly catcher	T	M
Passer hispaniolensis	Spanish sparrow	T	R
Fringilla coelebs	Chaffinch	T	R
Upupa epops	Hoopoe	T	R
Columba livia	Rock dove	T	R
Sfreptopelia turtur	Turtle dove	T	R
Lanius excubitor	Great grey shrike	T	R

A aquatic, *T* terrestrial, *Mr* migratory, *R* resident, *B* breeding. Heinzel et al. (1972), Bundy (1976), Hollom et al. (1988) were followed for identifications

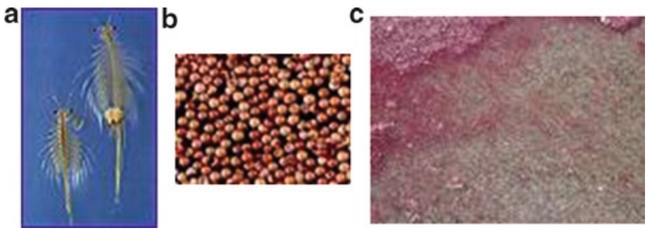

Fig. 2 *Artemia salina* general view (**a**), cysts (**b**), and imparting red colour(**c**)

to the surface of water of the sabkha. The *A. salina* is an arthropod which belongs to class Crustacea, subclass Branchiopoda, and order Anostraca, commonly known as fairy shrimp, which are the most primitive crustacean of our recent fauna. They are elongated, somewhat cylindrical, delicate animals without the carapace. *Artemia* is an extreme example of euryhalinity, since it can inhabit salt solution containing as little as 0.26% NaCl and concentrated brine having 30% salt (Croghan 1959), and in high salinity waters of over 200 parts per thousand (Allee et al. 1949). In the present study we found it in the sabkha with a salinity of more than 300 parts per thousand. This salinity is higher than that of the Great Salt Lake and that of the Dead Sea which have a salinity of 203 and 192 parts per thousand respectively. The present preliminary quantitative study of the Abu Kammash sabkha also revealed that its fauna has low diversity of species as well as number of planktons. This may be attributed to the scarcity of food, high salinity, soil texture and lack of different habitats, or all might be considered as limiting factors for the presence, abundance, diversity and stability of the planktons on the sabkha.

Next to the *Artemia* come the birds which are found in moderate numbers. Majorities of these are migratory depicting that the Abu kammach area (including the sabkha) may serve as a good refuge for such birds provided certain measures are taken. Moreover, the effect of distance as a barrier is less effective for birds than mammals. This is in accordance with our results where birds are the largest and the most abundant group of vertebrates recorded on the area. However, only few species of mammals were observed here; Gerbil, House mouse, Red fox, Jackal, Wild rabibit and three species of reptiles: Skink, Chamaeleon, Montpellier-snake and 24 species of insects (Annajar and Hussain 1984). Amphibians are not represented in the area due to the lack of moisture and high salinity that could be considered as limiting factors for their existence. Darlington (1957) staded that distribution of amphibians on these areas is limited because of high salinity. High salinity,coarse sand texture and semiarid condition lead to poor vegetation cover mainly halophytes and desert plant species.

5 Conclusions

From this quantitative and qualitative study we conclude that the Abu Kammash area (including the Abu-Kammash sabkha) has low general faunal diversity and number of mammals too is low. This may be due to the scarcity of food, high salinity, soil texture and lack of different habitats, even all might be considered as limiting factors for the presence, abundance, diversity and stability of the animals in the area. Moreover semiarid conditions are prevealing on the area. However, the sabkha could serve as a source of brine shrimp *Artemia* for research and development purposes.

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Halophyte-Fodder Species Association May Improve Nutrient Availability and Biomass Production of the Sabkha Ecosystem

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Abstract Sabkhas are often regarded as marginal non productive areas. Yet, a wide range of halophytes together with less salt-tolerant fodder species thrive in these ecosystems. In the present study, the potential of halophytes in improving biomass production and nutrient uptake of an un-grazed parcel edging an inland sabkha (100 km south-east of Tunis) was addressed. The vegetation of studied area was characterised by perennial halophytes tufts in association with fodder annuals, mainly *Medicago* species. Halophytes grew slowly and accumulated low contents of mineral nutrients (N, Pi, K^+) and high Na^+ concentrations in their shoots. Depending on the precipitation, the annual fodder species showed high growth activity (up to 40% of the plant annual biomass production of the ecosystem), which was sustained by a high capacity of nutrient uptake (up to 70% of the total nutrient uptake). The annuals were almost exclusively clustered under the halophyte tufts, or at their immediate vicinity, where soil N and Pi levels were significantly higher, and salinity significantly lower than between the tufts. The perennial halophytes provided optimal conditions for the growth of these annual Leguminosae, which valorised the nutrients accumulated around the halophytes, owing to their high growth rate, nutrient-absorption rate and use-efficiency. These data are of high ecological significance and suggest that the salt tolerant-fodder species association may constitute a low-cost and valuable approach for the restoration and reclamation of the marginal saline ecosystems.

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1 Introduction

Frequently associated with drought, salinity leads to considerable loss of fertile soils and threatens the world nutritional balance (Malcolm et al. 2003; Reynolds et al. 2005). About 1.5 billion ha of soils suffer excessive salt level throughout the world (Choukr-Allah 1996). Annually 10 million ha of arable lands are abandoned because of salt accumulation following the utilisation of saline irrigation water for agriculture. In Tunisia, 1.5 million ha (10% of the whole territory and 18% of its arable land) are affected by salt. Besides impacting plant water status, increasing salinity enhances plant nutrient requirements and may restrict the uptake of essential nutrients such as K^+, Ca^{2+}, and Mg^{2+} (Hu and Schmidhalter 2005), resulting in salt-induced nutrient stress. Such resource limitations control ultimately plant community properties (e.g. structure and species distribution), as well as ecosystem functions (i.e. productivity and nutrient cycling) (James et al. 2005).

Unlike conventional crops, halophyte plants are able to survive and to reproduce in environments (coasts, wetlands, inland deserts) where salt concentration reaches or even exceeds seawater salinity level. These species, which represent about 1% of the world's flora, have evolved complex mechanisms at different levels (whole plant, cellular, and molecular) enabling them to successfully cope with these hostile conditions.

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Restoration of saline areas using salt-tolerant vegetation is progressively emerging as a sustainable and low-cost approach (Aschenbach 2006; Ravindran et al. 2007; Sargeant et al. 2008; Khan et al. 2009). Concomitantly, better understanding of plant ecosystems and their dynamics that are capable of significant productivity under salt stress is of paramount importance. For instance, the analysis of plant association in their natural environments may provide key information about their intrinsic potentialities and the likely ways of their utilisation in order to restore marginal salt-affected areas.

Coastal or continental sabkhas are saline ecosystems frequently or occasionally subjected to flooding, which are typical of the semi-arid and arid areas around the world. Because of the extreme environmental (edaphic and climatic) conditions prevailing there, these biotopes are considered as non productive wastelands (Böer and Gliddon 1998). However, vegetation in sabkhas is diverse and heterogeneous, consisting in numerous perennial halophytic plants in association with annual species, more or less sensitive to salt and mineral deficiency stresses. In Tunisia for instance, the annual fodder plant *Hordeum maritima* (Poaceae) is common in the saline depressions in close association with strict halophytes, such as *Arthrocnemum indicum* and *Halocnemum strobilaceum* (Hafsi et al. 2007). Sabkhas could be valorised by implementing agro-ecosystems using "alternative" cash-crop halophytes (Böer and Gliddon 1998; Keiffer and Ungar 2002). Indeed, among the 2600 recognised halophytic species, some present economic (human food, fodder, materials of high economic values) or ecological (soil desalinisation, dune fixation, phytoremediation, landscaping and ornament) potentials (Abdelly et al. 2006; Ghars et al. 2006; Weber et al. 2007).

Despite sabkhas are common in Tunisia these unique biotopes remain poorly investigated with respect to their spatial and temporal dynamics, vegetation structure, nutrient relations, and their agro-economical potentialities. In the framework of the sustainable saline ecosystem valorisation, the present study investigates the role of halophytes on soil physico-chemical characteristics and nutrient relations, enabling enhanced primary production of fodder species. The chosen area borders a sabkha located in a semi-arid region of Tunisia (mean annual rainfall ranging from 250 to 700 mm). The flora of this site is composed of strict halophytes (*Arthrocnemum indicum*, *Halocnemum strobilaceum*, *Salsola cruciata*, *Suaeda fruticosa*) and of glycophytes (mainly *Medicago* species).

2 Material and Methods

2.1 Experimental Site and Sampling Periods

An experimental parcel covering about 1,000 m^2 was delimited and protected from livestock grazing, at the border of the sabkha of Enfidha (100 km south-east from Tunis), situated in the semi-arid bioclimatic zone (moderate winters and mean annual rainfall rarely above 300 mm). Biomass production of the plant cover (perennial halophytes and annual glycophytes) was assessed three times annually during two successive years. The first year was characterised by irregular and scarce rainfall (235 mm), and the second one was relatively rainy (423 mm). The first sampling took place shortly after of the establishment of the annuals, the second at their flowering stage (generally corresponding to the period of halophyte maximum growth activity), and the third one following ripening of the annuals. At the final sampling, biomass may have been underestimated since most of the desiccated organs were lost.

2.2 Plant Sampling Method

Perennial plants. A non-destructive, indirect sampling method was used to evaluate the contribution of each species to total biomass production. In the protected study area (Fig. 1) observations were made in a representative (with respect to the plant cover) homogeneous 5 m × 5 m plot. Within this experimental area, the halophytes were thriving in isolated tufts of different sizes. At each sampling, diameter and height of the perennial tufts inside the observation plot were measured. For each species, size classes were defined, and their populations were counted. Then, tufts with sizes representative for each class, outside the reference square, were sampled (green twigs and dry twigs separately), and fresh weight (FW), dry weight (DW) after drying for 3 days at 80°C, and mineral content determined. For each species j, with size classes $i = 1, 2, \ldots, k$, each containing $n_{i,j}$ plants of mass $m_{i,j}$, dry weight was calculated as:

$$DW_j = \sum_{i=1}^{i=k} n_{i,j}\, m_{i,j}$$

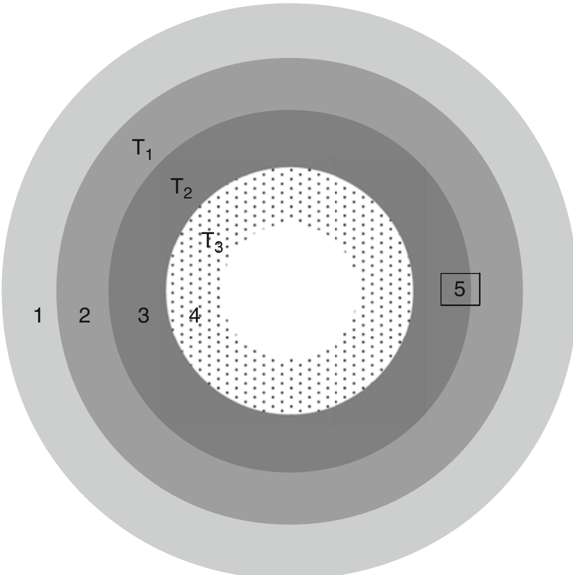

Fig. 1 Schematic representation of the studied parcel. T_1, T_2 and T_3 indicate the harvesting sites of tufts 1, 2, and 3 respectively. Numbers 1–4 represent the different vegetation zones from the periphery to the centre of the sabkha of Enfidha. 1: Most external zone, containing mainly fodder shrubs (*Acacia cyanophylla* and *Medicago arborea*), Poaceae and other annual glycophytes. 2: Transitional zone, between abundant and poor flora areas, characterised by *Atriplex halimus* and *Suaeda fruticosa* tufts, and other species typical of more saline (*Hordeum maritimum* and *Triglochin bulbosa*) or less saline (*Trifolium tomentosum* and *Limoniastrum guyonianum*) hydromorphic soils. 3: The third zone, colonised mainly by perennial halophytes, indicating temporarily inundated saline soils. The sssociation *Salsola tetrandra-Suaeda fruticosa* was frequent, in addition to *Arthrocnemum indicum* and *Phragmites cummunis*. 4: The fourth zone, characterised by the prominence of two species indicating high hydromorphy and salinity : *Halocnemum strobilaceum* and *Arthrocnemum indicum*. 5: Location of the studied parcel, delimited at the border of zones 2 and 3

Annual plants. Six 0.5 m × 1 m plots were selected inside the protected parcel, representative for the distribution of the annual species within the experimental area. Sampled shoots from each small area were partitioned into Leguminosae and Poaceae, and their respective FW and DW determined.

2.3 Soil Sampling Method

Three *Arthrocnemum indicum* tufts growing in association with annuals were selected. Tuft 1 was close to the sabkha periphery, whereas tufts 2 and 3 were close to its centre (Fig. 1). Soil samples (n = 4) were taken at the centre of each tuft, and along two orthogonal axes at 0.5, 1 and 2 m from the centre. At each position, five 20-cm wide soil horizons (from 0 to 1 m depth) were sampled.

2.4 Mineral Elements

Plants. Plant samples were finely grounded. Na^+, K^+ and inorganic phosphate (Pi) were extracted in 0.5% HCl and assayed by flame emission photometry and colorimetry respectively (Fleury and Leclerc 1943). For Pi, the extracts were first treated with organic carbon. Reduced nitrogen was determined by the Kjeldahl Ũmethod.

Soil. Assimilable phosphorous was extracted and estimated using the fine soil fraction according to the method described by Bonneau and Souchier (1979). Electrical conductivity (EC) was measured and soluble cations (Na^+ and K^+) were determined by flame emission photometry (Corning, UK) in aqueous extracts (soil/water: 1/10 w/w).

2.5 Statistical Analysis

A one way analysis of variance (ANOVA) at the $P < 0.05$ significance level was performed using the SPSS programme.

3 Results

3.1 Vegetation Inventory

Four vegetation zones were distinguished from the periphery to the centre of the sabkha (Fig. 1). The outer zone, which was partially cultivated, contained barley and fodder shrubs (*Acacia cyanophylla* and *Medicago arborea*), in addition to a mixture of naturally-growing vegetation, mainly comprising Poaceae (*Lolium regidum*, *Lagurus ovatus*, *Aeluropus littoralis*, *Cynodon dactylon*), Leguminosae (*Medicago ciliaris*, *Medicago truncatulata*, *Medicago polymorpha*, *Medicago hispida*, *Medicago minima*, *Astragalus hamosus*, *Trifolium tomentosum*, *Scorpirus muricatus*), and Compositeae (*Calendula arvensis*, *Anacyclus clavatus*, *Pteranthus* *dichotomus*, *Pallenis spinosa*, *Scolymus hispanicus*). The majority of these species is known to be salt-sensitive. However, *Aeluropus littoralis* is an indicator of moderately hydromorphic zones with variable EC (from 10 to 60 dS m^{-1}).

The second zone represents a transitional zone species-rich to species-poor areas. It was characterised by tufts of Chenopodiaceae, mostly *Atriplex halimus* and *Suaeda fruticosa*, tolerating a wide range in salinity (EC between 10 and 70 dS m^{-1}). Species typical of more saline (*Hordeum maritima* and *Triglochin bulbosa*) or less saline (*Trifolium tomentosum* and *Limoniastrum guyonianum*) hydromorphic soils, were also growing in this area. Indicator species of low EC soils (less than 25 dS m^{-1}: *Medicago ciliaris* and *Trifolium scabrum*) were also found.

The third zone (EC ranging between 10 and 70 dS m^{-1}) was mainly characterised by perennial halophytes, especially the association *Salsola tetrandra-Suaeda fruticosa*, also characteristic of low to moderate hydromorphic soils. Other species like *Arthrocnemum indicum* indicated temporarily flooded saline soils (EC up to 80 dS m^{-1}) or pronounced hydromorphy (*Phragmites cummunis*) or high salinity (*Halocnemum strobilaceum*). Four *Medicago* species, as well as *Trigonella maritima* and *Trifolium tomentosum* were also found.

Vegetation in the fourth zone distinguished by prominence of two species indicating strong hydromorphy and salinity: *Halocnemum strobilaceum* and *Arthrocnemum indicum*. The tufts of *H. strobilaceum* formed a suitable micro-habitat for *Spergularia salina* and *Trifolium tomentosum*.

Thus, the variations in species composition among the four zones indicated increasing salinity and hydromorphy gradients from the outer boundary towards the centre of the sabkha. Interestingly, the annual and perennial species were spatially associated, annuals thriving at the vicinity of the halophyte tufts, while almost no vegetation was found between these tufts.

3.2 Soil Salinity

Soil salinity (as EC, dS m^{-1}) in the centre of the tufts showed non-significant (at $P < 0.05$) spatial variation (0.55–0.88 dS m^{-1}) within the sabkha (Fig. 2a). These values correspond to a salinity ranging between 55 and 88 meq kg^{-1} dry soils, i.e. a relatively low salt level. EC

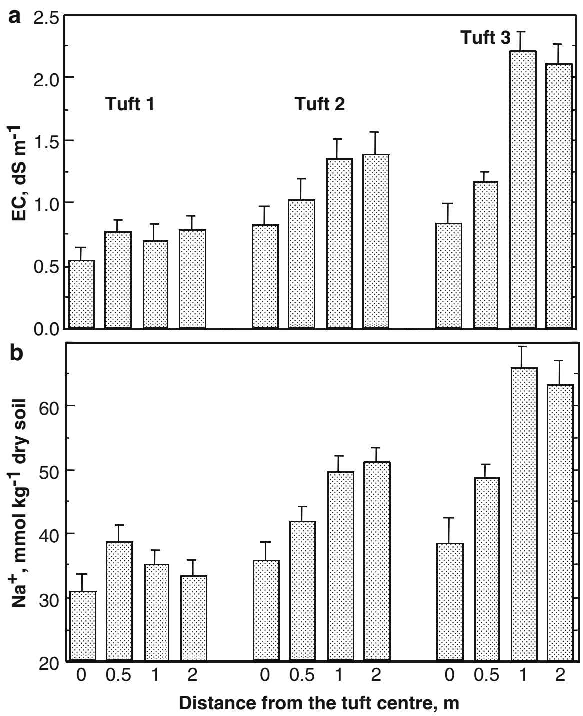

Fig. 2 Variation in soil (0–20 cm depth horizon) salinity with distance from the perennial halophytes. (**a**) EC of aqueous extracts (1 g de soil for 10 ml H_2O). (**b**) soluble sodium. Tuft 1 situated at the sabkha periphery, tufts 2 and 3 near its centre. Means of 4 replicates ± S.E. at $*P < 0.05$

generally increased with distance from the tufts, exceeding 1 dS m^{-1}, and even 2 dS m^{-1} (200 meq kg^{-1} dry soil), at 2 m from the tuft centre, i.e. characteristic for a highly saline soil.

EC was significantly higher (at $P < 0.05$) for tufts 2 and 3 (located inside the sabkha) than in tuft 1, closer to its periphery. This is consistent with the increasing salinity gradient from the periphery to the sabkha centre derived from vegetation analyzes. A horizontal salinity micro-gradient was thus observed from the centre towards the exterior of the halophyte tufts. Na^+ concentration varied in parallel with the EC (Fig. 2b), along both large scale gradients and micro-gradients, indicating its large contribution to the total soil salinity.

3.3 Soil Fertility

Potassium concentration in the soil (2–4 mmol kg^{-1} dry soil) did not vary systematically across the sabkha,

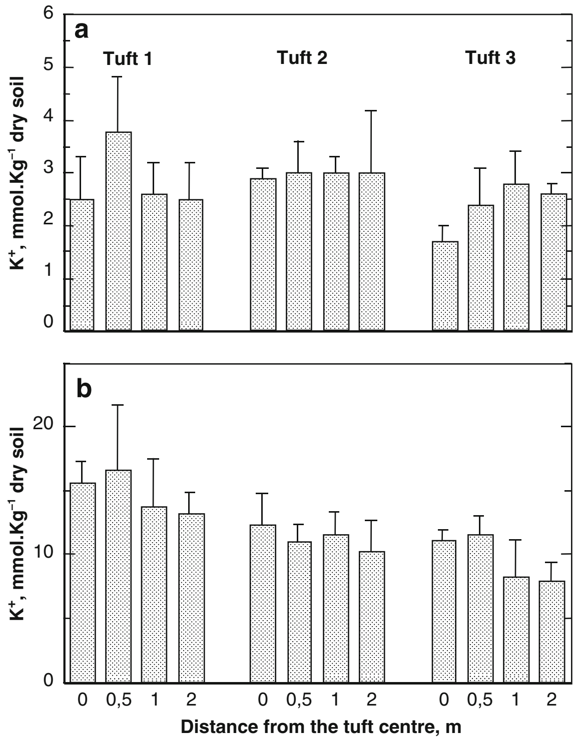

Fig. 3 Variation in soil (0–20 cm depth horizon) potassium content with distance from *Arthrocnemum indicum* tufts (**a**) soluble K^+. (**b**) exchangeable K^+. Tuft 1 situated at the sabkha periphery, tufts 2 and 3 near its centre. Means of 4 replicates ± S.E. at $*P < 0.05$

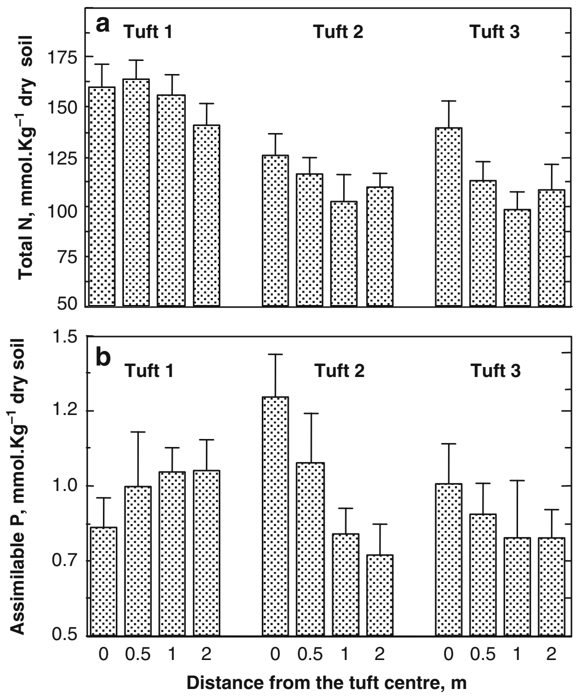

Fig. 4 Variations in soil N and P with distance from *Arthrocnemum indicum* tufts. (**a**) total N. (**b**) assimilable P. The samples were extracted from 0–20 cm deep horizon. Tuft 1 was situated at the sabkha periphery, tufts 2 and 3 were near its centre. Means of 4 replicates ± S.E. at $*P < 0.05$

nor with distance from the tufts (Fig. 3a). Exchangeable potassium concentration decreased from the periphery towards the sabkha centre (Fig. 3a) and with distance from the halophytes, though non significant. This gradient could be ascribed to substitution of K^+ by Na^+ in clay, which was abundant outside the tufts. Total soil nitrogen ranged from 1 to 2.5 mg N g^{-1} soil, equivalent to 71–178 mmol N kg^{-1} dry soil (Fig. 4a). Generally, significantly (at $P < 0.05$) larger amounts were found in tuft 1, i.e. higher nitrogen availability at the sabkha outer boundary. Moreover, total nitrogen decreased with distance from the tuft centre. These gradients, more or less pronounced according to the tuft size, reveal the importance of the litter for the soil nitrogen balance. Phosphorus concentration was variable among tufts (Fig. 4b). The upper soil horizon at the centre of tufts 2 and 3 contained more assimilable phosphorus than that farther from the tuft, suggesting that its availability was increased by soil enrichment with organic matter.

