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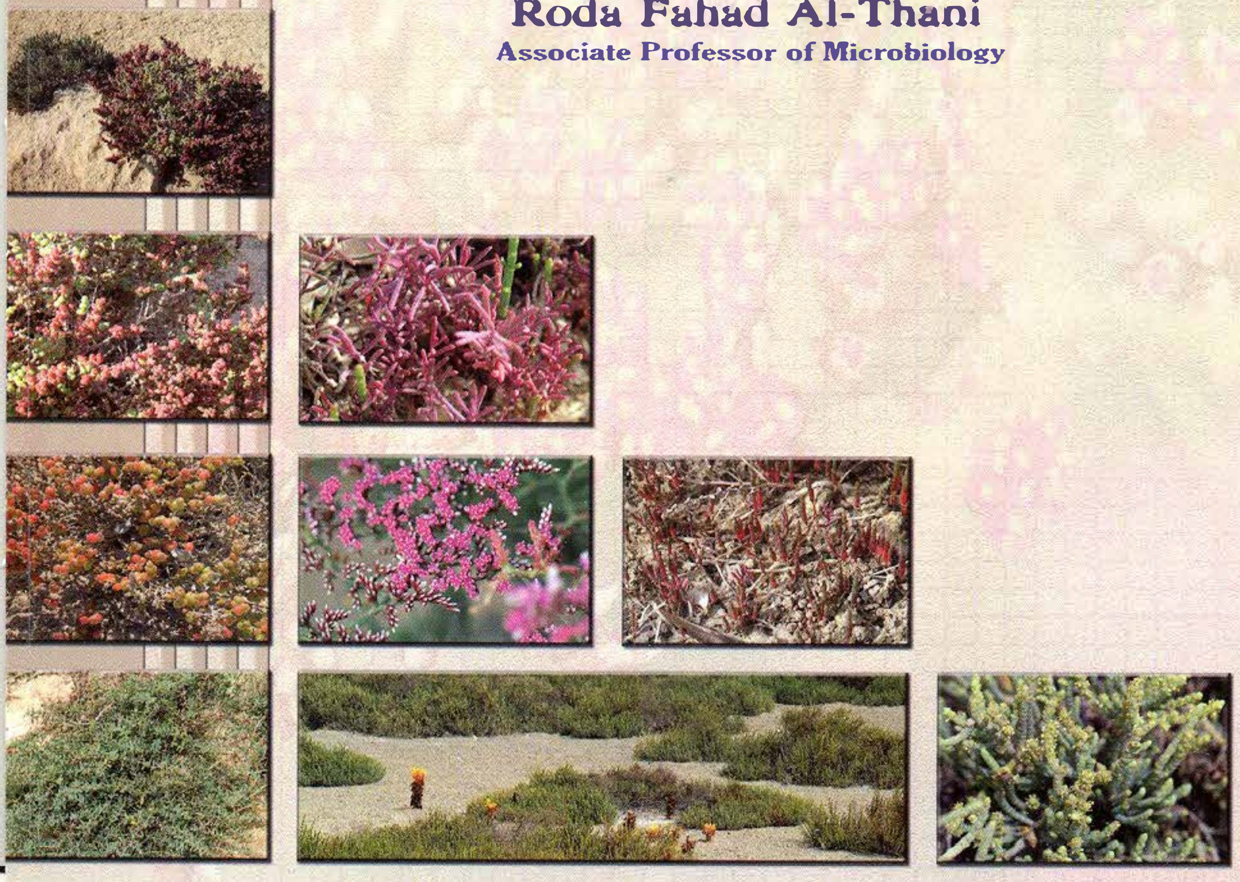

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Preface

In preparing this book, we intended to present the researcher and university students with a text that incorporates the theories and the research conducted in the study of halophytes in general and those in the Gulf States in particular. The book deals basically with those halophytic taxa being directly affected by the present activities incurring changes in their habitats in the Gulf region.

Whereas, there is voluminous literature on plants such as Spartinia and in recent years Arabidopsis, there is comparatively scanty information on the halophytes in the Gulf region. Equally, much of the more recent studies focus on laboratory studies with limited field investigations. This is expected with more recent advanced research directed towards the molecular level.

Though we drew heavily on literature relating to theories and scientific facts for confirmation or comparisons of results, we did carry out the detailed field investigations and laboratory studies. We believe that this will contribute to the basic knowledge on halophytes in the Gulf region.

The book is specially designed to provide a sound foundation of information on halophytes and is intended as a guide to further detailed studies focussing on saline habitats and ecosystems. Equally, it illustrates on how the physiology and biochemical features inherent in halophytic plants allow them to cope with salt tolerance.

The book comprises eight chapters, 17 tables, 7 figures and 79 plates. Chapters One and Two are introductory chapters that are intended to review the theories and scientific facts related to the biology of halophytes. Chapter Three details the methods followed in the study of the local halophytes. Chapters Four and Five cover the ecology and taxa of the selected locations. Aspects of halophyte anatomy are given in Chapter Seven and the general literature is listed in Chapter Eight.

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We were fortunate to receive technical support of members of ESCenter, the Central Laboratories and the Department of Biological Studies. Field photography was undertaken mainly by Ekhlas Abdel Bari. Plates with reference to Al Dhakhira Nature Park are courtesy of Khalid Al Bakri and close ups were done by Ahmed Abdel Aziz. We thank the following for their technical assistance: Mustafa Al Azhari, Ahmed Abdel Wahab [ESCenter]; Adil Mustafa[C.Labs]; Moneera Al Mesaifri, Fatima Al Haiky and Suad Helmi [Department of Biological Sciences].

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Executive Summary

Finding enough fresh water for survival has become one of the most urgent global problems and in many parts of the world fresh water resources are limited.

Many countries as in Africa and Asia possess many acres of land yet their population are in constant search for water. Some countries are surrounded by water but this water is saline and con neither support them or their much needed crop plants.
It is no wonder that much of the present day scientific research focuses on molecular biology, eco-physiology and agroforesty seeking species with salt-tolerance genes that might be genetically modified and utilized as crop plants grown on saline soils or soils irrigated with saline water.

The State of Qatar is a small country, with 4/5th of its land surrounded by sea water.

The flora of Qatar incorporates a number of halophytic species that are naturally salt-tolerant.

This contribution is a study on selected common halophytes and halo-xerophytes in the country and focuses on their morphology, microbiology, physiology and their chemistry at the micro- and macro-levels. The study includes detailed taxonomic descriptions of the selected taxa.

1 Theories and the Scientific Evidence

1.1 Introduction

About 70% of the earth's surface is covered with saline waters and 43 % of the land area is semi-arid or arid, half of which has highly saline soils (Epstein, 1976). Salinization of land is progressively increasing throughout the world and excessive salt concentration can transform fertile and productive lands into barren lands and often leading to habitat loss and reduction of biodiversity. Salinity is one of the world's oldest and most serious environmental problem, but it demands contemporary and innovative approaches (Epstein *et al.*, 1980) to deal with it.

The effects of salinity on plants have long attracted the interest of ecologists, physiologists, geneticists and molecular biologists. In fact, two main approaches have been suggested:

(1) Environmental manipulations: this can be achieved by implementation of large schemes of: (a) irrigation with high – quality water, (b) conservation of existing agricultural lands, (c) reclamation methods, (d) drainage systems, and (e) application of supplementary irrigation of lands of uncertain rainfall, including drip and sprinkling irrigations.

(2) Genetic manipulations: this offers the possibility of developing salt - tolerant crops which could improve agricultural production in saline regions and extend agriculture. Epstein (1983) suggested changes in the strategy of "Better soil for the crops we have" by a new one "Better crops for the soil we have.

Considerable attempts have been made to select and breed varieties of many crops for high yield under severe environmental conditions of salinity and drought (Norlyn, 1980; Winter *et al.*, 1988). Fortunately, genetic variability in sensitivity to these conditions already exists and is inherent in grains such as barley, wheat, rice and in vegetable species such as tomatoes. Much work has been carried out to determine the anatomical, physiological and biochemical features that are consistently associated with the resistance to water stress and salinity during the different stages of growth and development (Kelley *et al.*, 1979; Epstein *et al.*, 1980; Yeo and Flowers, 1986; Yasseen and Al- Maamari, 1995; Hasegawa *et al.*, 2000). Meanwhile, much attention is also focused on the wild and local cultivars in different countries and by the use of germplasm techniques, the characters of resistance to water stress and salinity will be transferred from them to cultivated cultivars. Progress has already been achieved in the isolation of osmotic stress – induced genes and their roles under water and salinity has been studied (Bray, 1993; Bohnert *et al.*, 1995; Hasegawa *et al.*, 2000). In fact, genetic engineering offers a powerful new tool for breeding plants with enhanced natural levels of stress resistance either by increasing the expression of endogenous genes or by introducing gene coding for a resistance mechanism from another species (Tarczynski *et al.*, 1993). Recent reports have described some recent developments and prospects in genetic analysis of salt stress resistance (Hasegawa *et al.*, 2000; Zhu, 2000) using *Arabidopsis* as a model system (Gong *et al.*, 2001).

There are three major hazards to plants living under saline habitats:

- water stress decreasing the potential of water absorption,
- specific ion effects usually associated with the excess of Na^+ and Cl^- uptake and,
- nutrient ion imbalance when the excess of Na^+ and Cl^- leads to considerable reduction in the uptake of essential elements such as potassium, calcium, magnesium, as well as, nitrates or phosphates or to impair the internal distribution of these ions.

Other physiological responses such as the decrease in CO_2 fixation and the inhibition of protein synthesis could be secondary effects of soil salinity.

1.2 Halophytes and Saline Habitats

All plants when exposed to saline environments must contend with three basic problems:

- maintaining favorable water relations,
- coping with potentially toxic ions, and,
- obtaining the required nutrient ions despite the predominance of other ions in the external media (Rains *et al.*, 1980).

It is commonly accepted that soil solutions with high salt concentrations causes growth retardation in most plants. Growth of common crop plants is affected by salinity when the electrical conductivity of the saturated soil extract is less than 2 $dS.m^{-1}$. Salt-tolerant crop plants may still grow at an electrical conductivity of the soil extract of 8 $dS.m^{-1}$. Some exceptionally salt-resistant plants may grow satisfactorily, even when the conductivity of soil solution is 10 $dS.m^{-1}$. Accordingly, plants have been classified as: (a) sensitive (susceptible), (b) moderate and (c) tolerant (resistant). Of the tolerant category, many wild plants have been recognized as halophytes which can survive and complete their life cycle in saline habitats, when the conductivity of the saturated soil extract exceeds these values at low osmotic potentials (Richards, 1954). In fact, the term halophyte literally means salt plant (hal ≡ salt, phyte ≡ plant), but the term is used specifically to denote those plants that can grow in the presence of high concentrations of Na salts: above 50 mM (Waisel, 1972). Because of marked differences in salt resistance found among halophytes, they have been subdivided into:

- Extreme euhalophytes (True halophytes)
- Moderate oligohalophytes.

True halophytes were defined as those plants that can thrive when watered with greater than 0.5% NaCl. According to Flowers *et al.* (1977), plants that are able to grow and complete their life cycle in the presence of high levels of salt (300 mM or more) are halophytes. In contrast to halophytes, plants that cannot grow in the presence of high concentrations of Na salts are called glycophytes (sweet plants), and most crop plants belong to the latter group.

Flowers *et al.* (1986) redefined halophytes as those plants growing where salinity exceeds 100 $molm^{-1}$. Therefore, halophytes can grow and complete their life cycles in saline environments and, do not only tolerate salt, but grow better in its presence than in its absence. These plants can tolerate concentrations of Na^+ and Cl^- that are high relative to other essential ions.

Halophytes must deal with interrelated stresses of excess ion content, including:

- decreased osmotic potential (i.e. more negative),
- toxicity of Na^+ and Cl^- ions to metabolic activities and membrane integrity,
- mineral stress due to ionic interference.

Species colonizing saline environments are from a variety of plant families that share certain morphological, anatomical and physiological characteristics that enable them in adaptation to their extreme habitats. However, there are five families, namely, the Chenopodiaceae, Gramineae, Compositae, Rosaceae and Rutaceae which include most of the known halophytes.

Though, many halophytes are able to grow perfectly normally in low or non-saline environments and are therefore, facultative halophytes, others, on the other hand, cannot grow in such conditions, and hence are obligate halophytes. Halophytes are often classified as: (1) Excretives, and (2) Succulents. Another classification recognizes: (1) Excluders, and (2) Includers, where the former has the ability to rid themselves from excess salt. Glandular cells in these plants are capable of secreting excess salts from plant organs. Some halophytes such as *Atriplex* species possess epidermal bladders with high concentrations of ions. Salt glands encountered in the saltgrass *Distichlis spicata* (family Poaceae) are in fact modified trichomes. Succulents, on the other hand, use the increase in their water content (stored within large vacuoles) to minimize salt toxicity.

It is quite possible that understanding how wild halophytes cope with high salinity may motivate geneticists and physiologists to develop new crops for saline areas as well as breeding salt – tolerant traits into existing crops.

1.3 Mechanisms of Salt Resistance

Some of the characteristics of halophytes that may give clues of the mechanisms involved in salt resistance include morphological, physiological and biochemical aspects. However, there are two main mechanisms of salt resistance in identified halophytes: avoidance and tolerance mechanisms.

1.3.1 Avoidance Mechanisms

Avoidance mechanisms involve structural features with physiological adaptations to minimize salt concentrations of the cells or physiological exclusion by root membranes. Plants can use one or more of the following mechanisms or methods to avoid the salt stress of their environment: (a) Exclusion, (b) Extrusion, and (c) Succulence (Dilution). Some halophytes have more than one mechanism to resist salt stress (Wu and Seliskar, 1998).

1.3.1.1 Exclusion mechanisms

Plants with salt avoidance due to exclusion must possess a low permeability to the salts such as sodium chloride even in the presence of relatively high salt concentrations. Thus, resistance to salinity according to the exclusion mechanism at organ's level, depends on the ability of the root to prevent potentially harmful ions from reaching the leaves. Roots may show impermeability to sodium salts since a large part of the Na^+ absorbed by their roots is retained in the roots accumulating in the vacuoles of the root cells, or roots may have the ability of back active transport of Na^+ to the outside.

Cl^-, on the other hand, is excluded by the low permeability of the root plasma membranes. In this case, the regulatory system must occur either, within the roots, (preventing the translocation of the salt) or, at the root surface where absorption is prevented. On the other hand, some plants of intermediate salt resistance may succeed in excluding the salt only from the shoot. These plants can use organic solutes to lower the solute potential and the water potential of the leaves.

There are some organic solutes that can be produced in the process of osmoregulation inside the plant such as proline, glycinebetaine, sorbitol and sucrose (Greenway and Munns, 1980; Morgan, 1984).

Recent studies have shown contradictory results on the ion accumulation in different parts of the halophytic plants. Roots of some halophytes, such as saltmarsh species, are capable of a high degree of selectivity in ion uptake. These species show a marked exclusion of Na^+ and Cl^- from the xylem sap with some evidence that the concentration of K^+ may be higher in the xylem sap (Adam, 1993). Thus, Na^+ is accumulated in the root, excluding it from the upper part of the shoot (Levitt, 1980). Na^+ and Cl^- ions seem to be excluded at the endodermis, while such a mechanism does not work in the case of K^+. Many halophytes retain more than 90% of the Na^+ in their shoots of which at least 80% is retained in the leaves. Moreover, there is evidence that a preferential transport of Na^+ over K^+ exists and most of the absorbed Na^+ is transported to the shoot. These results contrast with earlier evidence (Flowers *et al.*, 1977) for the retention of Na^+ in the roots of non-halophytes excluding it from the leaves.

Many halophytes absorb, rather than exclude, ions and accumulate them in the leaves. Ions are sequestered in the vacuoles of the leaf cells, where they can contribute to the cell osmotic potential without damaging the salt sensitive chloroplastic and cytosolic enzymes. In fact, the cellular basis of salt tolerance in halophytes depends upon the compartmentalization of ions necessary for osmoregulation in vacuoles and upon the osmotic adjustment of the cytoplasm by compatible solutes (Flowers, 1985).

1.3.1.2 Extrusion Mechanisms

Extrusion of salts, as an avoidance mechanism of salt resistance in many plants, is considered as an active process. However, it is difficult to distinguish between passive exclusion (as discussed above) and an active salt extrusion method. The latter process depends upon the ability to use metabolic energy to secrete ions such as sodium from the cells and to take up potassium. Many halophytes avoid an excessive accumulation in some of their tissues by mass excretion. Three main methods have been observed to achieve such excretion:

Shedding of older leaves: Accumulation of excess salts in older leaves may lead to the shedding of these leaves and their replacement by new leaves with low salt content (Ayoub, 1975; Albert, 1975). Older leaves in perennials are replaced by new leaves during the life span of the plant, and even in annuals, older parts may be shed during the course of the season (Adam, 1993). It has been suggested that the excessive accumulation of Na^+ and Cl^- ions in the leaves evoke leaf fall (Kostina, 1974; Maas and Nieman, 1978). Cl^- was found in large amounts in the dead leaves of wheat plants subjected to salt stress (Yasseen, 1983). Waisel (1972) considered such accumulation as a mechanism in controlling ion accumulation and thereby salt resistance in plants such as halophytes. Na^+, on the other hand, may be transported from leaves to roots and then to the rhizosphere (Adam, 1993).

Extrusion mechanism: In some halophytes, the mechanism is localized in salt glands. These glands consist of both collecting and excreting cells. Salt glands have been reported in many dicotyledonous families such as the Acanthaceae, Avicenniaceae, Combretaceae, Covolvulaceae, Frankeniaceae, Malvaceae, Myrsinaceae, Plumbaginaceae, Primulaceae, Tamaricaceae and Verbenaceae, and also in some monocotyledonous families such as the Gramineae. Salt glands are variable in structure, but, within a particular family these glands are similar and almost uniform. Salt glands excrete salt solutions to the outside of the leaves, and upon evaporation these form salt crystals which can be easily seen by the naked eye. In some plants these glands help in preventing the build up of salt in mature leaves. It has been found that the rates of salt excretion by salt glands vary considerably between these plants (Rozema *et al.*, 1981). Moreover, these salt glands show selectivity in the ionic concentration of the exudates. Halophytes, however, are different in how they maintain their salt concentration inside their tissues. Some halophytes showed an increase in salt gland density with increased salinity (Rozema *et al.*, 1977, 1981). In spite of all the efforts and intense study on the importance of salt glands, their detailed physiological roles are still imperfectly understood.

Possession of epidermal bladders: Several halophytes possess epidermal bladder cells or hairs with high ion concentrations. Leaves of these plants sequester excess electrolytes in the bladder cells, which release the salt back into the environment when they are ruptured. Halophytes having such structures accumulate Na^+, K^+ and Cl^- ions in the bladder cells and by active transport remove toxic ions from the active metabolic sites i.e mesophyll tissues, to the less active metabolic sites (bladder cells). These structures are vesiculated trichomes consisting of a stalk, of few cells and a balloon–like tip, in which ions accumulate during the life time of the plant. Unlike salt glands there is no secretion of salt solution from the salt hairs. When the bladder reaches its maximum volume, it may die either by shedding or bursting (Adam, 1993). This mechanism of avoidance by secretion is normally found in some species of *Atriplex*. In fact, leaves of *Atriplex* have a silvery reflectance due to the presence of this layer of trichomes which prevent ultra violet light from reaching the internal leaf tissues. These structures play a significant role in retaining much Cl^-, which is secreted against a concentration gradient (Levitt, 1980). Some other genera such as *Aeluropus* may have such structures, and the excretion process is highly selective for some ions such as Na^+ and K^+ (Pollack and Waisel, 1970).

1.3.1.3 Succulence (Dilution) Mechanism

Succulence or fleshiness occurs in many halophytic species and has been considered as a mechanism of avoidance by dilution. A clear definition of succulence is lacking which leads to some confusion in the comparison of various studies (Adam, 1993).

Jennings (1976) proposed that the water content or fresh weight per unit area is the most appropriate measures of succulence. Moreover, the degree of succulence in halophytes varies with external salinity. Succulence is an expression of the increased size of the individual cell, which can be considered as a consequence of an increase in ion uptake. Different ions may produce various degrees of succulence (Adam, 1993). In fact, some plants may have the ability to dilute the high ion concentrations either by growth and/or by increasing succulence. By growth, water is absorbed in sufficient amounts to prevent the increase in ion concentration. This mechanism may be found in halophytes and in glycophytes as well. Dilution by growth was found in many mangrove species such as *Rhizophora mucronata* and the saltmarsh composite *Iva oraria*. Cl^- and Na^+ concentrations in these plants remain almost constant for most of the plant's life - time. Water content (on a % fresh weight basis) also remains reasonably constant (Levitt, 1980; Adam, 1993).

The thickening of leaf blade due to salinity can be explained by the growth of mesophyll cells. Longstreth and Nobel (1979) noticed an increase in the thickness of mesophyll tissues of some crops and some halophytes, as a result of salinity. They concluded that this was due to an increase in the length of the palisade cells as well as in the number of spongy cells layers. The increase in the length of mesophyll cells due to salinity has been confirmed by measuring the number of lobes of mesophyll cells of Mexican wheat exposed to salt stress (Chonan, 1965; Longstreth and Nobel, 1979; Yasseen, 1983).

1.4 Tolerance Mechanisms

Salt tolerance mechanisms involve physiological and biochemical adaptations for maintaining protoplasmic viability as cells accumulate electrolytes. However, there are four secondary mechanisms for salt tolerance: osmoregulation, tolerance of nutrient deficiency, tolerance of primary indirect strain and tolerance of primary direct strain.

1.4.1 Osmoregulation

In higher plants, adaptation to saline conditions is associated with metabolic adjustments leading to the accumulation of inorganic ions such as Na^+, Cl^-, K^+, Ca^{2+}, etc., as well as low–molecular weight organic solutes such as proline, glycinebetaine, sugars and organic acids (Yasseen, 1992). In fact, if it is impossible for plants to avoid the osmotic stress of salinity, plants may lose turgor in severe salt stress. Therefore, salt tolerance under conditions of tissue dehydration can either be by **dehydration avoidance**, or by **dehydration tolerance.**

Dehydration avoidance permits rehydration of plant tissues by increasing the solute accumulation. This increase must be adequate enough to lower the osmotic potential (making it more negative) by a process of osmoreguation or osmotic adjustment.

Osmoregulation in plant tissues can be achieved either by the active uptake of salt ions and/or, by the synthesis of organic solutes, amino acids, sugars, proline, glycinebetaine and other organic compounds (Briens and Larher, 1982; Hanson and Hitz, 1982; Flowers, 1985; Gorham *et al.*, 1985; Paleg *et al.*, 1985 ; Alhadi *et al.*, 1997, 1999; Hasegawa *et al.*, 2000). Earlier, Levitt (1980) concluded that if osmoregualtion was due solely to the accumulation of organic solutes, it must be linked to stress avoidance by exclusion and extrusion of the salt. On the other hand, if it was due to the accumulation of salts, it must be linked to tolerance of the primary toxicity of the accumulated salt ions. It is now evident that osmoregulation by the accumulation of ions is apparently the main tolerance mechanism in higher plant halophytes.

Dehydration tolerance, on the other hand permits survival with the loss of turgor but maintains the cell in a non–growing state (Levitt, 1980).

1.4.2 Tolerance of nutrient deficiency

Any deleterious effects from excessive concentrations of sodium chloride in the root medium on plant growth could be due to specific effects of these ions. An excess of ions may be toxic to various plant physiological processes or may cause nutritional imbalance in plant tissues. Many reports have shown that the major elements, N, P, K, Ca and Mg increased or decreased in plant tissues as a result of salinity in the root medium (Yasseen, 1983). Some plants maintain the absorption of essential elements under osmotic stress conditions. There is evidence of increasing potassium absorption in some NaCl–resistant plants which avoid nutrient deficiency (Levitt, 1980). Equally, certain barley cultivars showed increased nitrogen and potassium in their leaves under osmotic stress conditions (Yasseen and Al–Maamari, 1995). Moreover, salt – tolerant cyanobacteria showed increased nitrogen and decreased carbohydrate with an increase in the NaCl supply, whereas, the less salt tolerant species showed the opposite relation (Schiewer, 1974).

1.4.3 Tolerance of primary indirect strains

The indirect strains include accumulation of toxins such as amines, growth inhibition and changing enzyme activity. Tolerance of indirect strains could be due to the ability of plants to metabolize toxins, maintaining the potential growth by osmoregulation and enzyme tolerance. According to Levitt (1980), toxic amines do not appear to be toxic to halophytes. There are a number of reports in which the effects of salt stress on the enzyme activities in various kinds of plants such as glycophytes and halophytes have been compared.

In general, studies have shown that the enzymes from halophytes and glycophytes have similar sensitivity to salt stress. Enzymes extracted from salt tolerant species are just as sensitive to the presence of NaCl as enzymes from salt-sensitive glycophytes (Pollard and Wyn Jones, 1979). Moreover, salt stress inhibits the activities of some enzymes and stimulates others in particular hydrolases. The resistance of halophytes to salts is therefore not a consequence of salt-resistant metabolic machinery but instead, other mechanisms that should be considered.

1.4.4 Tolerance of primary direct strain

This mechanism includes the tolerance of salt shock which is related to the properties of the plasma membranes. Alterations of both the structure (Pearce and Beckett, 1987) and functions (Hubac *et al.*, 1989) of the plasma membrane is a common response to water stress or salinity (Navari–Izzo *et al.*, 1988a) as well as, heavy metal toxicity (Meharg, 1993). Among the metabolic responses of plasma membranes to water stress and salinity, the metabolism of membrane lipids such as glycolipids and phospholipids, as well as the membrane transport system of ions are generally affected (Erdei *et al.*, 1980; Navari–Izzo *et al.*, 1988a, 1988b; Hubac *et al.*, 1989; Hajibagheri *et al.*, 1989; Jurjees *et al.*, 1996; Hasegawa *et al.*, 2000).

The difference between halophytes and glycophytes, seems to reside in the tonoplast. In halophytes, the tonoplast may be relatively less permeable than in glycophytes. It must also contain the ionic pumps and an expending energy so as to maintain the appropriate ion gradients (Adam, 1993). *Spartina patens* and *Mesembryanthemum crystallium* provide a good example of the role of plasma membrane H^+-ATPase in the regulation of ion movement across the plasma membrane for salt tolerance. It has been found that the activity of plasma membrane H^+-ATPase increased many times when the callus of these plants was grown on a media containing high concentrations of NaCl (Wu and Seliskar, 1998; Vera–Estrella *et al.*, 1999). This could explain the great ability of halophytes to accumulate high ion concentrations in their tissues. Moreover, activated oxygen (superoxide anion) may be formed in chloroplastic thylakoids under conditions of osmotic stress, which can damage the photosynthetic apparatus as well as the protein embedded in the membrane. Therefore, tolerance of free radicals of oxygen in stress – tolerant plants can be acquired at both levels: the membrane level and the level of the whole plant (Sgherri *et al.*, 1996). Some reports have shown changes in the properties of the structure of chloroplasts in leaf cells subjected to high salinity levels.

Disturbances of the outer membrane, twisting of the lamellae and swelling of stroma and the disturbed orientation and shrinkage of the lamellar system were among the abnormal characteristics found in mesophyll cells of many crops grown in high salinities (Lapina and Popov, 1970; Gausman *et al.*, 1972; Yasseen, 1983, 1992).

Some morphological and anatomical characteristics exist in halophytes to maintain water status as well as high ion level in order to cope with saline habitats (Strogonov, 1964; Levitt, 1980; Adam, 1993; Pessarakli, 1994).

1.5 Anatomy of Succulence

Succulence is due to the presence of mucilage or water storage tissue in the inner structure of a plant organ whether this organ is an underground organ such as rhizomes, corms, tubers, roots, etc. or part of the shoot system whether it is a stem, a whole leaf, or a petiole.