3.4 Ecosystem Productivity

Biomass production. Two plant groups contributed to ecosystem biomass production: the perennial halophytes (*Arthrocnemum indicum*, *Salsola cruciata* and *Suaeda fruticosa*) and the annuals, mainly the Leguminosae (*Medicago* sp.), the Poaceae (*Hordeum* sp.) and the Compositeae. Maximal biomass production of the whole ecosystem was about 50% higher in the rainy year than in the dry year, especially in samplings 5 and 6 (Fig. 5a).

The perennial halophytes consisted of dry as well as green twigs throughout the year. The green organ contribution to the total biomass production was predominant only during the spring, reaching 50–65% in *Arthrocnemum indicum*, *Salsola cruciata* and *Suaeda fruticosa*. In the remainder of the year, desiccated twigs part could make up 75% of the biomass (data not shown). While the primary production of *Arthrocnemum indicum* and *Salsola cruciata* was strongly improved by the rainfall (+23% and +45%, respectively), no impact was observed for *Suaeda fruticosa* (Fig. 5b). The rainfall effect was more pronounced for the annuals, especially the Leguminosae, which produced six times as much in the wet year. The proportion of these species to total ecosystem (perennials and annuals) biomass production increased from 15% in the dry year to 40% in the rainy year, of which the Leguminosae (mainly *Medicago ciliaris*, *Medicago polymorpha*, *Medicago truncatula*, and *Medicago minima*) contributed up to 80%.

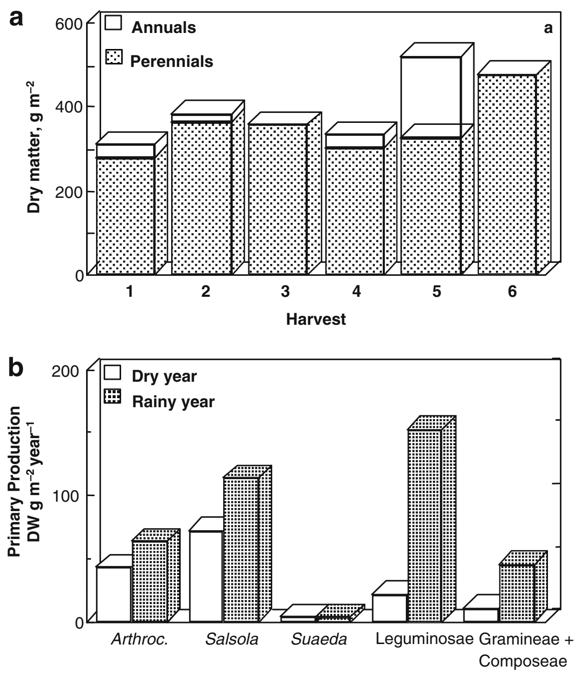

Fig. 5 Biomass production in the sabkha. (**a**) shoot dry weight (DW) per surface area unit as a function of the sampling dates. Annuals: essentially Leguminosae; perennials: halophytes. Samplings 1, 2 and 3: during the dry year, respectively in April, June and September. Samplings 4, 5 and 6: during the rainy year, respectively in January, March and June. (**b**) Primary production (DW) per surface area unit of the different plant types. For the halophytes, the annual production is estimated by the difference between the biomasses at the beginning (January) and the end (June) of the growing period. For the annuals, it corresponds to the spring harvests. Means of 4 replicates ± S.E. at $^*P < 0.05$

3.5 Nutrient Uptake

K^+ concentrations ranged between 0.3 and 0.8 mmol · g^{-1} DW in perennial halophyte shoots, being generally higher in the dry year (Fig. 6). Potassium concentration in the green twigs of halophytes was three times that in the desiccated twigs, suggesting a remobilisation or leaching from the former. In annuals, K^+ concentrations ranged from 0.4 to 1 mmol g^{-1} DW, and were higher in the rainy year. Halophyte green twigs contained more nitrogen than the desiccated ones (Fig. 6). The highest N concentrations in *Suaeda fruticosa* (up to 3 mmol g^{-1} DW) were always lower than those in the annuals, especially in the Leguminosae. For the latter, the fluctuations in N concentration were large (a factor two over the two years), depending on rainfall. For phosphorus, Pi concentrations in shoots of all species were relatively low (30–200 μmol g^{-1} DW). In halophytes, and in contrast to K^+ and N, Pi was uniformly distributed between the green and the desiccated twigs (data not shown). Pi concentrations of the annuals, particularly the Leguminosae, were four times higher in the rainy year than in the dry year. In spring, when the annuals attained maximal development, the Leguminosae (mainly including the four *Medicago* species), representing *ca*. 32% of the

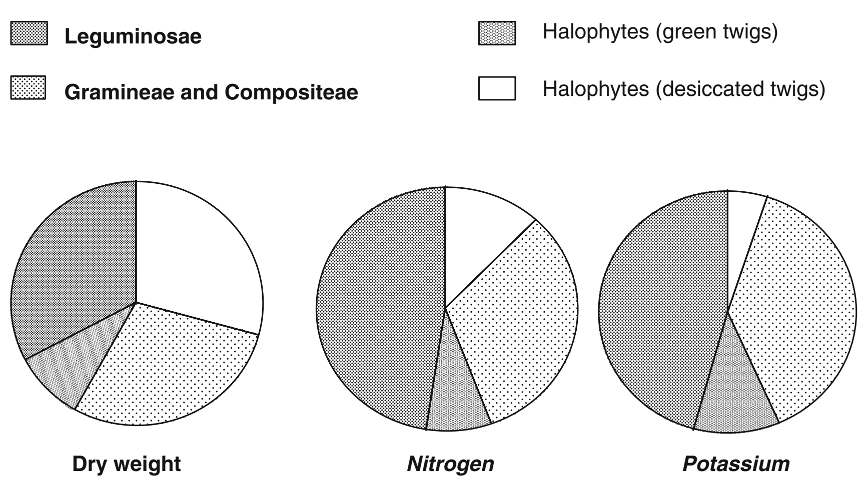

Fig. 6 Contribution of the plant groups to the biomass production and to N and K^+ uptake in the sabkha. Data from the spring harvest during the rainy year, corresponding to the maximal development of the annuals. Each sector area is proportional to concentrations in shoots, per soil surface area unit

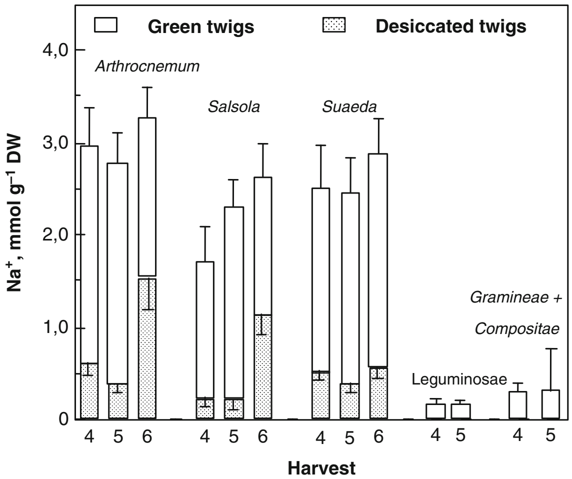

Fig. 7 Sodium contents of the shoots of different species growing in the sabkha. Harvests 4, 5 and 6 were made in January, March and June of the rainy year, respectively. Means of 6 replicates ± S.E. at $*P < 0.05$

total biomass, contained 45% of the total nitrogen and 48% of the potassium (Fig. 6). Thus, the *Medicago* species were more efficient than the other species in the uptake of nutrient resources.

3.6 Na^+ Accumulation

Most of the sodium transported to the plant cover was found in the halophytes. Na^+ strongly accumulated in the halophyte green twigs (up to 3 mmol g^{-1} DW) (Fig. 7), where it likely contributed to their osmotic adjustment. The tissue Na^+ concentration ranged from 0.5 to 1.5 M, while Na^+ concentrations in the desiccated organs represented only 20% of those accumulated in the green ones. Leguminosae and Poaceae tissues contained much lower (at $P < 0.05$) Na^+ levels (0.2–0.3 mmol g^{-1} DW), suggesting that (i) these plants may be provided with mechanisms for protection against sodium invasion, and that (ii) they exploited the low-salt levels superficial zones, while the halophytes owing to deeper roots, exploit more saline soil horizons.

4 Discussion

As reported by Turner (2004), the natural ecosystems of the Mediterranean-climate areas are usually characterised by a mixture of perennial shrubs and trees (mainly xerophytes and halophytes) and annual crops or fodder plants. Growth activity of the annual is governed by the rainfall regime, the rainy season extending from autumn to spring, while the perennials grow slowly, but are able to cope with water shortage and soil/water salinity. Variations in biomass and productivity among and within natural ecosystems may be attributed mostly to differences in water and nutrient (especially N) availability and salinity (Sherman et al. 2003). In the arid to semi-arid regions bordering the Mediterranean Sea, water quality is a major factor limiting crop production (Cantero-Martínez et al. 2007).

In the present study, both soil analyses and vegetation distribution indicated increasing salinity from the periphery to centre of the sabkha. Vegetation cover was more abundant in the peripheral zones, containing the less salt-tolerant perennial halophytes and the annuals. Plant diversity, lower in the depression centre, was dominated by two highly salt-tolerant halophytes: *Arthrocnemum indicum* and *Halocnemum strobilaceum*. Similar heterogeneous distribution of salinity has been reported in other studies (Loveland and Ungar 1983; Bekki 1995), and has been ascribed to salt transport by rainwater towards the basin centre. Our data showed an inverse fertility gradient (notably of nitrogen), decreasing from the periphery to the sabkha centre. The low nitrogen availability in the depression centre could be due to the depressive effect of salinity on soil organic matter accumulation (subsequent to the low plant biomass production) and on microbial activity (Rosenberg et al. 1986; Mc Clung and Frankenberger 1987).

We found that the spontaneous *Medicago* spp., characterised by high nutritive value, largely contributed to the ecosystem primary production in the absence of water shortage. These annuals mainly thrived within or very close to the halophytes tufts, while the soil was almost bare between the tufts. Parallel studies performed in our laboratory pointed out that these spontaneous *Medicago* are particularly sensitive to salinity (Abdelly et al. 1995), and to N (Abdelly 1997) and P (Abdelly et al. 1991) deficiency. Furthermore, shoots of the annuals growing in association with the *Medicago* species contained relatively low Na^+ concentrations (Fig. 7). Hence, the upper soil horizon, where these plants grew, was fertile and contained (relatively) low salt levels, as corroborated by the results of soil analysis (upper soil horizon in the tuft centre was always less saline than when taken at the tuft periphery). Desalinisation of the upper soil horizon by the superficial roots of halophytes could be responsible for this micro-gradient of salinity. Moreover, litter from the halophyte fallen organs and organic debris accumulated by the wind at the feet of tufts, may have contributed to localised soil enrichment in N and P (Fig. 4a, b). Soil aeration near these plants would be improved by this organic matter and by the higher soil level under the tufts, leading to better drainage capacity. Improved soil aeration is favourable for nitrification and N_2 fixation, favouring the colonisation of the halophytes tufts by the *Medicago* spp. Therefore, halophytes directly contributed to maintenance of a relatively low salinity and high fertility in the upper soil horizon, enabling the growth of annuals.

The halophytes may also play an indirect role by developing deep root systems exploiting the more saline soil horizons, as shown by the presence of halophyte roots at 1 m depth and by the vertical increasing salinity gradient (Table 1). The halophytes could thus limit rise of the salty water-table, allowing rainfall water infiltration into the upper soil layers. Several studies have demonstrated the role of halophytes in the soil desalinisation. Zhao (1991) showed that *Salsola salsa* biomass production could reach 20 t ha^{-1}, including 3 to 4 tonnes of salt exported from the soil. Less productive *Batis maritima* displays a similar desalinisation capacity (3 t ha^{-1}) (Le Houérou 1993), as does the succulent *Sesuvium protulacastrum* (Pasternak and Nerd 1996). The latter would be particularly interesting because of its high salt tolerance (growth stimulation up to 800 mM NaCl) despite accumulating high salt levels in the shoots (6 mmol g^{-1} DW, representing ca. 35% of the whole plant biomass) (Messedi et al. 2001). In a 4-year study, Keiffer and Ungar (2002) observed a significant decline in brine-affected soils, following introduction of halophytes (*Atriplex prostrata*, *Spergularia marina*, and *Suaeda calceoliformis*), so that glycophytes could successfully establish. On the other hand, involvement of halophytes in the creation of micro-habitats favouring the development of *Medicago* spp. and their microbial symbionts (namely, root-nodulating and nitrogen-fixing rhizobia), has been reported by Bekki (1995) who showed that *Medicago ciliaris* plants growing in combination with *Suaeda fruticosa*, had a higher growth rates and better nodulation and nitrogen fixation potentialities than the isolated ones.

Recently, Ravindran et al. (2007) assessed the desalinisation capacity of six halophytes (*Suaeda maritima*, *S. portulacastrum*, *Clerodendron inerma*, *Ipomoea pes-caprae*, *Heliotropium curassavicum*, and the tree *Excoecaria agallocha*), in terms of fast growth rate associated with high salt accumulation. All tested species decreased the EC of the saline soil used, in concomitance with an increase of the EC of plant samples. Salt removing capacity calculated over in 4 months of time was 504, 473.9, 396.3, 359.5, 325.2 and 301.5 kg ha^{-1} of NaCl in *S. maritima*, *S. portulacstrum*, *E. agallocha*, *C. inerma*, *I. pescaprae,* and *H. curassavicum* respectively. Similar to our findings (Fig. 7), the desalinisation potential of the species tested was mostly associated with their salt accumulation capacity within their above ground tissues, without adversely impacting the plant growth activity. Salt compartmentalisation in the leaf vacuoles and osmotic adjustment are key mechanisms of plant salt tolerance. Both of these processes enabling the use of Na^+ as a cheap osmoticum rather than its harmful accumulation in the cytosol, often take place in succulent halophytes lacking salt-excreting structures at their leaf surface (Tester and Davenport 2003; Debez et al. 2006).

5 Conclusions

This study revealed substantial soil and vegetation heterogeneity and diversity in the sabkha. In this area, the plant biomass production is largely determined by that of the forage annuals, especially the Leguminosae, growing in localised habitats surrounding bushy halophytes tufts. Thus, ecosystem micro-heterogeneity, combined with large-scale radial heterogeneity, is an important factor of its productivity, in addition to plant diversity. The salt-tolerant perennials improved the soil properties, mainly by decreasing the soil salinity owing to their high salt accumulation capacity. In addition, they provided "islands of fertility", enabling the growth

Table 1 Soil ionic characteristics in the central zone of the studied area in the Enfidha sabkha

	Horizon depth (cm)				
Parameter	0–20	20–40	40–60	60–80	80–100
EC (dS m^{-1})	0.13 ± 0.01	0.13 ± 0.02	1.21 ± 0.15	2.33 ± 0.2	2.62 ± 0.32

EC electric conductivity of the aqueous extract (1 g soil per 10 ml water) of fodder annuals with high agronomic value. The latter species used the mineral resources accumulated in the upper soil horizons, near the halophytes, owing to a sustained fats growth, associated to a high efficiency of nutrient availability. These data constitute a strong argument in favour of the practical utilisation of halophytes towards the restoration of marginal and/or cultivated salt-affected lands, by reducing the soil salinity level and improving its physical and chemical properties. Long-term data are required to better assess the positive impact of halophytes on the sabkha ecosystem.

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Potential Role of Salt Marshes in the Sabkhas of Egypt

Hassan M. El Shaer

Abstract Salinization is one of the major problems for food production in Egypt. It has significantly impaired agricultural productivity. The total area of salt affected soils is estimated to be 1.8 million ha. These are mainly located along the Red sea coast, in the Mediterranean part, some areas in middle, western and eastern parts of the Nile delta, El Fayoum, Wadi El Natroun and the Oasis in the western desert area. Out of these saline areas salt marshes are important habitats for grazing animals, waterfowl and fish. They are integral components of the coastal and inland ecosystems of the country with a great potential as a source for many raw materials like food for human, animal feeds, fiber materials, habitat for fish, insects,etc.). However these habitats are under threat due to the uncontrolled human and orther biotic interferences. An attempt will be made here to give some evaluations on these salt marshes and their potential role in the Sabkhas of Egypt.

1 Introduction

Salt marshes cover considerable areas in the Middle East region with altitudes ranging from − 300 m below sea level to almost 200 m above sea level. In Egypt these occur along the Red Sea coastal belt in South Sinai, East of the eastern desert, and in the vicinity of lakes in the Mediterranean part. There are large depressions and Siwa, Moghra, Wadi EL-Natroun and Bahariya, Kharga, Dakhla and Dungul oases in the Western Desert, which are accepted as the most productive ecosystems in Egypt. These are mainly inhabited by halophytes, therefore revegetation of these habitats with halophytes could be highly beneficial for all living beings in the area and lessen the risk of degradation (El Shaer and Zahran 2002; El Shaer 2009). This paper will focus on the characteristics of salt marshes and their potential role in the sabkhas of Egypt.

2 Salt Marshes in Egypt

There are three major types of salt marshes in Egypt namely; Red Sea, Mediterranean, and Oases (El-Khouly and Zahran 2002). The area from Suez to Mersa Halaib (near Sudan) is covered by the Red Sea salt marshes. The precipitation in the form of rains varies here between 4 and 25 mm per year. The soils are arid with insufficient leaching and salts form crusts on the surface (Younes et al. 1983), which thus effects the growth of plants, their zonation and distribution along the littoral part. The plant cover here is mainly composed of mangroves, reed swamps and salt marshes (Zahran 1993), dominated by *Avicennia marina*, *Rhizophora mucronata*, *Phragmites australlis, Typha domingensis*, *Arthrocnemum macrostachyum, Halocnemum strobilaceum, Halopeplis perfoliata, Zygophyllum album, Limonium axillare, Sporobulus spicatus, Halopyrum mucronaum, Nitraria retusa, Suaeda monoica, Atriplex farinosa, Juncus rigidus, Imperata cylindrica, Anabasis setifera and Tamarix nilotica.*

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The Mediterranean salt marshes are found in the vicinity of Bardawil, Manzalah, Mariout and Buroulos lakes occurring along the coast of Mediterranean Sea. These are generally oligotrophic (El Shaer 2009). Some like Bardawil are hypersaline. Biotic interferences, salinity and some other environmental parameters are the most important factors affecting the distribution of plants here with large zonation (Zahran and Willis 1992). More than 25 taxa of halophytes have been recorded from these habitats. The dominating ones are *Salsola tetrandra, Nitraria retusa, Zygophyllum album, Halocnemum strobilaceum, Arthrocnemum macrostachym, Suaeda aegyptiaca,* and *Sarcocornia fruiticosa* (Khedr 1999; Khedr and Zahran 2002). The areas with 2–5% of salinity in general lack any plant cover but wet sabkhas are coverede by some vegetation (Shaheen 1998). These lake systems are important habitat for a lrge number of migratory birds. These salt marshes are found in a region with extreme drought and are at the same time under a heavy presure due to grazing and trampling by Bedouin herds as well as severe sand shifting.

The Oases salt marshes characterized by large depressions occur in the Western Desert including northern oases like Siwa, Moghra, Wadi EL-Natrun and Bahariya and southern oases like Kharga, Dakhla and Dungul. The soils are calcareous with high $CaCO_3$ content and lower organic carbon (E1-Khouly 2001; El-Khouly and Zahran 2002). These are dominated by different types of plant covers like iced swamp, salt marshes, sand dunes and desert plains. A total of 32 taxa have been recorded from here and 46.9% of these belong to the families Poaceae and Chenopodiaceae. The most common genera was *Tamarix* spp., *Juncus* spp., *Cyperus laevigatus, AIhagi graecorum, Sporobolus spicatus, Zygophyllum album, Suaeda monica, Salsola imnbricate, Nitraria retusa, Sarcocornia fruticosa, Desmostachya bipinnata, Cressa cretica,* and *Aeluropus lagopoides*. These can be grouped under nine growth forms such as; rhizomatous (31.3%), succulents (25%), non-succulents (12.5%), stoloniferous (9.4%), non succulent herbs (6.3%), thorny shrub, leafless trees and succulent herb (3.1%). Many of these are characterised by salt lands and some have modified their organs for water storage (El-Khouly and Khedr 2000).

3 Salt Marshes as Potential Habitats

The wetlands like river Nile, estuaries (Damietta and Rosetta), coastal and inland swamps are dominated by reeds and rushes like *Phragrmites*, *Typha* and *Juncus* species. All these taxa tolerate salinity to different degrees (Serag et al. 2002). They provide nesting sites, substratum, and feeding materials for a wide range of organisms and are important part in the food chain of freahwater ecosystems as well as a source of nutrient rich freshwater habitats in river Nile and other lakes, drainage and irrigation canals. Average growth of these plants helps in the oxygenation of water and thus permits survival of fishes and invertebrates (Zahran and Willis 2002; El Shaer 2009). *Phragmites* is widely distributed in Nile, Oases, Mediterranean and Red Sea coastal zones, Desert area and Sinai (Boulos 1995). It is valued as animal fodder and fuel, and can be used to renovate wastewaters (Öztürk et al. 2005). The two species of *Typha* (*T. Domingensis, T. Elephantina*) found in Egypt are important as fish habitats if an overgrowth does not take place.They too play an important role in the nutrient cycling and renovation of wastertters (Serag et al. 1999; Öztürk et al. 2005). In addition to these two dominating taxa there are nine species of *Juncus* distributed in the salt marshes (Mohammed 1980; El Shaer 2009), majority being salt tolerant flourishing under hot and dry climate. These cab be used to produce fiber for a good quality paper; for making mats, baskets and sandals; leaves and culms have been used as pens for writing on papyrus (Zahran 1993; Snogerup 1993; Öztürk et al. 2008 ; El Shaer 2009). They can be evaluted at the industrial scale because their seeds are rich in oils, proteins, aminoacids, and carbohydrates (Serag et al. 2002; El Shaer 2009). The obligate halophytes *Inula crithmoides, Suaeda vera, Arthrocnemum macrostachyum, Halocnemum strobilaceum* and *Atriplex portulacoides* accompany these rush species in different habitats. These halophytes can provide 'indirect' and economical benefits like reclamation of degraded lands, CO_2 sequestration, and can be used as forage/fodder, oilseed crops, fertilizers, in soap industry, building materials, wood for furniture, timber, paper production, herbal tea, sea floor fixation, in lanscape architectural projects, fire wood and medicinal plants (Menzel and Leith 1998; Squires and Ayoub 1994; El Shaer 2009).

4 Prospects of Halophytes as Animal Feeds

The halophytes serve as important areas of primary production for coastal food chains and important habitat for the production of grazing animals, waterfowls and fish. The palatable halophytic taxa like the species of *Suaeda*, *Atriplex, Salsola* and *Nitraria retusa* are very common in the salt marshes and disappear fast due to overgrazing (El Shaer 1981). They are valuable fodders during drought season. Their nutritive value differs from species to species and several factors are invloved in this, the highest forage values are found during the wet season of the year. The nutritive value decreases with growth and maturation.The digestibility is generally higher in grazing season than in drought season (El Shaer 2009). Although many halophyte taxa are high in protein content they should not be offered as sole diet to animals for long time.The performance of animals on the halophytic ranges depends on factors like animal species, season of the year, forage abundance, and nutritional values of forage species. In addition to some physical and chemical defenses of the plants, main factors involved in poor intake are high Na, Ca and silica contents and higher levels secondary metabolites (El Shaer and Attia- Ismail 2002). In general feeding small ruminants with good quality halophytes can prove economical for the farmers.