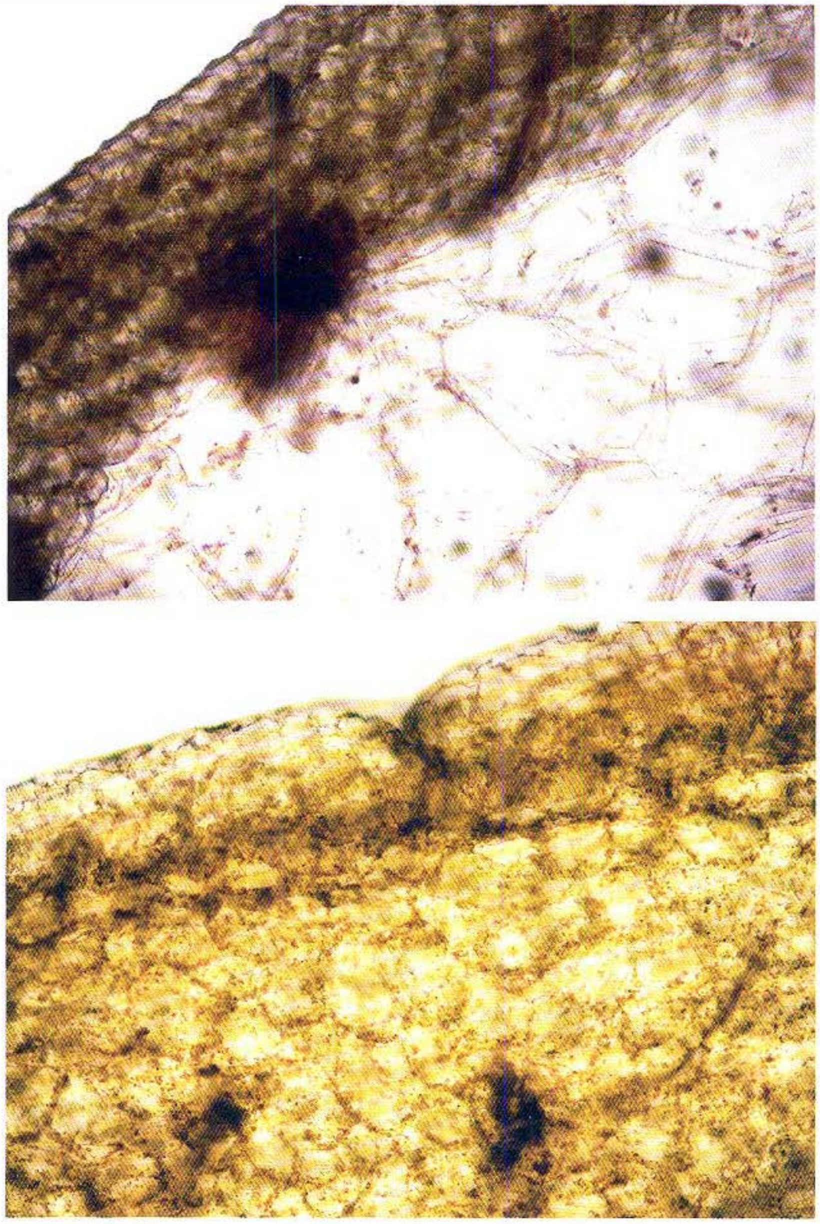
In arid conditions these storage cells are protected by their position in the plant organ. Commonly, a thick cuticle (wax layer of one or more layers) covers the outer epidermal cells.

In *Salsola kali* leaf, below the epidermis exists a compact layer of palisade parenchryma surrounding the leaf whereas the central region, almost x 4 of the width of the outer region, is filled with large water storage cells. In *Anabasis salsa*, the cortex is made up of two distinct layers: a parenchymatous layer followed by a photosynthetic layer of chlorenchyma appearing as a palisade layer. The whole central region is filled with large water cells with an intermingle of vascular tissue. In *Salicornia fruticosa*, the stem is composed of an outer region of palisade tissue whereas the central region is composed of a central vascular stele surrounded by a wide region of water storage parenchyma.

In *Aloe* leaf, below the thick cuticle of 2 layers is situated the wide chlorenchyma (photosynthetic) layer. Further, in the deeper layers lies the vascular bundle. These are surrounded by cells storing aloene (a mucilaginous substance) towards the upper surface. Below the vascular bundles are located large water storage cells (Plate 1).

1.6 Aspects of Aridity and Salinity in the Flora of Qatar

According to Meigs' (1953) classification, the State of Qatar belongs to the warm, semi-deserts of the world.



Pate 1. T.S. *Aloe* leaf (above) and T.S. *Bryophylum* leaf (below) showing water storage cells.

Being a peninsula in the Gulf, it is more than 4/5th surrounded by sea water. Add to that, the country is lowlands with salt pans on the coastline and a stony desert forming almost 85% of its land area.

The only source of fresh water is the scanty, erratic, seasonal, winter rains with a recorded annual average precipitation of 82 mm and high temperatures increase evaporation adding to the elements of dessication.

Beside the marine ecosystems, the different landshapes and soil types form a number of ecosystems. Most prominent is the 'Hamad' desert [Hezoom] with stony sandy soils, the sabkhas or salt flats with saline soils, the rawdat depressions with fine comparatively rich soil supporting trees and shrubs and the sandy coastal and inland dumes (Plates 2-4). Because of the harshness of the land and the dominance of poor and/or saline soils, the main elements in the flora of Qatar are ephemerals and seasonal herbs and grasses. Perennials are mostly of tussock forming grasses, low shrubs, few trees and a number of halophytic and xerohalophytic taxa. The halophytes are a common feature of vegetated sabkhas.

Plate 2a. The 'Hamad' or stony desert.

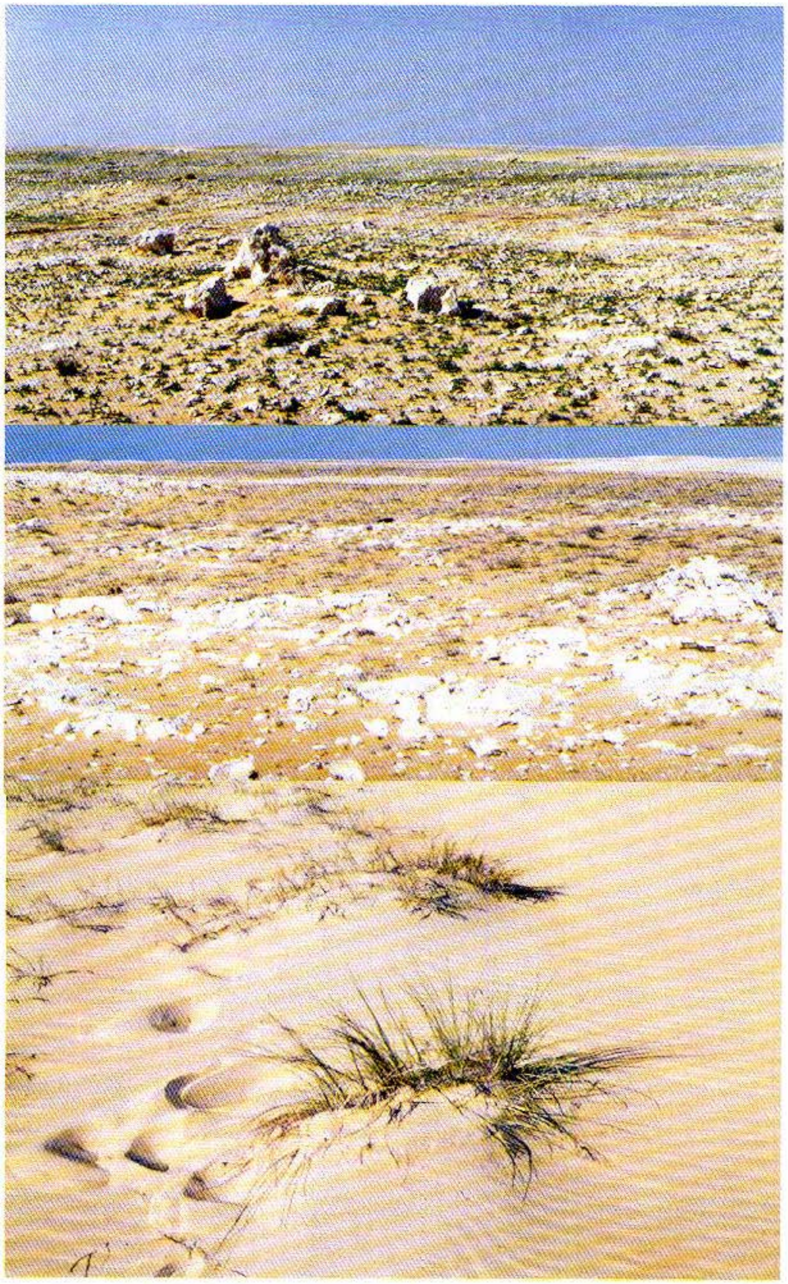


Plate 2b. Typical hezoom (above and middle); a sandy dune (below).

Plate 3a. General view of a densety vegetated sabkha at Ras Al Matbakh with *Avicennia marina* at the back ground.

Plate 3b. General view of a vegetated sabkhas at Ras Al Matbakh with dense growth of *Halocnemum strobilaceum*.

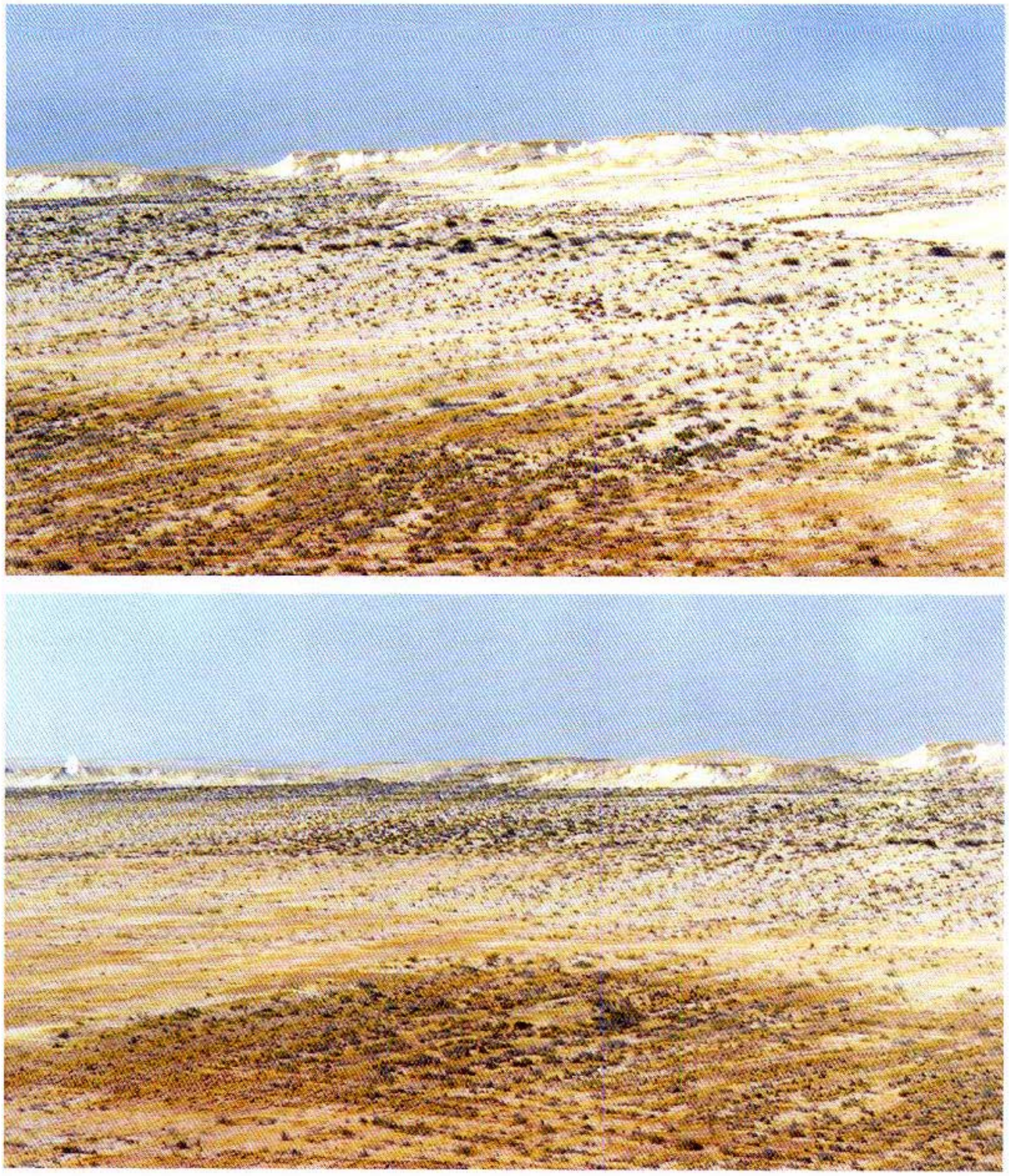


Plate 4. Dukhan sabkha. Note stressed growth of *Zygophyllum qatarense* and *Aeluropus lagopoides* due to excess salinity.

2 Aspects of Molecular Biology of Halophytes

2.1 Molecular Basis of Salt Resistance in Plants

Since 1980 there has been serious efforts by many scientists to persue genetic manipulation to improve the salt resistance of crop plants. Genetic approaches to develop crop varieties that can resist environmental stresses include the work of Epstein (1983) and Krizek (1983). Some attempts proved fruitful in determining some features associated with salt resistance in plants, focusing on wild plants, local cultivars and some cultivated crops such as barley, wheat, rice and tomatoes (Norlyn, 1980; Winter *et al*, 1988; Yasseen and Al-Omary, 1994; Yasseen and Al-Maamari, 1995; Hasegawa *et al*., 2000; Zhu, J-K, 2000; Hawkesford and Buchner, 2001 Xiong and Zhu, 2001; Flowers, 2004). Success in achieving salt resistant plants would make it possible to utilize saline soils and saline waters. This could increase the yield of crop plants and would be one possible solution of the mounting problems concerning world food demand (Tal, 1985). Genetic manipulation of crops can be achieved by one of the following methods:

Conventional breeding methods (selection and hybridization) which include backcrossing, progeny testing and pure line selection.

Tissue culture technique which is now a well established technique that may be used for either the selection of lines, or for physiological studies.

The selected lines are presumed to be genetic variants that upon regeneration, the whole plant will express the selected characteristics and provide genetic material for plant improvement programs. Selection of lines, however, has not been successful in developing plants with high tolerance to salinity. Many physiological and metabolic activities found in the whole plant such as photosynthesis and transpiration, etc., can not be portrayed when working with cultured cells as test material. This is the major disadvantage, since the life of the whole plant is more complex than individual cells. It was assumed that using cultured cells to study cellular responses to osmotic stress (water and salt) will yield information which will be applicable to our understanding of the response of the whole plant to these stresses. However, this technique has been successful in physiological studies particularly in studying the signaling and biochemical pathways involved in salt recognition and responses.

Modern technologies which include:

(a) Somatic cell genetics - a discipline that may be broadly defined as any genetic or physiological investigation involving cultured cells [gene transfer; gene regulation; cell selection for genetic variants; control of development and regulation of metabolism].

(b) Recombinant DNA techniques which involve several methods of introducing genes into plants including [infecting plant cells with plasmids as vectors carrying the desired gene; shooting microscopic pellets containing the gene directly into the cell].

In fact genetic engineering techniques are opening the door to a revolution in the biological sciences. This may be achived by offering a powerful new tool for breeding plants with enhanced natural levels of stress resistance, either by increasing the expression of endogenous genes or, by introducing genes coding for a resistance mechanism from another species.

2.2 Genetics of Salt Resistance

An understanding of the genetics of salt resistance of wild plants is essential for any efficient program aiming towards the improvement of salt resistance of various plants and/or using germplasm techniques to transfer the resistance to salinity from them to other plants including crops. Plants differ in their resistance to salinity because of differences in phenological, morphological, physiological, biochemical and molecular adaptive mechanisms. Much work has been carried out to determine which anatomical, physiological and biochemical features are consistently associated with the resistance to salt stress (Yasseen, 1983; Yassen and Al-Omary, 1994; Yasseen and Al-Maamari, 1995; Hawkesford and Buchner, 2001). Anatomical, physiological, and biochemical features that are consistently associated with resistance to drought and salinity can be determined and there are numerous documents reporting on the changes in cellular activities in higher plants in response to salinity and drought.

Physiological investigations can provide experimental material for comparative studies. Examples of such variables include growth processes including cell division and cell expansion, and accumulation of solutes such as proline, glycinebetaine and K. The outcome of these studies can be used by molecular biologists to determine the features and markers for salt resistance in plants. The main approach that has been adopted was the identification of cellular processes and genes, whose activities and expressions respectively, are regulated by salt stress. Genetic differences in salt resistance offer a unique opportunity to compare changes in metabolic processes in plants under salt stress that might be involved in the process of successful adaptation in the saline environment. A more detailed knowledge of the physiological and biochemical processes may be important for the application of specific strategies in genetic improvement programs of cultivated crops. The gene pools of crops can be enriched by the selection of mutants in cell culture, conventional mutagenesis or by the introduction of genes from wild species.

Halophytes offer unique genetic pools to be used for gene technology programs. Genes of salt tolerance can be determined and transferred from such plants to crops. Thus, much work should be done to adopt the main strategies of adaptation of halophytes to saline environments like those in the State of Qatar and the Gulf States. Such efforts are essential to determine the traits that are associated with salt tolerance. Moreover, genes responsible for the salt resistance should be isolated and transferred from halophytes and xerophytes to some crop plants to increase their ability to cope with salt stress. However, salt tolerance at the cellular level involves multiple genes that influence plasma membrane and the tonoplast transport and compartmentation of ions, particularly Na^+ and K^+, as well as other mechanisms such as the synthesis of compatible osmolytes and the sensing and signaling pathways associated with ionic and osmotic stresses (Warne *et al.*, 1999).

2.2.1 Genetic analysis of plant salt tolerance

Salt tolerance is a complex trait and is polygenic in nature involving responses to cellular osmotic and ionic stresses and their consequent secondary stresses. Both contribute to the difficulties in breeding salt tolerant crop varieties. In fact, the lack of understanding the different mechanisms of salt resistance and a lack of reliable screening tests such as physiological and molecular markers, increase difficulties to development of new cultivars that are able to cope with saline environments. However, in the last decade there has been some reports and reviews which focused on the genetic analysis of salt tolerance of selected plants such *Arabidopsis* (Hasegawa *et al.*, 2000; Zhu, 2000;

Xiong and Zhu, 2001). There is optimism when the outcome of the huge efforts of the researches of molecular genetics of salt tolerance of crop plants start fruiting (Flowers, 2004).

2.2.2 Salt tolerance genes and proteins

A large number of genes were induced and accumulated in response to salinity treatment. Some of these genes and proteins include genes associated with Ion Homeostasis: [H^+-ATPase transporters, and Na^+/H^+ Antiporters and Na^+/K^+ selectivity (Orcutt and Nilsen, 2000)]; Equally those genes involved in solute accumulation [the biosynthesis of many solutes such as proline and glycinebetaine are up-regulated by salt stress], genes associated with water homeostasis [Aquaporines], dehydrins, osmotin and, genes associated with the switch to CAM photosynthesis.

There have been some efforts in the last fifteen years to transfer salt tolerant genes from some wild plants or halophytes to some cultivated and crop plants. However, these faced difficulties. The main difficulties facing scientists in their desperate efforts to develop salt resistant plants using the molecular approaches comprise a number of facts.

Breeding efforts have thus been hampered by the lack of understanding of salt resistance mechanisms as well as a lack of field and laboratory screening test such as physiological and molecular markers. In fact, there is no single screening technique to differentiate salt resistant cultivars from salt sensitive ones. Plant scientists know little about the mechanisms that enable salt tolerant plants to survive, succeed and reproduce in saline environments that inhibit the salt sensitive ones.

Plant species differ in their reaction to drought and salinity during various stages of their life cycle. Resistance to salt stress can be classed in two main stages: a pre-flowering stage and a post-flowering stage. Resistance at both stages of development has not been observed in many crops. Some plant species build up a degree of tolerance to osmotic stress. Therefore, there is no particular stage in the crop life cycle that can be exploited for a reliable screening test, since the sensitivity to osmotic stress changed dramatically during the different stages of crop growth and development. Unfortunately, much of the successful work with breeding programmes and screening techniques done in the past was based on a particular stage of the crop life cycle (germination stage).

The complexity and polygenic nature of salt stress resistance are important factors contributing to the difficulties in elucidating salt resistance mechanisms and breeding salt –tolerant crop varieties:

- Physiological and metabolic changes are considered consequences of salt stress damage. It has been difficult to ascertain which of the physiological and metabolic changes are required for salt tolerance (Table 1).
- Despite the correlation of expression of numerous genes with salt stress, many salt – responsive genes do not contribute to resistance and their induction reflects salt damage. In fact, only a few genes are known to be essential for salt tolerance.
- The molecular approach has identified genes or gene products based on their expression. Many genes, however, that are important for salt resistance may not be induced by salt stress.
- If the halophytic and salt tolerant non-halophytic mechanisms are the main goal in genetic engineering techniques, the pools of germplasm available for certain crop species may not be suitable for developing such tolerant crops. For example halophytes translocate much salt into their vegetative parts, including their leaves. This is a disadvantage for all leafy vegetables crops and forage in which foliage is the part consumed by man or his animals.

2.3 The prospective and future work

Improvement of salt resistance of crop plants and increasing crop production horizontally as well as vertically is the main challenge facing mankind. FAO estimates that an additional 200 million hectares of new cropland will be needed over the next 30 years just to feed the burgeoning populations of the tropics and subtropics. Adopting the genetic approach to improve the salt resistance of crop plants has been the subject of many studies in the last fifteen years.

However, such efforts need solid ground of financial support because funding of agricultural research especially in the underdeveloped countries, and the patterns of food distribution coupled with political – economic policies are additional problems facing the vast majority of the population living in our planet. However, the current state of plant biotechnology in the Third World countries suggests finance as a major constraint to the development of new technologies and their applications traits to improve salt resistance of crops.

Table 1. Various Cellular activities in response to salinity.

Cellular activities	References
Decline in protein synthesis	Singh *et al.*, 1985; Hurkman and Tanaka, 1987
Overproduction of some proteins	Claes *et al.*, 1990; Borkird *et al.*, 1991; Wechsberg *et al.*, 1994; Cellier *et al.*, 1998; Liu *et al.*, 1998)
Decline in K content	Rains, 1972; Greenway and Munns, 1980; Yasseen, 1983
Increase in Na content	Watad *et al.*, 1983; Yasseen, 1983; Serrano and Gaxiola, 1994
Increase in organic solutes such as proline, glycinebetaine, etc.	Greenway and Munns, 1980; Yancey, 1982; Yasseen, 1983; McCue and Hanson, 1990; Delauney and Verma, 1993
Changes in growth processes	Sawalha, 1981; Yasseen, 1983; Yasseen *et al.*,1987; Yasseen and Al – Omary, 1994; Yasseen and al- Maamari, 1995, Al-Hadi *et al*, 1999
Changes in cell wall composition and structure	Jones and Turner, 1978; Longstreth and Nobel, 1979; Sakurai *et al.* 1987a, 1987b; Iraki *et al.*, 1989, Rascio *et al.*, 1990; Zwiazek, 1991; Neves–Piestum and Bernstein, 2001
Changes in structure and composition of plasma membranes	Pearce and Beckett, 1987; Navari – Izzo *et al.*, 1988 a, b; Hubac *et al.*, 1989; Mehrag, 1993; Navari – Izzo *et al.*, 1993; Olsson *et al.*, 1996; Sgherri *et al.*, 1996
Decline in photosynthesis	Seemann and Critchley, 1985; Locy *et al.* 1996

The Arabian Gulf States with their comparatively superior financial status may be leaders in the technological research in salinity stresses. Being coastal, they have soil salinity and halophytes, the two basic elements for such research. Halophytes and xerophytes living in these areas can be considered as good resources of salt resistant traits from which genes can be transferred to crop plants. Their main revenue is from the oil industry and agricultural development has its difficulties in the nature of the soil and the limited resource of fresh water.

3 Materials and Methods

3.1 The Study Locations

This study focused on selected plant species that are known to be widely distributed and cover a wide spectrum of species representing nearly all types of distinct habitats in the State of Qatar.

Many locations around Doha and other parts of the State of Qatar were studied. Samples of plants and soils were collected from these locations for the different types of analysis needed. The locations studied comprise 11 different areas which include inland and coastal areas (Figure 2). For each location, the main physical features of the land were recorded in the field and its geographical position was recorded. In addition to the eleven locations studied, the largest area studied, a sabkha near the University of Qatar was demolished during the survey period. The vegetation cover was removed and the area has been leveled with transported earth from elsewhere and apparently prepared for some sort of development. This was therefore excluded from the study. The field surveys commenced on September 2001 and continued throughout the growth seasons. The dates of the field surveys are given in Table 2. The details of the studied locations are outlined in Table 3.

3.2 The Studied Taxa

The species studied include the mangrove species *Avicennia marina*, a plant living in sea waters, 11 chenopods, 2 composites, 2 grasses and one representative of each of the families: Boraginaceae, Capparidaceae, Menispermaceae, Plumbaginaceae, Resedaceae, Rhamnaceae and Zygophyllaceae.

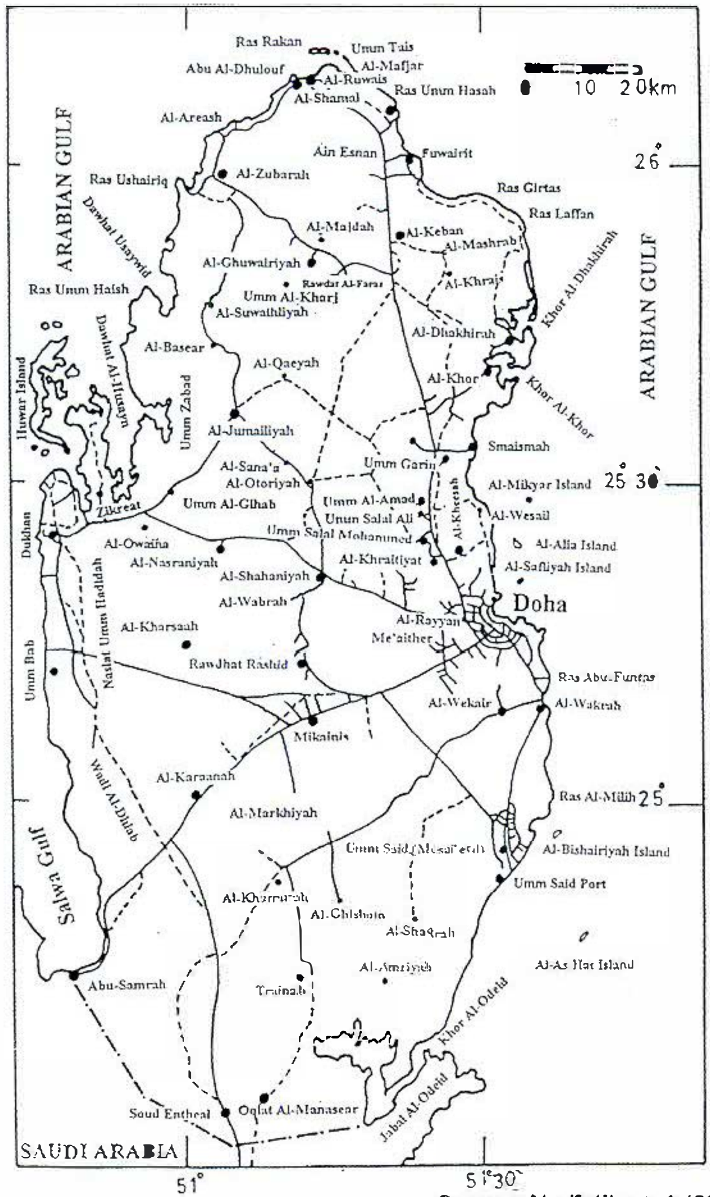
A total of 23 species were covered in this study. These fall in 20 genera belonging to 11 families of flowering plants (10 dicotyledons and 1 monocot.).

Table 2. Field surveys - Dates and locations.

Month	Dates and Locations
	2001
September	19 (A8), 23 (A1), 26 (A8), 30 (A1)
October	3 (A9), 10 (A6), 14 (A6), 17 (A1), 21 (A8), 24 (A8), 28 (A1)
November	11 (A7)
December	25 (A5)
	2002
January	5 (A2, A4)
February / March	--
April	18 (A10)
May	14 (A3, A4)

Table 3. Description of the studied locations.

Area code	Location	Coastal / Inland	Main features
A1	Seashore opposite Doha Golf Club	Coastal	Sandy beach
A2	Ras Al-Matbakh	Coastal	Salt flat with compact sandy soil
A3	Al-Khor	Coastal	Sabkha
A4	Al-Dhakhira	Coastal	Sabkha
A5	East of the Doha Golf Club	Inland	Undulating sandy mounds
A6	University of Qatar grounds	Inland	Salt flat with *Aeluropus* community
A7	The road to the University	Inland	sandy – clay and stony ground
A8	The main road to Khalifa Stadium	Inland	Sandy – sandy loam
A9	The main road to the Industrial Area	Inland	Loamy – sand, sandy clay loam
A10	Al – Shamal Highway, vicinity of Al – Khor town (Rawdat)	Inland	Rawdat with fine sandy loam clay soil
A11	Al-Shamal highway, vicinity of Al-Khor town (roadside)	Inland	Hard stony ground



Source: Abulfatih *et al.* (2001).