The salt marshes in Egypt are facing a severe threat from the biotic pressures. Some of the elements in the biodiversity of these habitats has vanished and some are endangered. There is a great need for the protection of these valuable habitats through suitable conservation measures and sustainable use of its biodiversity in particular the halophytes (Szabolcs 1994; Öztürk et al. 2006). For this purpose several approaches can be used like gene bank preservation system, in-situ conservation of endangered species, and cultivation of palatable and other multi-purposes halophytic taxa on saline marshes by using saline and brackish waters.

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Halophyte Plant Diversity, Coastal Habitat Types and Their Conservation Status in Cyprus

M. Öztürk, S. Gucel, A. Guvensen, C. Kadis, and C. Kounnamas

Abstract This chapter focuses on the identification, description and determination of the conservation status of the halophytic plant diversity and the coastal habitat types of Cyprus. The chapter presents the results of a study that was undertaken during 2006–2008 in the coastal zone of Cyprus, which revealed that a total of 457 plant taxa with distinct features are distributed along a 770 km long coastline; 129 being typical halophytes. The taxa dominating the major intact habitats along the coast are *Limonium* spp., *Mesembryanthemum* spp., *Euphorbia paralias, Pancratium maritimum, Eryngium maritimum, Medicago marina, Taraxacum aphrogenes, Otanthus maritimus* and *Cakile maritima.* The saline habitats along the coast and alongside the internationally important salt lakes of Larnaca and Akrotiri (both included in the Ramsar list of Wetlands of International Importance) abound in halophytic taxa like *Salicornia* spp., *Arthrocnemum microstachyum, Suaeda vera, Juncus* spp., *Halimione portulacoides* and *Inula crithmoides*. These salt lakes serve as migration stations for a large number of migratory birds during their route from Europe to Africa and back. Their conservation value is related not only to their function as important bird habitats but also to their significant floristic diversity. The coastal waters of the island give shelter to 197 fish species and various species of crabs, sponges and echinoderms. The Green and the Loggerhead turtles breed regularly on the island's sandy beaches, some of which are strictly protected. The coastal zone has been seriously degraded over the last 25 years. The habitats in this zone face serious degradation problems due to economic, recreational and intensive tourist development. An attempt has been made here to present the information on the life forms and other features of the major plant taxa occuring within the coastal zone. The conservation status of the plant taxa has been identified according to the Red Data Book of the Flora of Cyprus and the criteria set by the IUCN: 6 taxa critically endangered, 12 endangered and 14 vulnerable. Moreover, in the coastal zone of Cyprus 16 habitats types that are included in the Habitats Directive (92/43/EEC) Annex I have been identified out of which 3 are classified as priority ones and need immediate conservation measures. Information on coastal endemics has also been included so that it can be utilised for future effective conservation action.

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1 Introduction

Cyprus is an island lying at a strategic location in the East Mediterranean with an area of 9,250 km^2 and 770 km long coastline, having Turkey in the north, Syria and Lebanon in the west and Egypt in the south. The indented coastline of the island -the third largest in the Mediterranean - is full of cliffy or rocky parts interchanging with small or large sandy or gravelly beaches. It is 240 km long from end to end and 100 km

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wide at its widest point. The name of the island is said to have originated from the Greek word for the Mediterranean Cypress tree or from the Greek name of the henna plant. However, some historians report that the name stems either from the Eteocypriot or Sumerian word for copper (zubar) or for bronze (kubar), because large deposits of copper ore are found in the country. Cyprus has given its name to the classical latin word for copper via overseas trade through the phrase *aes Cyprium*, i.e. metal of Cyprus, later shortened to *Cuprum – Copper*.

The extinction of dwarf hippos and elephants depicts the arrival of first humans (Simmons 2001) on the island. The earliest site of human activity is said to lie in the southern coastal part Aetokremnos. The site shows remains of hunter-gatherers dating back to 10000 BC (Mithen 2005). The remains of the oldest known settlements on the island date from 7000 to 3900 BC around the well preserved neolithic village Khirokitia (Wade 2007; Walton 2004). These remains bear witness to the existence of an ancient civilization which developed along the North and South coasts. Most Chalcolithic settlements (3900–2500 BC) are found in Western Cyprus. One comes across here the oldest water wells in the world dating back to 9,000–10,500 years (BBC 2009).

The data published on the biodiversity of Cyprus reveals that 7, 26 and 357 species of land mammals, amphibians/reptiles and birds, respectively, distribute on the island. The coastal waters abound of various species of crabs, sponges and echinoderma and give shelter to 197 fish species. The largest wild animal that still lives on the island is the Cyprus moufflon (*Ovis aries ophion*), a rare type of wild sheep found only in Cyprus. The sandy beaches on the coastal zone are typical breeding habitats for Green turtle (*Chelonia mydas*) and Loggerhead turtle (*Caretta caretta*). The island is used by millions of birds during their migration from Europe to Africa and back, the main reason being the presence of Larnaca and Akrotiri Salt Lakes. Cyprus is one of the few places on earth where the geological processes and microclimate have played an important role in the development of its habitat diversity and thus the rich biodiversity (BBC 2009).

With its approximately 2000 taxa of flowering plants, it is an extremely interesting island, which make it a botanist's paradise. The island's isolation has allowed an evolution of a strong endemic flora. This richness is further strenghtened by an incorporation of botanical elements from the neighbouring land masses, where 8% of the indigenous plants (145 taxa) are endemics. The aim of this review is to enlighten the environmental threats faced by the coastal zone plant diversity in Cyprus and present information for a geographical/taxonomical/ecological database of European coastal zone plants, thus contributing towards effective conservation action during the future planning programmes. The list of threatening factors has also been compiled.

2 Geology, Hydrology, Soils and Climate

Geomorphologically, the island is characterised by the ophiolitic complex of large Troodos mountain range displaying a variable relief with a predominance of slopes and rounded peaks as well as prevalence of vertical cliffs, steep slopes, gorges and deep gullies. It covers most of the southern and western parts of the island and accounts for roughly half of its area. The highest peak is Mount Olympus (1952 m above sea level), located in the center of this range. The small Kyrenia mountain range extends along the northern coastline. Both are dominating the central Mesaoria plain. There are six districts in the country (IPI 2007); Nicosia (Lefkosia-Lefkosa), Famagusta (Ammochostos-Gazimagusa), Kyrenia (Keryneia-Girne), Larnaca (Larnaka-Larnaka/Iskele), Limassol (Lemesos-/Leymosun) and Paphos (Pafos/Bafos-Baf/Gazibaf) (Fig. 1). The country is traversed by rivers and small and large streams, the largest being Pediaios, Gialias and Serrachis which rise from Troodos. The significant natural salt lakes of Larnaca and Akrotiri accummulate large volumes of water. There are also smaller lagoons like Paralimni and Galateia-Mehmetcik. The largest water reservoirs are Kouris and Asprokremmos, the former being at the homonymous river with a capacity of 115 million m^3 and the later on the Xeros river with a capacity of 51 million m^3. The indented coastline is full of small or extensive cliffy or rocky parts interchanging with small or large sandy or gravely beaches (Pantelas et al. 2003).

The area of arable land of the island is approximately 15% and the irrigated land is about 400 $km^{2.}$ For the purposes of this study soil samples collected randomly and analysed at a soil laboratory in 2008.

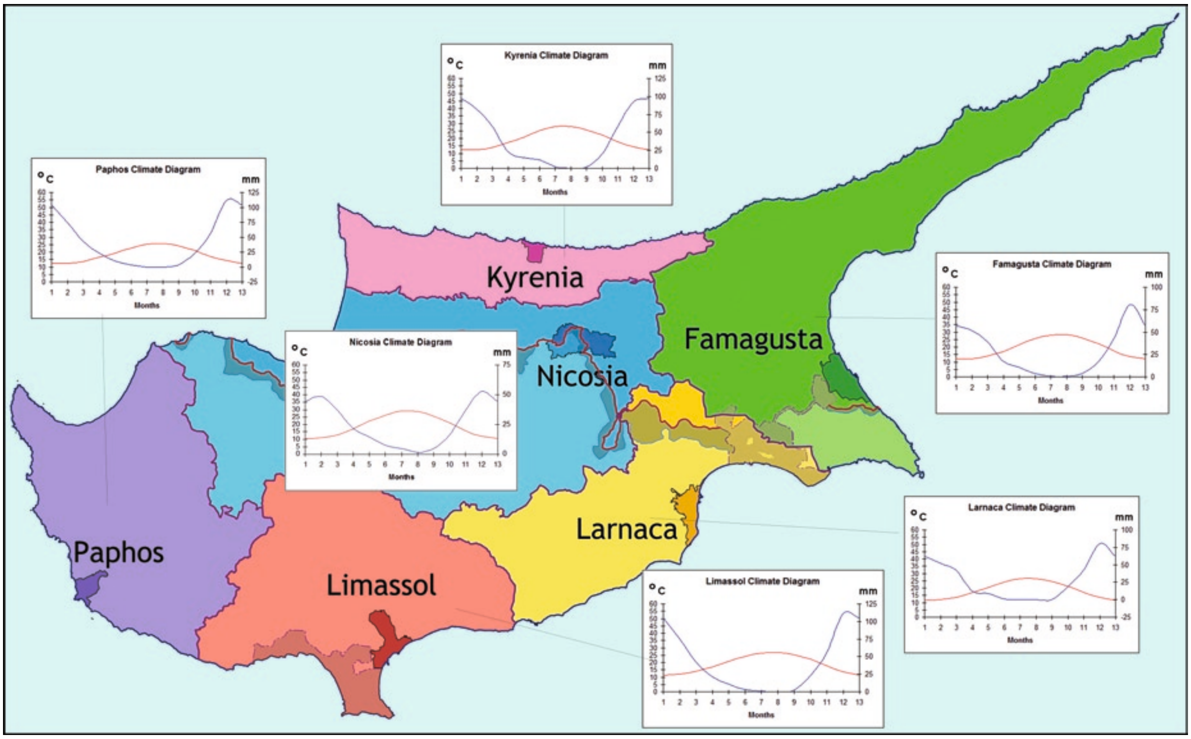

Fig. 1 Map of Cyprus with districts and their climate diagrams

The results obtained showed that the water potential of soils around coastal zone varies between 26.42–61.9%. The pH was found to be between 7.1 and 8.9. The texture is mainly sandy, soluble salts vary between 0.01 and 2.56%, organic matter from trace level to 1.94%, $CaCO_3$ between 22.2 and 52.5%, cation exchange capacity between 1.63–50 me/100 gr and Sodium between 50 and 6,300 ppm.

The climate is typical mediterranean with average daytime temperature lying around 32°C from June to September, 16°C from December to February and 25°C in the other 5 months. Rainfall is common in winter and precipitation in the form of snow occurs from January to March on the mountain peaks (Fig. 1).

3 Plant Diversity

Cyprus was known as the “Green Island” because most of it was covered with forests. Over time, this forest vegetation has been destroyed, mainly due to human activities, such as expansion of cultivations and human settlements, misuse and over exploitation, intensive grazing, fires and recently, climatic change. The varied microclimate and geology of the island has resulted in a great variety of habitats, which together with its isolation and location near the big neighbouring land masses has contributed a lot to its rich biodiversity. These factors have allowed the evolution of strong endemic flora which makes it an extremely interesting place for botanists (Gucel and Yildiz 2008). Nearly 8% (145 taxa) of the indigenous plants are endemics. The earliest systematic studies on the island were carried out by Sibthorp (1758–1796), Hawkins (1758–1841) and Bauer (1760–1826), and were followed by many others (cf. Yildiz and Gucel 2006). However, detailed studies were undertaken by Meikle (1977, 1985) who compiled the collected data in two volumes. He was followed by a large number of local investigators (Alziar 1985; Alziar and Guittonneau 2004; Alziar and Christodoulou 2006a, b; Christodoulou 2003; Christodoulou 2006a, b; Christodoulou and Hadjikyriakou 2006; Christodoulou et al. 2006; Chrtek and Slavik 1993; Costa et al. 1984a, b; Della and Iatrou 1995; Della 1994, 1996; Georgiades 1994; Georgiades and Hadjikyriakou 1993; Gucel and Yildiz 2008; Hadjichambis and Della 2007; Hadjichambis et al. 2003a, b, c; 2004; Hadjikyriakou et al. 1996; Hadjikyriakou et al. 2003; Hadjikyriakou and

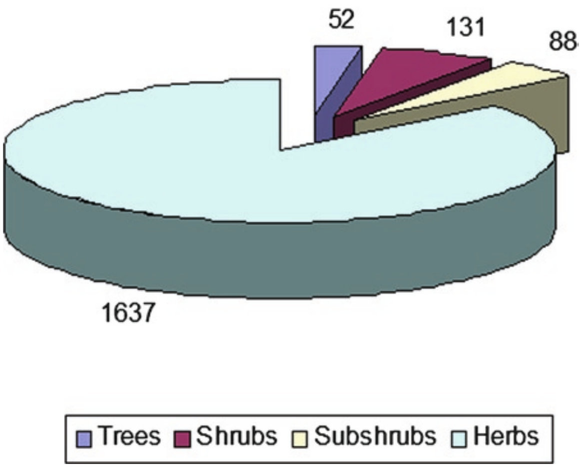

Fig. 2 Number of indigenous plant taxa in Cyprus

Alziar 2006; Hadjikyriakou 2009; Hand 2000, 2001, 2004, 2006; Hand and Hadjikyriakou 2009; Iacovou et al. 1995; Kephalas 2005, 2006a, b; Pantelas et al. 1997; Tsintides et al. 2007; Yildiz and Gucel 2006). The number of indigenous plant taxa recorded until now from Cyprus exceeds 1900 (Fig. 2).

The plant cover in general is composed of Forest, Maquis, Garrigue and Phrygana, accounting for 42.3% of the total land area and other high forests found on the Troodos and Pentadaktylos mountain ranges and along the coast of the Akamas peninsula in the west, the Akrotiri peninsula in the south, Cape Gkreko in the southeast, the Karpasia peninsula in the east, as well as along the northern coasts make up the 43.8%. These include species very common in the Mediterranean basin like *Pinus brutia* and *P. nigra* ssp. *pallasiana* accompanied by species like *Juniperus phoenicea, J. foetidissima, Olea europaea, Ceratonia siliqua, Arbutus andrachne, Myrtus communis, Rhus coriaria, Pistacia lentiscus, P. terebinthus, Berberis cretica, Sorbus aria* ssp. *cretica, Rosa chionistrae, Cotoneaster racemiflorus* var. *nummularia, Smilax aspera* and *Cistus* species. The most important are the natural forests of *Cedrus brevifolia* and *Quercus infectoria* ssp. *veneris*. The common broadleaved species are *Platanus orientalis, Alnus orientalis, Salix alba, Nerium oleander, Arundo donax, Laurus nobilis* and *Rubus sanctus*. The forests of the *Cupressus sempervirens* occur on mountainous areas, chiefly on limestone and marls and rarely on igneous formations. The most common shrubs are *Ziziphus lotus,Crataegus azarolus, Sarcopoterium spinosum* and *Thymus capitatu*s.

The flora includes a comparatively high proportion of endemic plants counting to about 145. Some of the most eminent among these are *Bosea cypria*; one of the three species of the genus Bosea occurring in the world; *Cedrus brevifolia;* one of the four cedar species occurring in the world; *Tulipa cypria, Crocus cyprius, C. hartmannianus* and *Quercus alnifolia.*

Another important constituent of the indigenous flora of Cyprus are the typical plants of the Eastern Mediterranean like *Pinguicula crystallina, Cyprinia gracilis* (a monotypic genus named after Cyprus), *Colchicum troodi, Glaudosciadium cordifolium,* and *Euphorbia thompsonii*. The halophytic vegetation is of special interest and high conservation value (Guvensen and Öztürk 2003: Guvensen et al. 2006; Öztürk et al. 2006a, b). This type of vegetation flourishes on saline habitats along the coast and around the Larnaca and Akrotiri salt lakes. Characteristic species of these habitats are *Salicornia* spp., *Arthrocnemum macrostachyum, Suaeda vera, Juncus* spp., *Halimione portulacoides* and *Inula crithmoides*.

The coastal vegetation is restricted along a 150 m wide narrow belt, where the dominant plants are *Limonium* spp., *Mesembryanthemum* spp., *Euphorbia paralias, Pancratium maritimum, Eryngium maritimum, Medicago marina, Taraxacum aphrogenes, Otanthus maritimus*, *Cakile maritima*, *Crithmum maritimum* and *Matthiola tricuspidata* (Gehu et al. 2000; Uslu 1998, 2001). The wetland vegetation that colonizes areas of the salt lakes, river mouths and other marshy places consists of *Arthrocnemum macrostachyum, Salicornia fruticosa, S. europaea, Halocnemum strobilaceum, Phragmites australis* and other species. The dominating halophytic taxa, their ecological features and a list of the families with the highest number of taxa are presented in Table 1 and Fig. 3.

The families with the highest number of taxa are given in Fig. 3. Out of a total of 129 taxa, *Poaceae* has the highest number. The families with lower taxa are; Apiaceae (5), Caryophyllaceae (5), Juncaceae (5), Brassicaceae (4), Gentianaceae (4), Liliaceae (4), Aizoiaceae (3), Convolvulaceae (2), Euphorbiaceae (3), Papaveraceae (2), Tamaricaceae (3), Frankeniaceae (2), Plantaginaceae (2), Agavaceae (1), Amaryllidaceae (1), Apocynaceae (1), Geraniaceae (1), Illecebraceae (1), Juncaginaceae (1), Linaceae (1), Neuradaceae (1), Orobanchaceae (1), Polygonaceae (1), Zannichelliaceae (1), Zygophyllaceae (1).

Table 1 List of halophytes and their ecological features

Families	Taxa	Life Form	Ecotype	Altitude (m above sea-level)	Flowering Time
Aizoaceae	*Aizoon hispanicum* L.	T	PH	0–70	3–5
	Mesembryanthemum crystallinum L.	C	X	SL	3–5
	Mesembryanthemum nodiflorum L.	C	X	SL	3–5
Agavaceae	*Agave sisalana* Perrine ex Engelm.	C	X	SL	8
Amaryllidaceae	*Pancratium maritimum* L.	C	PH	SL	8–10
Apiaceae	*Crithmum maritimum* L.	C	X	SL	4–7
	Cachyrs scabra (Fenzl) Meikle	CH	PH	SL-30	4–6
	Eryngium maritimum L.	C	PH	SL	6–8
	Ferulago syriaca Boiss.	CH	X	150–300	5–6
	Pseudorlaya pumila (L.) Graunde	T	X	SL	3–6
Apocynaceae	*Trachomitum venetum* (L.) Woodson	C	PH	SL	6–8
Asteraceae	*Achillea cretica* L.	CH	X	15–150	4–7
	Achillea maritima (L.) Ehrend. & Y.P. Guo ssp. *maritima*	CH	PH	SL	6–8
	Aetheorhiza bulbosa (L.) Cass.	C	X	0–400	4–6
	Ambrosia maritima L.	CH	X	SL	7–12
	Chlamydophora tridentata (Delile) Less.	T	HG	0–300	2–5
	Helichrysum conglobatum (Viv.) Steud.	CH	X	0–700	3–5
	Inula crithmoides L.	CH	HG	SL	6–8
	Launea resedifolia (L.) O.Kuntze	CH	X	SL	3–5
	Reichardia picroides (L.)Roth	H	X	SL-30	2–11
	Taraxacum aphrogenes Meikle	H	X	SL	10–12
Brassicaceae	*Cakile maritima* Scop.	T	PH	SL	2–7
	Enarthrocarpus arcuatus Labill.	T	X	SL-30	3–5
	Malcolmia nana (DC.) Boiss. var. *glabra* Meikle	T	PH	SL	3
	Matthiola tricuspidata (L.) R. Br.	T	PH	SL	2–5
Caryophyllaceae	*Silene colorata* Poiret var. *decumbens* (Bjv.) Rohrb.	T	X	0–800	3–6
	Silene discolor Sibth. et Sm.	T	PH	SL	3–5
	Silene kotschyi Boiss. var. *maritima* Boiss.	T	PH	SL	6–7
	Spergularia bocconii (Scheele) Aschers. et Graebn.	T	X	0–760	2–6
	Spergularia marina (L.) Griseb.	T	XH	SL	3–6
Chenopodiaceae	*Arthrocnemum macrostachyum* (Moric.) C. Koch	CH	HA	SL	5–7
	Arthrocnemum perenne (Miller) Moss	CH	HA	SL	4–7
	Atriplex halimus L.	CH	XH	0–150	7–10
	Atriplex patula L.	T	X	SL	5–7
	Atriplex prostrata Boucher ex DC.	T	X	SL	7–10
	Bassia hirsuta (L.) Ascherson	T	X	SL	7–9

(continued)

Table 1 (continued)

Families	Taxa	Life Form	Ecotype	Altitude (m above sea-level)	Flowering Time
	Beta vulgaris L. ssp. *maritima* (L.) Arcangeli	T	X	0–150	2–5
	Halimione portulacoides (L.) Aellen.	CH	HA	SL	6–10
	Halocnemum strobilaceum (Pall.) Bieb.	CH	HA	SL	8–10
	Halopeplis amplexicaulis (Vahl.) Ung.-Sternb. ex Ces.	T	HA	SL	7–9
	Salicornia europaea L.	T	HA	SL	5–10
	Salicornia fruticosa L.	CH	HA	SL	9–11
	Salsola inermis Forssk.	T	XH	0–150	9–11
	Salsola kali L.	T	PH	SL	5–9
	Salsola soda L.	T	PH	SL	5–9
	Suaeda aegyptiaca (Hasselq.) Zohary	CH	HA	SL	8–10
	Suaeda maritima (L.) Dumort.	T	HA	SL	8–10
	Suaeda vera Forssk.	CH	HA	0–30	10–5
Convolvulaceae	*Cressa cretica* L.	H	XH	SL	6–10
	Ipomoea imperati (Vahl) Griseb.	H	P	SL	7–11
Cyperaceae	*Bolboschoenus maritimus* (L.) Palla	C	HG	0–1500	4–9
	Carex divisa Huds.	C	HG	0–1700	3–5
	Carex extensa Good.	H	HG	SL	6–8
	Carex flacca Schreber ssp. *serrulata* (Bir.) Greuter	C	HG	0–1675	3–9
	Cyperus capitatus Vand.	C	HG	SL	2–5
	Eleocharis palustris (L.) Roem. & Schult.	C	HG	0–1500	3–6
	Isolepis cernua (Vahl) Roem. & Schult.	T	HG	SL-250	4–5
	Scirpoides holoschoenus L.	C	HG	0–1900	4–9
	Scirpus lacustris L. ssp. *tabernaemontani* (C.C.Gmel.) Syme	C	H	SL-1300	3–6
	Schoenoplectus litoralis (Schrad.) Palla	C	HG	SL	4–7
	Schoenus nigricans L.	H	HG	0–500	3–7
Euphorbiaceae	*Euphorbia paralias* L.	CH	PH	SL	2–11
	Euphorbia peplis L.	T	PH	SL	5–7
	Euphorbia terracina L.	CH	PH	0–300	2–6
Fabaceae	*Acacia saligna* (Labill.) Wendl. fil.	P	HG	0–100	4–7
	Alhagi maurorum Medik var. *Turcorum*	CH	PH	SL	6–8
	Argyrolobium uniflorum Jaub. & Spach	CH	X	SL	3–4
	Coronilla repanda (Poir.) Guss. ssp. *repanda*	T	PH	SL	2–4
	Lotus halophilus Boiss et Spruner	T	PH	SL	3–4
	Medicago littoralis Rohde ex Loisel. var. *littoralis*	T	X	0–200	3–5
	Medicago marina L.	H	PH	SL	2–4
	Ononis diffusa Ten.	T	PH	SL	3–6