Figure 1. The studied locations: Towns.

Figure 2. A detailed view of Doha City, State of Qatar.

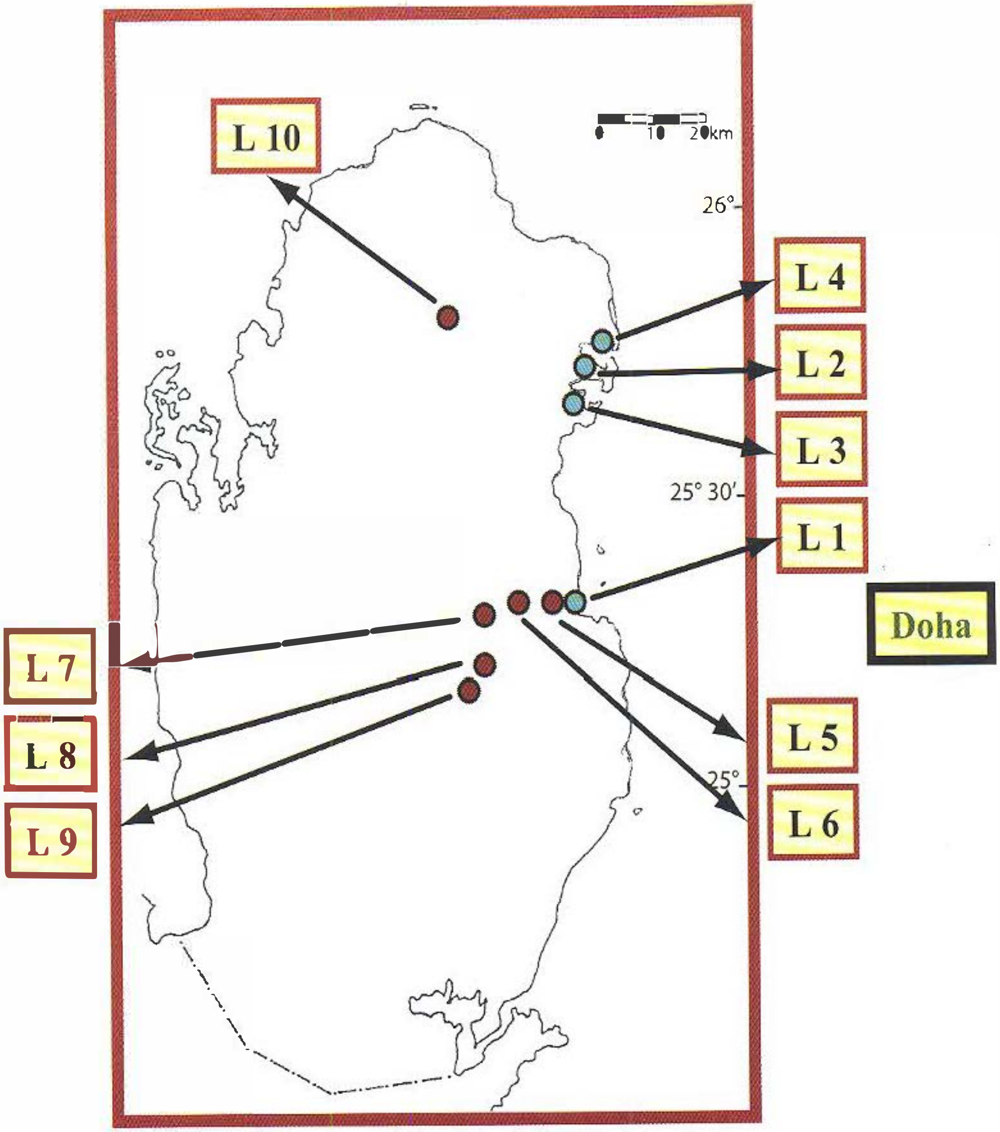


Figure 3. The studied locations in Doha City [L=location].

The genera of these families were selected to represent 7 categories beside the mangrove swamp:

- True halophytes living in saline depressions by the coastline
- Species common in disturbed areas throughout Doha City
- Typical xerophytes of stony grounds
- Typical xerophytes of sandy soils
- Representatives of a rawdat formation
- Representatives of a low inland depressions
- Representatives of a mangrove forest.

The field surveys commenced on September 2001 and continued up to the end of the growth season (Table 4). Numerous field trips were undertaken to the 11 selected locations for a period of 3 years ending in May 2004. Moreover, further field obserbations continued up to June 2005.

3.3 Sampling plant material

Plant material from each location was collected (Table 4) for the various studies proposed:

- Morphological and anatomical studies
- Physiological studies
- Chemical studies

3.3.1 For the morphological studies

Fresh plant material was collected in polythene bags and for anatomical study fresh material was collected in preservative (1:3 acetic acid : alcohol). The plants were photographed in the field and later in the laboratory.

3.3.2 For physiological analyses (chemical content study):

Vegetative parts were collected from different plants of the same species in large brown paper bags. For each sample, all relevant data was noted. Upon return from the field, the material was cleaned from dirt and soil and sorted. Samples of roots, leaves and top shoots were sorted and enclosed in previously weighed medium-sized brown paper bags.

Table 4. Sampling dates of the studied plant species, their families and there area codes.

Family	Species	The Studied Area	Date of Sampling
Avicenniaceae	*Avicennia marina*	A2	5-1-2002
Boraginaceae	*Heliotropium bacciferum*	A6	14-10-2001
		A7	11-11-2001
Capparaceae	*Capparis spinosa*	A10	18-4-2002
Chenopodiaceae	*Anabasis setifera*	A3	14-5, 2002
		A6	10-10-2001
		A10	18-4-2002
	Arthrocnemum macrostachyum	A1	17-10,28-10, -2001
		A2	5-1-2002
		A4	5-1-2002
	Halocnemum strobilaceum	A1	23-9, 28-10, 2001
		A2	5-1-2002
		A4	5-1-2002
	Halopeplis perfoliata	A1	23-9, 28-10, 2001
		A2	5-1-2002
		A5	25-12-2001
		A10	18-4-2002
	Haloxylon salicornicum	A8	19-9, 21-10, 2001
	Salsola imbricata	A4	14-5-2002
	Salsola soda	A4	14-5-2002
	Salicornia europaea	A1	30-9, 17-10, 2001
	Seidlitzia rosmarinus	A3	14-5-2002
	Suaeda aegyptiaca	A8	19-9, 21-10, 2001
	Suaeda vermiculata	A1	30-9-2001
		A2	5-1-2002
		A4	5-1-2002
		A9	3-10-2001
Compositae	*Pulicaria crispa*	A6	14-10-2001
	Pulicaria gnaphalodes	A6	10-10-2001
Gramineae	*Aleuropus lagopoides*	A8	26-9, 24-10, 2001
	Sporobolus spicatus	A9	3-10-2001
Menispermaceae	*Cocculus pendulus*	A10	18-4-2002
Plumbaginaceae	*Limonium axillare*	A2	5-1-2002
		A4	5-1-2002
		A5	25-12-2001
Resedaceae	*Ochradenus baccatus*	A7	11-11-2001
Rhamnanaceae	*Ziziplus nummularia*	A10	18-4-2002
Zygophyllaceae	*Zygophyllum qatarense*	A2	5-1-2002
		A5	25-12-2001
		A8	26-9, 24-10, 2001

Each bag carried the following information:

- A(No.) denoting the area of collection
- R(1,2,& 3) for the 3 replicates
- Date of collection
- Part of the plant collected (leaves, shoot or root)
- Scientific name of the plant species.

The material was secured by the triple folding of the top of the brown bags. The fresh weight of material in each bag was determined. These bags were then placed in an oven at 80°C for three days and the bags were reweighed. The procedure was repeated till a constant weight was obtained for each bag. The difference between the fresh and dry weights of the plant material gave the absolute water content.

The dried material was then ground to a fine powder using a Retsch sample mill (Germany, SK – 100 Standard Gußeisen) grinder. The poudered samples were placed in vials with secure covers and labeled. These were sent to the Environmental Studies Center (ESC, ex SARC) for the initial digestion of the samples and were later sent to the Central Laboratory at Qatar University where their chemical content was analysed using an atomic absorption spectrophotometer (Model Analyst 700, Perkin Elmer).

Powdered samples of plant parts were also used in the determination of soluble sugars and the total soluble nitrogen. Some samples of the shoots were kept in an ice bath during the sampling work at the field. Immediately upon arrival to the laboratory, these samples (stored in the ice bath) were used for the determination of proline, photosynthetic pigments and water content.

Except for two annuals (*Salicornia europaea* and *Salsola soda*), all the remaining species are perennials of which 3 are trees, 2 are shrubs, 2 are grasses, and the remaining 14 are undershrubs of varying habit and morphological features (Table 5).

Table 5. The plant species studied, their main features and their distribution.

No.	Species	Family	Life-form	Xerophyte / Halophyte	Succulence	Area Code
1	*Aeluropus lagopoides*	Gramineae	Grass	Xerophyte	*	8
2	*Anabasis setifera*	Chenopodiaceae	Low undershrub	Xerophyte	Leaves	3,6, 11
3	*Arthrocnemum macrostachyum*	Chenopodiaceae	Low circular undershrub	Halophyte	Shoots	1,2, 4
4	*Avicennia marina*	Avicenniaceae	Mangrove tree	Mangrove	*	2
5	*Capparis spinosa*	Capparidaceae	Prostrate shrub	Xerophyte	*	10
6	*Cocculus pendulus*	Menispermaceae	Woody liane	Xerophyte	*	10
7	*Halocnemum strobilaceum*	Chenopodiaceae	Low circular under-shrub	Halophyte	Shoots	1,2, 4
8	*Halopeplis perfoliata*	Chenopodiaceae	Undershrub	Halophyte	Shoots	1,2, 5
9	*Haloxylon salicornicum*	Chenopodiaceae	Undershrub	Xerophyte	Stem	11
10	*Heliotropium bacciferum*	Boraginaceae	Undershrub	Xerophyte	*	6, 7
11	*Limonium axillare*	Plumbaginaceae	Undershrub	Halophyte	Leaves	2,4, 5
12	*Ochradenus baccatus*	Resedaceae	Shrub	Xerophyte	*	7
13	*Pulicaria crispa*	Compositae	Suffrutescent	Xerophyte	*	6
14	*Pulicaria gnaphalodes*	Compositae	Suffrutescent	Xerophyte	*	6
15	*Salsola imbricata*	Chenopodiaceae	Undershrub	Xerophyte	*	8
16	*Salsola soda*	Chenopodiaceae	Herb	Halophyte	Whole plant	4
17	*Salicornia europaea*	Chenopodiaceae	Herb	Halophyte	Whole plant	4
18	*Seidlitzia rosmarinus*	Chenopodiaceae	Undershrub	Halophyte	Shoots	1
19	*Sporopolus spicatus*	Chenopodiaceae	Grass	Xerophyte	*	9
20	*Suaeda aegyptiaca*	Chenopodiaceae	Undershrub	Halophyte / Xerophyte	Shoots/ Leaves	3,8
21	*Suaeda vermiculata*	Chenopodiaceae	Undershrub	Halophyte	Shoots / Leaves	1,2,8,9
22	*Ziziphus nummularia*	Rhamnaceae	Tree	Xerophyte	*	10
23	*Zygophyllum qatarense*	Zygophyllaceae	Undershrub	Xerophyte	Shoots / Leaves	2,5,8

*** Not succulent**

3.4 Measurements

Measurements were carried out on 7 parameters. These included:

3.4.1 Water content

Fresh weight (FW) of samples were determined, and the dry weight (DW) was obtained after keeping these samples in an oven at 80°C for 3 to 4 days. The percentage of the water content of the plant materials was calculated.

3.4.2 Photosynthetic pigments

Chlorophyll a and b as well as the carotenoids were determined according to the method described by Metzner *et al.* (1965) and used by Alhadi *et al.* (1999).

Half a gram of fresh plant material from leaves or young shoots was homogenized in 85 % aqueous acetone for 5 minutes. After centrifugation, the supernatant layer, which contained the pigments, was made up to 25 ml with 85 % acetone. The extinction co-efficient was measured against a blank of 85 % aqueous acetone at three-wave length 645, 664 and 445 nm using a u. v.spectrophotometer (Jenway model 6405 UV/VIS). The concentrations of the pigments were determined using the following equations:

Chlorophyll a (microgram / ml) $= 10.3 * E_{664} - 0.918 * E_{645}$

Chlorophyll b (microgram / ml) $= 19.7 * E_{645} - 3.87 * E_{664}$

Carotenoids (microgram / ml) $= 4.3 * E_{452} - (0.0265 \text{ Chl. A} + 0.426 \text{ Chl. B})$

The fractions and their totals were calculated as $\mu g\ g^{-1}$ fresh weight of plant material.

3.4.3 Proline determination

Proline was determined according to the method described by Bates *et al.* (1973).

Half a gram of fresh plant material (leaves or young shoots) was homogenized in 10 ml of 3 % aqueous sulfosalicylic acid. The homogenate was filtered through Whatman filter paper No. 2. Two ml of the filtrate was reacted with 2ml of acid – ninhydrin and 2 ml of glacial acetic acid in a test tube for one hour at 100 °C. The reaction was terminated in an ice bath. The reaction mixture was extracted with 4 ml toluene, mixed vigorously for 15 – 20 seconds. The chromophore containing toluene was aspirated from the aqueous phase and warmed to room temperature. The absorbance was measured at 520 nm using toluene as a blank. The proline concentration was determined from a standard curve, and the calculations on a fresh weight basis (Figure 4).

3.4.4 Soluble sugar estimation

100 mg of oven-dried plant material was extracted with 5 ml of borate buffer (28.63 g. boric acid + 29.8 g. KCl + 3.5 g. NAOH in a liter of hot distilled water), left for 24 hrs, then centrifuged and filtered. The filtrate was used for the determination of the direct reducing value (DRV) [which includes all free monosaccharides], and the total reducing value (TV) which includes all soluble sugars (Alhadi *et al.*, 1999).

- **DRV estimation:** Nelson's method was adopted for the estimation of DRV (Nelson, 1944), which was described by Bell (1955) and has since been used by many authors (Alhadi *et al.*, 1997; 1999). One ml of borate extract is added to Nelson's alkaline copper reagent and well shaken. The tube was placed in a boiling water bath for 20 minutes. The tube was then placed in a beaker of cold water. After cooling the tube, 1 ml of arsenomolybdate reagent was added and the mixture was well shaken for at least a 5 minutes period to dissolve the precipitated Cu_2O and to reduce the arsenomolybdate. After the Cu_2O has dissolved, 7 ml of distilled water were added and mixed thoroughly. The absorbance was read at 540 nm by a spectrophotometer.

- **TRV estimation:** 1 ml of borate extract was added to 0.5 ml invertase (1%), then incubated at 37 °C for half an hour. After the sucrose has been digested by the enzyme invertase, TRV was estimated by the same procedure described above.

- Sucrose was estimated (in terms of glucose) by the differences between the value obtained from the TRV and that of DRV multiplied by a factor of 0.95. [Source = (TRV-DRV) X 0.95]

  DRV and TRV were determined as glucose from the prepared standard curve (Figure5).

3.4.5 Determination of total soluble nitrogen (TSN)

1 ml of borate extract was digested using 50 % sulphuric acid followed by 2-3 drops or more of 35% perchloric acid for complete oxidation (till the whole mixture turned colourless). The mixture was made up to a 5 ml volume.

- **Neutralization method:** In a separate test tube, 1 ml of digested borate extract was added to one drop of phenolphthalein. A drop of NaOH (3N) was added till a pink colour appeared, this was followed by drops of 0.5 m H_2SO_4 till the colour became colourless. The number of drops of NaOH and H_2SO_4 must be counted. The remaining sample of 4 ml digested extract was taken (with the same amount of drops of NaOH and H_2SO_4 for neutralization) for the estimation of ammonia.

- **Estimation of free ammonia:** This method was described and followed by Fawcett and Scott (1960); Chaney and Marbach (1962) and Alhadi *et al.* (1999). To 1 ml of neutralized extract was added one ml of 5 % phenol containing 25 mg sodium nitroprusside followed by one ml of 3 % sodium hypochlorite dissolved in 0.63 N sodium hydroxide. The mixture was incubated at 37 °C for 15 minutes and made up to 25 ml. Then the absorbance was read by the spectrophotometer at 630 nm. TSN was determined as ammonia according to the standard curve prepared for this purpose (Figure 6).

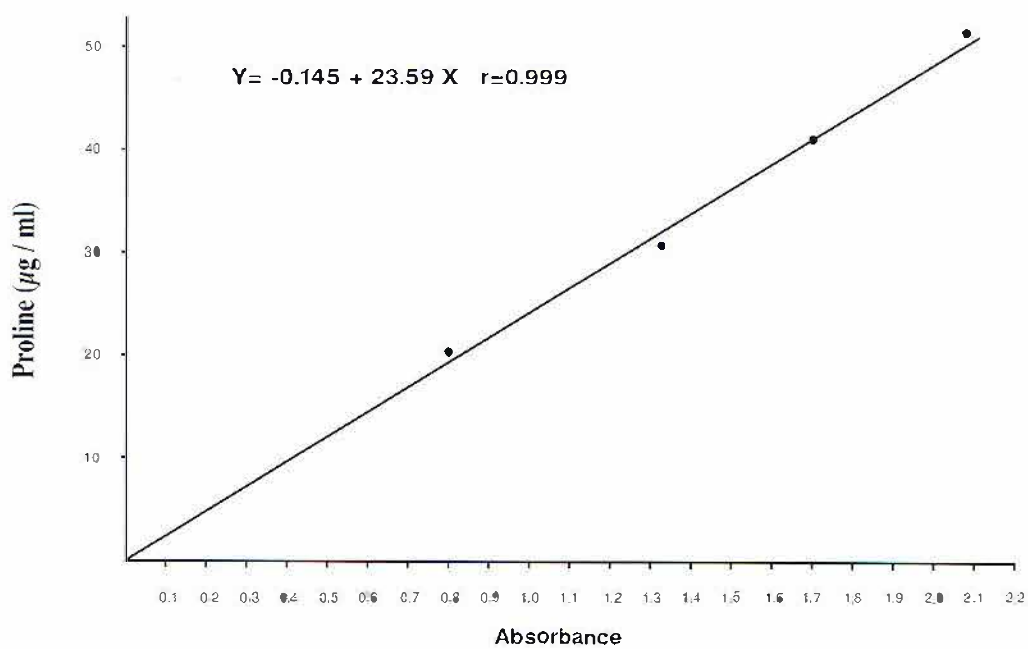


Figure 4. The standard curve used in the determination of proline.

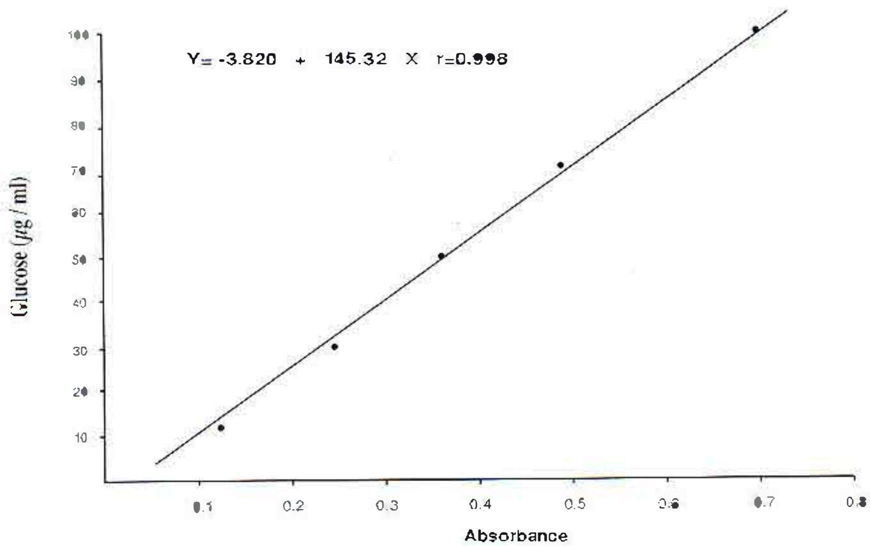


Figure 5. The standard curve used in the determination of glucose.

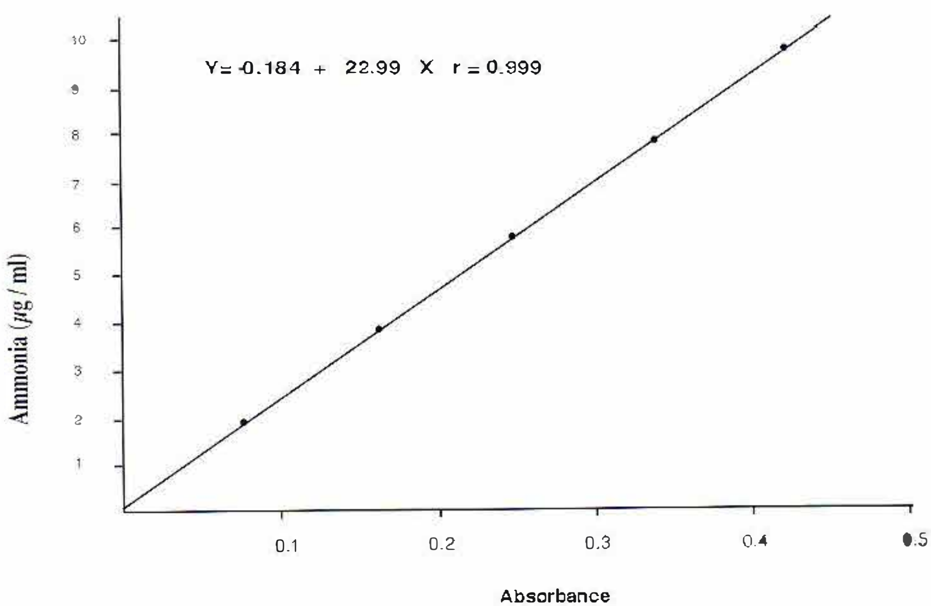


Figure 6. The standard curve used in the determination of ammonia (for total soluble nitrogen).

3.4.6 Ionic composition.

Wet digestion of the ground oven dry samples with concentrated nitric acid was used to prepare solutions for the determination of Na, K, Ca, Mg and some trace elements including Fe, Cu, Zn, Co, Ni, Cr and Cd. One gram of dried and ground plant material was digested in 10 ml concentrated nitric acid for 24 hours. The acid was then removed by volatilization at 180° – 200° C and the soluble constituents were dissolved in 25 ml of deionized water. Filteration followed to remove the non-soluble material.

The atomic absorption spectrophotometer (Model Analyst 700, Perkin Elmer) was used to determine all cations. The instrument was adjusted by fixing the appropriate wave length, slit width, run time and delay time. Calibration of the instrument was done using 7 concentrations giving linear relationship, and a known standard was tested. The samples were placed in the auto-sampler with their codes using standard procedure for measurements. The system was checked after running 10 samples.

3.4.7 Chloride determination

The following steps were followed to determine chloride in plant materials (roots and shoots) according to the method described by Chapman and Pratt (1961).

The plant material was placed in an oven at 80° C for 3 to 4 days. The material was then ground using a suitable mill. One g of the ground sample was placed in a conical flask containing 20 ml distilled water. The mixture was well shaken for 1 hour using an electric shaker. The mixtures were filtered and the filtrate was kept for further analysis.

The pH of the filtrate was adjusted to pH 6-7 using diluted acetic acid (20%).

5 drops of potassium chromate (1%) were then added and the solution was titrated with silver nitrate 0.025 or 0.1 until the appearance of the permanent red colour of silver chromate. The concentration of chloride was then calculated in accordance with the equation: N. ($AgNO_3$) x Volume of $AgNO_3$ = N. (Cl^-) x Volume of the filtrate.

3.5 Soil Sampling and Analysis

Soil samples were collected from the root zone of the selected plants (below the surface) on the same date of the material sampling and transported to the laboratory in large strong clear polythene bags. These were properly labeled. The samples were analyzed at the Laboratory of Ecological Studies of the Department of Biological Sciences, Qatar University.

The main features of the samples were noted in the field. In the laboratory, the soil samples were placed in previously weighed tin containers and weighed. The soil study included:

- Water content
- % gravel
- Soil texture
- pH (soil extract)
- Ece
- Minerals
- field capacity (%) – range of the samples collected.

The samples were then subjected to oven drying at 105° C for 3 days and then reweighed. The procedure was repeated till a constant weight was obtained. The soil extract was obtained from a saturated soil solution and the electric conductivity was obtained using a Conductivity Meter (Jenway, 4200).

3.5.1 Water content

Soil water content was determined by taking a known weight of soil samples collected from the studied areas and left in a drying oven at 105° C for 24 hrs. The weight was rechecked and drying continued till the weight became stable. The water content was calculated as a percentage.

3.5.2 Field capacity

Field capacity is the moisture content in the soil after draining the gravitational water (free water). This can be done by leaving water – saturated soil for two to three days till the free water is drained under the influence of gravity. The following method was used to obtain the soils' field capacity.

Samples of soil were sieved with a sieve mesh 2 – mm in diameter. 100 g. of air dried soil were weighed and placed in perforated metal cans on filter paper. These cans were placed in a container with some water (1 – 3 cm depth). The cans were left to imbibe water for 24 hrs.

Cans with saturated soils were removed and left for 2 to 3 days to drain the free water. These were weighed and the percentage moisture content was determined which represents the field capacity of the soil.

3.5.3 Physical and chemical properties of soil

The percentages of sand, silt and clay in the soil samples were determined by the Hydrometer method. Other physical properties of the soil were equally determined: Sat. Ext. Ece (dSm^{-1}) by using a Conductivity Meter (Jenway, 4200), pH by using pH Meter (Jenway, 3305), field capacity as (%) and the water content of the soil as described (Tables 4 and 5 in Chapter 4).

The concentration of major elements and trace elements (K^+, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, Fe, Cu, Zn, Co, Ni, Cr and Cd) in the water soil extracts were determined and the results are shown in Tables 7 and 8 (Chapter 4). Cations were determined using an Atomic Absorption Spectrophotometer. Chloride was determined according to Chapman and Pratt (1961) titration method using silver nitrate.

4 General Features and Ecology of the Studied Locations

4.1 Introduction

One most important reason for studying sites, their plant cover and the life they support, is the fast rate at which many habitats are disappearing specifically all over Doha as well as other areas in the State of Qatar.

The present day, higher activities in land development and the upgrading of the infrastructure with establishment of roads and highways, is not coupled by any studies on habitat destruction, fragmentation or disturbance. There is fear that before knowledge is obtained on what is in existence in the nature of flora and fauna, their natural habitats will be lost without redemption. A good example of this is well demonstrated by what was the first choice of a study area in this project. This is a location near the University of Qatar, due east, along the new road to Al-Khor. The new road to Al-Khor crosses an earlier well established vegetated sabkha with part of it due east of the road and a section now inside Qatar University grounds and a sabkha beyond.

Development on the West Bay Lake and its surrounding areas took over most of the eastern part of the sabkha. During the last few years, the remaining area which was rich in flora and fauna, was finally lost to a development scheme in progress. The sabkha was flattened and filled with tons of transported earth (Plates 5 and 8).

Unfortunately, the location within area 8 has since been converted to residential blocks and the location east of the Doha Golf Club is now under construction. The remaining areas vary between vegetated coastline sabkhas to dry arid areas.

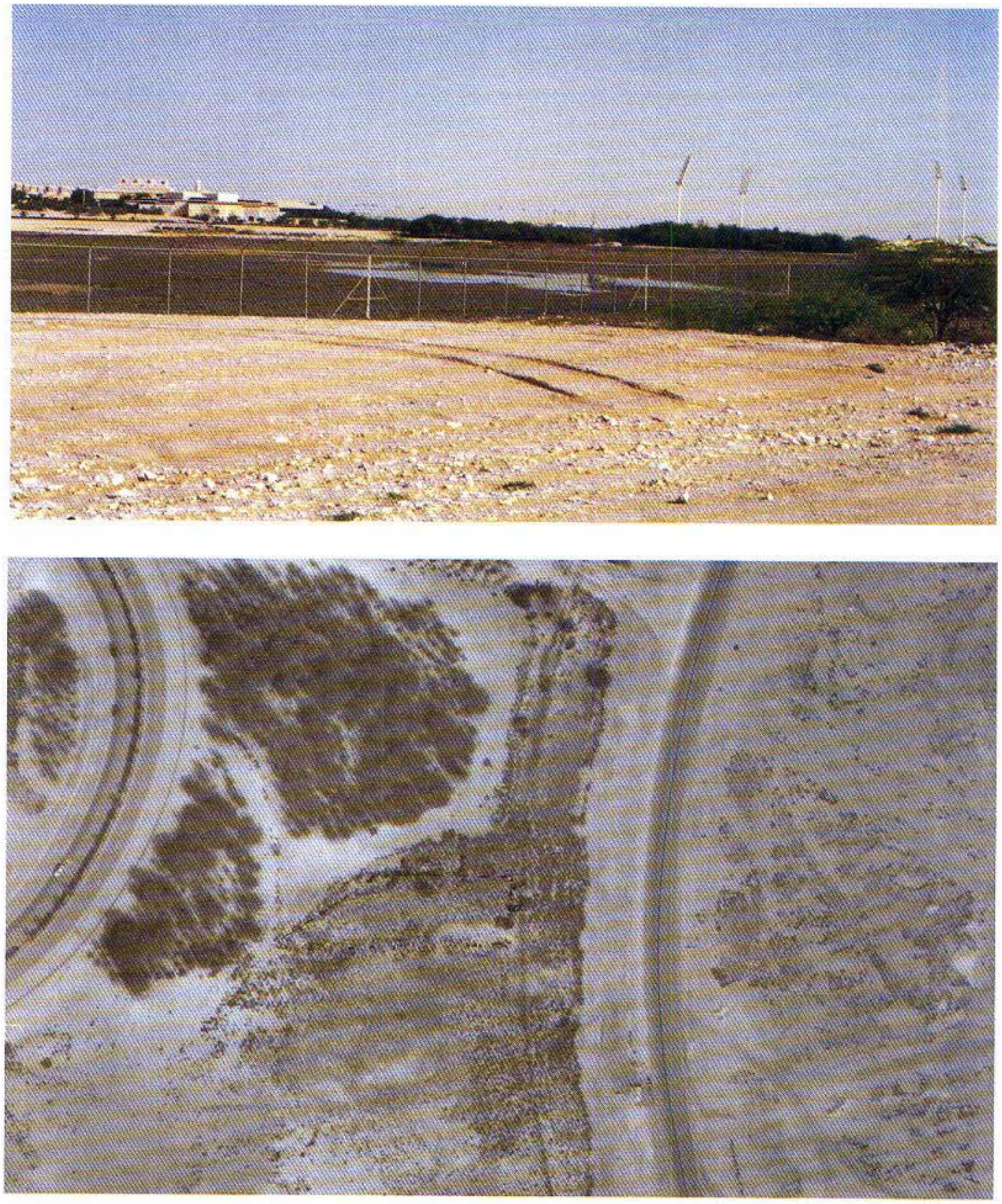


Plate 5. View of the sabkha within the premises of the University of Qatar (above) and an aerial view of the same sabkha (bisected by the road to Al Khor) below.

Source : QNG, Doha.

Plate 6. General view of the sabkha opposite Qatar University after the seasonal rains.

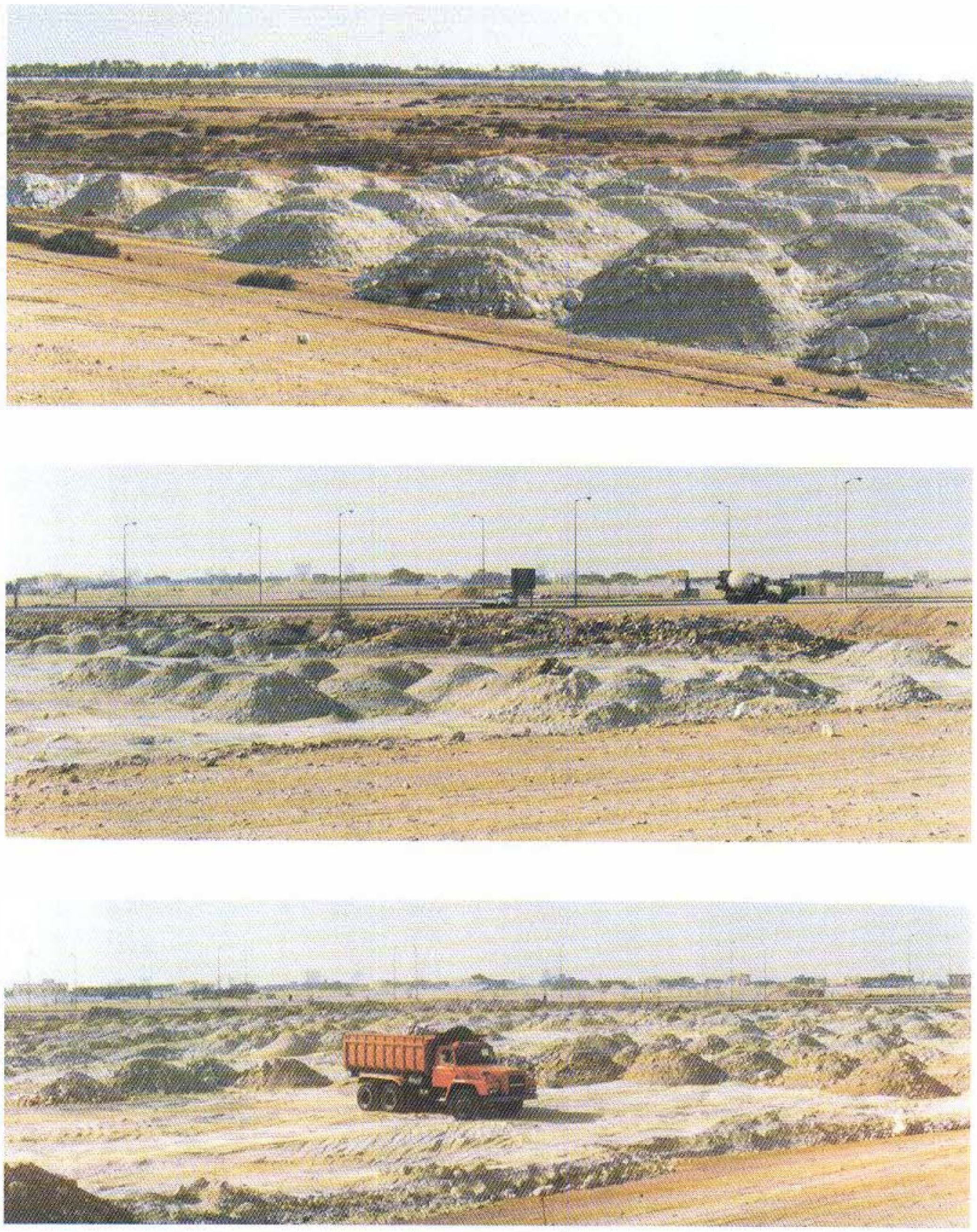


Plate 7. Same sabkha as in Plate 3 being filled with transported earth.

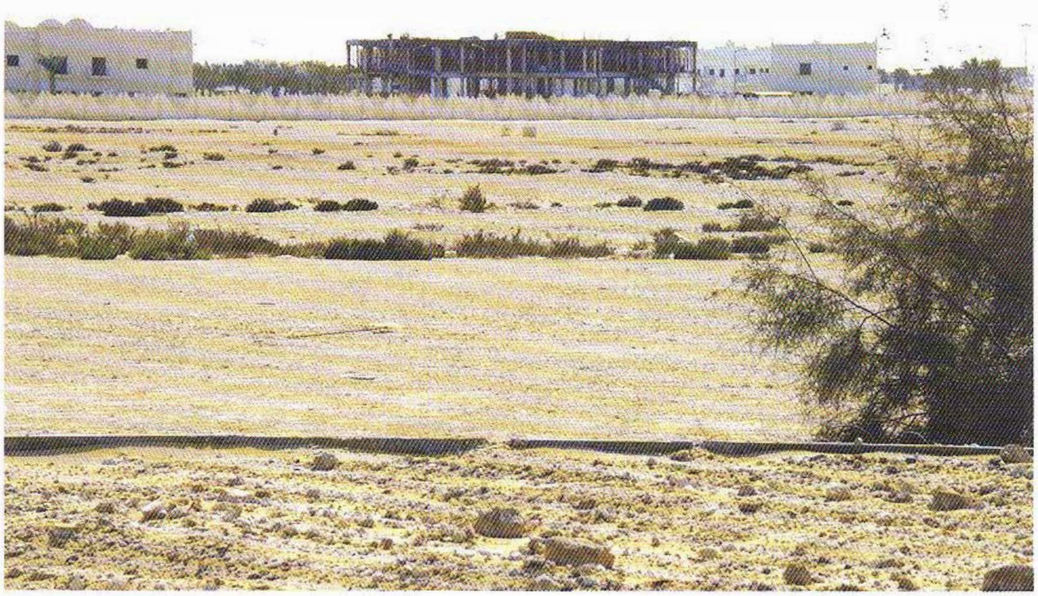


Plate 8. Present views of same sabkha as in Plates 3 and 4 [May, 2006].

4.2 Study Locations

The studied locations include coastal areas and inland areas. Most of the areas studied are in Doha City and its vicinity. The coastline areas include Al-Khor and Al-Dhakhira as well as a location due east of the Doha Golf Club and further east on the coastline. These locations are distinguished by their specific habitats and their plant communities.

The coastline of the State of Qatar is over 900 km long. The natural tilt of the land is towards the East which has given the eastern coastline a characteristic plant cover different from the western coastline. The Khor Al-Odeid to Ar Ruwais coastline strip is apparently some km longer than Ar Reweis to Salwa coastline strip (see Figure 1).

A number of factors affect the natural habitat along these coastlines. These stem from petro-chemical activities located at Mesaieed, Ras Laffan (on the eastern coastline, 80 km north Doha) and Dukhan on the western coastline.

The western coastline falls in a closed system (near Saudi Arabia and Salwa bay), whereas the northern coastline and the eastern coastline face open waters extending for miles.

Tidal zones extend in certain locations to coral reefs. The best coral reefs are located along the coastline of Halul Island. A common feature of undisturbed coastline is detriuts of seaweeds and seagrasses (Plate 9) in particular along sandy shorelines. Throughout, brown algae dominate the seaweeds.

The floristic composition of the tidal zone varies from site to another and is dependent upon the nature of the coastline whether it is rocky, sandy (fine or coarse sands) or muddy, the inclination from the sea towards the higher grounds and on the nature of the inclination whether it is gentle or uprubpt. The densiest vegetated strip of Qatar's coastline is Al-Dhakhira – Al-Khor – Ras Al-Matbahk strip (see Plate10, 11, 12 and Figure 7).

These sites are with natural mangrove forests and as well, active mangrove reforestation programme. Studies on the State of Qatar's mangrove forests are numbered but cover the main aspects of interest in mangrove vegetation (Suda and Al Kawari, 1990).

Plate 9. Detriuts of seagrasses and seaweeds.

The distinct zonation that changes from the zone of the mangrove forest to higher grounds is accompanied by change in species composition and no doubt with changes in the levels of the water-table and soil salinity. There is no doubt that a salinity gradient exist from the sea and the edge of the sabkha depressions and from the sabkha to the dominant rocky soils.

4.3 Sabkhas

Sabkhas or salt pans are, as expected in a country almost surrounded by seawater, widespread. These are mostly coastal, though inland sabkhas do occur.

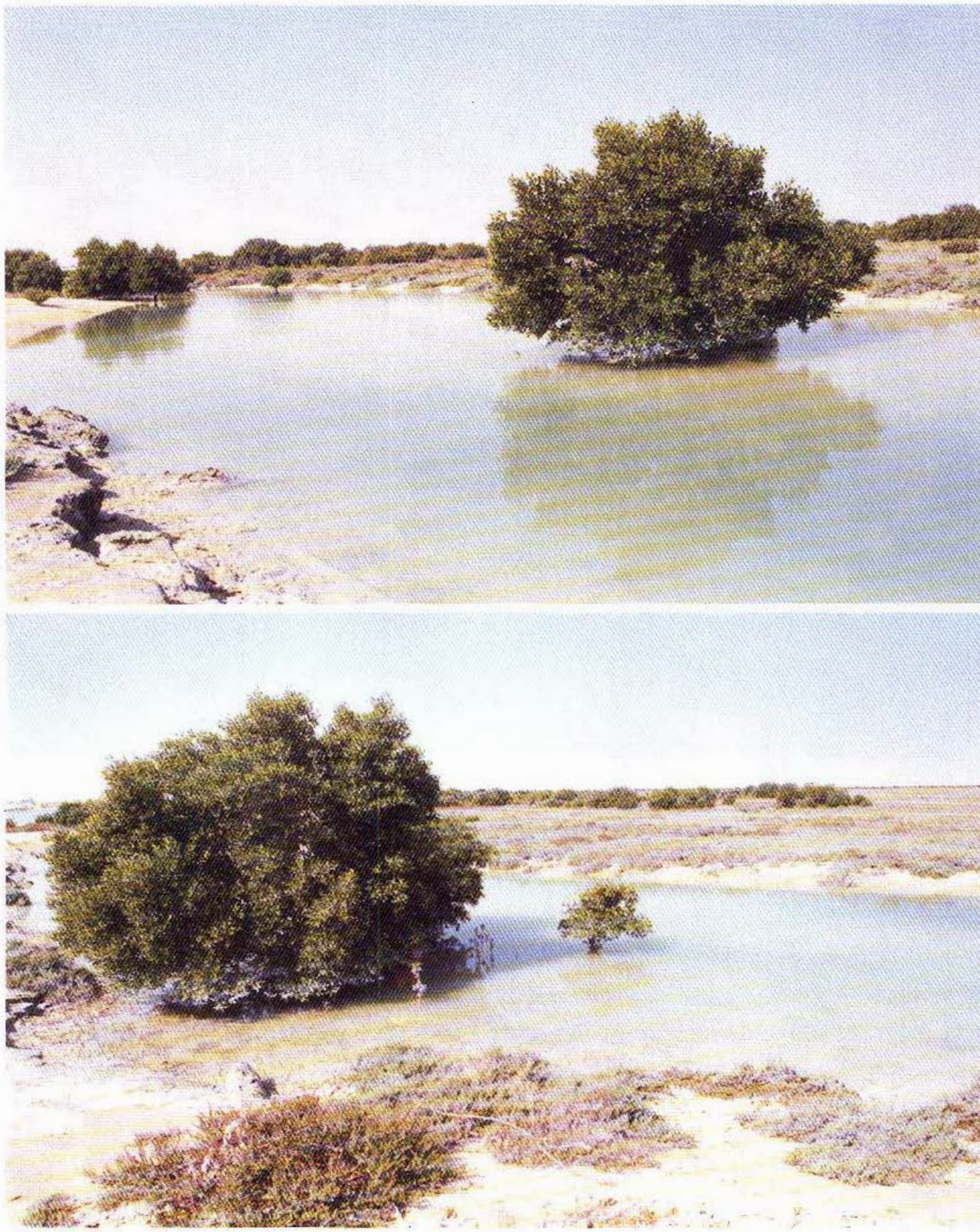
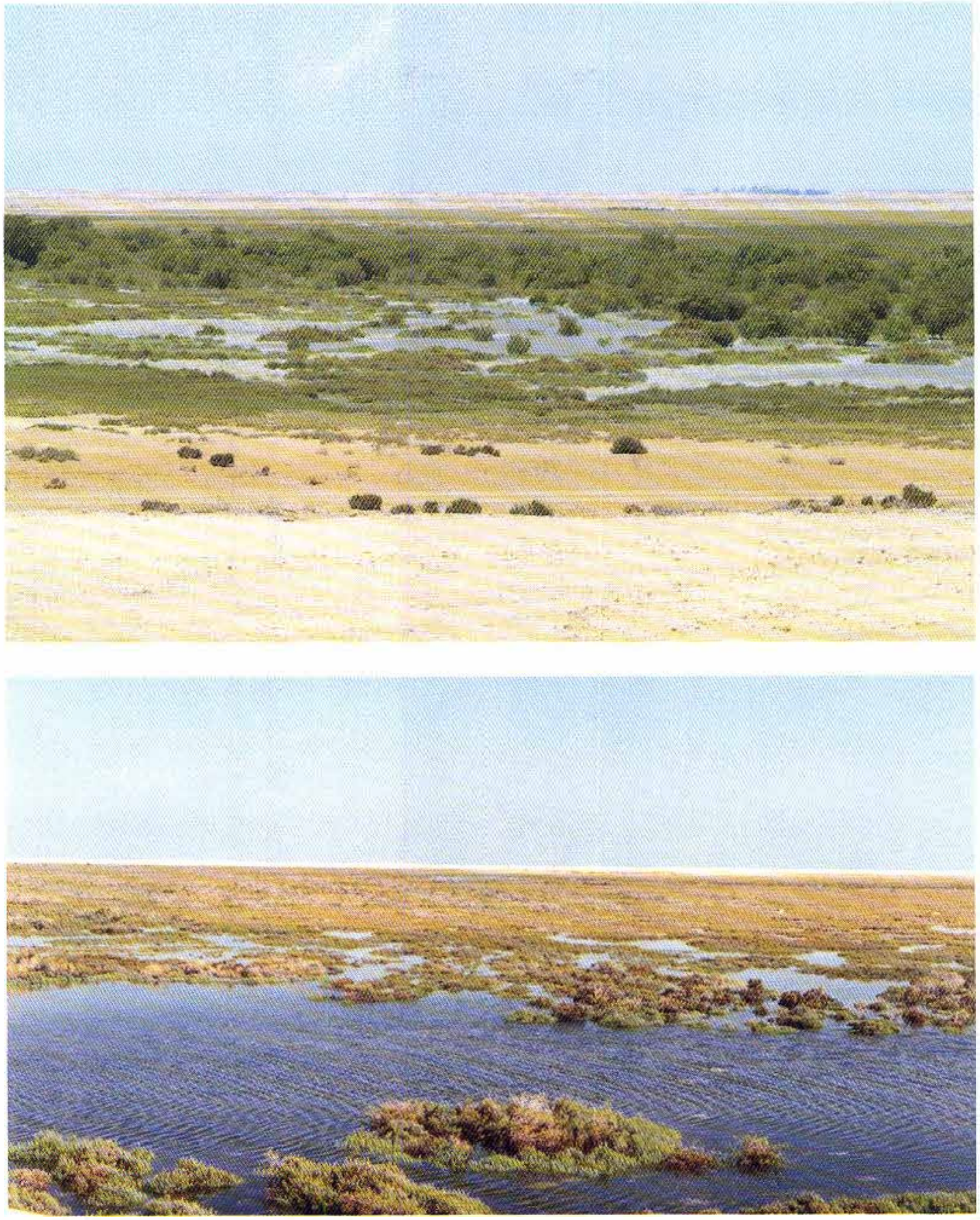


Plate 10 . *Avicennia marina.* Low tide at Al-Dhakhira Nature Park.



Platel 1. Dense growth of halophytic plants in a sabkha seen at-high tide.

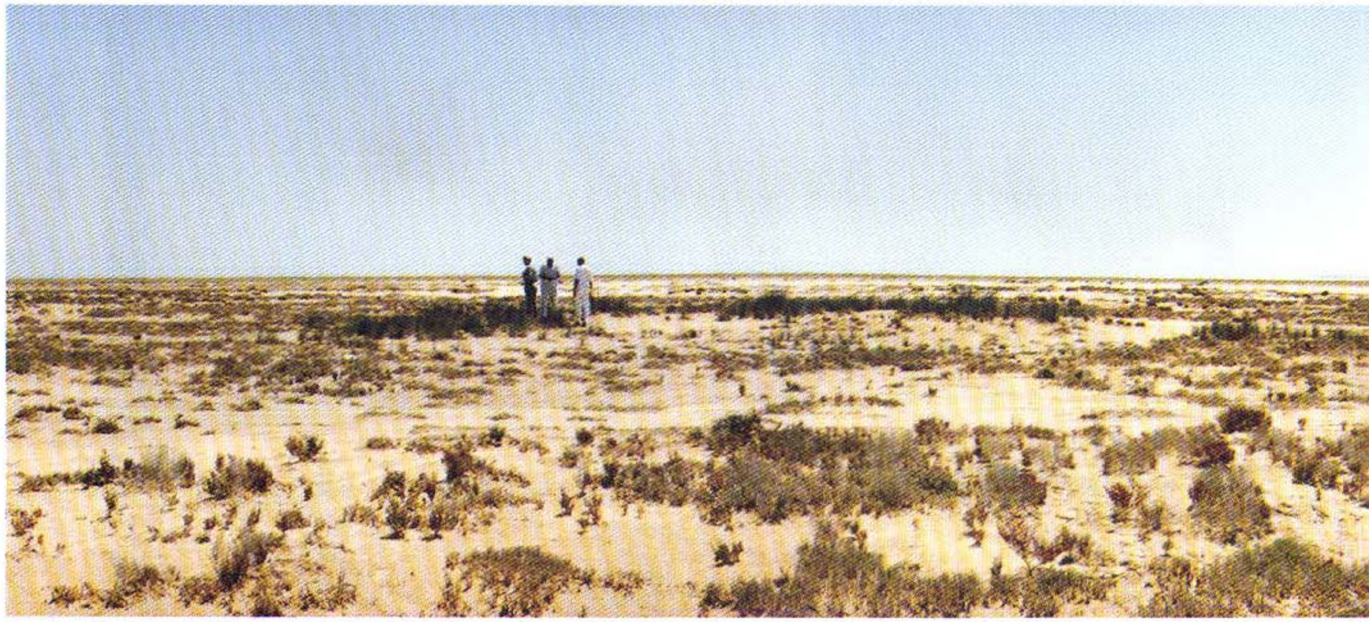


Plate 12. Large sabkha with a *Juncus* stand, few *Zygophyllum*, *Aeluropus* on mounds and a zone of *Halocnemum strobilaceum* in the distance [vicinity of Al Wusail, on the eastern coast north of Doha].

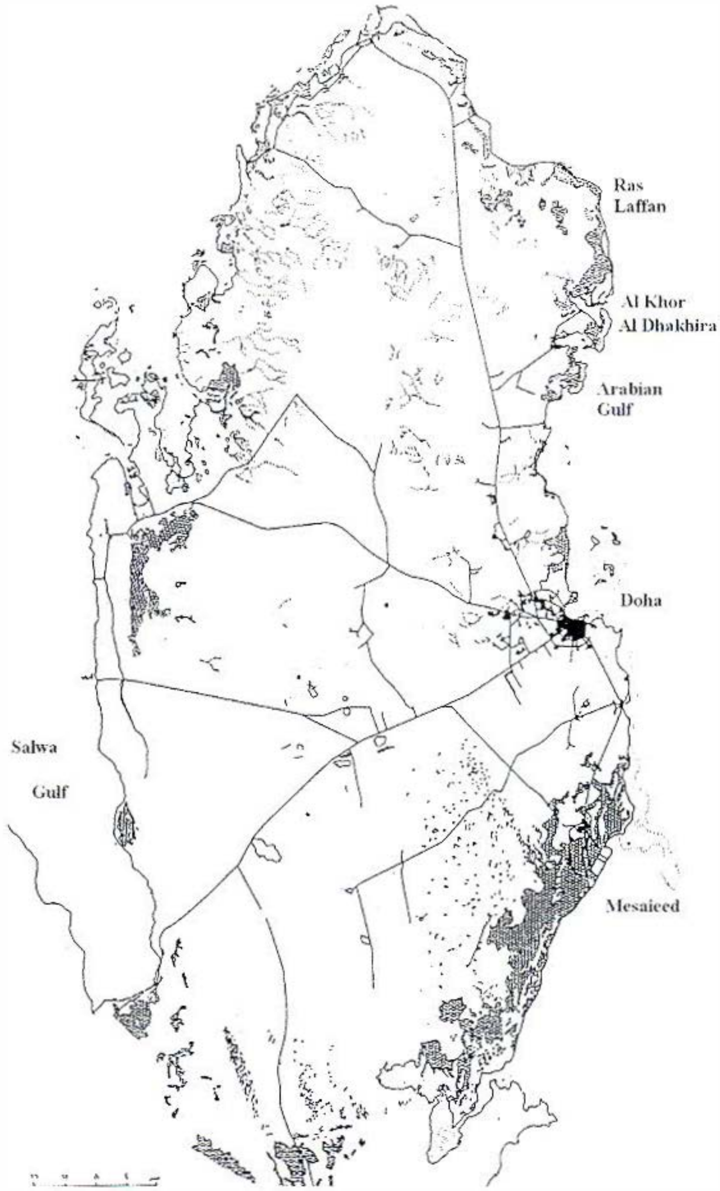


Figure 7. Map of the State of Qatar showing coastal and inland sabkhas and barchan dunes.

Source : Ashour *et al.* (1991).

The sabkhas may be vegetated or barren. Sabkhas are characterized by their soil salinity. If salinity is too high, halophytic taxa which are quite salt-tolerant might not be able to cope and the sabkha would then be a barren area. One of the largest inland sabkhas occurs in the vicinity of Dukhan with few species which are highly stressed by both salinity and aridity. Thus, the vegetation cover is poor, sparse and includes *Zygophyllum qatarense*, *Anabasis setifera* (mainly on the edges of the massive depression) and *Aeluropus lagopoides*, a grass living under extreme stress.

Zygophyllum qatarense though it seems quite tolerant of salinity, it does not in fact enjoy healthy growth on extremely saline soils. Its vegetative growth seems to be limited to few shoots during the rainy season when the excess salinity is diluted by the rains. Throughout, it will be localized to slightly (few cm) on raised mounds.

On the other hand, most of the coastline sabkhas beyond the mangrove forests are vegetated. They commonly support dense growth of halophytic taxa such as *Arthrocnemum*, *Halocnemum*, *Halopeplis* and *Limonium*. The latter two are halophytes which perform equally well on highly saline, slightly raised land which is drier than the conditions favoured by *Arthrocnemum* and *Halocnemum*.

Saline vegetated depressions i.e. vegetated sabkhas are a common feature of the northeastern coastline beyond the mangrove forests as at Ras Al Matbakh.

Vegetated sabkhas are unique habitats that once were an outstanding feature of the State of Qatar. Unfortunately, they are being continuously converted to areas for various land uses mainly developmental (hotels, clubs, etc.) or residential.

4.4 Soils

Saline soils differ in their composition, grain size and texture. The salinity of local soils is mainly attributed to sodium chloride. Coastal sabkhas receive seawater by seepage, via runnels or creeks or simply from high water table that had mixed with seawater.

The appearance of saline soils differ: sometimes they appear flaking with crusty layers in square-like pattern, or they may be mixed with clay and shells or simply of fine soils (Plates 13 – 14).

Soils of high salinity pose two main problems to plants. First, the accumulation of sodium ions can lead to the poisoning of the plant. Second, high levels of NaCl cause the water potential of the soil to become more negative. In the latter case, the ability to uptake water from the soil is decreased and plant's survival made impossible. Many areas throughout the State of Qatar are covered by highly saline soils, particularly in the regions immediately adjacent to the Gulf. The term "highly saline" is somewhat subjective. However, 0.5% NaCl (equivalent to ~85mM) is accepted by most to be the lower limit of such a classification.

Plate13. Exposed salt (above); typical pattern of heavily saline soils (below).