Frankeniaceae	*Frankenia hirsuta* L. var. *hispida* (DC.) Boiss.	CH	PH	SL	4–10
	Frankenia pulverulenta L.	T	PH	0–200	4–10
Gentianaceae	*Blackstonia perfoliata* (L.) Hudson	T	HG	0–700	6–7
	Centaurium tenuiflorum (Hoffmanns. & Link) Fritsch	T	HG	0–800	6–8
	Centaurium maritimum (L.) Fritsch	T	X	SL-400	4–5
	Centaurium erythraea Rafn. ssp. *rhodense* (Boiss. et Reut.) Melderis	T	HG	0–1065	5–7
Geraniaceae	*Erodium crassifolium* L'Her.	CH	HG	SL	3–5
Illecebraceae	*Paronychia argentea* Lam.	H	PH	0–1500	12–7
Juncaceae	*Juncus acutus* L.	C	HG	0–1150	3–5
	Juncus heldreichianus Marsson ex Parl.	C	HG	0–1800	4–8
	Juncus littoralis C.A. Mey.	C	HG	0–150	4–6
	Juncus maritimus Lam.	C	HG	SL	7–8
	Juncus rigidus Desf.	C	HG	0–150	6–8
Juncaginaceae	*Triglochin bulbosa* L.	C	HG	SL	3–5
Liliaceae	*Allium curtum* Boiss. & Gaillard	C	PH	0–30	4–5
	Allium trifoliatum	C	XH	0–300	3–5
	Asparagus stipularis Forssk.	C	X	0–700	3–6
	Asphodelus tenuifolius Cav.	T	X	SL	3–4
Linaceae	*Linum maritimum* L.	H	HG	SL	5–10
Neuradaceae	*Neurada procumbens* L.	T	P	SL	3–6
Orobanchaceae	*Cistanche helypaea* (L.) P. Coutinho	H	HA	SL	3–5
Papaveraceae	*Glaucium flavum* Crantz	H	X	SL	5–7
	Hypecoum procumbens L.	T	X	0–300	3–6
Plantaginaceae	*Plantago coronopus* L. ssp. *commutata* (Guss.) Pilger	T	PH	0–800	2–7
	Plantago maritima L. ssp. *crassifolia*	T	PH	0–150	3–10
Plumbaginaceae	**Limonium albidum* (Guss.) Pignatti ssp. *cyprium* Meikle	H	X	SL	6–11
	Limonium echioides (L.) Mill. ssp. *echioides*	T	HA	0–230	4–6
	Limonium echioides (L.) Mill. ssp. *exaristatum*	T	HA	0–200	4–7
	Limonium meyeri (Boiss.) O.Kuntze	T	HA	SL	7–10
	Limonium mucronulatum (H. Lindb. fil.) Greuter&Burdet	H	HA	SL	6–9
	Limonium sinuatum (L.) Mill.	H	HA	SL	3–7
	Limonium virgatum (Willd.) Fourr.	H	HA	0–160	5–8

(continued)

Table 1 (continued)

Families	Taxa	Life Form	Ecotype	Altitude (m above sea-level)	Flowering Time
Poaceae	*Ammophila arenaria* (L.) Link	C	PH	SL	5–7
	Arundo donax L.	C	HG	0–600	6–10
	Aeluropus lagopoides (L.) Trin.	C	PH	0–160	4–7
	Aeluropus littoralis (Gouan) Parl.	C	PH	SL	4–7
	Brachypodium distachyon (L.) P. Beauv.	T	X	0–400	3–6
	Bromus madritensis L.	T	X	0–1000	3–7
	Catapodium marinum (L.) *C.E.* Hubb.	T	PH	0–100	4
	Elymus farctus (Viv.) Runemark ssp. *farctus* var. *farctus*	C	PH	SL	6–8
	Hordeum marinum Hudson	T	PH	0–100	5–6
	Imperata cylindirica L.	C	PH	0–300	4–6
	Lagurus ovatus L.	T	PH	0–50	4–6
	Parapholis incurva (L.) C.E. Hubb.	T	HG	SL	4–5
	Parapholis marginata Runemark	T	HG	0–230	4–5
	Phragmites australis (Cav.) Trin. ex Steudel	H	HG	0–1500	8–10
	Polypogon maritimus Willd.	T	PH	0–150	5–6
	Sporobolus virginicus (L.) Kunth.	C	PH	SL	6–9
	Trachynia distachya (L.) Link.	T	PH	0–1500	3–5
	Triplachne nitens (Guss.) Link	T	P	SL	4
	Vulpia brevis Boiss & Kotschy	T	PH	SL	3–4
Polygonaceae	*Polygonum maritimum* L.	H	PH	SL	6–11
Tamaricaceae	*Tamarix smyrnensis* Bunge	P	HA	0–1000	4–8
	Tamarix tetragyna Ehrenb.	P	HA	0–300	2–4
	Tamarix tetrandra Pall. ex M. Bieb.	P	HA	0–1300	5
Zannichelliaceae	*Zannichellia palustris* L.	T	HG	0–1500	3–6
Zygophyllaceae	*Zygophyllum album* L.	CH	XH	SL	3–5

Life Forms: *C* = Cryptophytes, *CH* = Chamaephytes, *H* = Hemicryptophytes, *P* = Phanerophytes, *T* = Therophytes
Ecological Types: *HA* = Halophyte, *HG* = Hygrohalophytes, *PH* = Psammohalophytes, *X* = Xerophyte, *XH* = Xerohalophytes
* Endemic
SL = Sea-level
Flowering Time: Month 1 is January and month 12 is December

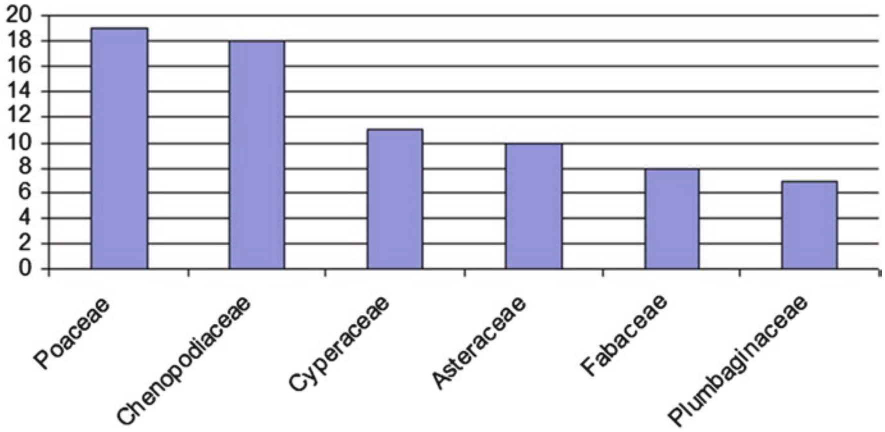

Fig. 3 Families with the highest number of taxa

4 Endemic, Rare and Threatened Plants of Cyprus

Biodiversity in Cyprus is threatened by a number of factors, the principal ones being the expansion of built-up areas, tourism development, heavy tourist use of sandy coasts, trampling of beaches with machinery installation of tourism infrastructure, sand removal, habitat degradation, recreation activities, stochastic events, demographic changes, fires, deforestations, agricultural activities, agricultural expansion, overgrazing, road maintenance, off-road driving, invasion by exotic species like *Acacia saligna*, changes in water balance, drought, habitat degradation and loss, changes in land use, drying out of watercourses and climatic change (Fig. 4a).

A Red Data List for the Cyprus flora compiled by Tsintides et al. (2007) indicates that about 300 plant species are threatened and need immediate protection measures. In this list *Achillea cretica* (Fig. 4b) was recorded as vulnerable (Table 2), but no mention was made for *Pancratium maritimum* (Fig. 4c) and *Trachomitum venetum* (Fig. 4d) which, in our opinion, should be included in the list as endangered species.

Approximately 145 taxa are endemics and some of these are very rare. Twenty-three endemic and other native plants are listed in Appendix I of the Convention for the Conservation of the European Wild Life and the Natural Habitats (Council of Europe 2000) and they are charactewrised as strictly protected. 18 species (16 endemics and 2 other native plants) are of community importance and are listed in Appendices II & IV of the European "Habitats Directive" (92/43/EEC), which provides for the conservation of species through the conservation of their habitats (Council of Europe 1992). It is noted that Appendix II includes the threatened animal and plant species of European Union interest, whose conservation requires the designation of special areas of conservation, while Appendix IV includes animals and plants of European Union interest in need of strict protection. Also, 51 species are included in *the Red List of the Threatened Plants* prepared by IUCN (Walter and Gillett 1998). Moreover, six endemic plants of Cyprus are included in the IUCN & SSC - Species Survival Commission edition " *The Top 50 Plants of the Mediterranean Islands*" which presents fifty of the most threatened plant taxa of the Mediterranean (Montmollin and Strahm 2005). The above information indicades that a significant number of endemic and other plants on the island are part of world's natural heritage.

The situation on the coastal habitats in the country is not different. During the studies carried out between 2006–2008 along 770 km long coastal zone, a total of 457 taxa were found in this area. Out of these plant taxa, 129 halophytic taxa were surveyed at length and their life forms, ecological types, altitudinal distribution and phenology were recorded. The conservation status of 32 of these species is described according to the Red Data Book of the Flora of Cyprus (Tsintides et al. 2007), which evaluates the conservation status of the Cyprus flora based on the criteria set by the International Union for Conservation of Nature (IUCN 2003); 6 were found to be critically endangerd, 12 endangered and 14 vulnerable (Table 2, Fig. 5).

Regarding the habitats diversity observed within the coastal zone, a total of 16 habitat types were

Fig. 4 Land degradation along the coast-Bafra (**a**), *Achillea cretica*-Vulnerable species (**b**), *Pancratium maritimum*-Endangered species (**c**), *Trachomitum venetum*-Endangered species (**d**)

Table 2 Conservation status of the Halophytes of Cyprus

Latin name	Threatened category: IUCN Criteria (IUCN 2003)
Achillea cretica	VU: D2
A. maritima subsp. *maritima*	VU: A4C
Aizoon hispanicum	EN: D1
Ambrosia maritima	CR: B1 ab (i–v) + 2ab(i–v); C2a(i); D1
Ammophila arenaria	EN: B1ab(iii,v) + 2ab(iii,v)
Argyrolobium uniflorum	CR: B1ab(iii,v) + 2ab(iii,v)
Cachyrs scabra	EN: B1ab(iii,v) + 2ab(iii,v)
Centaurium maritimum	EN: B1ab(iii) + 2ab(iii)
Cistanche phelypaea	CR:D1
Coronilla repanda subsp. *repanda*	VU: D2
Enarthrocarpus arcuatus	VU:D2
Erodium crassifolium	VU:D2
Euphorbia paralias	EN:A4ac
Ferulago syriaca	VU:D2
Ipomoea imperati	EN:C2a(i)
Isolepis cernua	EN:D1
Juncus littoralis	VU:D2
Juncus maritimus	VU: D1+2
Limonium mucronulatum	CR: B1ab(iii,v) + 2ab(iii,v); C2a(ii)
Linum maritimum	VU:D2
Malcolmia nana var. *glabra*	CR: B1ab(iii,iv) + 2ab(iii,iv); C2a(ii)
Mesembryanthemum crystallinum	VU:D2
Neurada procumbens	EN:B1ab(iii,v) + 2ab(iii,iv)
Ononis diffusa	EN:B1ab(iii,v) + 2ab(iii,v)
Reichardia picroides	VU:D1+2
Salsola soda	VU:D1+2
Scirpus lacustris ssp. *tabernaemontani*	EN:D1
Silene kotschyi var. *maritima*	EN:B1ab(iii,v) + 2ab(iii,v)
Suaeda aegyptiaca	EN:B1ab(iii,v) + 2ab(iii,v)
Taraxacum aphrogenes	VU:B1ab(iii,v) + 2ab(iii,v)
Triplachne nitens	VU:C2a(i)
Vulpia brevis	CR:B1ab(i–v) + 2ab(i–v)

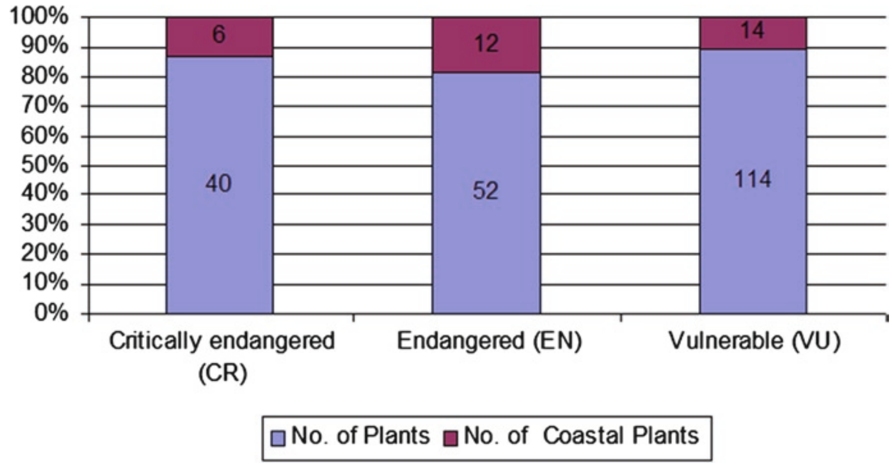

Fig. 5 Percentage of endangered coastal plants among endangered plants of Cyprus

Table 3 Description of habitats

No	Code Name	Importance
1	1110 Sandbanks which are slightly covered by sea water all the time	HD I
2	1140 Mudflats and sandflats not covered by seawater at low tide	HD I
3	1150 Coastal lagoons	HD I*
4	1210 Annual vegetation of drift lines	HD I
5	1240 Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp.	HD I
6	1310 Salicornia and other annuals colonising mud and sand	HD I
7	1410 Mediterranean salt meadows (Juncetalia maritimi)	HD I
8	1420 Mediterranean and thermo-Atlantic halophius scrubs (Arthrocnemetalia fructicosae)	HD I
9	1430 Halo-nitrophilous scrubs (Pegano-Salsoletea)	HD I
10	1510 Mediterranean salt steppes (*Limonietalia*)	HD I*
11	2110 Embryonic shifting dunes	HD I
12	2190 Humid dune slacks	HD I
13	2230 Malcolmietalia dune grasslands	HD I
14	2240 Brachypodietalia dune grasslands with annuals	HD I
15	2250 Coastal dunes with Juniperus spp.	HD I*
16	2260 Cisto-Lavendulatalia dune sclerophyllous scrubs	HD I

classified as habitat types of the Annex I of the Habitats Directive, according to the Interpretation Manual of European Union Habitats - EUR 25. Out of these habitats, three were found to be priority ones (Table 3). It is noted that Annex I includes the natural habitat types of European Union interest, whose conservation requires the designation of special areas of conservation. As priority habitat types are defined the natural habitat types in danger of disappearance, which are present on the EU territory and for the conservation of which the EU has particular responsibility in view of the proportion of their natural range which falls within its territory.

Code_Name: Included in Annex I of Directive 92/43/EEC, HD I – included in Annex I, HD I* – priority habitat of Annex I.

In the ecological survey of coastal shores, dunes and cliffs in Europe, under the title "Dry Coastal Ecosystems of the World" a lot of information has been presented on the occurrence of endemic littoral plant species (van der Maarel 1996). An evaluation of this data as well as other detailed surveys together with present studies were used for an evaluation of the coastal zone plant diversity in Cyprus.

This evaluation includes plant taxa from salt marshes, tidal flats and saline waters i.e. lagoons. Although species like *Ammophila arenaria* and *Hippophae rhamnoides* ssp. *maritima* and *Puccinellia maritima* are important for the dunes and salt marshes, many coastal species have limited role in the composition and structure of littoral plant communities. Moreover, many species dominating coastal zone habitats do not belong to these habitats at all such as *Phragmites australis*, *Salix* spp., *Juniperus* and *Quercus* species.

5 Conclusion

We do not always realize how relatively small the areas occupied by coastal ecosystems are and how vulnerable the coastal flora is. We hope that this survey will prove helpful in the preservation of coastal zone plant diversity and habitats. The coastal ecosystems harbour numerous littoral plant taxa of which the majority can be considered endemics in a strict sense. For most of these species their future existence seems to very uncertain, since initiatives to protect rare and threatened coastal species are insufficient. The data presented here will serve as a reference source to build up a detailed database for littoral plant diversity in Cyprus.

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Salt-Affected Soils and Their Native Vegetation in Hungary

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Abstract Approximately 13% of Hungary is considered to be salt-affected and with this large extent it is unique in Europe. There are large areas of naturally saline and sodic soils, but also secondary salinization is known to occur. Due to the geological and hydrological conditions, the country demonstrates the most characteristic features of natural continental (not marine) salinization, sodification and alkalinization. Since the most important direct source of soil salinization is the shallow groundwater level below the lowland surface, there is a chance of irrigation-related salinization in two dominant situations: when the abundant use of river waters causes waterlogging and rise of saline groundwater (salinization from below); and when typically saline tubewell-waters are used for irrigation (salinization from above). The spatial assessment of salt-affected areas began with the systematic mapping of salt-affected areas. There are a series of ten maps describing different aspects (salt-affected soil types, vegetation types, salt-efflorescences) of the salinity-status nation-wide from 1897 onward, with the latest survey finished last year. Besides the national scale of 1:500,000, soil salinity is also mapped at the scale of 1:100,000 on the "AGROTOPO" map sheets and 1:25,000 in the "Kreybig"-practical soil information (spatial vector data for maps and database for profiles and borings) systems. In spite of the two systems being digitally available, the most detail information collected at the scale of 1:10,000 is available only for 2/3 of the country and is not digitised. Very early maps at field scale, later at regional scale showed numerical salinity/sodicity values. At present field scale numerical maps are analysed in order to optimise salinity mapping in space and time. Parallel to soil studies, the assessment of the vegetation of saline and sodic lands is a traditional topic of Hungarian botanists. The vegetation of these areas is used for millennia by grazing and provides medicine and raw material for several purposes.

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1 Introduction

Traditionally the study of salt-affected soils (SAS) is one of the most popular topics among Hungarian soil scientists. The origin, properties and reclamation of these soils (in Hungarian "szik") were investigated thoroughly during the last two centuries. A complete list of the 22 monographs on salt-affected soils is reported by Tóth and Szendrei (2006). The mapping of these soils started in 1897, mapping at the scale of 1:25,000 was finished by the 1950s, and their last assessment, now of the areas covered with native halotolerant vegetation, was carried out in the years 2003–2006 (Bölöni et al. 2003), see Fig. 2. This summary is based on Tóth (2008).

2 Environmental Conditions in Hungary

About one third of the soils on the Great Hungarian Plain (N 46–48.5° and E 19–22.5°) are affected by salinity/sodicity, mainly by sodification, one third of the territory is covered by potential SAS, and one third does not have such soils. Potential SAS are defined as

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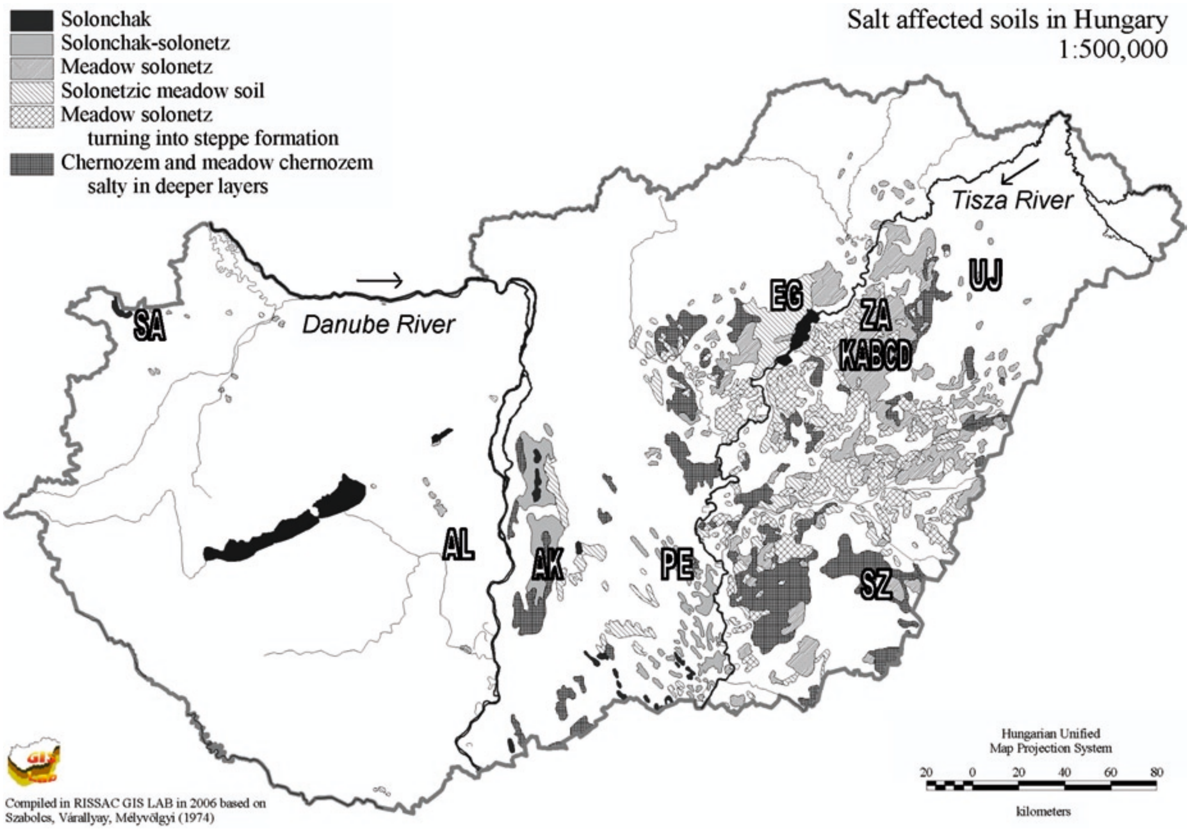

Fig. 1 Map of Hungarian salt-affected soils as published by Szabolcs (1974) and the location of the profiles described in Tables 2–4

soils, which are not salt-affected at present, but which could become considerably saline or sodic as a consequence of irrigation (Szabolcs 1974). The territorial segregation of some types of SAS is evident (Fig. 1). Soil types Solonchak and Solonchak-Solonetz are concentrated mainly in the Danube-Tisza Interfluve, types "Meadow Solonetz" and "Deep Mollic Solonetz"[1] are more typical in the Tisza Plain.

3 Meteorological Conditions

The Great Hungarian Plain is the hottest and driest region of the Carpathian Basin, which is otherwise characterized by temperate climate. In the central region, where SAS are most common, data describing annual averages and dynamism is summarized in Table 1. The area of Hungarian SAS, is located at an elevation of 80–90 m above sea level, under temperate continental climate, with 10°C mean annual temperature of −2°C in January and +21°C in July, 527 mm average annual precipitation (June is the most rainy month with 71 mm, March has the least precipitation with 28 mm), and 900 mm mean annual pan evaporation.

4 Hydrological Conditions

The Great Hungarian Plain is a basin filled with sediments deposited by rivers and wind. Therefore, the position of surface waters had an important impact on soil formation. These rivers, as typical lowland rivers, affected a vast territory by the periodic floods, creating huge marshlands. According to their origin, sediments deposited from the rivers differ much and the base materials of soil formation reflect these differences.

[1] In this report the term "Meadow Solonetz Turning into Stepp Formation" of Szabolcs, 1966 and Szabolcs, 1989 p 245 has been replaced by the term "Deep Mollic Solonetz" for reasons of clarity.

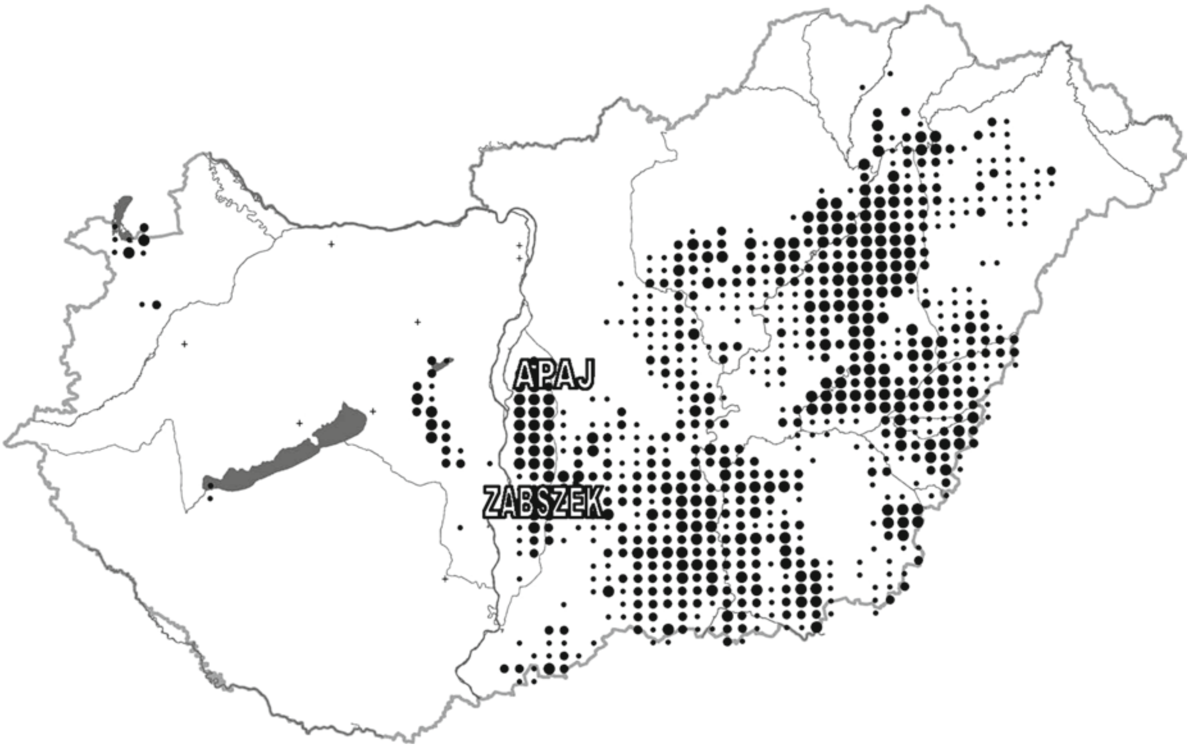

Fig. 2 The distribution of F2, "Salt meadow" habitat, copied from Molnár et al. (2008) and the location of study sites (Tables 5–6)

Table 1 Average meteorological parameters in the middle of the Great Hungarian Plain

Parameter (monthly)	1	2	3	4	5	6	7	8	9	10	11	12	Year
Precipitation (mm)	30	30	28	41	51	71	53	50	34	33	46	46	527
Potential Evaporation	12	19	40	78	112	136	156	144	106	58	25	14	900
Drought Index	0.40	0.63	1.43	1.90	2.20	1.92	2.94	2.88	3.12	1.64	0.54	0.30	1.71
Actual evap (mm)	11	15	27	63	102	91	76	58	35	21	16	12	527
Air temp (°C)	1.8	0.5	5.2	10.9	16.0	19.7	21.3	20.5	16.4	10.7	5.3	0.6	10.0

In the formation of salt affected soils a decisive role is played by saline groundwater, so the different types of SASs in the Hungarian soil classification system are closely related to distinct groundwater table depths. There are regional and local differences in the composition and concentration of groundwater that resulted in the wide variety of salt-affected soils.

5 Soil Conditions

According to the general Hungarian classification of soils, there are soils of the Atlantic region (Brown Forest soils) in the hilly marginal regions of the plain and of the steppe region (Chernozems) in the inner plateaus of the plain. Important "azonal" soils are the salt-affected soils and Meadow soils. These, together with the "intrazonal" Alluvial soils, form a catena. As the parent material between the Danube and Tisza$_{\text{Hungarian}}$ (=Theiß$_{\text{German}}$ or Tisa$_{\text{Slovakian\&Ukrainian}}$) rivers is rich in calcium-carbonate, the Solonchak and Solonchak-Solonetz soils developed on the alluvial sandy soils are classified as "Calcareous Sodic soils", whereas the more or less leached Solonetz-like soils that were developing on the more acidic sediments of the Tisza River (loamy and clayey parent material) are frequently referred to as "Non Calcareous Sodic Soils". The latter is characterized by higher clay-content and unfavourable hydrophysical properties, high ESP (Exchangeable Sodium Percentage) and high pH in the columnar B horizon and, as a rule, low salt content.

The unfavourable properties that limit the fertility of these soils are the consequence of the high clay content, high ESP, high pH and the resulting special moisture regime. The climatic conditions, e. g. the unequal distribution of the precipitation, the high aridity index and the high fluctuating saline groundwater call for a complex approach for improvement for agricultural purposes.

6 Groundwater Conditions

The Great Hungarian Plain consists of a variable layered and textured deep aquifer where the groundwater table varies between 0.5 and 4.0 m below surface, with an average fluctuation of 0.5–2.0 m. The shallow water table often causes waterlogging on the lower parts of the fields. Surface waterlogging appears also on the low-lying, low permeability plots at the end of winter, after snowmelt and/or during high-precipitation periods. The high salt content of the groundwater and its high $Na^+/(Ca^{++} + Mg^{++})$ ratio often result in salinization and alkalinization of the soils.

7 The Formation of the SAS of Hungary

At the beginning of the Miocene geological Era (23–5.3 million years before present) between the ancient "Carpathian" and "Dinaric" Mountains a vast gulf of the "Tethys" ancient sea flowed in to create the "Parathethys". This sea gulf later became detached from the Tethys and – known as the "Sarmathian" or "Pannonic" Sea – by the end of the Pliocene Era (5.3–1.8 million years before present) has been filled up with several hundred meter thick alluvial sediment. During the Pleistocene Era (1.8 million to 11,550 years before present) this process continued and loess formation took also place on the previously deposited alluvial sand. In some areas the sand was blown into dunes.

On the parent materials formed during the Pleistocene Era the influence of shallow fluctuating, saline-sodic groundwaters, as well as the permanent or temporary waterlogging created the conditions of SAS formation. The sodium ions, being considered as the most important factors, either dissolved from the Tertiary Era (65–1.8 million years before present) deposits into the groundwater (supported by data of Mádlné Szőnyi et al. 2005) or concentrated during consecutive drying and wetting of infiltrated water (as argued by Bakacsi and Kuti 1998). Szöőr et al. 1991 have shown that salinization has been present in the Great Hungarian Plain at least 30,000 years before. Among the anions in the groundwater and soil solutions there were plenty of bicarbonates, carbonate and other ions with alkaline hydrolysis and these caused almost irreversible sodium exchange processes.

8 Classification of Hungarian Salt-Affected Soils

In the late US classification of SAS the term "white alkali soil" stood for Solonchak soils and "black alkali" for Solonetz soils. The modern Hungarian soil classification is based on these categories as well. The categories like saline, sodic and saline-sodic as suggested by Richards 1954 and de Sigmond 1938, are also still in use. In agronomic practice the limit for a soil to be called SAS is 0.1% soluble salt content, as suggested by de Sigmond 1938 and Richards 1954.

The current classification system of Hungarian SAS meets two requirements: it fits the general principles of genetic soil classification, first developed in Russia (described in Gerasimov 1960) and later further developed in Europe (Kubiena 1953) and USA (Marbut 1927; Soil Survey Staff 1951) up to the middle of the twentieth century, and it keeps the traditional categories of Hungarian SAS.

The Hungarian SAS, belonging to the "Main soil type" of "Halomorphic soils" of the national soil classification system (Szabolcs 1966) are divided into five soil types: Solonchak soils, Solonchak-Solonetz soils, Meadow Solonetz soils, Deep Mollic Solonetz, Secondary Salt-Affected soils. The following list shows the current "official" classification of the main types of "salt-affected soils" of Hungary (Szabolcs 1966; Guidelines 1989). The acreage of the soil types was calculated from the Agrotopographical Map Database (in short AGROTOPO) database, (described by Várallyay et al. 1985). The map of salt-affected soils as shown by Fig. 1 was compiled by Szabolcs (1974).

9 Solonchak Soils (Total Area 47 km²)

These soils are *per definitio* the saline soils, which are mainly located in low-lying areas, typically shorelines of saline/sodic lakes, in the region between the Danube and Tisza Rivers, but also occur in patches east of the Tisza River. These soils are characterized with 60–80 cm deep groundwater table and an average total soluble salt content of 0.3–0.5% at the surface. Dominant salts are sodium-carbonate, bicarbonate, sulphate and chloride. There is calcium-carbonate in the whole profile. It is difficult to distinguish horizons in the profile of this soil. These soils are not cropped, but sustain native halophyte vegetation which is grazed.

10 Solonchak-Solonetz Soils (Total Area 659 km²)

These saline-sodic soils are also located mostly between the Danube and Tisza Rivers, but above deeper groundwater level, ca at 1 m. In the profile a weakly developed columnar/prismatic natric (= solonetzic) B horizon can be distinguished. There is calcium-carbonate in the whole profile. These soils sustain native halophyte vegetation which is grazed.

11 Meadow Solonetz Soils (Total Area 2,749 km²)

The typical "solonetz" soils of Hungary are the typical sodic soils on the Great Hungarian Plain, mostly east of the Tisza River, but also west of the Danube River. These soils are characterized by large exchangeable sodium percent and not high salt content. This latter can be low enough in the "A" horizon to permit cultivation on these soils. Otherwise these soils sustain native halophyte vegetation which is grazed. The fertility of the soil is proportional to the thickness of slightly saline "A" horizon. In the characteristic columnar/prismatic natric B_1 horizon, where the maximum of the sodium adsorption can be encountered, the value of exchangeable sodium percent (ESP) is at least 20–25%. The maximum of salt accumulation can be found in the B_2 horizon, where the soil structure is prismatic or "nutty" (= large subangular blocky). Calcium-carbonate is generally absent from the A and B_1 horizons. The depth to the groundwater table is between 150 and 350 cm.

12 Deep Mollic Solonetz (Total Area 2,122 km²)

When the groundwater table is lower (3–4 m below the soil surface) the leaching reduces the soluble salt and calcium-carbonate content of the upper horizons of these sodic soils. "Turning into steppe formation", the term originally used for this soil type by Szabolcs (1966) denotes soil forming processes similar to those of the steppe (Chernozem) soils. These soils are typically ploughed.

13 Secondary Salt-Affected Soil (Not Distinguished on the Agrotopo Database as Polygons)

This soil type comprises all soils, which were originally not salt-affected, but due to human influence became salt-affected. Besides the mentioned SAS there are other SAS types which belong not to the main type of "Halomorphic soils" but to other main soil types, such as "Solonetzic Meadow soils" with total area of 2,419 km², and "Chernozem soils with saline/sodic subsoil" with total area of 4,185 km². These soils are typically ploughed.

In Hungary the total area of salt-affected soils, based on the AGROTOPO database (printed on the map sheets by the Kartográfiai Vállalat in 1983), is 12,181 km². With this acreage the overall area of SAS covers 13% of the national territory. The map provided by the Hungarian Central Statistical Office, 2006 is almost the same as published by Stefanovits (1963), based on his map of the soils of Hungary at the scale of 1:200,000. Although there are differences in the acreages of the distinct SAS types between the two sources, but the total acreages, as 11,087 (Stefanovits 1963) or 12,181 km² (AGROTOPO) are close.

14 The Utilization of SAS in Hungary

Though the improvement (reclamation or amelioration) of these soils is scientifically well founded, it is a rather costly operation. This is a reason why large tracts of these soils are kept as grazeland or hayfield, land for afforestation, paddy field or fishpond. Most of the Hungarian National Parks have salt-affected grasslands, hayfields, marshes, reedlands, lakes and these provide habitat for protected animals (mainly birds), plants and attract lots of tourists. Many of the protected animals barely find a place for feeding and breeding on other soil types, since most of those are cropped or otherwise intensively utilized. In total some 88% of the surface of the country has no natural vegetation cover (cropland, tree plantations with exotic species, orchards, vineyards, settlements, roads, etc.).

Among the crops that may be grown economically on these soils the most important is winter wheat. It covers above the half of the area of the SAS. Other important crops are winter barley, sunflower, Sudangrass, vetch, rice and sometimes maize, sugarbeet and pea.

15 Information Available on the Spatial Extent of SAS

There is an outstanding record of collecting soil information in Hungary. The historical past is summarized in several publications (Ballenegger and Finály 1963). Just like in other countries in the early period of soil mapping, before the First World War there were two tendencies: special mapping of selected, usually small areas and preparation of very small-scale maps, based on scarce observations and continental-scale conceptual models. In Hungary the first Hungarian soil (that time called agrogeologic) map was compiled in 1861 (Szabó 1861) for the area of two counties at the scale of 1: 576,000. Few years later the soil map of Tokaj-Hegyalja intended to improve the production of the famous Tokaj wine in the region (Szabó 1865–6). A major achievement was the first complete soil map of Hungary prepared by Timkó in 1914. During the pre-war and after-war periods of 1935–1951 the “Kreybig” practical soil mapping was completed and displayed on maps at 1:25,000. From the 1960s the 1:10,000 scale mapping of the agricultural lands was performed. From 1989 no systematic large-scale soil mapping is carried out.

16 Agrotopo Map Database

It was the 1:100,000 scale AGROTOPO soil spatial database, which became available first digitally. This database, which was developed in 1990s, integrates the dominantly small-scale soil related data into digital format and is organized into spatial soil information systems (AGROTOPO: Várallyay 1989; HunSOTER: Várallyay et al. 1994; MERA: Pásztor et al. 1998). Information in the AGROTOPO is provided for nine properties, such as soil types, soil parent material, soil texture, clay-mineral composition, soil water regime category, soil reaction and carbonate status, soil organic matter stock, depth of solum and soil bonitation value. There are altogether 3,312 polygons for the total area of 93,000 km^2 of the country. As background to the soil polygons there is a general topographic sheet with landuse categories, elevation contour lines, settlements, waterways, roads, etc.

16.1 The 1:25,000 Soil Information System (Kreybig Digital Soil Information System)

The national soil mapping project initiated and led by L. Kreybig was unique, being a national survey based on both field and laboratory soil analyses and at the same time serving practical purposes (Kreybig 1937). Due to inactivity during the Second World War it was carried out between 1935 and 1951 in several stages. In the fifties, when the mapping was successfully completed, Hungary was among the first countries in the world to have such detailed soil information for the whole country. These maps still represent a valuable treasure of soil information. The soil and land use conditions were shown jointly on the maps. Altogether three characteristics were attributed to soil mapping units and displayed on each mapsheet. First feature distinguished was land use, both ploughland and grassland was not distinguished. Second was the chemical reaction shown by colours and third feature was the physical soil properties of the soil root zone. Some further soil properties were determined and measured in soil profiles. A very remarkable feature of the map series is that it distinguishes three different categories of SAS by colour codes:

Reddish purple colour: SAS suitable for cropping.

Light purple colour: SAS potentially suitable for cropping, can be reclaimed with $CaCO_3$.

Dark purple colour: SAS not suitable for cropping, which cannot be reclaimed with $CaCO_3$.

The GIS adaptation of soil information originating from the soil maps displayed on 1:25,000 scale is still under construction (Pásztor et al. 2006). There is much more utilizable information originating from this survey, than it was processed earlier and published on the map series and in reports, and what is provided by simply archiving them digitally. The surplus information should be exploited by the new technologies provided by GIS and DSM (digital soil mapping) and provide the basis of improved management of the soils.

16.2 Genetic Soil Maps of 1:10,000 Scale

In the early 1960s a mapping technology was elaborated by the Hungarian soil scientists, soil surveyors and soil-mapping specialists for the large-scale soil survey to satisfy the practical needs of soil information of large farming units (state and co-operative farms), which characterized the Hungarian agriculture between 1950 and 1990. Such maps were prepared for about one-third of the area of Hungary, representing two thirds of the cropland (ca 35,000 km^2). The mapping reports consist of four main parts: (i) genetic soil map, indicating soil taxonomy units, and the parent material; (ii) thematic soil maps on the most important physical and chemical soil properties; (iii) thematic maps, indicating recommendations for rational land use, cropping pattern, amelioration, tillage practice and fertilization; (iv) explanatory booklets including a short review on the physiographical conditions; description of soils, recommendations for their rational utilization; field description of soil profiles; results of field observations or measurements and data of laboratory analyses (Szabolcs 1966). These maps were widely and successfully used in Hungary and became an easily applicable scientific basis of intensive, large-scale agricultural production, in spite of the fact that generally these maps were not published in printed form and are available only as manuscripts at the given farming units or at the Plant and Soil Conservation Stations. The large-scale soil-mapping programme was restarted in 1986 within the framework of the National Land Evaluation Programme (Guidelines 1989). The aim of this Programme was to valuate the agricultural land based on soil survey at the scale of 1:10,000, but was also left uncompleted. These huge archives provide appropriate raw material for recent digitally based applications. Spatial soil information systems based on these data could be efficiently used in numerous fields.

Szabolcs (1966) described the methodology to be used in the detailed mapping of soils. For example in the case of SASs this method at the scale of 1:10,000 can be illustrated best with the set of individual map sheets which might make up a complete soil mapping document.

17 Exemplary Data of Hungarian Salt-Affected Soils

Twelve soil profiles were selected to demonstrate the characteristics of Hungarian salt-affected soil types from Jozefaciuk et al. (2006). Basic properties of the studied soils are presented in Tables 2–4. The studied profiles were described in different regions of the Hungarian Plain, a floodplain with varying thickness of alluvial sediments. Occurrence of salt-affected soils is closely related to groundwater depth and salinity, being the most important factors of salinization, and also to surface waters – the frequency and time of waterlogging. During the last 200 years great changes in the hydrological situation in the Plain took place and the distribution of salt-affected soils reflects these changes closely (Tóth et al. 2001). At most of the sampling sites the groundwater level has been sufficiently close to the surface and enough saline to cause salt accumulation.

Very slightly salt affected Karcag (K) profiles represent the best stands for crops: Chernozems (KA (irrigated), KB and KD) and a Vertisol (lower elevated site KC, irrigated). The native vegetation on higher areas is thick grasses and the soil is fertile. In the lowest patches fine particles have been settled and the soil is cracking, but also shows frequent waterlogging. As it is typical for such soils, sodicity is observed only in deeper layers of the subsoil (where the capillary water-rise affects the chemical features) and the topsoil is salt-free (Table 2).

Among the other soils taken from native sites, some occurred at relatively higher elevation in the toposequence (Egerlovo EG, Szabadkigyos SZ and Alap AL)

Table 2 Characteristics of the sites of the profiles

Site	Sarród	Egerlövő	Szabadkígyós	Zám	KarcagM1	KarcagM1K	KarcagM2	KarcagM2K
Code in Table 4	SA	EG	SZ	ZA	KA	KB	KC	KD
Description	Grassland	Grassland	Grassland	Grassland	Cropland	Cropland	Cropland	Cropland
Geographic coordinates northern	47º39.253′	47º43.600′	46º36.232′	47º31.669′	47º18.628′	47º18.650′	47º18.606′	47º18.655′
Eastern	16º48.764′	20º35.706′	21º5.815′	21º2.381′	20º48.737′	20º49.969′	20º48.632′	20º48.633′
Elevation m	118	95	91	94	88	87	86	87
Soil type	Stagnic	Vertic	Mollic	Haplic	Haplic	Haplic	Haplic	Haplic
World reference base	Solonchak	Solonetz	Solonetz	Solonetz	Chernozem	Chernozem	Vertisol	Chernozem
Hungarian classification	Solonchak	Medium Meadow Solonetz	Crusty Meadow Solonetz	Crusty Meadow Solonetz	Meadow Chernozem	Lowland Chernozem	Meadow Soil	Lowland Chernozem
Native plants	Salicornea europea Suaeda salsa Plantago maritima	Suaeda salsa Limonium gmelini Artemisia santonicum	Camphorosma annua Puccinellia limosa Artemisia santonicum	Salicornea europea Suaeda salsa Plantago maritima	na	na	na	na
Groundwater depth (cm)	190	180	204	250	200	200	220	220
EC	6.0	1.5	5.0	7.5	7.4	5.7	2.8	4.1
pH	7.7	7.8	8.0	8.1	8.5	8.4	7.7	8.2
SAR	19	4	68	65	49	43	11	24
Ca (me/l)	5	5	0.62	0.77	1.08	1.04	2.89	0.6
Mg	18	3	1	4	4.07	3.74	3.91	2.28
Na	66	9	61	100	79.4	67.2	20.95	28.8
K	0.25	0.24	0.07	1	0.04	0.03	0.04	0.03
SO_4	68	9	9	1	3.55	5.2	2.1	1.85
Cl	16	1	27	73	35.7	14.0	4.41	3.07
CO_3	4	2	7	2	4.66	2.54	0	1.2
HCO_3	13	7	20	26	19.44	27.31	8.44	17.70

Site	Újfehértó	Péteritó	Alap	Akasztó
Code in Table 4	UJ	PE	AL	AK
Description	Grassland	Grassland	Grassland	Grassland
Geographic coordinates northern	47º47.795′	46º34.635′	46º48.927′	46º40.578′
Eastern	21º41.250′	19º53.984′	18º39.503′	19º9.121′
Elevation (m)	114	93	92	94
Soil type world reference base	Stagnic Solonchak	Gleyic Solonchak	Calcic Solonchak	Salic Solonchak
Hungarian classification	Solonchak	Solonchak	Solonchak	Solonchak-solonetz
Native plants	Kochia scoparia	Puccinellia limosa	Camphorosma annua	Lepidium crassifolium
	Puccinellia limosa	Lepidium crassifolium Aster tripolium	Limonium gmelini	Puccinellia limosa
Groundwater depth (cm)	150	80	200	95
EC	4.7	11.0	11.0	7.5
pH	8.15	8.3	8.2	9.6
SAR	45	90	80	145
Ca (me/l)	1	0.1	1.4	0.05
Mg	2.5	7	6	1
Na	60	169	154	105
K	0.2	2.3	0.3	0.5
SO_4	2.3	0.9	121	7.2
Cl	5.2	31	37	16
CO_3	7.5	35	5.3	45
HCO_3	60	56	17.3	79

na – not applicable

Table 3 Colour, texture and structure of the horizons distinguished in the studied soil profiles