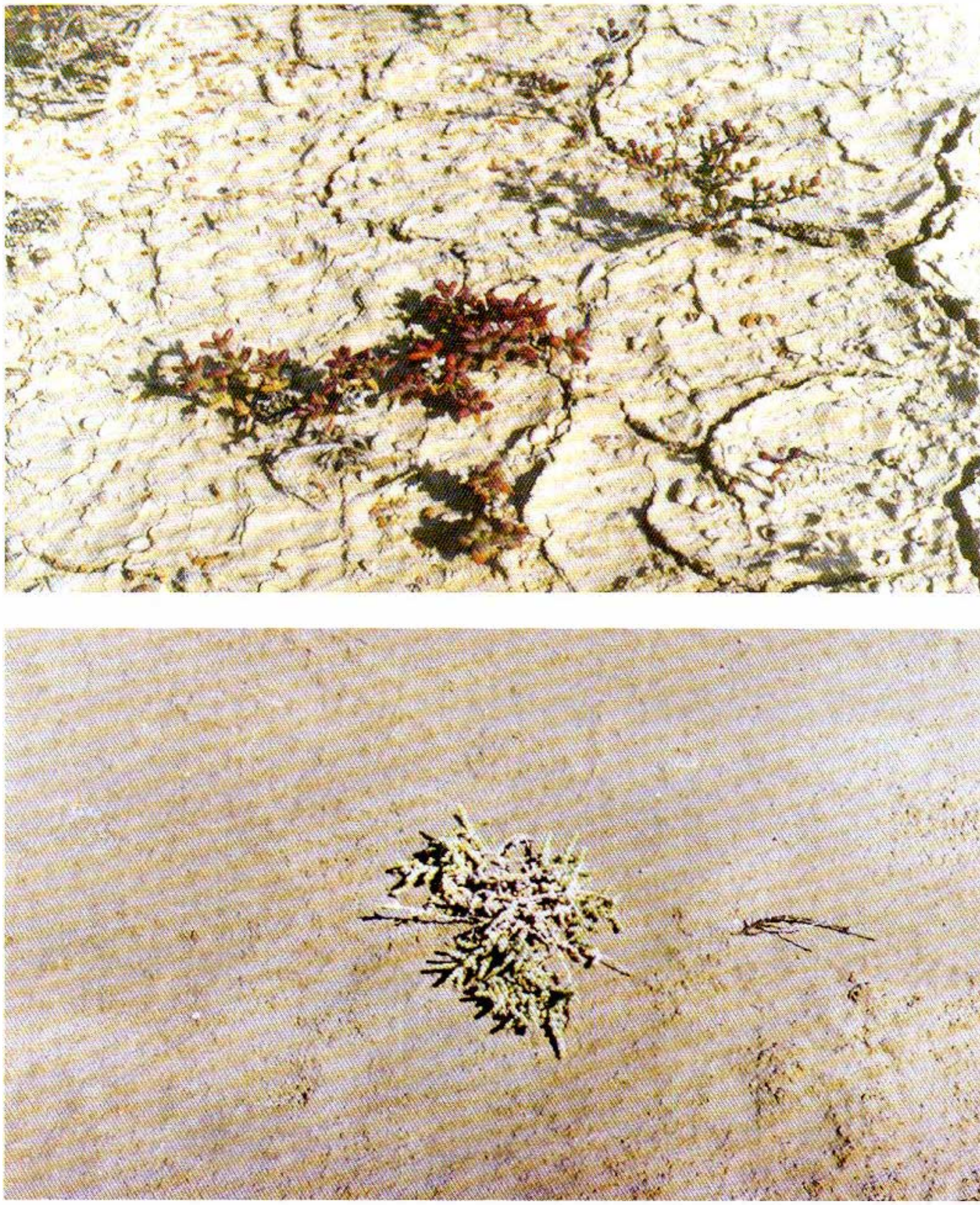


Plate 14. Saline soils: Flaking clayey sandy shelly soils with poor growth of *Anabasis setifera* and *Zygophyllum qatarense* (above); compact dry mud with sapling of *Arthrocnemum macrostachyum* (below).

It was noted that salinity levels in some areas were high enough to cause precipitation of salt on the surface which was covered by only 1-2 cm of wind transported soil. At lower levels of salinity, the plant populations of selected species thrived.

Depressions occupied by *Tamarix* spp. (Plates 15, 16 and 17) usually associated with *Aeluropus* and occasionally halophytes (including *Suaeda aegyptiaca*, *Suaeda vermiculata*) and other succulents including *Salsola imbricata* and *Halopeplis perfoliata* seem to be a common feature in many locations in Doha City.

Plate 15. Typical saline (crunchy) soils in old sabkha, opposite Qatar University. Large bushes at left hand corner are of *Suaeda vermiculata*.

Plate 16. A stand of *Tamarix* near residential area in Doha City on saline soils.

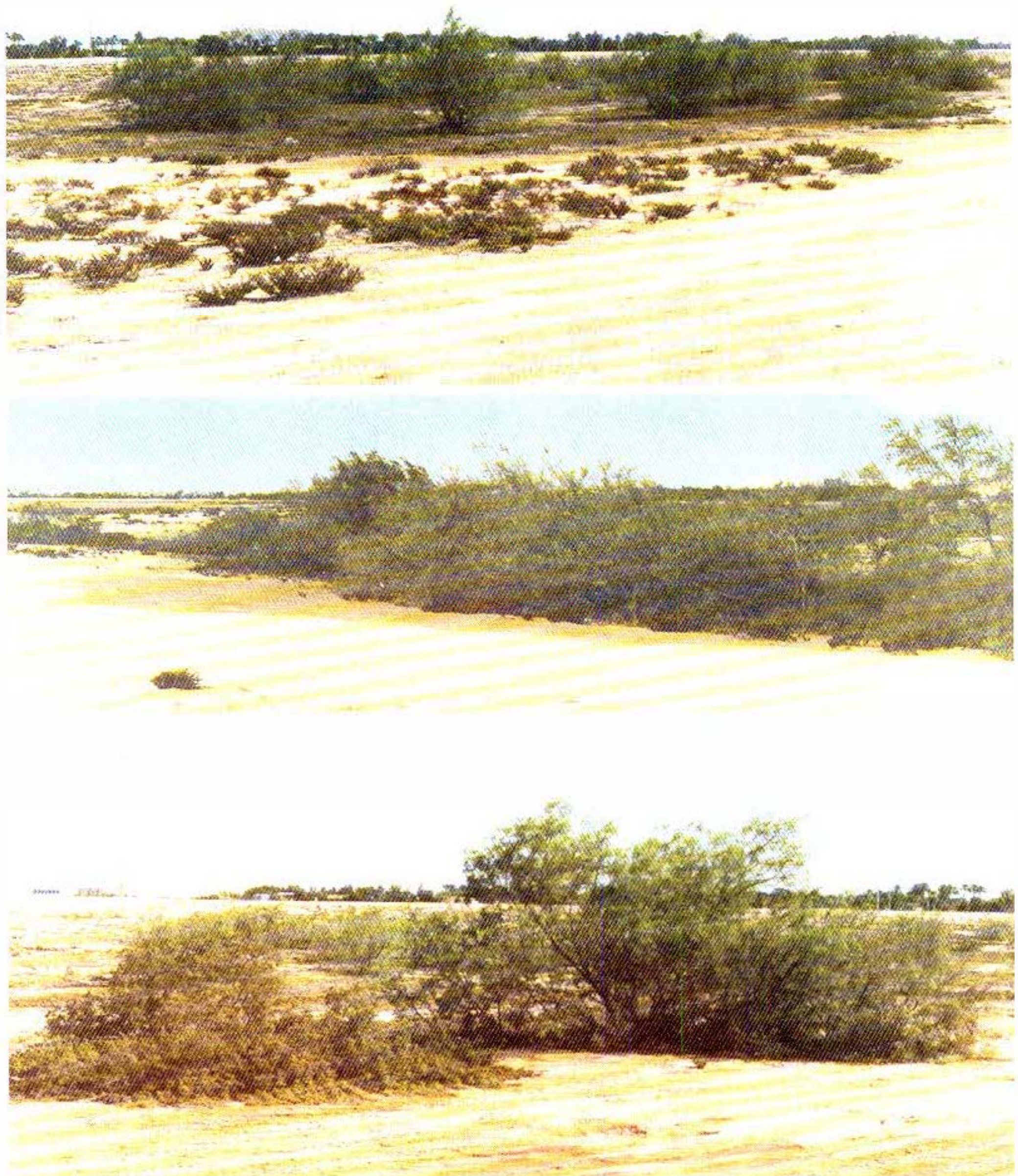


Plate 17. Common feature of saline depression occupied by *Tamarix*, *Aeluropus* and *Zygophyllum*.

Note: Salt crust on view below.

4.5 Soil Salinity

The studied taxa fall under two main categories: Halophytes and xerophytes.

The salinity, the water table depth and soil structure are the three main factors that control the distribution of plants in the State of Qatar. Salinity gradients affect the response of the different halophytic species; whereas most plants might suffer from increased salinity, few respond well in growth. High concentrations of NaCl are not essential for optimal growth and accordingly halophytes can be categorized either as facultative or obligate halophytes.

On land, soil salinity affects growth, dominance and distribution of the different halophytic species. Throughout, each of the halophytic plants has a well-defined tolerance limit. This is apparent from the zonation pattern which is so well illustrated in any sabkha zone annexed to a mangrove forest. When salt salinity is tested from the root zone of the various halophytes, a salinity gradient was encountered. This usually reflects in the distribution of species (Plate 18).

Plate18. Distribution along a sea-inland zone showing mangrove, *Salicornia*, *Salsola soda* and *Arthrocnemum*.

Soil types and water gradients, as well as inundation and land topography are the main factors influencing vegetation zonation.

Salt marshes are distributed along the intertidal zone. Mangrove forests and halophytes, mainly chenopods, dominate the moist saline soils. Poineer species such as drifting mangrove seedlings colonise sediments frequently with time and coupled with no disturbance, these will convert into mangrove forests (ESCenter, 2005).

Salt marshland plants such as *Arthrocnemum* and *Halocnemum* colonize 15-30 psu isoline range. Further inland, the vegetation is of even more salt tolerant species [xero-halophytes] where soil salinity is high coupled with more drier soils. The higher salinity is due to evaporation on the inland exposed areas.

Land inundated by high tide or seasonal tides only are the inner sabkhas commonly colonized by *Limonium*, *Halopeplis*, *Aeluropus*, *Sporobolus* and other xero-halophytes and their distribution depends on soil topography. Analysis of soil samples collected from different locations of the studied areas, revealed considerable variation in all parameters studied including the electrical conductivity of the saturated soil extracts. Details of the physical properties of the soils in the locations studied are given in Table 6.

Arabian Gulf waters may be the primary source of salts in the coastal areas. However, the high figures of salinity level in the inland areas (beyond the coastline), are attributed to the intrusion of seawater into the underground waters (Abulfatih *et al.*, 2001). Moreover, great variation in the Ece values was found even with the same small area. Although, there is no specific explanation for such variation, climate, scarcity of rainfall, and human activities might have contributed to such variation in the Ece values of the soils from the different locations. Table 6 shows clearly that areas (A10 and A11) are a good example of such variations.

The area (A10) on one side of the road in a Rawdat (Ece 4.8 – 12.2) and the area (A11) on the opposite side of the road is of stony compact soils (Ece 85.4) on which plants such as *Haloxylon salicornicum*, have been established on high salinity levels (Ece of 80 – 90 dSm^{-1}). The remaining areas (A6, A7, A8, and A9) have highly saline soils. This is attributed to the formation of isolated small pools from dumped waters containing soluble salts.

Table 6. Physical properties of the soil samples collected from different sites of the studied locations.

The studied location	Properties				
	% of gravel	Soil texture	Field capacity (%)	pH (soil extract)	Ece (dSm^{-1})
A1	1.2 – 36	Sandy – Sandy loam	12 – 37	6.8 – 9.5	31.5 – 177.1
A2	14 – 17	Sandy – Silty loam	22 – 55	6.5 – 7.7	12.3 – 49.3
A3	15	Sandy loam – Loamy sand	37	8.3 – 9.2	> 200
A4	27	Sandy loam	30	8.2 – 8.4	> 200
A5	7 – 42	Sandy – Sandy loam	23 – 55	6.8 – 8.2	57.3 – 187.7
A6	26 – 50	Loamy sand – Sandy loam	22 – 43	6.6 – 6.9	4.2 – 71.3
A7	5 – 41	Sandy – Sandy clay loam	14 – 48	5.9 – 7.5	7.4 – 72.3
A8	13 – 42	Loamy sand – Sandy clay loam	24 – 50	7.0 – 8.4	45.1 – 195.0
A9	25 – 31	Sandy loam – Sandy clay loam	31 – 33	6.7 – 7.9	113.7 – 141.9
A10	2	Loamy sand – Sandy clay loam	40.0	4.8	4.8
A11	22	Compact stony	35.7	8.1	85.4

All coastal areas are occupied by halophytic plants, few of these spread out landward to about one – two km from the shoreline. Some xerophytic plants are also found in these areas (A6, A7, A8, A9 A10). All the areas studied are stressed either from salinity or water deficit or both as shown in Table 7. Therefore, it is expected that all plants living in these areas are well adapted to drought and salinity.

Table 7. Ece and water content of soils from different locations of the studied area.

The studied area	Absolute water content (%)	Soil water content *(of FC %)	Ece of the soil (dS m-1)
A1	18.1 – 2.3	61.4 – 7.3	177.1 – 31.5
A2	27.8 – 2.5	50.7 – 11.4	49.3 – 12.3
A3	2.8 – 2.3	10.0 – 6.0	200 <
A4	26.1 – 12.9	71.3 – 43.0	200 <
A5	22.0 – 7.5	45.6 – 32.1	187.7 – 57.3
A6	3.4 – 2.2	11.7 – 7.9	71.3 – 4.2
A7	2.6 – 1	9.5 – 5.4	72.3 – 7.4
A8	25.7 – 2.9	65.9 – 9.8	195.0 – 45.1
A9	13.8 – 10.7	43.7 – 32.5	141.9 – 113.7
A10			
A11	4.1 – 3.7	11.5 – 9.3	85.4 – 4.8

The most abundant ions detected in the soil samples are Cl^- and Na^+ which increase the Ece values to above 200 dSm-1 in some locations (Tables 8 and 9). Other ions such as Ca^{2+}, Mg^{2+}, and K^+ were also detected.

Table 8. The concentration of soluble elements in the water extracts of the soil samples collected from different locations of the studied soils.

The studied area	mg / L of soil extract				
	Na+	K+	Ca2+	Mg2+	Cl-*
A1	207 – 768	98 – 124	59 – 104	33 – 73	25 – 151
A2	202 – 716	88 – 118	59 – 80	44 – 87	6 – 62
A3	450 – 530	85 – 110	75 – 85	65 – 70	450 – 490
A4	511 – 814	96–97	81 – 97	40–83	575 – 714
A5	383 – 480	86 – 115	74–97	53 – 87	68 – 437
A6	234 – 523	68 – 92	71 – 80	63 – 80	2 – 70
A7	356 – 452	60 – 92	67 -76	70–78	3 – 55
A8	186 – 726	79– 108	63 – 113	34 – 69	77 – 344
A9	238 – 258	99 – 108	66 – 81	72 – 82	197 – 260
A10 and A11	367 – 686	98 – 132	76 – 104	34 – 55	3 – 60

* g / l of soil extracts.

Table 9. The concentration of soluble trace elements in the water extracts of the soil samples collected from different locations of the studied areas.

The studied area	µg / L of soil extract						
	Fe *	Cu	Zn	Co	Ni	Cr	Cd
A1	6.1 – 13.1	3.2 – 47.3	11.5 – 38.7	0.1 – 4.7	20.7 – 91.2	0.6 – 4.0	0.09 – 0.71
A2	2.2 – 8.6	4.0 – 52.8	9.9 – 27.2	2.8 – 27.2	17.0 – 81.5	2.2 – 7.2	0.18 – 0.63
A3	12.4 -17.0	60.1 – 80.1	60.1 - 72.4	2.0 – 5.5	85.2-98.2	1.6 – 4.2	0.13 – 0.76
A4	6.3 – 11.0	14.7 – 31.7	15.8 – 34.8	1.9 – 4.9	32.2 – 37.3	1.1 – 3.4	0.71 – 0.99
A5	2.4 – 7.0	10.0 – 15.0	28.4 – 71.9	1.1 – 4.6	35.6 – 50.6	2.1 – 4.0	0.66–0.96
A6	8.6 – 16.7	1.0 – 41.8	27.7 – 43.3	1.3 – 3.6	27.7 – 58.5	1.9 – 12.3	0.02 – 0.31
A7	9.2 – 13.7	1.0 – 4.7	25.0 – 68.5	2.5 – 22.0	37.5 – 95.9	1.2 - 11.0	0.01 - 0.57
A8	4.6 – 9.8	13.9 – 54.3	18.0 – 59.1	1.8 – 26.7	37.0 – 61.0	1.8 – 16.4	0.25 – 2.35
A9	2.1 – 7.4	22.4 – 35.3	48.0 – 67.2	9.3 -15.7	15.2- 39.1	1.7 – 2.3	0.10 – 0.44
A10 and A11	7.2 – 10.0	49.2 – 126.0	36.3 – 42.5	8.6 – 69.8	46.1 – 86.8	0.1 – 7.9	0.03 -0.12

* mg / l of soil extracts

5 The Taxa Studied

5.1 Introduction

The taxa studied and their families have been given in Chapter 2 (Table 3). Almost half of the taxa covered in this study belong to the family Chenopodiaceae. These are either well known halophytic plans or xerophytes or haloxerophytes. In all three conditions, they are plants that display marked external and internal modifications to cope with either extreme conditions of salinity or severe aridity. The details of each taxon are presented in this Chapter. They include the citation and synonomy, descriptions of habit, form of vegetative and reproductive parts, and their habitat and distribution in the State of Qatar.

5.2 Morphological features of the studied taxa

The vegetative and reproductive characters of the taxa under investigation (Table 3, Chapter 2) has been studied in detail. The morphological features are described following the standard methodology in plant systematics. The habitat and distribution of each taxon are included and wherever possible with plates showing their plant community and special features. The sequence followed is an alphabetical order of the families, genera and species: (Avicenniaceae, Boraginaceae, Capparidaceae, Chenopodiaceae, Compositae, Menispermaceae, Plumbaginaceae, Resedaceae, Rhamnaceae, Zygophyllaceae [Dicotyledons] and Gramineae [Monocotyledons]).

FAMILY AVICENNIACEAE

Genus *Avicennia* L.

The genus *Avicennia* L. belongs to the family Avicenniaceae (Verbenaceae) which is a family of mangroves common in warm waters such as the Arabian Gulf and the Red Sea. The family is locally represented by one genus only i.e. *Avicennia* to which *A.marina* (Forssk.) Vierh., the only mangrove species in Qatari waters belongs. *A. marina* is internationally known as the Grey Mangrove.

Avicennia marina (Forssk.) Vierh. in Denkschr. Akad. Wien, Math. – Nat. 71 : 435 (1907).

Syn. *Sceura marina* Forssk. 1775 : 37 cv. 85; Cent. II 18.

Germ. Schora (Ar.) قرم . شورة

Evergreen dark green mangrove trees or shrubs not exceeding 4 m high producing a cable network of breathing roots (pneumatophores), each root 40-60 cm long, corky and covered with lenticels. Leaves opposite, shiny green, glabrous above, grey and hairy beneath, ovate to ovate-lanceolate. Inflorescences terminal and axillary clusters of small yellow flowers. Fruit 1-1.5 cm across; seeds vivaporous germinating in the fruit on the mother plant and exposing 2 very large fleshy cotyledons.

Habitat and Distribution:

Mangrove forests are common on the muddy shorelines of the eastern coast of Qatar (widespread from Al Reweis to Al Wakra) where many experimental plots and plantations are on trial since the eighties. They seem to be more successful on the north-central parts of the eastern coastline on the tidal zones and the lagoons than elsewhere.

Seedlings drop and drift with the slow and gentle water current. Many are lost but some set in sheltered bays where due to gravity, their primary root sinks in the heavy, sticky and muddy substrate in the intertidal zone and form dense natural forests.

Mangrove forests were the main source of wood and camel fodder in the past. Extensive camel grazing destroys the forests. However at present, they are semi- protected.

Plates 19 and 20.

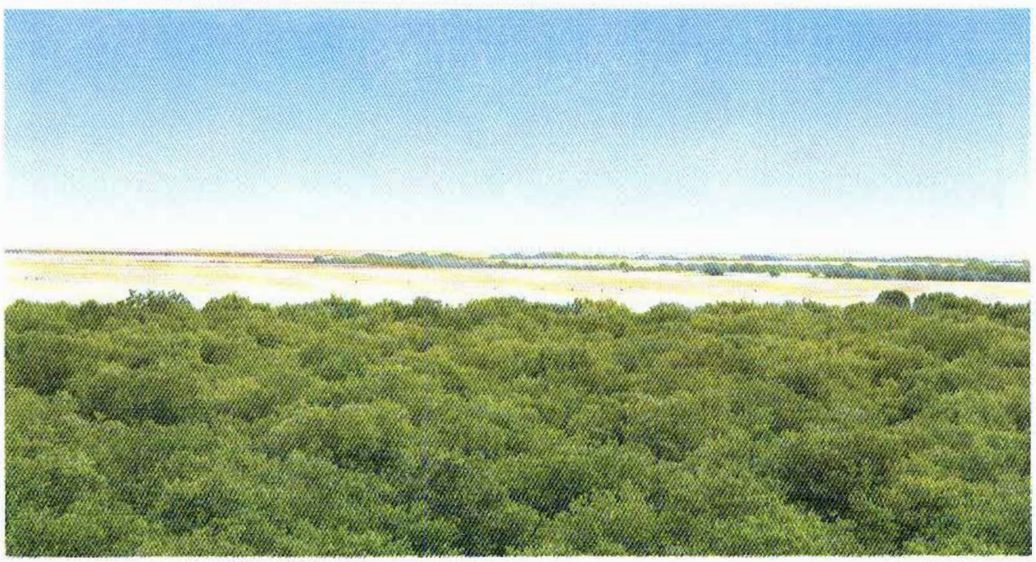


Plate 19. *Avicennia marina* in blume (Ras Al Matbakh 18.02.06). Courtesy of Fatima Al Haiki (above); *Avicennia marina* forest at Al Dhakhira Nature Park (2003) (below).

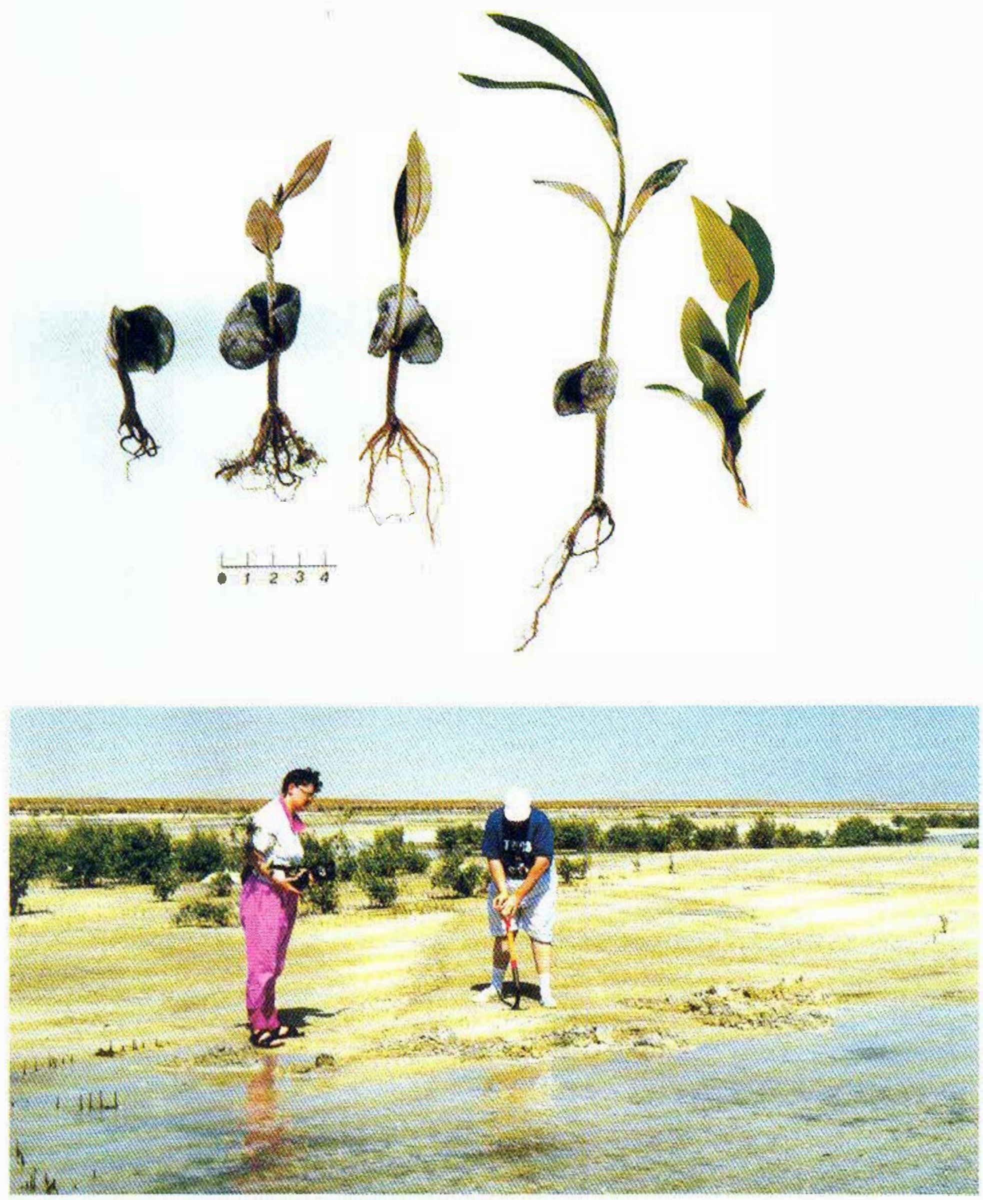


Plate 20. Stages in *Avicennia marina* development from seeds (above); volunteers of the Qatar Natural History Group (QNHG) planting *Avicennia marina* saplings at Ras Laffan Industrial City (below).

FAMILY BORAGINACEAE

Genus *Heliotropium* L.

The genus *Heliotropium* belongs to the family Boraginaceae which is characterized by its hispid bulbous-based hairs and scorpioid cymes inflorescences.

Heliotropium bacciferum Forssk., Fl. Aegypt. – Arab. 38 (1775).

Danab al agrab, Ramram (Ar.) ذنب العقرب . رمرام

Low spreading hispid evergreen bush with terminal branches easily breaking off. Leaves sessile, narrowly linear-lanceolate, with tapering bases and sinuate margins. Inflorescences cymes with small white tubular flowers. Fruit nutlets, hard.

Habitat and Distribution:

Widespread in all disturbed areas both inland and coastal areas on sandy, rocky and saline soils.

Plates 21 and 22.

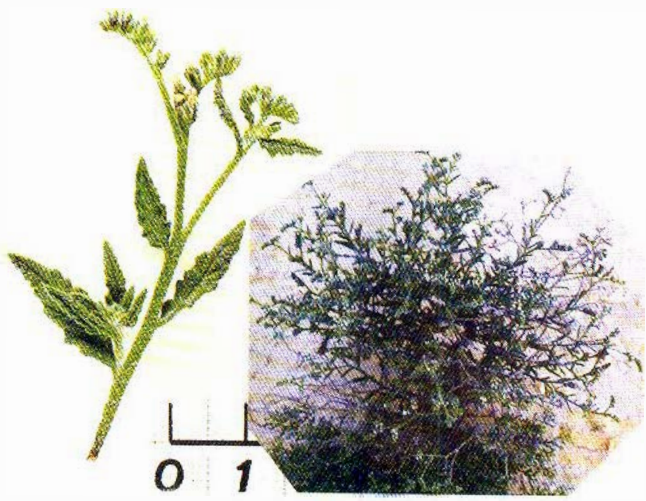


Plate 21. *Heliotropium bacciferum* flowering branch and habit.

Plate 22. Spreading habit of *Heliotropium bacciferum.*

FAMILY CAPPARIDACEAE

Genus *Capparis* L.

The genus *Capparis* L. belongs to the family Capparidaceae which is represented locally by two genera: *Capparis* and *Cleome*. One *Capparis* species i.e. *C. spinosa* L. occurs and is common in low depressions with fine silty and sandy soils. *Cleome* is an annual herb, localized and appearing after the seasonal rains. The local species of *Cleome* is characterized by its strong pungent smell.

Capparis spinosa (Lam.) L. var. *aegyptia* (Lam.) Boiss., Fl. Orient. 1 : 420 (1867).

Syn. *Capparis aegyptia* Lam., Encycl. 1 : 605 (1785).

Dabayee, Shefallah, Lasaf (Ar.) شفلح ، لصف ، دباي

Trailing – scandent spiny shrub forming circular mats ca. 2-2.5m across of rambling branches radiating from a central base. Spines at leaf bases, recurved. Leaves simple, entire, ovate-orbicular, 3-5 cm long and 3-4.5 cm across, leathery. Inflorescences axillary, solitary. Flowers large, white to pale rose, of 4 sepals and petals and numerous stamens surrounding an elongated ovary on a distinct gynophore. Fruit ellipsoid, pear-shaped and gourd-like, fleshy, splitting into 4, exposing grey pepper-like seeds on red pulp. Mature pericarp of fruit never dries completely. Flowers and fruits in summer (May-August).

Habitat and Distribution:

Common in central and north-eastern Qatar, rare elsewhere. In depressions with fine sandy loams along roadsides (Al Dhakhira – Ras Laffan and on sides of Ash Shamal road from Al Khor and beyond).

A favoured camel browsing plant. Flower buds and immature fruits are locally pickled (caper).

Plate 23.