Site and date of sampling	Code of horizon	Depths (cm)	Wet colour	Texture	Structure
Sarród 2000 Aug 29	1	0–10	10YR5/2	SL	s-SUB
Sarród 2000 Aug 29	2	10–18	10YR3/2	C	s-SUB
Sarród 2000 Aug 29	3	18–52	2.5Y7/3	CL	s-SUB
Sarród 2000 Aug 29	4	52–54	10YR4/3	LS	nps
Sarród 2000 Aug 29	5	54–75	2.5Y7/2	CL	nps
Újfehértó 1999 Aug 16	1	0–4	5Y5/3	SL	PLA
Újfehértó 1999 Aug 16	2	4–14	5Y5/3	CL	ABL
Újfehértó 1999 Aug 16	3	14–40	2.5Y5/4	L	SAB
Újfehértó 1999 Aug 16	4	40–85	2.5Y5/6	L	SAB
Péteritó 2000 Jul 28	1	0–3	2.5Y4/2	SL	PLA
Péteritó 2000 Jul 28	2	3–13	2.5Y5/2	LS	s-SAB
Péteritó 2000 Jul 28	3	13–39	2.5Y4/2	LS	s-SAB
Péteritó 2000 Jul 28	4	39–58	2.5Y5/2	LS	s-SAB
Péteritó 2000 Jul 28	5	58–77	2.5Y6/1	LS	s-SAB
Alap 2OOO Aug 24	1	0–2 (efflorescence)	7.5YR2/2	SC	nps
Alap 2OOO Aug 24	2	2–28	7.5Y2/2	SC	COL
Alap 2OOO Aug 24	3	28–57	7.5Y3/2	SC	SAB
Alap 2OOO Aug 24	4	57–71	2.5Y7/4	SG	SAB
Alap 2OOO Aug 24	5	71–82	2.5Y7/6	SL	SAB
Akasztó 1998 Jul 30	A	0–3	5Y5/2	SL	s-SAB
Akasztó 1998 Jul 30	B	3–19	5Y6/2	CL	COL
Akasztó 1998 Jul 30	BC	19–38	5Y6/3	L	SAB
Akasztó 1998 Jul 30	C1	38–58	5Y6/3	L	SAB
Akasztó 1998 Jul 30	C2	58–90	5Y6/3	L	SAB
Akasztó 1998 Jul 30	C3	90–92	5Y5/3	LS	SAB
Egerlövö 2000 Aug 9	A/e	0–8	2.5Y3/1	L	PLA
Egerlövö 2000 Aug 9	B1	8–21	2.5Y2/1	CL	PRI
Egerlövö 2000 Aug 9	B2	21–46	2.5Y3/1	CL	l-SAB
Egerlövö 2000 Aug 9	B3	46–78	2.5Y2/1	C	ABL
Egerlövö 2000 Aug 9	BC	78–118	2.5Y3/1	C	ABL
Egerlövö 2000 Aug 9	C	118–130	2.5Y4/1	LC	SAB
Szabadkígyós 2000 Sep 8	A	0–2	10YR4/2.5	L	PLA
Szabadkígyós 2000 Sep 8	B1	2–17	10YR2/1	CL	COL
Szabadkígyós 2000 Sep 8	B2	17–36	10YR2/2	CL	SAB
Szabadkígyós 2000 Sep 8	BC	36–67	2.5Y4/3	CL	PRI
Szabadkígyós 2000 Sep 8	C	67–90	2.5Y4.5/5	CL	PRI
Zám puszta 2001 Aug 23	A/e	0–7	2.5Y3/2	L	PRI
Zám puszta 2001 Aug 23	B1	7–22	2.5Y3/2	C	s-SAB
Zám puszta 2001 Aug 23	B2	22–38	2.5Y3/2	C	ABL
Zám puszta 2001 Aug 23	BC	38–68	2.5Y4/2	C	ABL
Zám puszta 2001 Aug 23	C1	68–75	2.5Y5/3	C	SAB
Zám puszta 2001 Aug 23	C2	100–120	2.5Y5/3	C	SAB
Karcag_M1 1998 Oct 22	Ap	0–18	10YR3/1	CL	ABL
Karcag_M1 1998 Oct 22	A	18–32	10YR3/1	CL	ABL
Karcag_M1 1998 Oct 22	B	32–51	2.5Y3/1	CL	s-SAB
Karcag_M1 1998 Oct 22	BC	51–92	10YR3/2	CL	s-SAB
Karcag_M1 1998 Oct 22	C	92–100	10YR4/3	CL	s-SAB
Karcag_M1K 1998 Oct 22	Ap	0–21	10YR2/2	CL	s-SAB
Karcag_M1K 1998 Oct 22	A	21–46	10YR3/1	CL	s-SAB
Karcag_M1K 1998 Oct 22	B	46–68	10YR3/2	CL	SAB
Karcag_M1K 1998 Oct 22	BC	68–111	2.5YR4/2	CL	ABL
Karcag_M1K 1998 Oct 22	C	111–118	2.5YR4/3	CL	ABL

(continued)

Table 3 (continued)

Site and date of sampling	Code of horizon	Depths (cm)	Wet colour	Texture	Structure
Karcag_M2 1998 Oct 22	Ap	0–20	10YR2/1	CL	ABL
Karcag_M2 1998 Oct 22	A	20–36	10YR2/1	CL	PRI
Karcag_M2 1998 Oct 22	B	36–75	10YR2/1	CL	ABL
Karcag_M2 1998 Oct 22	BC	75–95	10YR2/1	CL	PRI
Karcag_M2 1998 Oct 22	C	95–105	10YR3/2	CL	ABL
Karcag_M2K 1998 Oct 22	Ap	0–28	10YR2/2	CL	ABL
Karcag_M2K 1998 Oct 22	A	28–45	10YR2/2	CL	ABL
Karcag_M2K 1998 Oct 22	B	45–68	10YR2/2	CL	ABL
Karcag_M2K 1998 Oct 22	BC	68–105	10YR3/3	CL	ABL
Karcag_M2K 1998 Oct 22	C	111–115	2.5YR4/3	L	ABL

SL sandy loam, *L* loam, *CL* clay loam, *C* clay, *PLA* platy, *SAB* subangular blocky, *ABL* angular blocky, *COL* columnar, *PRI* prismatic, *l* large, *s* small, *nps* no pedological structure has developed

Table 4 Selected properties of the studied profiles

Sample	pH	OM	Carb.	Clay	CEC	SP	EC	Na	SAR
SA5	8.98	0.89	22.1	15	6.1	33	27	345	45.1
SA14	8.93	0.93	33.7	38.1	12.9	62	16.2	167	33.5
SA35	8.94	0.56	57.9	45	10.6	55	15.3	162	30.8
SA53	9.21	0.48	26.6	17.8	7.9	33	11.2	110	26.5
SA65	9.13	0.42	53.7	36.6	8.6	57	11.6	111	26.2
EG4	8.08	4.31	1.3	29.4	25.4	66	25.2	440	69.7
EG14	8.66	2.33	9	50.6	32.3	93	21	342	64.2
EG34	9.11	1.55	14.8	50	32	128	14	192	73.6
EG62	9.14	1.3	13.3	46.9	31.4	143	8	97	71
EG98	9.24	0.99	12.6	42.2	28.3	140	2.7	28	40.8
EG124	9.39	0.71	28.2	38.1	22.3	98	2.5	11.2	21.8
SZ1	9.26	2.2	4.24	30	23.6	53	21	380	223
SZ9	9.56	2.37	12.7	44.5	26.3	67	25.4	456	357
SZ26	9.8	1.74	18.2	41.1	23.7	69	19.5	345	361
SZ53	9.92	1.18	20.4	38.5	20.4	73	11.8	187	258
SZ78	9.97	0.59	22.9	37.1	16	86	6.9	100	171
ZA3	9.21	2.05	0.3	28.5	18.2	52	36.2	489	409
ZA14	9.68	1.56	0.3	34.7	21.8	66	22.8	289	282
ZA30	9.75	1.41	0.8	44.9	25.6	93	16.3	200	249
ZA53	9.73	1	5.6	48.2	25.7	116	10.5	117	137
ZA71	9.72	0.84	21.4	44.3	19.5	98	8.3	87	110
ZA110	9.48	0.49	20.6	33.6	16.6	88	7.2	75	77.4
UJ2	10.2	0.79	6.72	10.3	6.3	37	20	405	684
UJ9	10.4	0.4	11.13	21.8	9	44	8	138	223
UJ27	10.3	0.38	36.8	28.8	11	57	4.7	82	160
UJ62	10.3	0.21	26.25	22.8	11	50	3.5	62	111
PE2	9.95	1.29	15.2	7.1	5.2	37	71	1080	620
PE8	10.2	0.69	20.2	10.7	3.7	33	7.9	100	197
PE26	10.4	0.3	13.5	9.8	3.9	33	6.3	80	169
PE48	10.4	0.22	20.2	15.8	3.8	47	6.2	75	180
PE68	10.3	0.22	31.6	20.4	3.9	44	6.2	74	136
AL1	9.87	1.18	2.5	14.2	8.3	33	78	1750	2060
AL15	9.84	1.17	4.2	22.7	15.2	48	25	386	387
AL43	10	0.68	16.9	21.7	9.6	46	16.2	220	339
AL64	10.2	0.06	13.9	4.2	3.8	33	10	124	560
AL76	9.87	0.16	23.2	17.2	10.5	73	9.5	114	260

(continued)

Table 4 (continued)

Sample	pH	OM	Carb.	Clay	CEC	SP	EC	Na	SAR
AK2	9.88	1.19	29.3	9.2	5.4	35	70	1000	2100
AK11	10.2	0.63	33.9	20.1	7.3	39	29	398	3370
AK28	10.1	0.2	38.2	17.8	7.3	43	27.5	374	7780
AK48	10.1	0.23	33.9	13	7.5	40	24.3	329	10,000
AK74	10.5	0.23	26.3	3	5.8	35	12.7	120	10,000
AK92	10.5	0.13	18.7	3.6	4.9	30	12.8	134	484
KA9	7.33	5.32	0	41.3	26.7	47	1.1	3.8	2.05
KA25	6.91	4.08	0	40.8	33.3	46	0.7	2.3	1.69
KA42	7.67	3.15	1.4	41.4	34.5				
KA72	8.51	2.59	7.2	41.7	33.2	52	0.5	3.6	5.19
KA96	9.52	0.94	8.8	39.3	15.7	51	1.2	12	19
KB11	7.4	6.48	0	40.2	24.3	48	0.8	2.7	1.62
KB33	7.84	2.99	1.2	39.5	24.4	52	0.6	2.5	1.94
KB57	8.38	2.54	5.8	40.3	27.3	53	0.5	2.9	3.08
KB89	9.25	1.83	9.5	40.3	17	47	1	9.3	13.4
KB114	9.72	0.07	9.9	35.9	14	56	2.1	22	30.7
KC10	7.47	5.61	0	39	24.1	48	0.6	3.5	3.46
KC28	7.67	3.87	0	40.1	21.6	45	0.7	5.6	6.55
KC56	8.76	2.91	0	49	31.8	46	1.2	11	15.9
KC85	8.95	1.99	0	47.8	29.8	49	2.6	27	31.1
KC100	8.97	1.22	0	46.6	19.6	55	2.6	27	33.2
KD14	7.53	5.42	0	40.1	27.7	48	1.1	9.1	10
KD26	7.39	3.37	0	40.3	31.5	53	0.6	3	2.92
KD56	8.05	2.71	4.9	38.5	22.3	55	0.5	2.2	2.05
KD87	8.28	2.02	8.8	39.8	18.8	52	0.5	2.9	3.34
KD113	9.03	1.54	11.4	37.8	20.3	46	0.7	6	8.81

Sample is identified by horizon depth mid-point (cm). pH H_2O, *OM* organic matter %, *Car.* carbonates %, *Clay* clay %, *SP* saturation percentage, *EC* electric conductivity of the soil saturation extract (mS cm^1), *Na* sodium concentration in the soil saturation extract (mM dm^{-3}), *SAR* sodium adsorption ratio

where the salt efflorescenses can be found in small patches only. Solonetz is the typical soil type in this situation, but Solonchak limited to small patches is found also. The latter soil type is the most typical one in waterlogged areas and beside saline lakes. The above soils have *Artemisia santonicum* as the dominant plant species. Intermediate elevation is occupied at (Akaszto AK), which was earlier a temporary lake, already being dried out and covered by sparse vegetation stands of *Camphorosma annua*. From lower elevations we sampled Ujfeherto (UJ) and Zam (ZA) profiles, temporary waterlogged sites, where *Kochia scoparia* and *Salicornia europaea* are characteristic plant species, respectively. The lowest elevation sites (Sarrod SA and Peterito PE) are close to typical saline lakes, where *Suaeda salsa* and *Aster tripolium* plus *Puccinellia limosa* (more hydrophytic vegetation) dominate, respectively, although these soils are not usually covered by lake water. The drier, upland sites of highly saline soils are grazed by sheep and the lowland ones, especially those beside lakes, are grazed by wild geese.

Chernozem and Vertisol profiles at Karcag are more brown (10YR) than salt-affected soils. Profiles close to lakes are paler in colors. The variable layering of the subsoil of Sarrod profile, caused by depositions, is evidenced in color and texture as well (Table 4).

The texture of the studied soils ranges from loamy sand to clay. The eluvial A/E horizons of Solonetz soils have coarser texture and a lower clay content than the illuvial horizons. In Solonetz soils prismatic and columnar structure reflects high sodicity. The amount of clay in soils of higher salinity is usually the highest in illuvial B horizons while in less saline or non-saline soils this is rather uniform throughout the whole profile.

The presence of calcium carbonate is common all over the Hungarian Plain because of the frequent occurrence of loessial and carbonatic deposits of River Danube. All studied profiles contain carbonates except the Vertisol profile KC. As it is typical for chernozems, calcium carbonate occurs in deeper layers in KA, KB and KD. Leached (low carbonate) topsoil layers are characteristic for Solonetz soils, whereas Solonchak contain rather high amounts of carbonates right at the surface (Table 4).

Electrical conductivity of the saturated soil extracts ranges between 2 and 78 dS/m for salt-affected soils and this is significantly lower for slightly salt-affected soils. Solonchak soils show continuously decreasing EC values down from the topsoil. Solonetz soils show small electric conductivities at the surface and a maximum in B2 horizons. In non saline soil types (Chernozem and Vertisol) largest EC values are found in the deepest horizon, affected mostly by saline groundwater. The electric conductivity of the saturated soil extracts decreases in general with the profile depth for all soils which is also noted for the sodium adsorption ratio (Table 4).

Except one horizon all samples are alkaline and mostly reach pH values higher than 9. More leached horizons of slightly saline and Solonetz profiles can have neutral pH at the surface. Soil pH increases down the profiles, similarly as the carbonate content (Table 4).

As a minimal value, soil organic matter of 0.8% was determined. Solonchak soils typically do not have SOM larger than 1.5%. SOM content around 3% can be found in the uppermost horizon of Solonetz soils. Chernozem and Vertisol profiles show SOM above 5%. The amount of soil organic matter accumulated in the profiles studied is closely related to their pH. Presence of such dependence was very surprising for us, because amount of soil organic matter in soils depends on many environmental factors, conditions of soil genesis and physical soil properties, and not on a single parameter. However all studied soils are located within rather small area and, as far as the pH is a main parameter responsible for organic matter leaching, one may suspect that at higher pH its accumulation has been prevented by the extreme conditions for plants and microbes. Where there is better plant growth there is larger soil organic matter content, that dissolves $CaCO_3$, plants use the Ca and it results in a decrease in pH.

18 Vegetation of Saline and Sodic Areas

The list of plant species of saline and sodic habitats is best represented by the floras of the National Parks. Out of the ten National Parks, there are five parks possessing saline and sodic areas. The first flora was written about the first Hungarian National Park, the Hortobágy National Park (Szujkó-Lacza et al. 1982) and others followed.

Soó (1980) listed the 25 saline and sodic plant associations, belonging to the division "*Puccinellio-Salicornea*" in two association class, 4 association series, 7 association groups. The most frequent of these are the following: *Salicornietum prostratae, Suaedetum pannociae, Salsoletum sodae, Crypsidetum aculeatae, Puccinellietum limosae, Pholiuro-Plantaginetum tenuiflorae, Hordeetum hystricis, Camphorosmetum annuae, Lepidio crassifolii-Puccinellietum limosae, Agrostio-Alopecuretum pratensis, Eleochariti-Alopecuretum geniculati, Agrostio-Beckmannietum, Achilleo-Festucetum pseudovinae, Artemisio-Festucetum pseudovinae*.

There are other associations, which are related to saline and sodic soils, such as *Bolboschoenetum maritimae continentalis, Glycerietum maximae*, typical for salt marshes.

There is a sodic woody association, the *Galatello-Quercetum roboris* and on its clearings the *Peucedano-Galatelletum*.

Recently a full list of associations was given by Molnár and Borhidi (2003).

Molnár et al. (2008) summarizes the actual distribution of saline vegetation. Here we copy their map (Fig. 2) only on one habitat, the salt meadows (Code F2 according to Bölöni et al. 2003), which are the most frequent grassy habitats in the country. Most characteristic associations belonging to this category are *Agrostio-Alopecuretum pratensis, Agrostio-Caricetum distantis, Eleochari-Alopecuretum geniculati, Agrostio-Glycerietum poiformis, Agrostio stoloniferae-Beckmannietum eruciformis, Rorippo kerneri-Ranunculetum lateriflori, Loto-Potentilletum anserinae.*

19 Example of the Soil and Vegetation Conditions in Two Characteristic Kiskunság Sites

The soil properties and vegetation at two nearby sites is described here based on Tóth et al. (2003). The study region is the Danube valley where there was a drop in groundwater level and soil desalinization was observed together with a shift in vegetation (Table 5). Data on more than five years monitoring are presented here.

The "Artemisia saline puszta" vegetation at Apaj is a result of gradual drying and groundwater sinking. Right after the drainage of the area probably Bolbo schoenetum maritimi, after which Lepidio crassifolii-Puccinellietum limosae plant associations was characteristic, of these two characteristic species was found in the quadrats. The official nomenclature of the present plant association is Artemisio–santonici–Festucetum pseudovinae Soó (1933) 1947 corr. Borhidi 1996 (Molnár and Borhidi 2003).

This plant community is named as ***Artemisia* saline puszta (15.A113)** by Devillers and Devillers-Terschuren (1996) and we use this name in the text. Its characteristics are described under the code of F1a by Molnár et al. (2003) and can be summarized as:

- Typical soil is Solonetz, the soil is affected by shallow groundwater and surface waterlogging as well.
- There are no shrubs or trees among these grasses, neither tall grasses.
- Most characteristic species are *Artemisia santonicum* subsp. *monogyna* subsp. *patens*, *Festuca pseudovina*, *Limonium gmelini*, *Podospermum canum*, *Trifolium retusum*, *Trifolium angulatum, T. parviflorum*, *Ranunculus pedatus*, *Bupleurum tenuissimum*, *Gypsophila muralis*, *Lotus tenuis* (*L. glaber*), *Cerastium dubium*.
- They occur in an elevation zone between Pannonic *Puccinellia limosa* hollow (lower neighbor) and slightly saline **Grassy saline puszta** or **nonsaline Pannonic loess steppic grasslands** (upper neighbor) (names according to Devillers and Devillers-Terschuren 1996).
- Regenerative potential is good, but the details are not known.

At present the site is grazed by sheep.

The "Pannonic Puccinellia limosa hollow" vegetation at Zabszék lake is the result of continous drying of the lake and the shifting of lake margin towards the bottom of the lake. The previous stage might have been lake-margin vegetation and *Bolboschoenetum maritimi* plant association. The official nomenclature of the plant association is Lepi diocrassi folii–*Puccinellietumlimosae* Soó 1947–puccinellietosum.

This plant community is named as **Pannonic Puccinellia limosa hollows (15.A131)** by Devillers and Devillers-Terschuren (1996) and EUNIS(2002) and as used in this text. Its characteristics are described under the code of F4 by Bagi and Molnár (2003) and can be summarized as:

- Typical soil is Solonchak. A condition of its occurrence is shallow saline groundwater and repeated waterlogging, typical on the bank of saline lakes. The spring and late summer aspects might be very different.
- Physiognomy is determined by waterlogging. If there is no waterlogging the *Puccinellia limosa* is small, on wet places it grows high, forms tussocky patches.
- Most characteristic species are *Puccinellia limosa*, *P. festuciformis* subsp. *intermedia*, sometimes important species are *Lepidium crassifolium* (*L. cartilagineum*), *Aster tripolium* subsp. *pannonicus, Artemisia santonicum* subsp. *santonicum* and subsp. *patens, Plantago maritima.*
- They occur in the neighbourhood of saline lakes.
- Regenerative potential is very good.

At present the only major grazing animals are wild geese, mostly *Anser anser*.

The two sites represent the most typical salt-affected habitats of Kiskunság region, Hungary.

Although the clay percent is similar at the two sites (Table 6), the "Pannonic Puccinellia limosa hollow" site has less sand and more silt particles, which is the result of the effect of the sedimentation onto the lake bottom. The same process might have resulted in the larger $CaCO_3$ content of the soil in the same community. These differences are reflected in the Cation Exchange Capacity values, water retention values and soil hydraulic conductivity values as well. The surface soil of "Pannonic Puccinellia limosa hollow" site binds the water with stronger force and permits its movement less (Tóth and Kuti 2002).

Due to the complete plant cover at the "Artemisia saline puszta" site, the soil organic matter content is larger. The surface salinity is shown by the electrical conductivity (EC) of the saturation extract (Richards 1954). This standard indicator of soil salinity was analyzed for the profile characterization from the soil genetic horizons one time and showed three times as large EC at the "Pannonic Puccinellia limosa hollow"

Table 5 Some characteristics of the main species of the two exemplary associations based on Horváth et al. 1995 and the sources indicated

Name	Festuca pseudovina Hack. ex Wiesb.	Artemisia santonicum L. (ssp.)	Bromus hordaceus L. ssp hordaceus	Plantago maritima L.	Podospermum canum C. A. Mey.	Puccinellia limosa (Schur.) Homberg.	Aster tripolium ssp. pannonicus (Jacq.) Soó
Synonym	–	Artemisia maritima L.	–	–	Scorzonera cana (Mey.) Griseb.	–	–
Family	Poaceae	Compositae	Poaceae	Plantaginaceae	Compositae	Poaceae	Compositae
Mean (min–max) cover%	50.5 (5–76)	11.7 (0–29)	1 (0–9)	0.95 (0–4)	0.50 (0–2.5)	36 (0–80)	0.22 (0–4.75)
Site	Artemisia saline puszta	Artemisia saline puszta	Artemisia saline puszta	Artemisia saline puszta	Artemisia saline puszta	Pannonic Puccinellia limosa hollow	Pannonic Puccinellia limosa hollow
Raunkiaer life-form	Hemicryptophyton	Chamaephyton-Hemicryptophyton	Therophyton	Hemicryptophyton	Hemicryptophyton-Hemitherophyton	Hemicryptophyton	Hemicryptophyton
Vertical distribution	Plain–mountain	Plain	Plain-subalpine	Plain–mountain	Plain–mountain	Plain	Plain–hill
Flora element	Continental	Eurasian	Cosmopolitan	Circumpolar	Pontic-Submediterranean	Pannonian endemism	Eurasian
Vegetative propagation (Csontos 2001)	Bunching grass	Bunching grass	None	None	None	Bunching grass	Bunching grass
Dispersion of seeds (Thompson et al. 1997, Csontos et al. 2002)	Endozoochory	Anemo-, endozoo-, epizoochory	Endozoochory	Anemo-, endozoochory	Anemochor	Endozoochort	Anemo-, zoochory
Flowering (months)	6, 7	7, 8, 9, 10	5, 6, 7,	6, 7, 8, 9	5, 6, 7, 8, 9, 10,	6, 7	7,8,9
Seed ripening (months)	7	8, 9, 10,11	6, 7, 8	8, 9, 10	6, 7, 8, 9, 10	7, 8	8.9
Naturalness (Simon, 1988, 1992)	Disturbance tolerant native species	Native accessorial species	Disturbance tolerant native species	Native accessorial species	Native accessorial species	Native accessorial species	Native accessorial species
Strategy (Borhidi, 1995)	Competitor	Competitor	Disturbance tolerant	Generalist	Generalist	Competitor	Specialist
Heat supply (Borhidi, 1995)	Submediterranean woodland and grassland belt	In accordance with thermophilous forest or woodland belt	In accordance with submontane broad leafed forest belt	In accordance with mesophilous broad-leaved forest belt	Submediterranean woodland and grassland belt	In accordance with thermo-philous forest or woodland belt	In accordance with thermophilous forest or woodland belt

(continued)

Table 5 (continued)

Name	Festuca pseudovina Hack. ex Wiesb.	Artemisia santonicum L. (ssp.)	Bromus hordaceus L. ssp hordaceus	Plantago maritima L.	Podospermum canum C. A. Mey.	Puccinellia limosa (Schur.) Homberg.	Aster tripolium ssp. pannonicus (Jacq.) Soó
Soil moisture (Borhidi, 1995)	Xero-tolerants, but occasionally occurring on fresh soils	Xero-tolerants, but occasionally occurring on fresh soils	Plants of semi-humid habitats under intermediate conditions	Plants of fresh soils	Plants of semi-dry habitats	Plants of moist soils not drying out and well aerated	Xero-indicators on habitats with long dry period
Soil reaction (Borhidi, 1995)	Basiphilous plants	Basifrequent plants, mostly on basic soils	Mostly on neutral soils, but also on acidic and basic ones, generally widely tolerant more or less indifferent plants	Basiphilous plants	Basiphilous plants	Basifrequent plants, mostly on basic soils	Basiphilous plants
Nitrogen supply (Borhidi, 1995)	Plants of moderately oligotrophic habitats	Plants of sub-mesotrophic habitats	Plants of mesotrophic habitats	Plants of moderately oligotrophic habitats	Plants of habitats very poor in nitrogen	Plants of mesotrophic habitats	Plants of moderately oligotrophic habitats
Light intensity (Borhidi 1995)	Full light plants of open habitats	Full light plants of open habitats	Halflight plants mostly livingin full light, but shadow tolerant	Light plants	Light plants	Full light plants of open habitats	Full light plants of open habitats
Continentality (Borhidi, 1995)	Subcontinental, area in eastern CE	Continental species, reaching only eastern part of CE	Oceanic–suboceanic species area in whole Central Europe (CE)	Continental–subcontinental species, main area in Eastern Europe	Continental–subcontinental species, main area in Eastern Europe	Continental–subcontinental species, main area in Eastern Europe	Eucontinental species, main aera in Siberia and Eastern Europe
Salinity tolerance (Borhidi, 1995)	Beta-mesohaline plants living in soils of little chloride concentration 0.3–0.5%	Alfa-mesohaline plants living in soils of intermediate chloride concentration 0.7–0.9%	Species not occurring in saline or alkali soils	Polyhaline plants living in soils with high chloride concentration 1.2–1.6%	Alfa-mesohaline plants living in soils of intermediate chloride concentration 0.7–0.9%	Euhaline plants living in soils of very high chloride concentration 1.6–2.3 %	Polyhaline plants living in soils with high chloride concentration 1.2–1.6%

Table 6 Abiotic characteristics of the studied sites

Plant community	Artemisia saline puszta	Pannonic Puccinellia limosa hollow
Site	Apaj	Zabszék
Coordinates latitude	N 47° 05′14.0″	N 46° 50′ 34.8″
Coordinates longitude	E 19° 05′ 54.7″	E 19° 10′ 37.1″
Soil type	Solonetz	Solonchak
Soil clay % in 0–40 cm depth	30	34
Soil sand % in 0–40 cm depth	13	8
Soil physical properties in the uppermost layer of 3–9 cm		
Soil bulk density (g/cm^3)	1.7	1.76
Soil water retention at 0.1 kPa (saturation) (gravimetric %)	22	23
Soil water retention at 20 kPa (field capacity) (gravimetric %)	18	20
Soil water retention at 1500 kPa (wilting) (gravimetric %)	4.5	13
Soil saturated hydraulic conductivity (cm/day)	0.07	0.028
Chemical properties of 0–10 cm layer		
Soil organic matter in 0–10 cm layer %	2.2	0.9
Soil $CaCO_3$ content %	12	32
Exchangeable Na %	23	39
Cation exchange capacity-me/100 g soil	23	31
pH	8.3	8.5
Electrical conductivity of saturation extract (mS/cm)	1.8	5.3
Equivalent Na in cation composition of saturation extract (%)	76	98
Equivalent Ca in cation composition of saturation extract (%)	13	1
Equivalent Mg in cation composition of saturation extract (%)	1	1
Equivalent Cl in cation composition of saturation extract (%)	23	34
Equivalent SO_4 in cation composition of saturation extract (%)	18	14
Equivalent HCO_3 in cation composition of saturation extract (%)	53	44
Equivalent CO_3 in cation composition of saturation extract (%)	6	8
Average dynamic groundwater and lakewater properties		
Average (minimum, maximum) depth of groundwater level (m)	1.62 (0.6–2.3)	0.95 (0.7–1.5)
Average (minimum, maximum) EC of groundwater (mS/cm)	4.0 (0.92–5.5)	3.19 (1.45–3.82)
Average (minimum, maximum) pH of groundwater	8.7 (8.1–9.2)	8.2 (7.5–8.9)
Average (minimum, maximum) elevation of lake water level (m)	–	−0.26(−0.55+0.27)
Average (minimum, maximum) EC of lake water (mS/cm)	–	8.3 (2.2–31.9)
Average (minimum, maximum) pH of lake water	–	9.3 (8.1–9.9)
Average dynamic properties of 0–40 cm layer		
Average (minimum, maximum) $EC_{2.5}$ of soil in 0–40 cm layer-mS/cm	0.85 (0.45–1.17)	1.0 (0.75–1.78)
Average (minimum, maximum) pH of soil in 0–40 cm layer	9.6 (9.0–10.2)	10.0 (9.7–10.4)
Average (minimum, maximum) pNa of soil in 0–40 cm layer	2.36 (1.99–2.89)	2.2 (1.69–2.9)
Average (minimum, maximum) soil moisture of soil in 0–40 cm layer (%)	17.6 (5.2–38.3)	20.9 (14.6–29.3)

site than at the "Artemisia saline puszta" site in the surface layer. The reason for the difference is the contrastive soil types, which is Solonchak at the more saline "Pannonic Puccinellia limosa hollow" site. This soil type has the maximum of salt accumulation right at the surface. On the other hand, the Solonetz of the "Artemisia saline puszta" site has less saline, and alkaline, somewhat leached surface horizon, and reaches its maximum of salt concentration at greater depth. Consequently plants with low salt tolerance can live on Solonetz soils. On the other hand the differences in the temporal, depth average values (0–40 cm depth, 67 months) were not great.

The chemical composition of saturation extract of the surface layer (Table 6) shows that there is more Ca ion and less Cl at "Artemisia saline puszta" site, indicating the tendency of evaporative concentration of solutes. With increasing concentration of solutes Ca has a tendency of precipitating and Cl the tendency of increasing concentration, since this anion is the last to precipitate (Tanji 1990).

The groundwater was shallower at the lakeside "Pannonic Puccinellia limosa hollow" site and both average levels corresponded well to the characteristic groundwater depths in Solonchak (<1 m) and Solonetz (1.5–3 m) soils. The salinity of groundwater is only slightly higher at "Artemisia saline puszta" site probably due to less effect of atmospheric water. During the 5.5 years study period extreme low values were observed in one winter and were related to shallow groundwater. The average pH of soil at surface and in 0–40 cm layer is slightly higher at lakeside "Pannonic Puccinellia limosa hollow" site. There is an opposite tendency in the pH values of the groundwater, since it fluctuates in the more saline layers of "Artemisia saline puszta" site (Solonetz) and less saline layers of "Pannonic Puccinellia limosa hollow" site (Solonchak). The average value of lake elevation shows that it was 0.26 m deeper than the surface of the "Pannonic Puccinellia limosa hollow" site. During the driest period, when the salinity of lake water approached the concentration of sea, the level of lake was 0.55 m deeper. On the other hand the maximum level was 0.27 m above the surface, when the data collection was suspended for 16 months in the year 1999 due to extreme large precipitation. Lake water pH showed a clearly positive linear relationship to the EC. The dilution of the lake water by precipitation results in the lower dominance of carbonates (Dvihally 1960; Tóth et al. 2003).

Average dynamic properties of 0–40 soil layers showed the tendencies expected because of soil type (salinity = $EC_{2.5}$, pH) and presence of lake (moisture). The largest average moisture percentages measured at the two sites were within the limit of "available moisture range" defined between the field capacity and wilting point. On the other hand in the surface 0–10 cm layer soil moisture decreased below wilting capacity from time to time.

The plant composition of the sites, being dominated by Poaceae, Compositae and Plantaginaceae as shown in Table 5 is very similar to other temperate inland saline habitats and reflect the abiotic conditions. Compared to "Artemisia saline puszta" site the plants in "Pannonic Puccinellia limosa hollow"site prefer wet soil, light places and tolerate high salinity.

At "Artemisia saline puszta" site out of the five dominant plants four are typical for Pannonic saline grasslands. *Bromus hordaceus* is a common weed and its spreading is a relatively new feature in these vegetation types (Bagi 1989). Most of the ecological characteristics of *B hordaceus* are very different from the other four dominant species and show that the site is in change. At the surface where the plant roots live the conditions has become permissible for this plant.

At "Pannonic Puccinellia limosa hollow" site *Puccinellia limosa* is an endemic species, and the accompanying *Aster tripolium* is represented by an endemic subspecies. As Table 6 indicates, the surfaces of the quadrats were not covered completely with green vegetation during most of the study period. The bare surface changed between 0% when large stalks and leaves covered the soil surface and 100% during and immediately after waterlogging.

20 Utilization of Halophytes in Hungary

The first and most important utilization of the native vegetation is the grazing by domestic animals. Earlier grazing was typical for each of the saline and sodic vegetation types ranging from the tall grass occurring in the highest lying areas down to the lowest lying marshes. At present grazing is not typical in the wetlands. Loess steppes and taller grass sodic grasslands were and are grazed by horses and cattle. Shortgrass sodic grasslands were and are grazed by sheep. In the salt meadows typically there is no grazing, but hay cutting. Water buffalo and pigs were grazing the wetlands earlier. Also the Hungarian Grey Cattle are able to graze wet habitats, including reeds.

Besides grazing and hay cutting, reed (*Phragmites australis*) cutting is also typical in the wetlands belonging to saline and sodic vegetation. Also cattails (*Typha* sp) are collected here.

Bare sodic habitats have *Matricaria chamomilla* (chamomile) stands, which are collected as medicinal plant. Also *Achillea* sp, *Artemisia* sp, *Symphytum officinale, Althaea officinalis* are collected for medicinal purposes. *Limonium gmelini* and *Aster sedifolius* are collected from time to time as decorative plants.

Among mushrooms it is the *Agaricus bernardii* and *Marasmius oredes* which are collected most.

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Halophytes in Republic of Macedonia

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Abstract Republic of Macedonia is situated in Balkan Peninsula with a total area of 25,942 km^2 and 1.26 million hectares of agricultural land, where 560,000 ha are arable land (44.2%) mainly located in the valleys and 700,000 ha are pastures (55.6%), located in hilly and mountainous regions of the country. There are approximately 11,000 ha saline soils, mainly found in four valleys (Ovche Pole, Pelagonija, Skopska and Strumica). These soils are of natural origin, but anthropogenic factors play important direct and indirect role in their genesis. The halophyte vegetation on these soils has been studied at length. This vegetation is facing great biotic interferences as a result of this some species or associations are threatened with extinction. This paper will therefore try to enlighten the current situation of this vegetation in Macedonia.

1 Introduction

Republic of Macedonia is situated in Balkan Peninsula with a total area of 25,713 km^2 (Fig. 1). Around the half of the total area (1.26 million hectares) belongs to the agricultural land with 560,000 ha arable land (44.2%) and 700,000 ha pastures (55.6%). From the total arable land, 461,000 ha are (82%) cultivated area and horticultural crops, 58,000 ha meadows (10%), 26,000 ha vineyards (5%) and 15,000 ha orchards (3%). Presently, the cultivated area in the country has been recorded as 0.625 ha per person, which is higher than the standard in EU-25 (National Strategy for Agriculture and Rural Development for Republic of Macedonia 2007–2013 (2007)). According to the statistics, 1/3 of the total cultivated area is abundaned every year because of the migration of rural people into the towns and industrial developments. The agricultural land has declined from 633,000 ha in 1999 to 560,000 ha in 2004.

The country enjoys two major types of climate due to its specific natural and geographical characteristics; Mediterranean and continental. There are two seasons cold, wet winters and dry, hot summers. However, the high mountainous areas are characterized by a mountainous climate with short, cool summers and considerably cold and moderately wet winters, with precipitation being mainly in the form of snow. In spite of the fact that Macedonia lays relatively close to the Aegean and Adriatic Seas, the influence of the Mediterranean climate does not reach very deeply into the country, except within a few valleys. This is a result of the high mountains which rise up in the west and south of the country. The average annual temperature is 11.3°C. The towns of Valandovo and Gevgelija show the highest average temperatures laying around 14.5°C and 14.3°C, respectively. In the mountainous areas, the mean annual temperatures are 4.7°C in Popova Shapka, 6.8°C in Lazaropole and 8.2°C in Krushevo.

The average precipitation in the country is 683.7 mm/year. Humidity is higher in October and December, less in March and May. Rain splash in spring and autumn is very often exuberant, and contribute much to the soil erosion and local overflow. During the vegetative period, very often dry spills occur, signifying that water is limited factor for intensive agricultural production. Late spring frosts, and early autumn rimes happen very often. The areas of highest precipitation occur in

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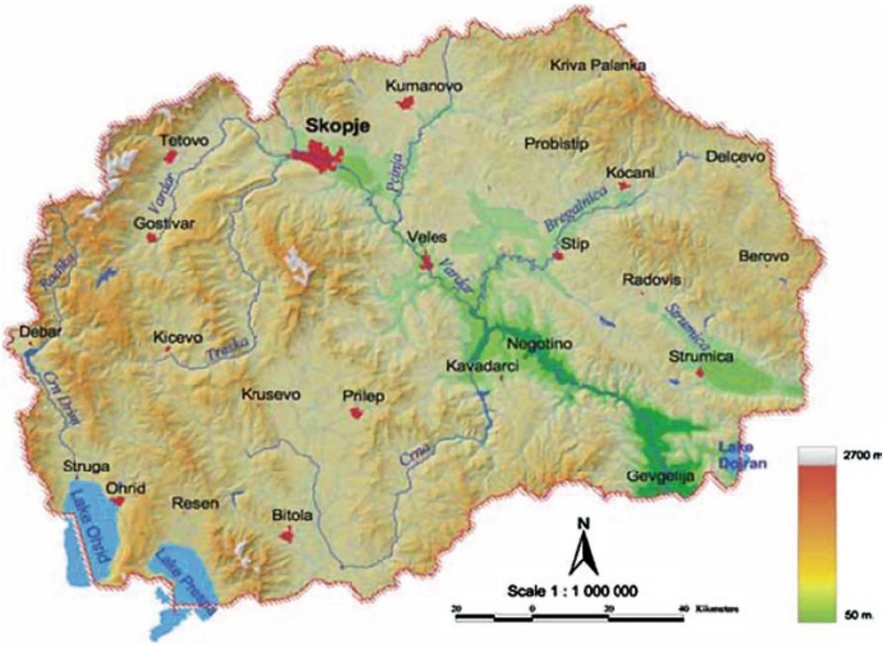

Fig. 1 Map of Republic of Macedonia

Mavrovi Anovi and Resen, with 1,197 mm and 757.9 mm, respectively, and the least in Ovche Pole Plain with only 490.3 mm.

2 Genesis and Classification of Saline Soils

The landform in the Republic of Macedonia is characterized by complex geotectonic features, which produce developed relief, complex geology and diversity of soil types: automorphous, hydromorphic, halomorphic, subaquatic) (The Country Study for Biodiversity of the Republic of Macedonia 2003). There are over 30 soil types, due to the diversity of the relief, climate, vegetation, geological formation and the anthropogenic factors. We come across eight climate–vegetative–soil areas, very heterogenic in climate, vegetation and soil profile. The arable area is located mostly in sub-Mediterranean and warm continental area between 50 and 900 m above the sea level (Filipovski 1985).

The area of saline soils is 0.42% of the total country area. There are approximately 11,000 ha of saline soils, mainly placed in four valleys: Ovche Pole, Pelagonija, Skopje and Kochani, where halomorphic soils extend on large areas, and in Valandovo and Strumica, where the halomorphic soils can be found in the form of small patches of several square meters located on the arable lands (Filipovski 1985). According to Second National Ecological Action Plan (2006) irrigation, especially in arid areas is leading to increased soil salinization, but because of the absence of monitoring or research, the intensity and current situation of salinization cannot be defined precisely.

According to Filipovski (1985), halomorphic soils are formed under certain climatic, relief, hydro-geographic and vegetation conditions. They mostly occur in arid and semiarid areas, halomorphic soils in the region of Ovche Pole, belongs mostly to the type of solonchak and solonetz. The concentration of salts in the underground waters of the solochak soils in this valley is very high 25–100 g/L. In other valleys the concentration of salts in underground waters does not exceed 2–4 g/L. The typical solonchak soils are formed under the influence of shallower underground waters, which contain more salts, but the neutral salts are predominant (chlorides and sulfates).

The bedrock plays very important role in the genesis of halomorphic soils. These soils are formed only on the top of sediments (alluvium, lakesides, marine, eolic), at accumulation grounds, where soils have been precipitated together with sediments in the past. The anthropogenic factors are very important for genesis and evolution of these soils. The irrigation is contributing towards the expansion of such soils. The erosion contributes by filling the rivers and through an alleviation of underground waters. Intensive grazing and destruction of natural vegetation, especially grasses, encourage the process of evaporation of saline underground waters and accumulation of soils on the surface horizon.

3 Plant Diversity of Saline Soils

The halophyte plant communities show a restricted distribution in the country. These develop on small area in Ovche Pole and in the steppe-like area between Veles, Shtip and Negotino. The halophyte vegetation in the steppe-like areas is categorized as center of high floristic diversity. This vegetation is found on small areas. Although detailed studies have been undertaken, discussions on definition on certain halophytic associations is still continuing (Tzonev et al. 2008).

Very few botanists have worked on the saline soil plant diversity in Macedonia. The earliest research on the taxonomy and phytosociology of halophytes has been conducted by Micevski (1965). He has given a detailed description of vegetation and floral classes, orders and communities in Ovche Pole. Although the area is very small, Micevski (1965) has defined 11 floral associations with a mosaic distribution of the halophyte communities conditioned by the relief and heterogenic chemical composition of the soil (Fig. 2).

The following associations have been recorded by Micevski (1965) on the saline soils in Ovche Pole.

1. Class *Salicornietea* on saline soils (solonchaks and soloneotzs) Br. Bl. et Tx. 1952. The halophytic associations presented here are:

   – Ass. *Suaedetum maritimae balcanicum* is very poor in plant taxa characterised by *Suaeda maritime* Dum. and individual specimens of *Punccinellia convolute* (Horn.) Hay. The association is accompanied by *Hordeum maritimum* Huds. and *Matricaria chamomilla* L. This association develops only on solonchak soils.
   – Ass. *Camphorosmetrum annuae balcanicum* is represented by the characteristic species of *Camphorosma ovata* W.K. and characteristic species for the alliance *Punccinellion convolutae* is *Punccinellia convoluta* (Horn.) Hay. The association shows poor species composition and because of high salt concentrations, only two species are growing on solonchak soil, related to the eroded solonetz rich in sodium.
   – Ass. *Puccinellietum convolutae* is represented by the characteristic species of *Puccinellia convoluta* (Horn.) Hay. and its companion species are *Hordeum marinum* Huds., *Lepidium ruderale* L., *Matricaria chamomilla* L. and where water is dwelled *Phragmites communis* Trin.
   – Ass. *Hordeo-Trifolietum parviflori* is represented by the characteristic species of *Trifolium parviflorum* Ehrh. and *Podospermum canum* C.A.Mey. This association is rich in companion taxa such as *Hordeum marinum* Huds., *Cynodon dactylon* Pers., *Matricaria chamomilla* L., *Trifolium nigrescens* Viv., *Poa bulbosa* L., *Trifolium echinatum* M.B., *Lepidium ruderale* L., *Trifolium resupinatum* L., *Crepis setosa* Hall., etc. Although this association is under an impact of heavy grazing it is richer in species because of the favourable chemical conditions of the soils.
   – Ass. *Camphorosmetum monspeliaceae* is represented by the characteristic species of *Camphorosma monspeliaca* L. and *Plantago coronopus* L. var *commutata* (Guss.) Bég. The association develops on solonetz soils in small patches with dimensions 1–3 m. *Camphorosma monspeliaca* L. is protecting the solonetz from erosion.
   – Ass. *Pholiureto-Plantaginetum balcaninicum* is represented by the characteristic species *Lepturus pannonicus* Kunth. and *Plantago tenuiflora* W.K. This association is rarely found and developes on very small areas, connected to microdepressions with stagnant waters.
   – Ass. *Crypsidetum aculeatae balcanicum* is represented by the characteristic species *Crypsis aculeata* Ait. and *Spergularia marginata* DC. It is typical for wet lands rich in salts. In the area of Ovche Pole it is developing on small depressions and around the water channels where water stays during spring and summer. The association flourishes during the last part of summer, mostly in August.

Fig. 2 Typical halophytic vegetation next to agricultural fields in Ovche Pole

Matevski et al. (2008) have conducted a study in the central part of the country, in the triangle between Veles, Shtip and Negotino. This is a special region used to be called steppe or semi-desert by some researchers who worked there. The bedrock in this area is composed of Paleogenic and more rarely Neogenic sediments. All Paleogenic sediments are salt-rich, thus halophytic vegetation develops at the site. Matevski et al. (2008) has given floristic valorization of endemics and rare species, halophytes, and steppe species. The survey on halophytes shows endemic taxa like *Artemisa martima* L., *Krascheninnikova ceratoides* (L.) Gueldenst., *Camphorosma monspeliaca* L., *Camphorosma annua* Pall. distributed in the steppe region. Their ecology differs significantly from the halophytes species growing on solonchaks in Ovche Pole. The halophytes in the steppe region grow on undeveloped soils, where the erosive processes are even more intense due to the completely degraded forest ecosystems (Matevski et al. 2008).

The halophytic vegetation communities in Macedonia are considered as communities with restricted distribution and they are seriously endangered and threatened with extinction. The most threatened is Ass. *Camphorosmetum monspeliacae*, and there is a great probability that other associations (e.g., Ass. *Crypsidetum aculeatae balcanicum* and Ass. *Pholiureto-Plantaginetum balcanicum*), which develop in small, shallow depressions, will also disappear if steps are not taken to preserve these.

The cultivation on the saline soils of the Ovche Pole Plain has endangered some halophytic species and communities. This especially refers to the species *Camphorosma monspeliaca* L., but also to other halophytes such as: *Crypsis aculeatus* (L.) Aiton, *Puccinellia convolute* (Horn.) Hay, *Suaeda maritima* L. etc. The species *Allium obtusiflorum* DC is now considered to be extinct (Fig. 3).