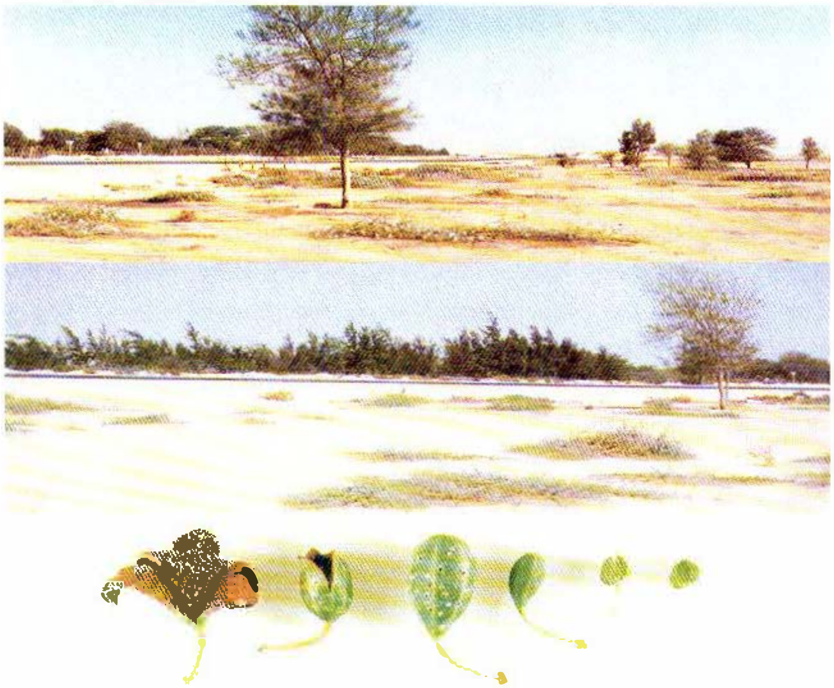


Plate 23. *Capparis spinosa*: Habitat (above); Habit (middle) and stages from flower buds to mature fruit (below).

FAMILY CHENOPODIACEAE

The family Chenopodiaceae is represented in the local flora by 15 genera comprising 22 species. Most members of the local chenopods are halophytes widely distributed along the saline coastline of the country. One species is a widespread notorious weed i.e. *Chenopodium murale*. Many of the halophytes are morphologically distinct by their jointed stems, rudimentary leaves and with stem/stem and leaves succulence.

This study includes 11 chenopods: *Anabasis setifera*, *Arthrocnemum macrostachyum*, *Atriplex leucoclada*, *Halocnemum strobilaceum*, *Halopeplis perfoliata*, *Haloxylon salicorincum*, *Salicornia europaea*, *Salsola imbricata*, *Salsola soda*, *Suaeda aegyptiaca* and *Suaeda vermiculata*.

Genus *Anabasis* L.

Anabasis setifera Moq. Chenop. Monogr. Enum. 164 (1840).

Syn. *Seidlitzia lanigera* Post, Fl. Syr., Pal. et Sinai, ed. 1, 689 (1896).

Shuayran (Ar.) شعيران

Stiff undershrub with erect branches. Upper branches and leaves succulent, jointed, breaking easily; upper stem joints narrowed below, expanding above, ± angled; lower parts of branches dry and woody, commonly desicated. Leaves opposite and decussate, sessile, ± spathulate, terete. Inflorescences axillary, congested. Flowers small; calyx becoming membranceous and winged in fruit.

Habitat and Distribution:

Anabasis setifera is a common plant appearing in many disturbed areas in Doha, along highway roads and the periphery of sabkhas. The plants show marked plasticity in response to water availability. On very dry saline soils, the plants appear small, stunted and highly stressed as compared to plants on non-saline soils.

Anabasis setifera is widespread in the State of Qatar.

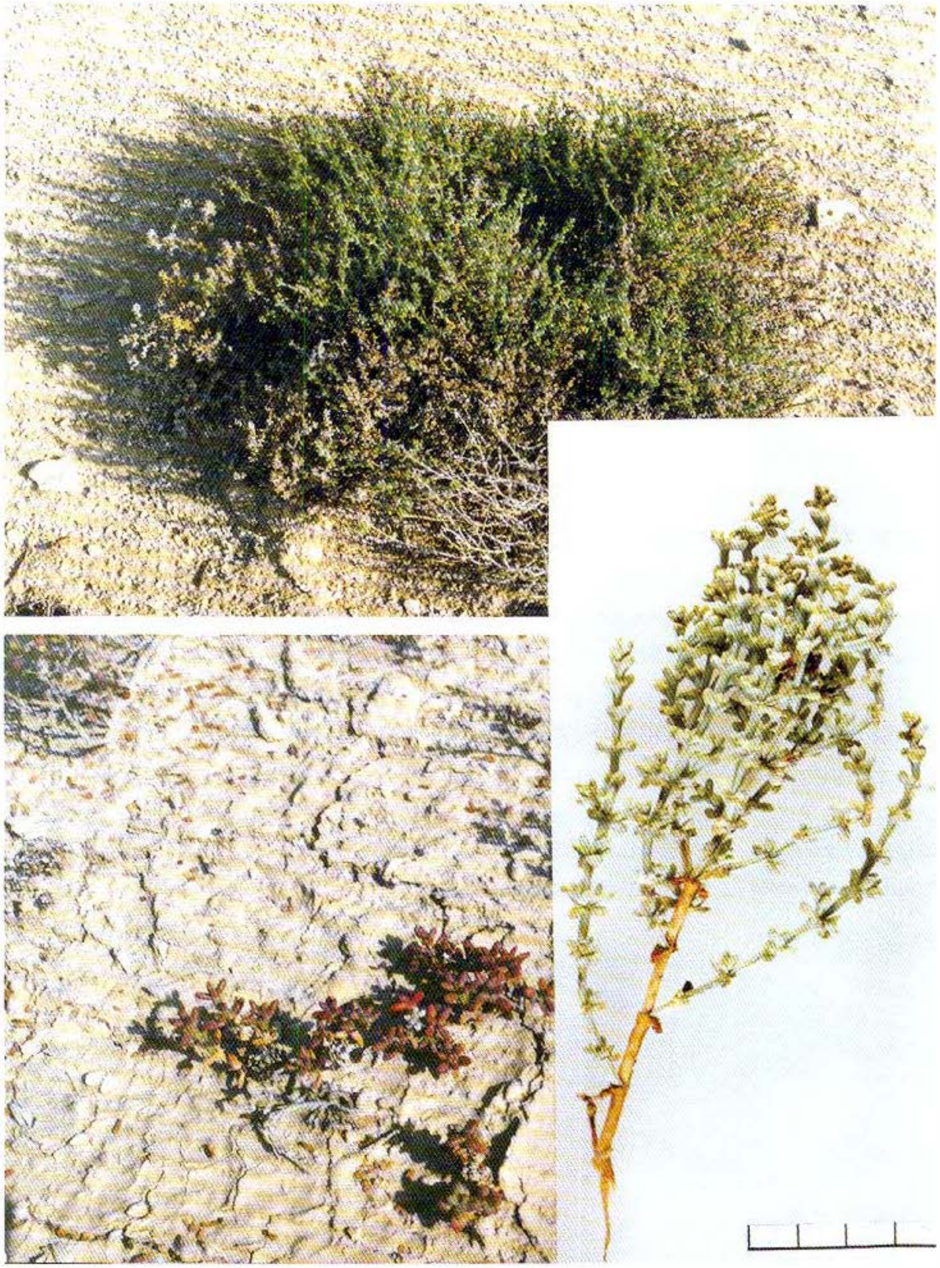


Plate 24. *Anabasis setifera* undershrub with normal growth (above); plant with stunted growth due to extreme stress (below); vegetative branch [LHS].

Genus *Arthrocenum* Moq.

Arthrocnemum macrostachyum (Moric.) Moris, Enum. Sem. Hort. Taur. 1854:35 (1854).

Syn. *Salicornia macroatachya* Moric., Fl. Venet. 2 (1820); *S. glauca* Delile, Descr. Egypte, Hist. Nat. 49 (1814), non Stokes, Bot. Mat. Med. 1:8 (1812); *A. glaucum* (Delile) Ung.-Sternb., Atti Cong. Bot. Firenze 1874:283 (1876). nom. illeg.

Gullam (Ar.) قلام

Low mat-forming succulent undershrub with jointed stem. Branches numerous, dark green with stout internodes. Leaves rudimentary to absent (represented by minute growth at the nodes) opposite and decussate. Branching axillary, dense, resulting in horizontal spread and upright shoots. Inflorescences axillary, short spikes on the upright and horizontal shoots. Flowers naked; stamens exposed. Fruit minute, wingless.

Habitat and Distribution:

The most common plant in the intertidal zone and sabkha annexed to the mangrove forests, covering large areas with circular low growing mats. Plant growth traps the soil and mounds are formed. These as well as mats of *Halocnemum*, which is the second species in the zonation from mangrove inland, are the refuge of many animal species including species of crabs, insects, reptiles, small mammals and birds.

The distribution of *Arthrocnemum* is restricted to the coastal inundated intertidal zone. In many areas it forms extensive single communities' species appearing as circular mats on moist saline soils. It is not uncommon to find a number of the total parasite *Cistanche phelypaea* scattered in the *Arthrocnemum* zone.

Plates 25 - 27.

Plate 25. *Cistanche phelypaea* in bloom (Al Dhakhira Nature Park).

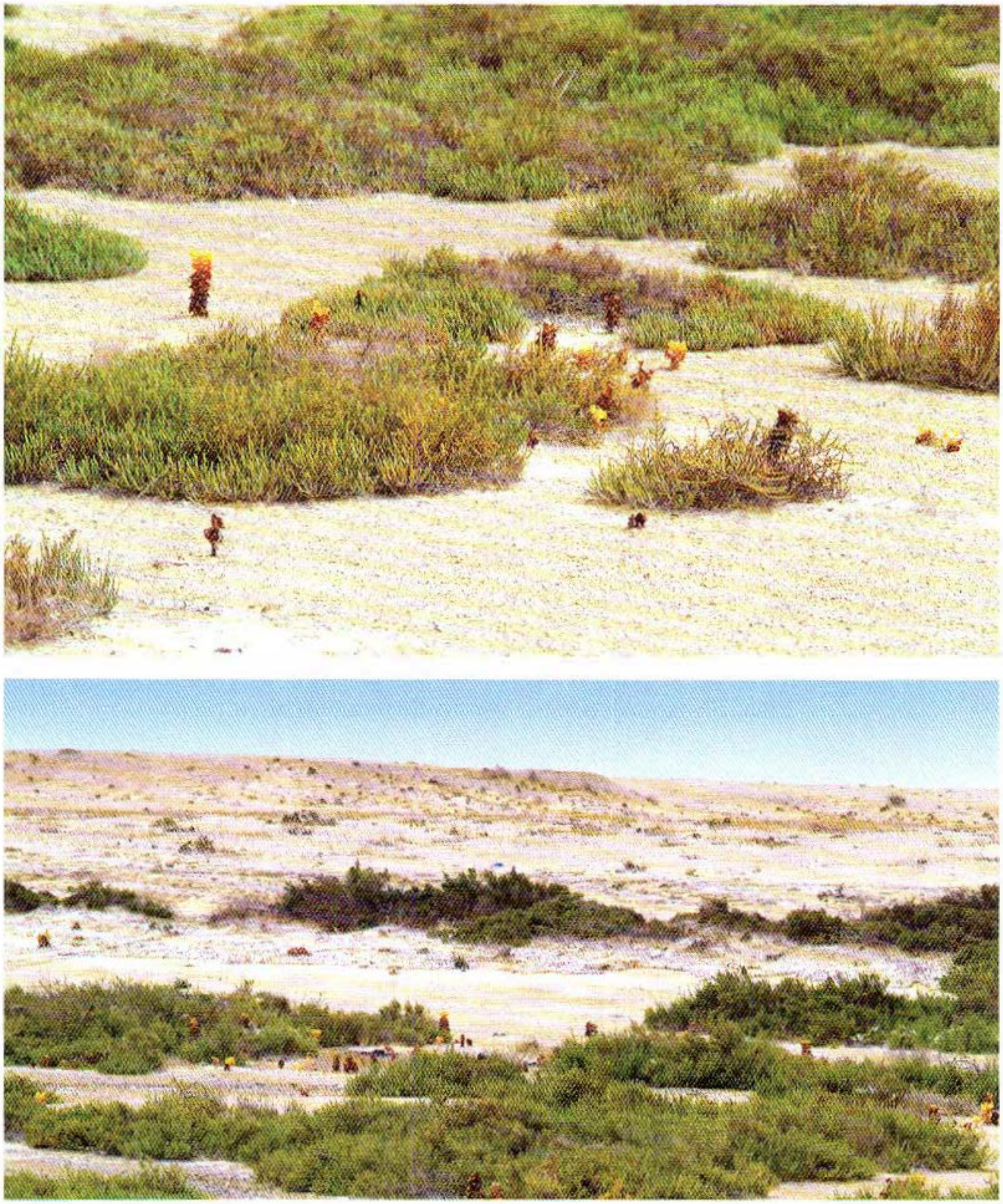


Plate 26. *Arthrocnemum macrostachyum* community with the total parasite *Cistanche phelypaea*.

Plate 27. *Arthrocnemum macrostachyum* in bloom.

Genus *Halocnemum* Bieb.

Halocnemum strobilaceum Bieb., Fl. Taur.-Cauc. 3:3. (1819).

Syn. *Salsola alopecuroides* Del., *Agathophora alopecuroides* (Del.) Bunge

Salicornia strobilacea Pall., Reise 1:412, 431, 1771.

Hamd, Gullam (Ar.) حمض . قلام رفيع

Low mat-forming undershrub almost identical to *Arthrocnemum macrostachyum* in habit but with much more slender branches and olive green colour. Branches numerous, dense spreading horizontally to form circular mats reaching 2m across; internodes succulent, short, jointed and upright. Leaves rudimentary, opposite. Inflorescences axillary and terminal spikes, similar to *Arthrocnemum*. Flowers small, sessile, in groups of 2 or 3 flowers; stamens exposed.

Habitat and Distribution:

Common on saline soils on the vegetated sabkhas, more common on the north-eastern coastlines forming pure communities or a mixed community with *Arthrocnemum*. It covers extensive areas at Fewairit, Ras Al Matbakh (south of Al-Dhakhira) and if associated with *Arthrocnemum*, it occupies the inner zone beyond the mangrove forests.

Plates 28 and 29.

Plate 28. *Halocnemum macrostachyum* habit [vicinity of Al Wusail on the eastern coast north of Doha] .

It is quite common for mat-forming halophytes on vegetated sabkhas to die at the centre showing bare patches of dead branches and green growth at the periphery. These gradually spread towards the periphery, the edges of the mat. Partial death is known to be a strategy of escaping stress of salinity and/or aridity by a number of plant species (Plate 29).

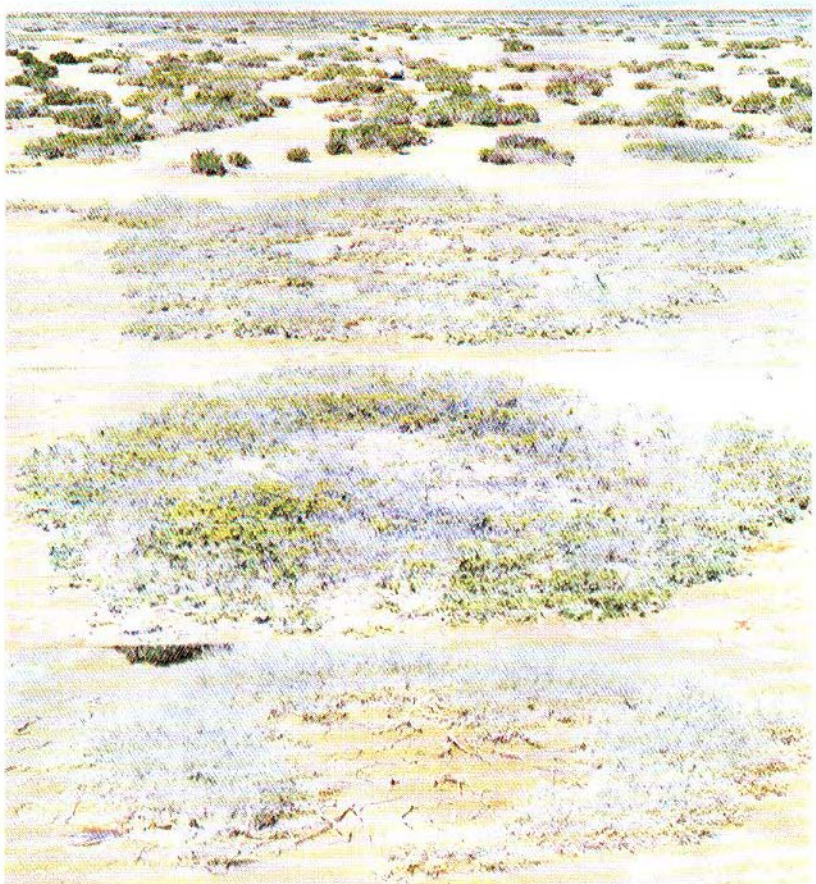


Plate 29. *Halocnemum strobilaceum.*

Genus *Halopeplis* Bunge ex Ung.-Sternb.

Halopeplis perfoliata (Forssk.) Bunge ex Aschers.

Syn. *Salicornia perfoliata* Forssk., Fl. Aegypt.-Arab. 3(1775).

Khureiz, Inab al Bahr (Ar.) خريز، عنب البحر

Perennial succulent undershrub with many upright jointed branches; up to 50 cm high; joints beaded, fleeshy; bulging at internode positions, commonly green and may become yellowish or red (hence the name sea grapes). Leaves rudimentary, alternate, globose, succulent. Infloresences terminal, much branched, spicate, of minute clustered green flowers. Stamens exposed; ovary ovate. Dead infloresences of previous seasons' flowering remain intact on the plants. Fruit not winged.

Habitat and Distribution:

Halopeplis is a halophyte occurring on coastal saline soils and has a wide range of tolerance. It can grow next to the open sea or by meandering creeks, or further inland on soft shelly ground or even on compact hard soils with marked aridity but occasionally moistened by high tide. Throughout its range *Halopeplis* performs well displaying more green shoots during the rainy season and becoming more reddish towards the period of extreme aridity.

Halopeplis is a common halophyte of saline sabkhas on coastal areas. The local name sea grapes fits well with the multi-coloured beaded and jointed succulent shoots of the plant.

Plates 30 - 33.

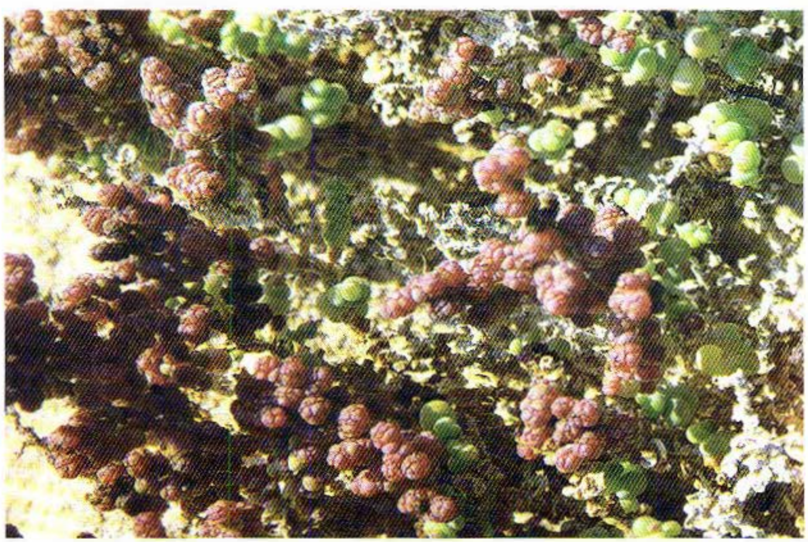


Plate 30. *Halopeplis perfoliata*.

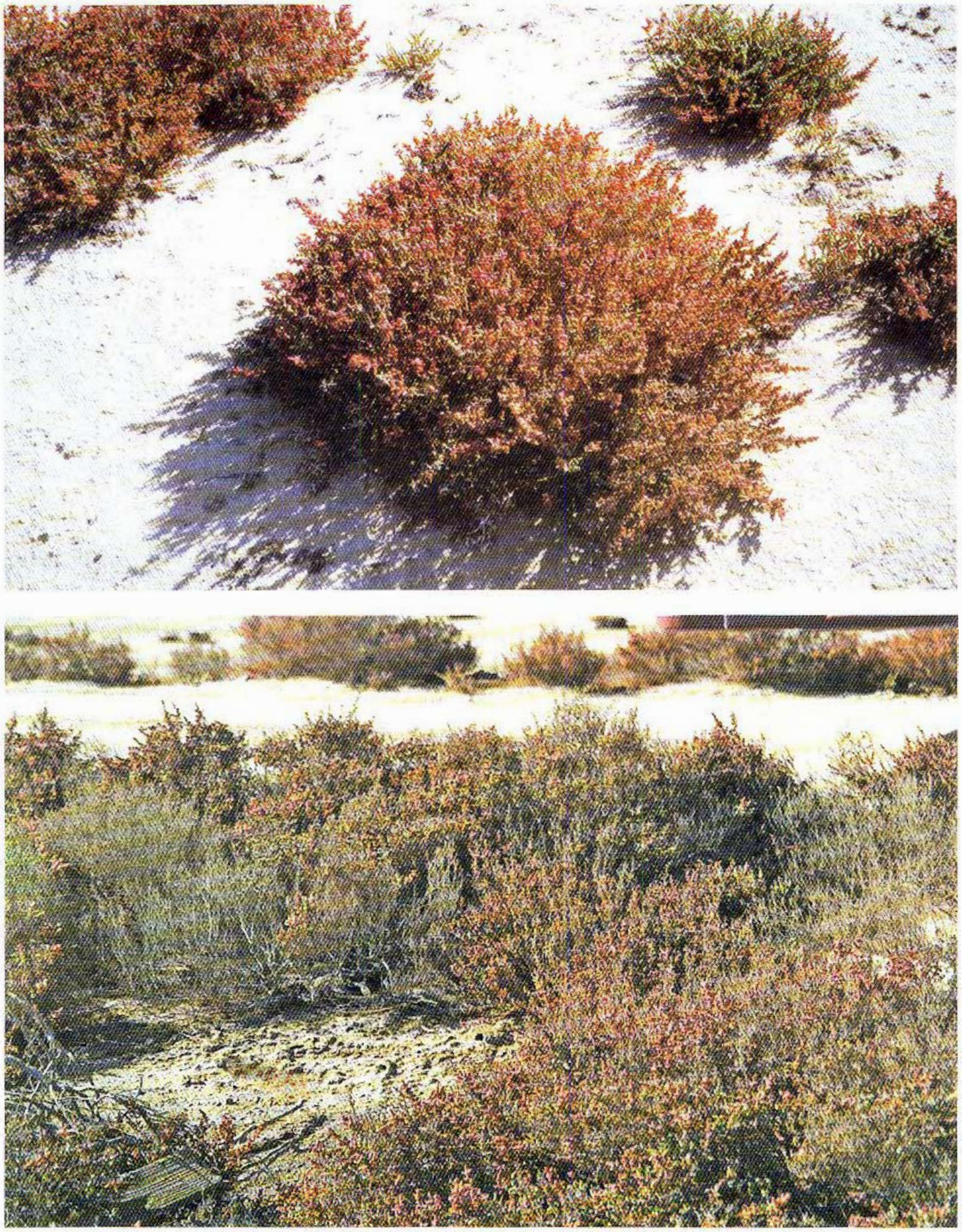


Plate 31. *Halopeplis perfoliata* habit (above); *H. perfoliata* community (below).

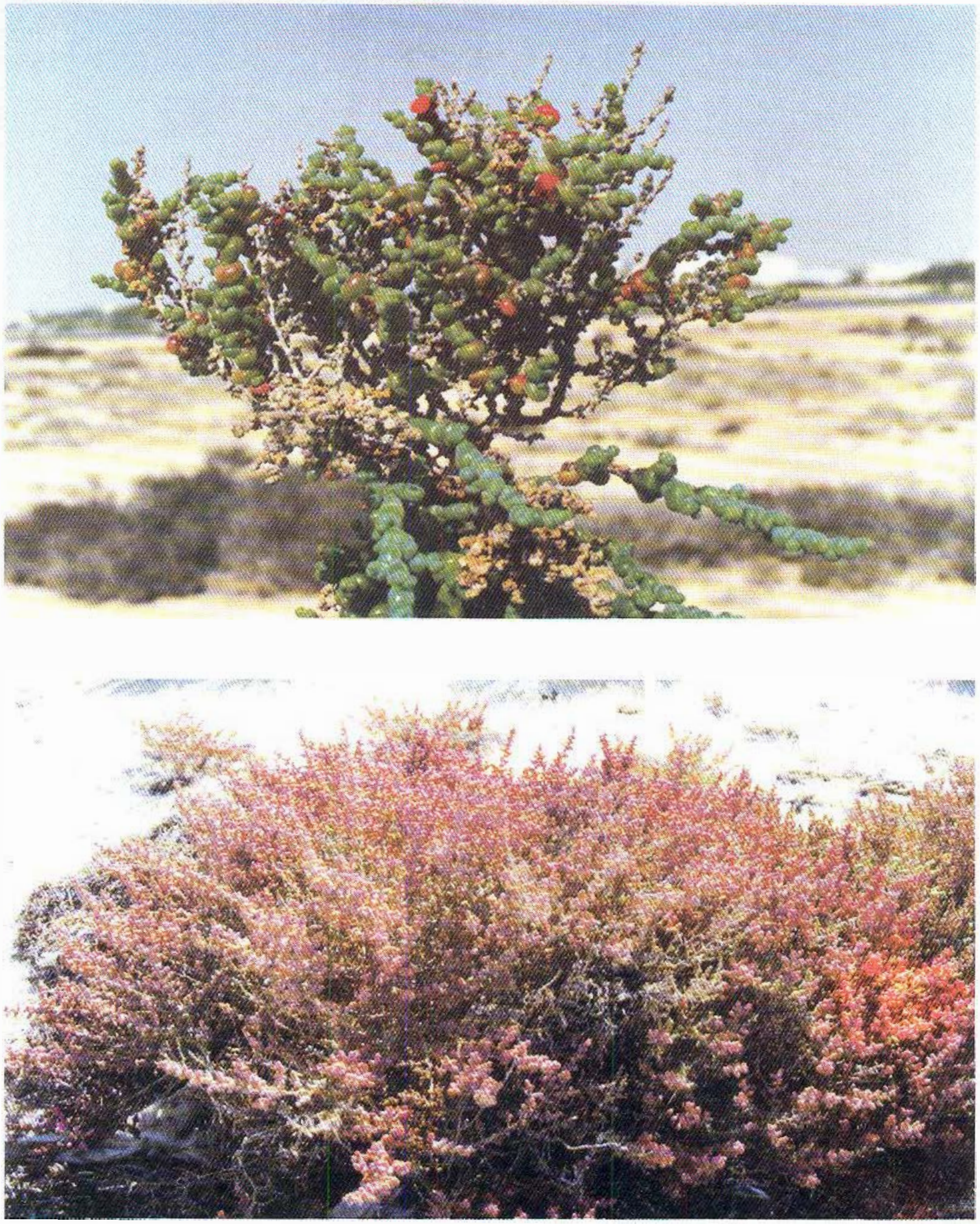


Plate 32. *Halopeplis perfoliata* in green form (above); *H. perfoliata* in red form (below).