Heavy agricultural activity is posing a severe threat to the biodiversity of Macedonia, especially due to the current unfavorable conditions and negative developmental trends like draining of wetlands, destruction of valuable habitats like halophytic vegetation, pollution of soils, destruction of bio-corridors, etc. (Capacity self-assessment within the thematic area of biodiversity in Republic of Macedonia 2004). Filipovski (1985) has estimated the agricultural production value of saline soils in the country. The production characteristics of solonchak and solonetz soils depends on the total salt content, Na-ions content, physical characteristics, etc. The worst solonchak soils are without vegetation (so called bald places) or just with halophytic vegetation. Some of the solonchak/solonetz soils are used as poor pastures which are green only in spring when the soil is wet and salts are diluted. Also, they are

Fig. 3 Saline soils in Ovche Pole under severe anthropogenic influence

used in the production of field crops such as barley, sunflower, alfalfa, but without amelioration only chamomile can be grown, but the productivity and crop yields are very low.

4 Conclusion

The distribution of halophytic vegetation is restricted to saline soils and the total area under saline soils in the Republic of Macedonia is 11,000 ha. Thus, the halophytic vegetation has limited distribution, mainly in Ovche Pole and between Veles, Shtip and Negotino. The species composition of the halophytic vegetation is represented by plants typical for continental and Mediterranean climate types, specific soil composition, hydrological and relief characteristics. Although the taxonomy of halophytes has been studied in details, there is a need for future studies on the ecological and higher rank syntaxa. This vegetation type is under significant anthropogenic pressures and some of the halophytic taxa and associations are seriously endangered and threatened with extinction.

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Low-Cost Mapping of Sabkha-Ecosystems Using Satellite Imagery: An Example from SE Qatar

Jörg Beineke and Andreas Kagermeier

Abstract The article tries to show up an easy way to acquire satellite images (SPOT monochromatic/grayscale) for free, using the internet portal "Geoengine", maintained by the National Imagery and Mapping Agency (NIMA) of the United States. In a second step, these images (in this case sabkha-dune ecosystems in south-eastern Qatar) are loaded into a GIS (Geographical Information System)-program (ArcView® 3.2) and analysed for reflectance values, correlated with the values for known sabkha areas, that were taken during earlier field trips in Qatar.

The combination of satellite imagery and ground control points within areas of known geomorphological and geoecological characteristics produces an approximate map of the spatial extent and distribution of sabkha ecosystems in south-eastern Qatar.

1 Introduction

Systematic mapping of ecosystems using satellite imagery – especially for education purposes – is often hindered by the availability of adequate metadata and sufficient financial support to acquire the necessary scenes. Even though this is still true for most of the actual and high resolution data, there are few possibilities to acquire satellite images through the internet free of charge, except online-fees.

The online distribution of satellite images was limited by the data transfer rate for a long time. Up to the end of the 1990s, only enterprises, universities or other governmental institutions could afford fast internet access. In the meantime, the demand for high-speed internet connection has risen, so that a complete coverage system of fast internet access is available in most industrial countries.

Following the spread of fast and reliable internet access, some companies – like Microsoft®'s Terraserver – developed systems that allowed the user to view and print small parts of satellite images for private purposes. However, the user could not save whole images to disk or print large scenes, nor were the images ready to use in Geographical Information Systems or other professional digital imaging tools.

2 The Geoengine: Data Acquisition

One of the rare opportunities to acquire images at a larger scale is provided by the Geospatial Engine (http://geoengine.nima.mil) (Fig. 1). Managed by the National Imagery and Mapping Agency (NIMA), this internet portal offers satellite images, digital elevation data and vectorized basemaps for many parts of the world.

The data coverage includes the western central part of the United States, Europe/Eurasia excluding Portugal, Ireland and Scandinavia, major parts of the Arabian Peninsula including the Sinai and some scattered areas (e.g. Central America, Libya, Korea and South Eastern Asia). South America, major parts of Asia and Africa, as well as Australia and Antarctica are not covered (Fig. 2).

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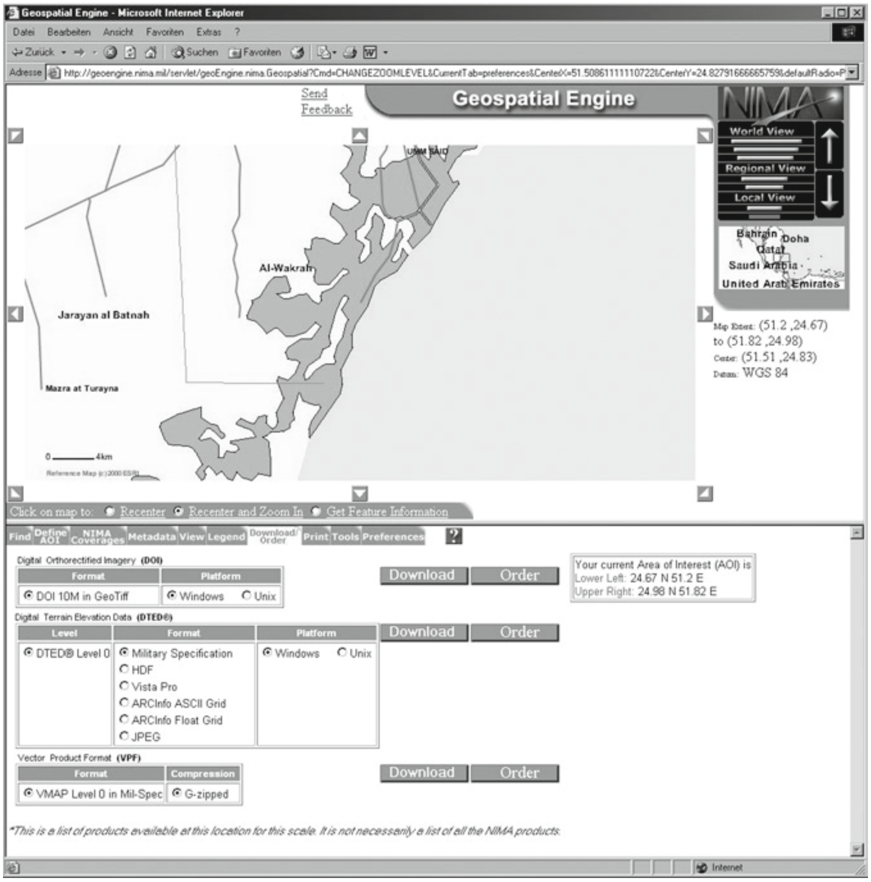

Fig. 1 The Geoengine website

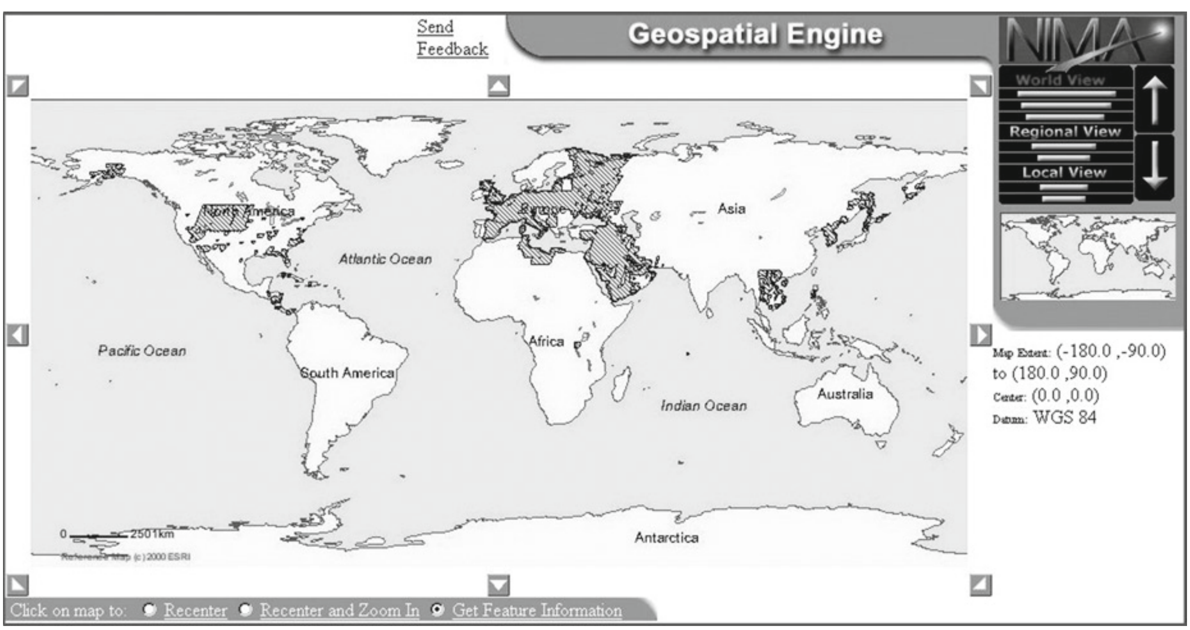

Fig. 2 Spatial coverage of DOI 10M satellite images

The offered satellite images were originally obtained from the SPOT Image Corporation under an unrestricted license. They are delivered as 10 m digital resolution orthorectified imagery (DOI-10M) and were acquired between 1992 and 1994. Depending upon operating system, the images are delivered in the georeferenced GeoTiff-format for Windows or UNIX and can be used in professional GIS-Software as well as in conventional low cost image processing systems without making full use of all advantages of the given format.

Data access is very simple. The website is divided into two frames: the upper frame contains a browsable map of the world, based on ESRI®'s mapserver technology. The window allows users to choose their area of interest via browsing and zooming on a "world" to "local view" level. The lower frame is subdivided into several categories regarding file format, data source, date and extend of data acquisition, download proceedings and data find, which allows users to search images via spatial coordinates.

When the reference map in the upper frame is centred on the appropriate area of interest, the data can be downloaded in the required format from the "download" button in the lower frame. If the user is not sure, whether the requested spatial extent is covered by the DOI-10M or needs a preview of the area, the "view" button gives a quick (low quality) overview of the availability and quality of the existing imagery. The initial download request is followed by the determination of the estimated download size, which has to be below 50 MB to reduce the server load of the Geoengine-Website. If the file-size is bigger than 50 MB, the user is asked to reduce the spatial extent and an optional part of the area is presented. To speed up the download time, the satellite imagery is automatically compressed to a ZIP-archive afterwards, which reduces the file-size to about 50% of the original image. This process takes several minutes (depending on server load), but the building progress is documented on the website every few seconds. When the build of the compressed file is finished, the server indicates the final size of the ZIP-archive and draws attention to the licence conditions that are implied in the use of these images. The download time of the compressed archive depends on the size of the original image, the type of the internet connection and the server load of the NIMA Geoengine. Given a high speed internet access, download time should be in the range of minutes with maximum transfer rates of about 400–500 KB per second. Users with slower access can use download managers to stabilize the data connection, because the Geoengine-Server supports the "resume"-function of most of these programs. After download is complete, the ZIP-file has to be decompressed using an unzip utility. The resulting GeoTiff-file can now be viewed or analysed in the corresponding software programs.

A similar procedure is necessary for the download of digital elevation data (DTED®), that is available in various specifications like ARCInfo ASCII or Float Grid, JPG or HDF etc. The Digital Terrain Elevation Data (DTED®) Level 0 was developed by the NIMA to provide the scientific community as well as the interested public with basic quantitative terrain data on a digital basis. In contrast to other high resolution elevation data that is intended for military purposes, the DTED® Level 0 data was deliberately "thinned" from the original NIMA DTED® Level 1 to a nominal resolution of 1 km per pixel (= 30 Arc Second Terrain Data). This specification is suitable for the modeling of whole regions or countries, but only of limited use on a local level. The diverse specifications of the data permits the use of the data in most GIS-systems and makes it accessible to the general public.

Apart from the described satellite imagery and digital terrain data, the Geoengine-website offers many other features that can be used in a geographical context, but are not listed here for clarity reasons. One example for additional data is the availability of vectorized basemaps (VMAP Level 0 in military specification) in the Vector Product Format that can be used in most GIS programs. The map preview in the upper frame is based on the VMAP Level 0 and gives a first impression of the quality of the downloadable files available on a CD-ROM sized basis.

3 Geographical Aspects of the Study Area

The study area is located in the southeastern part of Qatar, south of Umm Said Industrial City (Fig. 3). It is part of an approximately 60 km long and 30 km wide belt of active dunes, that are moving from NNW to SSE (Embabi and Ashour 1993). The up to 40 m high dunes are orientated perpendicular to the dominant "Shamal" winds from NNW and increase their density towards the SSE (Al-Sheeb 1998). In upwind direction the sand accumulations mainly consist of single barch-

Fig. 3 Location of the study area

ans, whereas they coalesce into complex/compound barchans and transverse dunes further downwind due to a higher sediment supply.

Most dunes – especially in the inland area – are underlain by Eocene limestones and dolomites of the Upper Damman Formation, that crops out in major parts of Qatar peninsula. Near the southeastern coastline, these Tertiary rock formations are overlain by an up to 30 m thick sequence of sabkha deposits, mainly composed of siliciclastic sands and minor parts of dolomite or other carbonate fragments (Shinn 1973). This approximately 500 km^2 large area of sabkha is partly covered by sandsheets and active sand dunes that are migrating over the damp surface towards the sea. In contrast to most coastal dunefields, where dunes are driven inland by onshore winds, the Umm Said Dunes are prograding offshore, thereby creating small pools between dune-arms that are frequently flooded during high tides.

The origin of the dunes in southeastern Qatar is still uncertain. Most researchers believe that the siliciclastic sands of the Umm Said dunefield are of external origin and were not generated on Qatar Peninsula (Shinn 1973; Ashour 1987). The mineralogy of the dune sands indicates to an origin on the Arabian mainland, that nowadays is separated from Qatar peninsula by the Gulf of Salwa. It is speculated that during late glacial lowstands of the Arabian Gulf, combined with the enhanced "Shamal"-Winds of this time period, dunes were piled up in the Eastern Province of Saudi Arabia and moved onwards in SSE direction towards the Gulf of Salwa (Shinn 1973). Sandbars (former transverse dunes today covered by coastal waters) which are detectable on satellite images of this area (Al-Hinai et al. 1987), point to the fact that the dunes moved over the then dried out Gulf and reached the northwestern coast of Qatar. As sea-level rose in the early Holocene, the dunes were cut off from the sediment source areas in the NW and were eroded by undersatured winds, thereby moving further to the SSE. Due to an almost flat territory, the sands passed the Eocene limestone formations of central Qatar without major disturbances and reached the southeastern coast, where huge amounts of sand were spilled into the low-lying coastal areas and the sea.

Interspersed with small portions of local carbonate grains, these siliciclastic sands were responsible for the development of the sabkha sequence, whose thickness is controlled by the sea-level as an absolute erosion basis. Given the limited to exhausted sand supply and steady winds from the NNW, the sand dunes of the Umm Said area will be gone in a matter of 1,000 years (Shinn 1973), thereby producing larger sabkha areas, that will be overformed by coastal processes after the depositions of quartz sands ends.

4 Methods

This study uses Esri's ArcView 3.2 GIS program to analyze the satellite images. Although most image processing programs are able to execute the basic manipulation processes of this study like grouping of color values, GIS-systems simplify and enlarge the possible modifications to a certain degree. To make full use of ArcView's image processing capabilities, it was necessary to load the Spatial Analyst 2.0 extension in addition to the core program.

After downloading the selected sample imagery of southeastern Qatar (Fig. 4) from the Geoengine website, the GeoTIFF satellite image was extracted from the ZIP-archive and loaded into ArcView using the

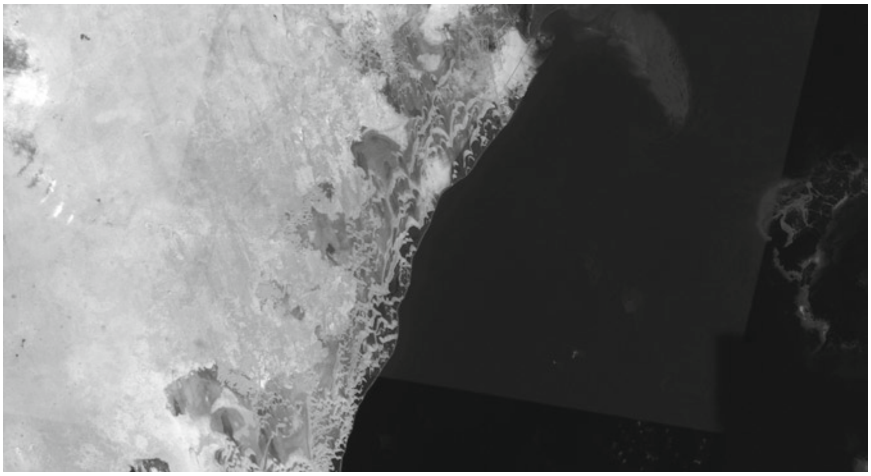

Fig. 4 Unchanged original satellite image from the Geoengine website. See Fig. 3 for scale (© CNES/SPOT Image 1992–1994)

TIFF 6.0 Image Support module. Due to its data format that contains spatial references, the image is directly placed in its correct geographical position. This feature makes it possible to avoid problems with the Geoengine's limitation of 50 MB per image because related files can be placed in the right position without further efforts, thereby facilitating the analysis of larger areas.

Afterwards, the GeoTiFF was converted into an ArcView Grid using the Spatial Analyst extension. Even though basic information like gray values can be directly derived from the original image, this transformation is necessary to classify single color values into distinct groups and to mark areas with special characteristics. By default, the image conversion produces nine distinct classes (equal distance) of color values and one field for missing data using a random color ramp. Although no intentional modifications of the image were made at this point, the combination of single values into groups results in the basic structuring of dominant landscape elements. This effect can be recognized extremely well in the northeast of the grid, where underwater features like longshore-drift of sediments are detectable, that are barely visible in the original satellite image (Fig. 5). Something similar applies to the sabkha areas that are marked by dark (original) values due to their high water content, whereas the sea is characterized by its unmistakable black value.

To refine this random classification, ground control points were set in the study area during an earlier field trip. These points were taken in areas that were visually identified in the field as sabkha areas using a handheld GPS (Garmin etrex, 5 m average resolution). They were converted into shapes (point theme) and loaded into the ArcView project. Comparison of the ground control points with the color values of the grid theme showed that all known sabkha areas have values in the range of 30–90 (based on the original color scheme of the gray scale image). If applied to the random grouping, setting values below 30 as sea and above 90 as other terrestrial environments, this classification produces an approximation of the sabkha areas in southeastern Qatar. To avoid the inclusion of marine elements like shallow waters in the "sabkha ecosystems group" (compare with Fig. 5), only pixels west of the coastline were included in the reclassification, whereas all pixels east of the coastline were classified as sea (Fig. 6).

Due to the simple processing measurements, this classification of the sabkha ecosystems in southeastern Qatar is far from perfect. As can be seen in the upper right corner of the random classification, reflectance values of sabkha areas with a high moisture content are very similar to those of very shallow waters. Sabkhas in a more continental setting are often covered by thin veneers of blown sand that falsify the readings as well. Taken all these things together, this method is not appropriate (and not intended) for high resolution interpretation of satellite images with the concentration on single elements, but for a quick low-cost overview of landscape elements with similar reflectance characteristics.

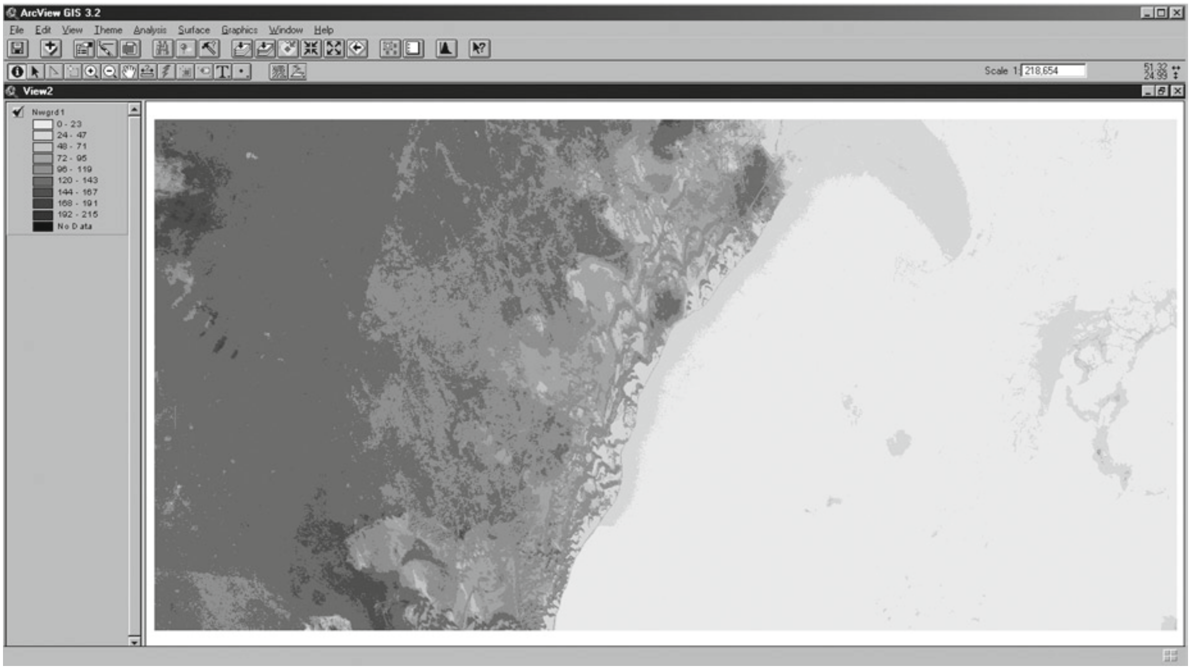

Fig. 5 Random classification after conversion into ArcView Grid. Please note the visibility of shallow water in the NE of the image that was barely recognizable in the original image

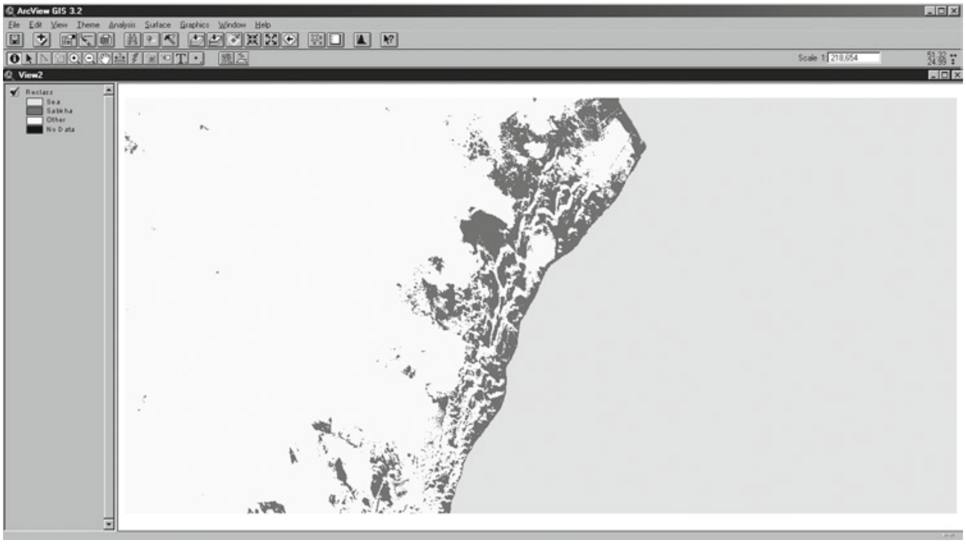

Fig. 6 Approximate map of sabkha ecosystems in southeastern Qatar after reclassification

5 Conclusion

The presented study shows that it is possible to acquire high quality satellite images for free, using the Geoengine internet portal. The images are not appropriate for the mapping and study of short-term processes like infrastructure planning, because of its pre-determined date, but are suitable for landscape classification purposes. This classification can be done by the use of GIS programs like ArcView without major efforts. The combination of image processing and comparison with reflectance values of known geoecological specification produces an approximate map of the existing landscape units.

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