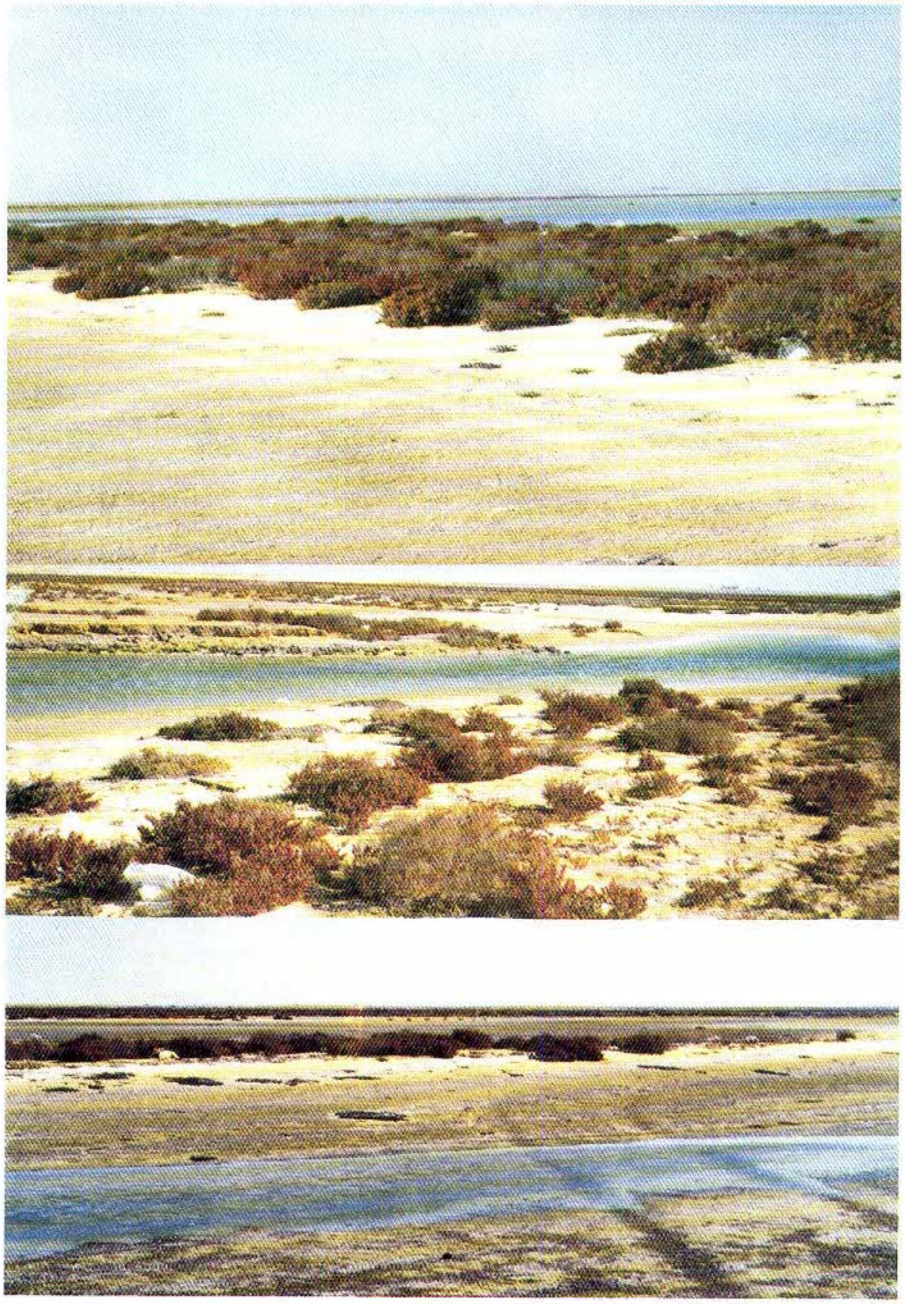


Plate 33. *Halopeplis perfoliata* by the open sea and creeks.

Genus Haloxylon Bunge

Haloxylon salicornicum (Moq.) Bunge ex Boiss., Fl. Orient. 4 : 949 (1879).

Syn. *Caroxylon salicornicum* Moq. in A.DC., Prodr. 13 (2) : 174 (1849); *Hammada salicornia* (Moq.) Iljin, Bot. Zhurn. (Moscou & Leningrad) 33 : 583 (1948); *Hamada elegans* (Bunge) Botsch., Novosti Sist. Vyss. Rost. 1 362 (1964).

Rimth (Ar.) رمث

Much branched xerophytic perennial undershrub with jointed stems; older branches white, new growth green and fleshy. Leaves whorled, scale-like. Inflorescences on upper branches indistinct but prominent in fruit where the imbricate calyx becomes papery and flower-like. Fruit enclosed in membraneous calyx appearing winged.

Habitat and Distribution:

Widespread in S. Qatar forming large communities on wind blown sands over rocky-stony ground. Equally common on Doha road to Salwa nearer to Doha. Widespread in Al-Shahaneya in farm lands.

Plates 34-36.

Plate 34. A branch of *Haloxylon salicornicum*.

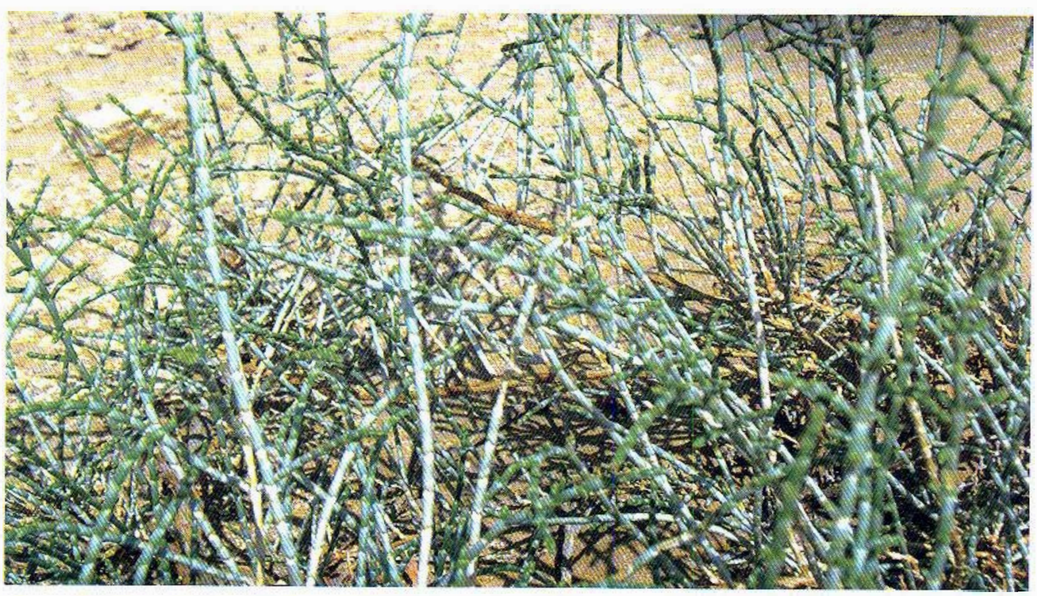


Plate 35. *Haloxylon salicornicum* by roadside [Al Shahaneya].

Plate 36. *Haloxylon salicornicum* on sandy soil (above); *H. salicornicum* on rocky grounds (below).

Genus *Salicornia* L.

*Salincornia europaea** L., Sp. Pl., 3, 1753.

Small dwarf annual short-lived succulent halophytic herb hardly exceeding 2cm high. Stem erect of one or few jointed branches. Branches dark green with usually some bright coloured joints of light green, yellow and orange. Leaves rudimentary with sheathing bases. Inflorescences spicate, short-pedunculate. Flowers axillary, in groups of 3 flowers in dichasial cymes; perianth succulent; stamens exposed; ovary ovate; stigmas bifid.

Flowering and fruiting during cool winter season.

Habitat and Distribution:

Appears in dense growth on the regularly flooded landwards side of the mangrove swamps on sticky muddy soft wet clays of the swampy areas mostly associated with the similar species *Salsola soda* and both in the mangrove forest at the lower strata zone. Its distribution is more restricted to the north eastern coastline and is widespread at Fewairat, Al Khor, Ras Al Matbakh and Al-Dhakhira.

Plates 37-39.

Plate 37. A stand of *Salicornia* at low tide [Al Dhakhira Nature Park].

* In recent publication, the identify of the *Salicornia europaea* occurring in the Gulf has been disputed.

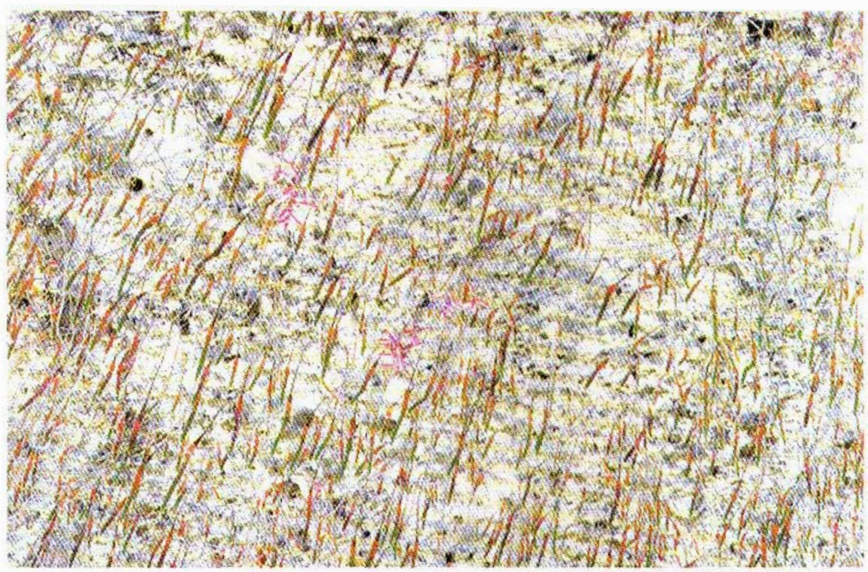


Plate 38. *Salincornia europaea* individuals showing variation in size and colour (above); a stand at low tide [Al Dhakhira Nature Park] (below).

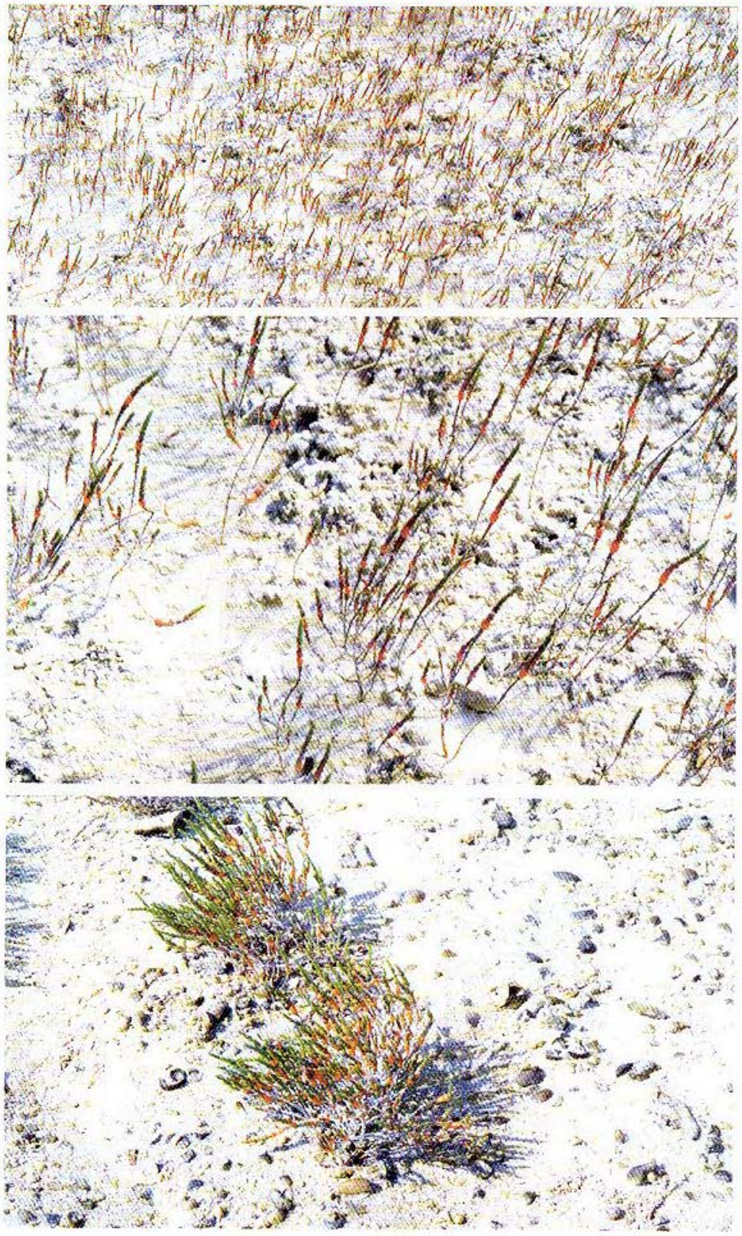


Plate 39 . Typical habitat and soils of *Salicornia* in the subtidal zone.

Genus *Salsola* L.

The genus *Salsola* is represented in the Flora by 5 species of which *S.imbricata* Forssk. is the most common.

Salsola imbricata Forssk., Fl. Aegypt.-Arab. CVII, CVIII, 57 (1775).

Syn. *Salsola baryosma* (Roem. et Schult.) Dandy in Andrews, Fl. Pl. Anglo-Egypt. Sudan I : 111 (1950); *Chemopodium baryosmom* Schult. ex Roem. et Schult., Syst. Veg., ed. 15, 6 : 269 (1820); *Salsola foetida* Delile ex Spreng, Syst. Veg. 1 : 925 (1824).

Hamd Zefer (Ar.) حمض زفر

Evergreen low much-branched woody undershrub up to 60 cm high and spreading up to 1.5 m across with succulent young shoots and new growth. Whole plant with distinct sardine/fishy odor. Leaves clustered in new growth with rudimentary laminas and bases clasping and encircling branches. Older branches bare. Inflorescences spicate, of minute green flowers with distinct calyces that enlarge and turn pappery and persistent in fruit (appearing as white flowers). Dispersal of enclosed fruit in membraneous sepals is by wind.

Habitat and Distribution:

Widespread in all main cities and represents the most common local succulent undershrub on saline coastal soils beyond the tidal zone.

Plants can respond to extreme heat stress by partial physiological death of older branches. As a halophyte it is widespread in sabkhas (saline depressions and salt flats) and may be encountered in moist habitats, sewage disposal areas, edge of agricultural fields and as a roadside weed in residential areas, throughout with lush pale green growth. It is the most common plant in Doha.

Insect infestation of some branches produce a dense growth of white hairy small leaves appearing as groups of white flowers.

Plates 40 and 41.

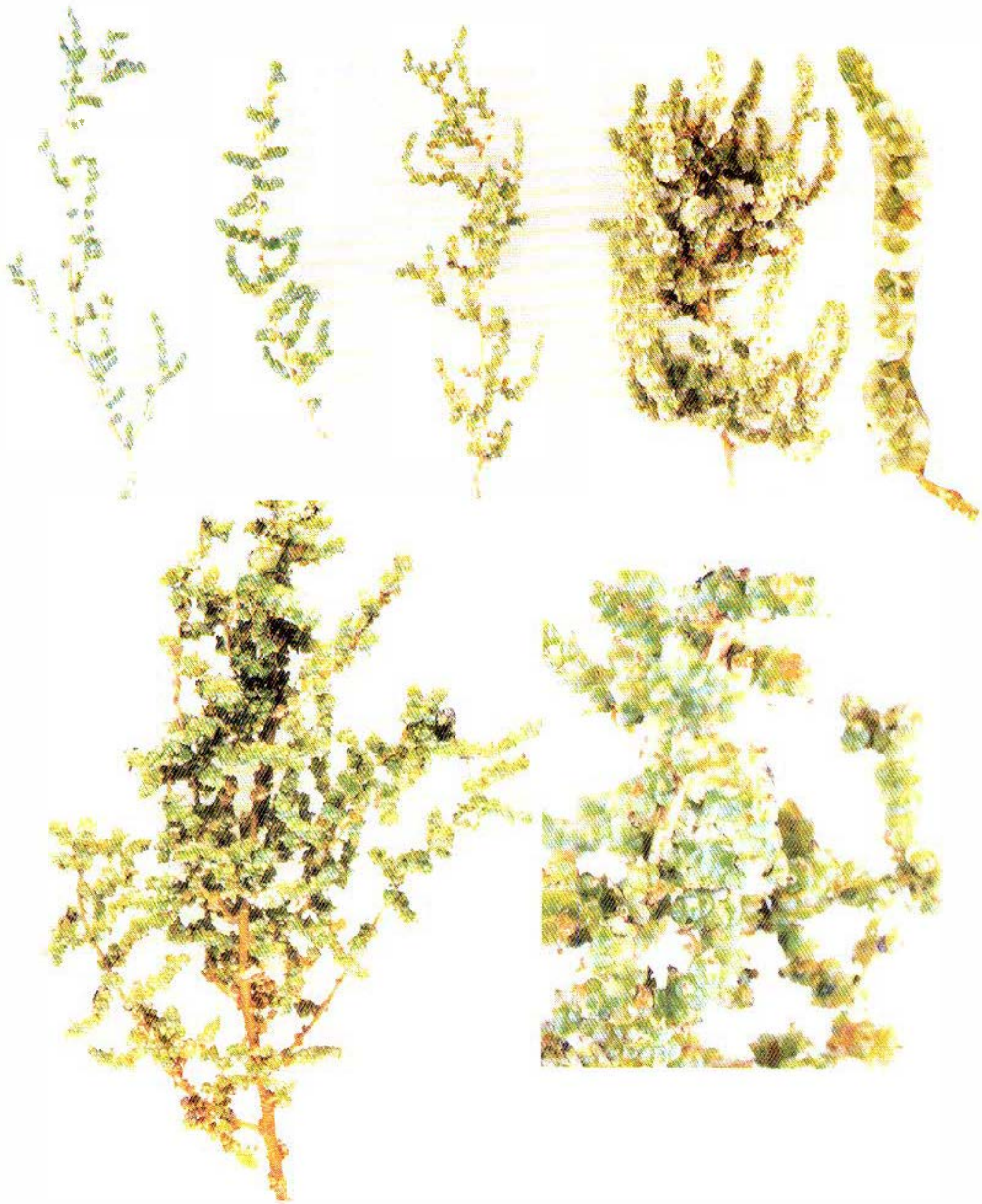


Plate 40. Sterile, flowering and fruiting braches of *Salsola imbricata*.

Plate 41. Dense growth of *S. imbricata* on rocky slopes in Halul Island

Salsola soda L.

Small annual herb hardly reaching up to 15 cm high. Plant succulent, ash-green usually with purple tinge. Leaves sessile, fleshy.

Habitat and Distribution:

Occurs in association with *Avicennia marina* on muddy coastlines in N.E.Qatar at Al-Khor, Al-Dhakhira and Ras Al-Madbakh and rare elsewhere.

Plates 42 and 43.

Plate 42. *Salsola soda*. Note the deep pink colour.

Plate 43. *Salsola soda* individual plants (above); habit at Al-Dhakhira (below).

Genus *Seidlitzia* Bunge ex Boiss.

Seidlitzia rosmarinus Bunge ex Boiss., Fl. Orient. 4:951 (1879).

Syn. *Suaeda rosmarinus* Ehrenb. ex Boiss., pro syn. *Salsola rosmarinus* (Bunge ex Boiss.) Solms, Bot. Zeitung (Berlin) 59:171 (1901).

Multi-basal woody halophytic shrub with soft succulent new shoots. Leaves fleshy, sessile. Inflorescences of small, indistinct flowers. Fruit winged

Seidlitzia is a sand stabilizer and traps sand and debris within its low growth. Large communities occupy the sandy dunes south of Mesiaeed. Elsewhere it is occasional and rarely it could be encountered in abondaned fields and by the shoreline north of Doha City.

S. rosmarinus has been reported as a soap substitute and as a tenderizer for beans with hard seed coats.

Habitat and Distribution

Common on sand dunes south of Mesaieed on barcan sand dunes and sand dunes on the eastern coastline receiving the salty sea spray. Known as excellent sand stabilizer in dunes.

Plates 44 and 45.

Plate 44. A vegetation branch of *Seidlitzia rosmarinus*.

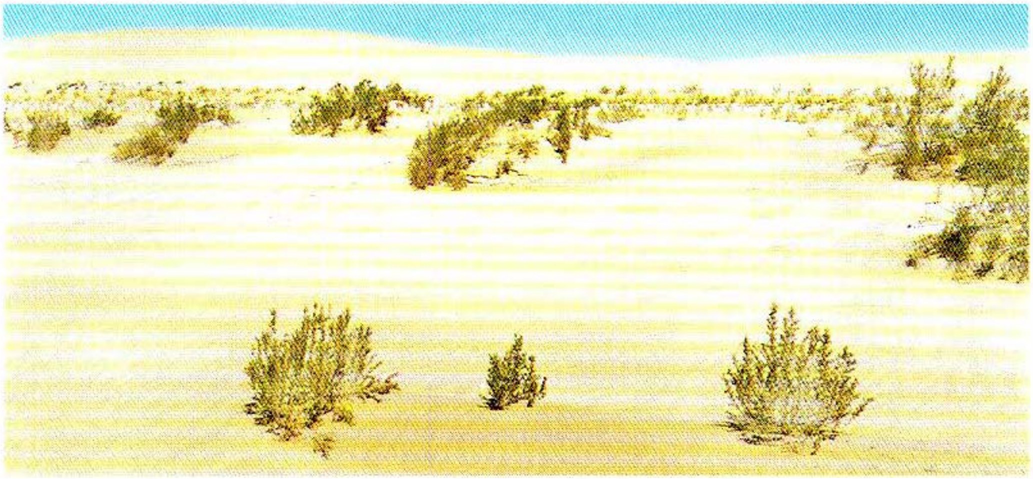


Plate 45. A community with mature shrubs and seedlings on Maesaeed costal dunes [Note standard position of plant growth on the dune].

Genus *Suaeda* Forssk. ex Scop.

The genus *Suaeda* Forssk. ex. Scop. is represented in the local Flora by two species: *S. aegyptiaca* (Hasselq.) Zohary and *S. vermiculata* Forssk. ex J. F. Gmel.

Suaeda aegyptiaca (Hasselq.) Zohary in J. Linn. Soc. 55 : 635 (1957).

Syn. *Chenopodium aegyptiacum* Hasselq., It. Palaest. 460 (1757); *Suaeda baccata* Forssk. 1775:69 (LXIV No.186, Clx No.221; Cent. III No.15); *Schanginia baccata* (Forssk.) Moq.-Tand, Chenopod. Monogr. Enum. 119 (1840); *Schanginia aegyptiaca* (Hasselq.) Aellen in Rechinger, Fl. Lowland Iraq : 195 (1964).

Al-Ikreet (Ar.) الإخريط

Low glossy green succulent bush with woody easily broken leafless older branches. Leaves slightly curved upwards (claw-like), ± terete, succulent, about 2 cm long. Inflorescences long terminal spikes of small green or reddish purple sessile flowers with fleshy calyces drying and decentigrading in fruit leaving behind a bare axis.

Habitat and Distribution:

Common on coastal sabkhas and moist saline soils; occasional in farms and agricultural land with marked soil salinity or water salinity. Frequent on Doha roadsides.

It is apparent from field observations that *S. aegyptiaca* is at its best phase of growth in October unlike other species in the Flora that perform best after the seasonal rains i.e. January-April.

Plates 46 and 47.

Plate 46. *Suaeda aegyptiaca* inforescences (above); unripe fruits (below left), in *Zygophyllum qatarense* community (below right).

Plate 47. General appearance of *Suaeda aegypticea* bushes and close up of shoot

Suaeda vermiculata Forssk. ex J.F. Gmel., Syst. Nat. ed. 13, 2 : 503 (1791).

Syn. *Suaeda fruticosa* Forssk. ex J.F. Gmel., Syst. Nat. ed. 13, 2 : 503 (1791); *Salsola mollis* Desf., Fl. Atlant. 1 : 218 (1798); *Suaeda mesopotamica* Eig., Pal. J. Bot., Jerusalem ser., 3 : 127 (1945).

Suwaid (Ar.) سويد

Subwoody undershrub reaching to heights over 125 cm, usually much shorter and more bushy. Branches many, basal and axillary; older branches woody, new growth soft and succulent. Leaves linear, ash grey green or purple-tinged. Inflorescences terminal and axillary much branched spikes of minute green flowers maturing to soft-floccose units.

Habitat and Distribution:

Coastline vegetation by edge of mangrove forest between the tidal zone and higher grounds. Widespread but more common on the eastern coastline.

Plate 48.

Plate 48. *Suaeda vermiculata* habit with the total parasite *Cistanche phelypaea.*

FAMILY COMPOSITAE

The family Compositae is well represented in the flora of Qatar by a number of genera including the genera *Launaea* and *Pulicaria.*

Genus *Pulicaria* Gaertn.

Pulicaria crispa (Forssk.) Olive. in Grant, Trans. Linn. Soc. London 29. 96 (1876).

Syn. *Aster crispa* Forssk., Fl. Aegypt.-Arab. 150 (1775); *Francoeuria crispa* (Forssk.) Cass. Dict. Sci. Nat. 34 : 44 (1825).

Subwoody low, densely branched aromatic herb; whole plant covered with soft tomentum. Leaves sessile, linear. Inflorescences terminal on slender peduncles; capitula many with minute ray and disc florets. Fruit cypselas with short soft pappus.

Flowers and fruits throughout the year with peak of flowering in spring.

Habitat and Distribution:

Pulicaria crispa is common and widespread occurring in shallow depression, rain pools and rawdats with clayey loamy sandy soils.

Plate 49 (top)

Pulicaria graphalodes (Vent.) Boiss.
Similar to *P.crispa* but extremely woolly and with a more pleasant aromatic smell [cf. *Salvia*].
Habitat and Distribtution:
Less common than *P.crispa* and more tolerant of salinity, occurring in shallow runnels, stony grounds, roadsides and depressions in central and northern Qatar.
Plate 49 (below).

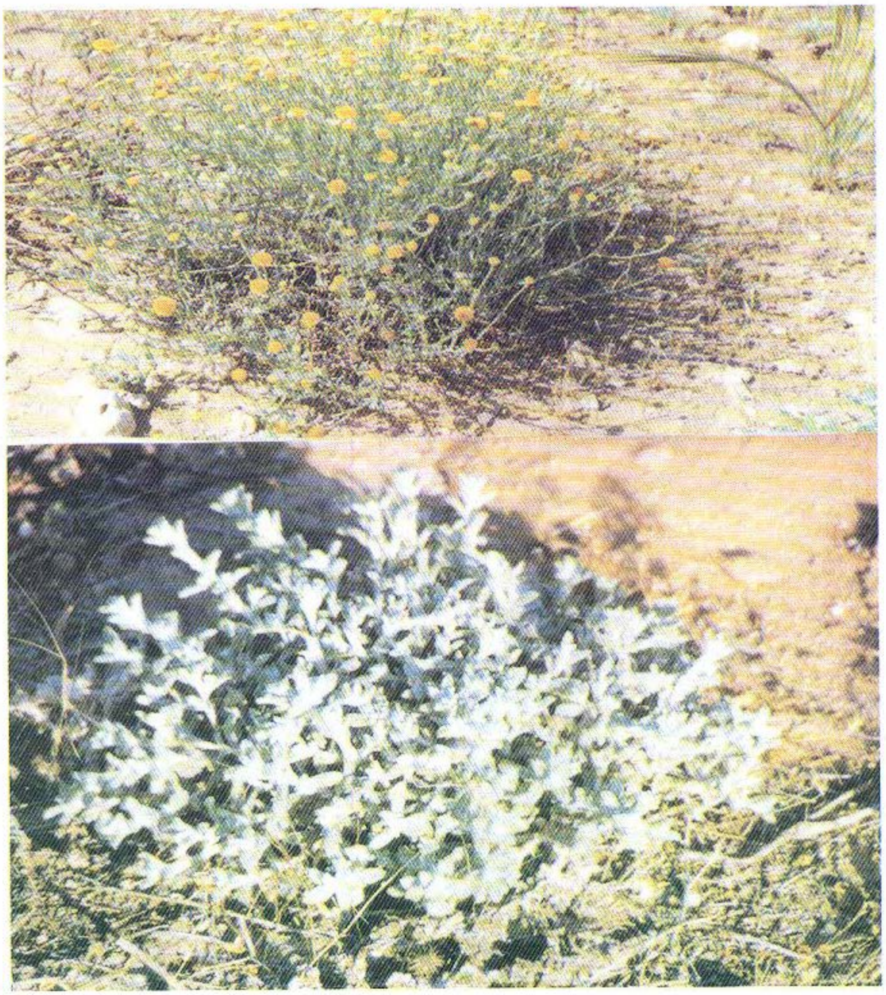


Plate 49. *Pulicaria crispa* (above); *P. gnaphalodes* (below)

FAMILY MENISPERMACEAE

Genus *Cocculus* DC.

The genus *Cocculus* DC. belongs to the family Menispermaceae which is represented by only one species in the local flora.

Cocculus pendulus (J.R. & G. Forst.) Diels in E.P., IV. 94 : 237, Fig. 78 (1910).

Syn. ***Epibaterium** pendulus* J.R. & G. Forst., Char. Gen. : 108, t.54 (1776); *Menispermum leaeba* Del., Fl. Egypt. : 140, t.51, fig. 2-3 (1813).

Kheneig خنيق

Epiphytic liane reaching top of supporting trees and shrubs and spreading over their canopies. Stems coiled, fluted, whitish, fissured. Branches drooping, soft, green. Leaves petiolate, palmately tri-nerved, smaller leaves oblong, older leaves hastate–trilobed, ca.2 cm long. Flowers unisexual, solitary or male and female on cymose fascicled inflorescences. Sepals 3-18; inner whorl imbricate. Fruit small, of 3-6 carpels, fleshy, glossy, orange red.

Habitat and Distribution:

Confined to rawdahs in central and north Qatar with deep fine well drained soils supporting *Ziziphus nummularia* and *Acacia ehrenbergiana* trees which support the lianes.

Plates 50 and 51.

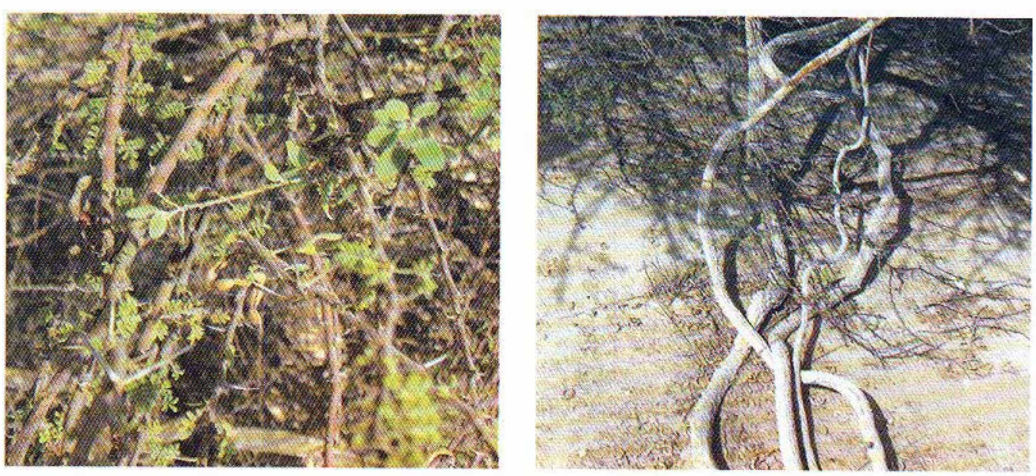


Plate 50. Leaves and lower branches of the epiphytic liane *Cocculus pendulus*.

Plate 51. Liane of *Cocculus pendulus* with twisted stems and spreading top growth over *Acacia tortilis* shrub.

FAMILY PLUMBAGINACEAE

Genus *Limonium* Mill., nom conserv.

Limonium is a member of the family Plumbaginaceae. In the flora of Qatar it is represented by one species only, *L. axillare*.

Limonium axillare (Forssk.) Kuntze, Revis. Gen. Pl. : 395 (1891).

Qataf (Ar.) قطف

Low woody shrub with fleshy leaves. Leaves oblanceolate, crassulate, large, with distinct salt glands, usually basal. Inflorescences hansome much branched; branches of the inflorescences in a tiered-pagoda pattern. Flowers minute appearing rose, pink, deep magenta and white at maturity. Flowers Dec.-May.

Habitat and Distribution :

Widespread on sabkhas and coastlines; usually associated with *Halopeplis* on shelly sandy soils.

Plates 52 – 54.

Plate 52. Leaves with salt glands in *Limonium axillare*.

Plate 53. *Limmonium axillare* flower buds (above); *L. axillare* in full bloom (below).

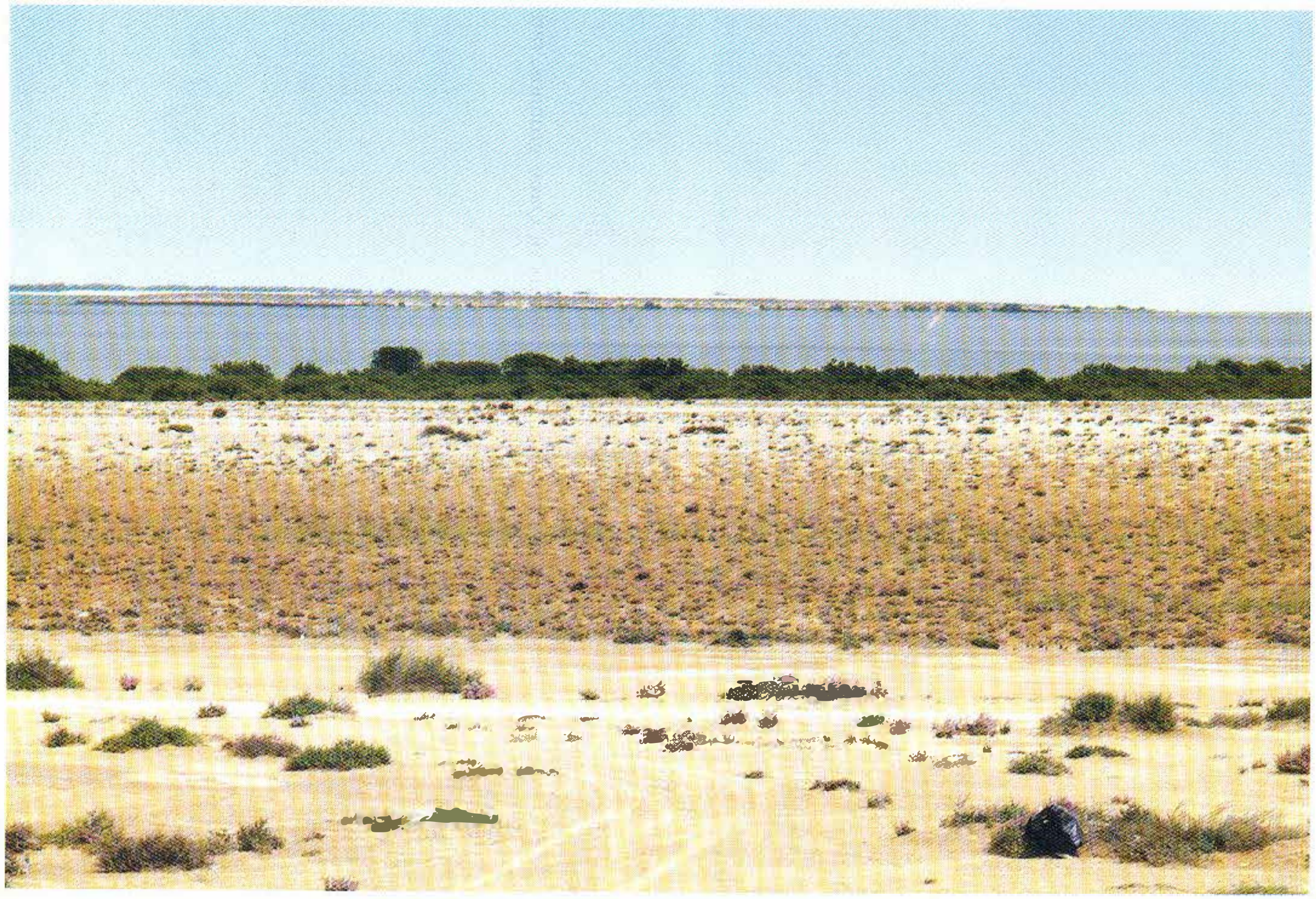


Plate 54. An inner depression with a community of *Limonium axillare* in bloom (Al Dhakhira Nature Park, Spring 2005).

FAMILY RESEDACEAE

Genus *Ochradenus* Delile

The genus *Ochradenus* Delile belongs to the family Resedaceae which is represented in the local Flora by 3 genera: *Ochradenus* Delile, *Oligomeros* Cambess. and *Reseda* L. The 2 former genera with one species only wherecasas *Reseda* is represented by two species.

Ochradenus baccatus Delile, Descr. Egypte, Hist. Nat. 63 (1814).

Kardi (Ar.) قرضي

Densely branched bush appearing dome-shaped with long green ± leafless branches; crown not exceeding 2 m spread and up to 1-1.5 m high. Plant dioecious or very rarely unisexual, monoecious. Inflorescences simple spikes (rarely pedicellated) of small yellow flowers; male flowers yellow, at anthesis producing large amount of pollen attracting flies, bees and various other insects feeding on the pollen; female flowers producing white oval berries about 1 cm long with black seeds on ± sweetish pulb always eaten by birds.

Habitat and Distribution:

Common in Doha in disturbed areas. Widespread on University of Qatar grounds, rare in rodats and usually occurs under *Acacia* trees on fine to stony-sandy soils.

Unlike most desert plants which flower after the seasonal rains, *Ochradenus baccatus* flowers all year round.

During a study on the vegetation of Qatar (Abufatih *et al*. 2001), the plants were noted to vary in growth whether they are growing in an exposed location (erect, leafless, shrubs, many-stemmed) or hidden under shade of trees such as *Acacia tortilis* where they become scandent shrubs with leafy softer shoots.

Wolfe and Shmida (1995) in a study on sexual dimorphism on this species reported that of the male plants representing 35%, were solely (pure) males whereas 65% were inconsistent males bearing staminate and pistillate flowers on the same plant (i.e. unisexual, monoecious).

Ochradenus baccatus is a known dioecious plant with female and male plants. Plants examined in the field were found to be either females, males or basically males carrying also female flowers.

Plate 55.

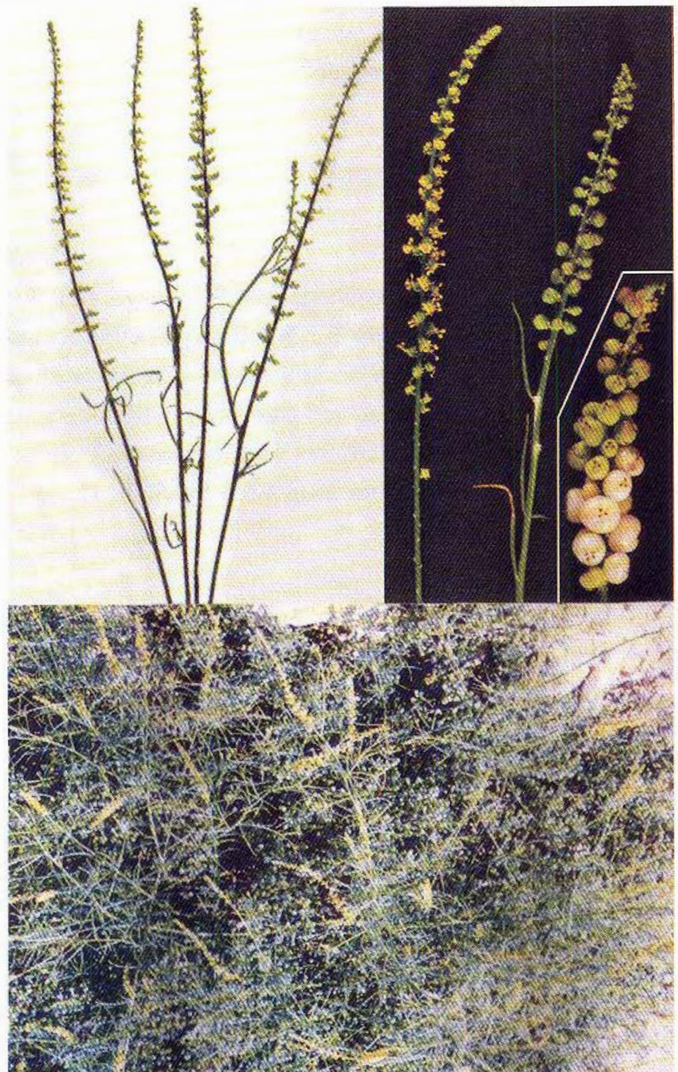


Plate 55. *Ochradenus baccatus* Delile: male inflorescence (above, L.H.S) and female inflorescence (R.H.S); flowering bush (below).

FAMILY RHAMNACEAE

Genus *Ziziphus* Mill.

The genus *Ziziphus* belongs to the family Rhamnaceae represented by only this genus in the flora of Qatar.

Ziziphus nummularia (Burm. f.) Wight & Walk, Arn. Prodr. 162 (1834).

Syn. *Rhamnus nummularia* Burm. f. Fl. Ind. 61 (1768).

Sidir (Ar.); Kanar, Nabag (Ar.) for fruits. سدر ; كنار و نبق (ثمار)

Armed perennial stout woody trees or rambling shrubs reaching up to 3.5 m high or more but usually stunted by extensive over grazing forming low thickets of dense growth. Branches zigzaging with alternate stipulate leaves. Stipules a pair of spines: one erect and the second down-curved. Leaves ovate-orbicular, palmately 3-nerved, glabrous and shiny above, dull green and tomentose beneath; ± 1-2 cm long; smaller leaves may be produced on lower tree trunks by activated buds in response to extreme stress. Inflorescences a fascicle of greenish yellow discoid small flowers with a distinct strong fruity smell attracting many insect pollinators. Flowers with 5 symmeterical petals and 5 distinct alternating stamens. Fruit a spherical orange drupe ± 1 cm across bitter or sweet, edible and usually infested with insect larvae (eggs laid during flowering in ovaries). Flowers and fruits Dec.- May.

Habitat and Distribution:

In rawdahs with deep fine soils indicative of proximity of the water level and deep depressions with seasonal flooding. More common in central and north Qatar and is a much favoured heavily grazed plant by all animals in particular camels and goats.

Plates 56 and 57.

Plate 56. Rawdat with *Ziziphus nummularia* trees.

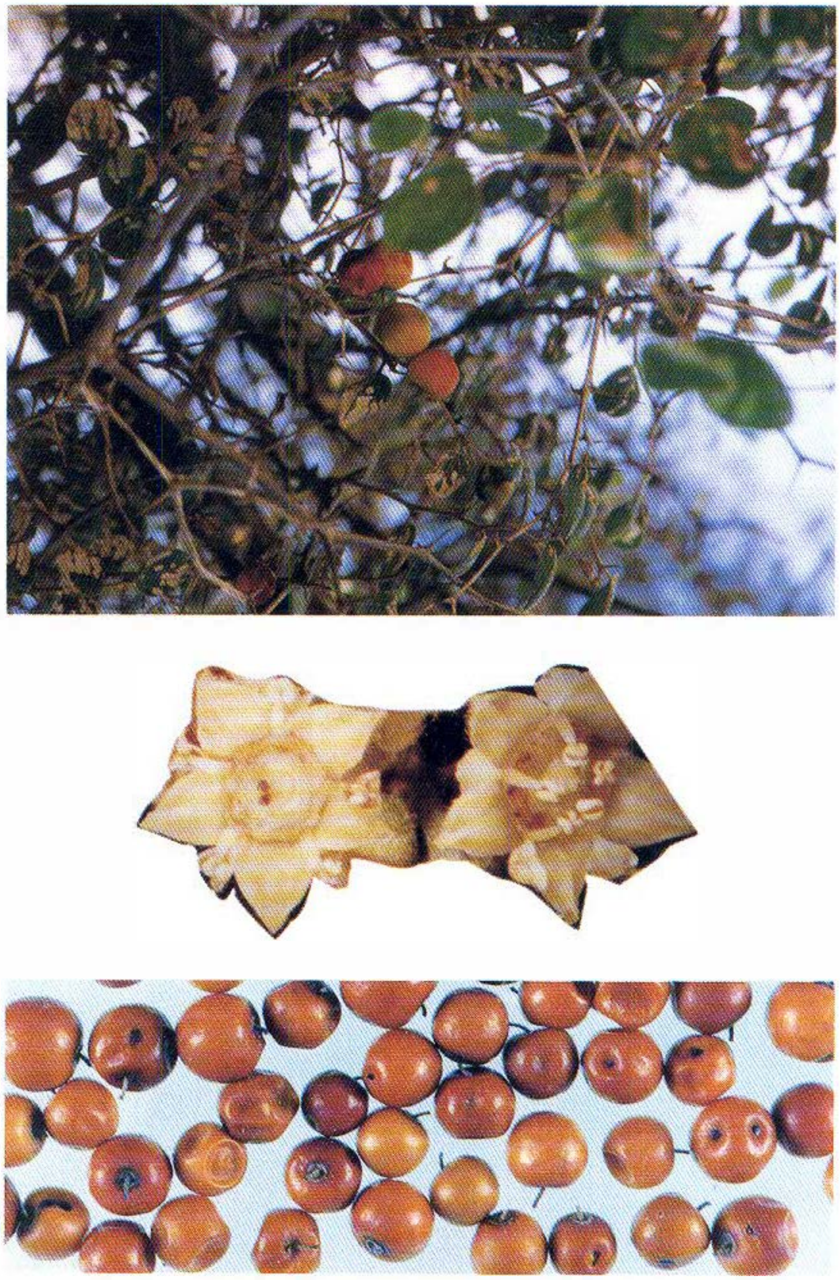


Plate 57. *Ziziphus nummularia*, fruiting branches flowers and ripe fruits.

FAMILY ZYGOPHYLLACEAE

Genus *Zygophyllum* L.

Zygophyllum qatarense Hadidi, in Boul., Webb. 32, 2:394 (1978).

Low spreading bush with more or less fleshy terminal branches; Bases hard and woody. Leaves succulent, usually simple, rarely bifoliate [where moisture is available], petiolate; petioles terete, fleshy. Inflorescences solitary on short peduncles. Flowers slender, pale yellow. Fruit elongated pale berries and splitting longitudually. Flowering Mar.-Apr.

Habitat and Distribution:

Z. qatarense is by far the most common undershrub, occurring on rocky and sandy grounds throughout the country and is widespread in all disturbed areas including the coastline. It covers extensive grounds in the State of Qatar *Z. qatarense* can grow on saline soils but appears greatly stressed if the sabkha is not overlaid with sandy soils e.g. as in Dukhan's sabkha.

Plates 58-60.

Plate 58. Colour variation in *Z. qatarense*.

Plate 59. *Zygophyllum qatarense* habit (above); branch with fleshy leaves and petioles (below).

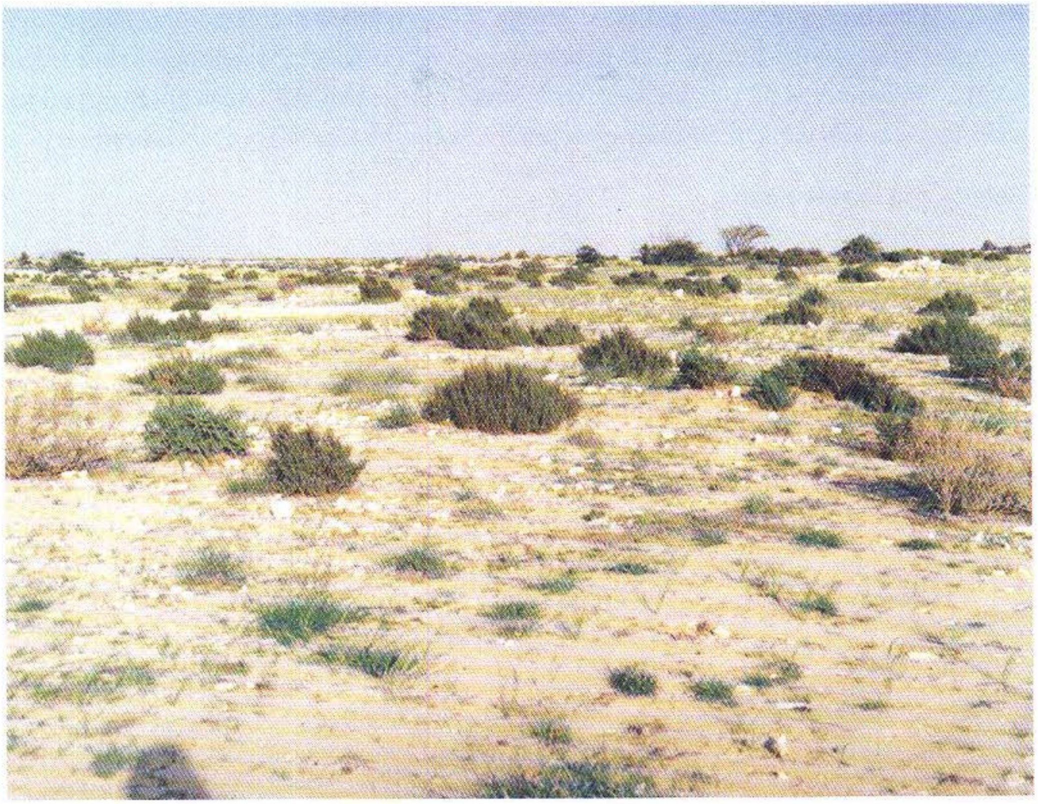


Plate 60. *Zygophyllum qatarense*. A community with bush growth after the seasonal rains en route to Umm Bab.

FAMILY: GRAMINEAE = POACEAE; Sub-Family: Chloridoideae; Tribe: Eragrostideae; Sub-Tribe: Monanthochoinae

Genus *Aeluropus* Trin.

Aeluropus lagopoides (L.) Trin. ex Thw., Enum. Pl. Zeyl: 374 (1864)

Syn. *Dactylis lagopoides* L., Mant. 1:33 (1767).

Shirraib/Iqrish/Ikrish (Ar.) شريب ، عكرش

Prostrate trailing perennial rigid grass giving off upright short culms up to 15 cm high terminating in inflorescences. Leaves distichous, with small blades ending in sharp rigid points. Inflorescences 1-3 cm long with small congested and overlapping spikelets, short spicate–sub-capitate broadly pyramidal – sub-orbicular. Caryopsis minute.

Habitat and Distribution:

Two forms are reported (Chaudhary, 1989): var. *lagopoides*, a softer plant to the touch and var. *mespotanica* (Nab) Bor, a more rigid pungent plant. Locally, the rigid variant is more common on littorial salt marshes (coastal highly saline soils) whereas the softer variant is common on wind blown sands along roadsides and as a weed of cultivation on partially saline soils.

Plates 61 and 62.

Plate 61. *Aeluropus lagopoides* on sandy mound.

Plate 62. *Aeluropus lagopoides* habit with inflorescences; (above); *A. lagopoides* community on saline soils (below).

FAMILY: GRAMINEAE = POACEAE; (The Genus *Sporobolus* R. Br. belongs to Sub-Family: Chloridoideae) Tribe: Eragrostideae; Sub-Tribe: Sporobolinae

Genus *Sporobolus* R.Br.

The genus *Sporobolus* is represented by two species in the flora of Qatar.

Sporobolus ioclados. (Nees ex Trin.) Nees, Fl. Afr. Aust. 161(1841).

Syn. *Vilfa arabica* (Boiss.) Steudel, Syn. Pl. Glum. 1 : 421 (1855).

Sukham (Ar.) صخام

Perennial grass forming tough circular mats usually with no central growth, reaching over 50 cm high, usually less. Inflorescences terminal open pyramidal panicles of slim spikelets, up to 2.5 mm long, spikelets falling at maturity leaving behind the persistent glumes.

Flowers during February-April.

Habitat and Distribution:

Most dominant grass species of coastal depressions forming pure stands or communities associated with *Aeluropus lagopoides* on soft saline sands and sandy stony grounds. Not known to spread on inland areas.

Plate 63a

Sporobolus spicatus (Vahl) Kunth, Rev. Gram. 1:67 (1829).

Syn. *Agrostis spicatus* Vahl, Symb. Bot. 1 : 9 (1790).

Sukham (Ar.) صخام

Pale yellow-green short tufted perennial stoloniferous grass. Basal growth arising from the branched stolons is leafy rigid spiky and pungent leaf-blades. Culms slender terminating in very slender spicate inflorescences. Spikes long narrow with minute clustered spikelets all along inflorescence axis. Caryopsis ellipsoidal.

Habitat and Distribution:

A very common grass flowering throughout the year where moisture is available in cultivated and arable lands, in sewage disposal localities, near residential areas, etc. Less common in the wild where *S. ioclados* dominates saline habitats.

Plate 63b.

Plate 63a. *Sporobolus ioclados* community on hard saline soils (above); *S. ioclados* as a sand trapper (below).

Plate 63b. *Sporobolus spicatus* growing in furrows in an abandoned field, North Qatar.

6 Anatomical Investigation

6.1 Introduction

The use of external vegetative and floral characters in plant studies is as ancient as the plant sciences and continous to be utilized because of their relative ease in study and vouchering. These characters include all parts of the plant body including hair.

The use of indumention (hairs) in particular trichomes in taxonomic studies is well docmumented and has been specifically useful in studies of the family Cruciferae and the family Boraginaceae, the latter with bulbous-based hairs. Midi-fixed hairs are an important character in distinguishing taxa at the generic level in the family Fabaceae.

The use of anatomical characters on the other hand, developed and expanded with the invention and modifications of the microscope and later on with the invention and advancement of the electron microscope. Moreover, relating anatomy to ecology and physiology is comparatively of more recent application. The use of anatomy to explain modifications and adaptations to environmetal conditions and stresses is still at its prime. Many queries relating to plant behaviour have been successfully cleared by the investigation of the plants' internal structures.

Variations in the internal structures of both leaves and stems can be utilized in the classification of taxa and the determination of their habitats or growth conditions.

The internal structure of succulent plants is on the other hand instrumental in verifying the plants' adaptations to both salinity and aridity and in fact it illustrates how these plants cope with stresses in extreme conditions.

Members of chenopods occupying local saline coastlines are succulent perennials except for *Salsola soda* (an annual). They are characterized by their distinctly jointed stems, sessile fleshy leaves or rudimentary leaves clasping the stems and much branched inflorenscences with dense and minute greenish flowers forming minute fruits (nutlets) usually surrounded by persistent calyces. These become papery and aid in dispersal. Generally, succulent plants cover a wide range of taxomonically diverse groups of plant species.

6.2 Materials and Methods

Samples selected for anatomical studies were preserved in acetic alcohol and kept refrigerated. For anatomical investigations the standard methods of permanent slides preparation in wax embedding was followed. Commercial prepared slides were also used for clarifications and comparisons.

Prepared slides were examined using the light microscope and photographed using a digital camera fitted to the light microscope. Commercial prepared slides include *Elodea*, *Hakea*, *Nerium*, *Nymphaea*, and *Sedum*.

The plant species chosen for sectioning belong to 5 categories:

- Typical mangrove represented by *Avicennia marina*.
- Typical halophyte represented by *Halocnemum strobilaceum*.
- Halo-xerophyte represented by *Limonium axillare*, *Anabasis setifera* and *Salsola imbricata*.
- Typical xerophyte represented by *Leptodenia pyrotechnica*.
- Salt-tolerant annual represented by *Cressa cretica*.

6.3 Results and Discussion

The internal structure of chenopods [Watson and Dallwitz (1995)] forms the basis of some of the most interesting forms of anamolous secondary growth via concentric cambia. In many, cork cambium is present and corky surfaces are hense a common feature in older stems that become exposed once they lose their fleshy leaves. Anatomy C_4 type has been found in *Anabasis, Atriplex, Salsola and Suaeda*. These plants cope with stresses in extreme conditions.

6.3.1 The Chenopodiaceae

The Chenopodiaceae is a dicotyledonous family of the order Caryophyllales widespread in temperate to sub-tropical areas. Most members of the family are herbaceous and rarely shrubs but the majority are halophytes of saline habitats characteristic of sea coastlines or are agricultural weeds.

The family Chenopodiaceae bears much resemblance to the Amaranthaceae and both are members of the Centrospermae. However, the Amaranthaceae is not a family considered as displaying succulence whereas chenopods are common succulent halophytes widespread along the coastlines of subtropical zones.

The family Chenopodiaceae is represented in the flora of the State of Qatar by 22 species belonging to 14 genera. As such, species number within the genera are quite low with most genera represented by one or two species only (Batanouny, 1981).

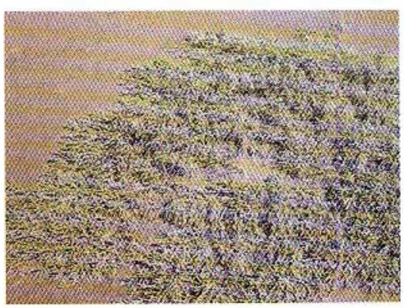
The genus *Salsola* however, has the highest number of species [5] and includes *Salsola imbricata* the most widespread taxon in all major cities of the country.

The Chenopod species in this study include 10 species (Plates 64 a, b):

- *Salsola imbricata* (xerophyte)
- *Salsola soda* (halophyte + intertidal zone)
- *Suaeda aegyptiaca* (inland + coastal)
- *Suaeda vermiculata* (mainly coastal)
- *Seidlitzia rosmarinus* (coastal)
- *Anabasis setifera* (xeroplyte + coastal)
- *Arthrocnemum macrostachyum* (coastal)
- *Halocnemum strobilaceum* (coastal)
- *Halopeplis perfoliata* (coastal)
- *Haloxylon strobilaceum* (inland + xeroplyte)

Arthrocnemum macrostachyum

Salicornia europaea

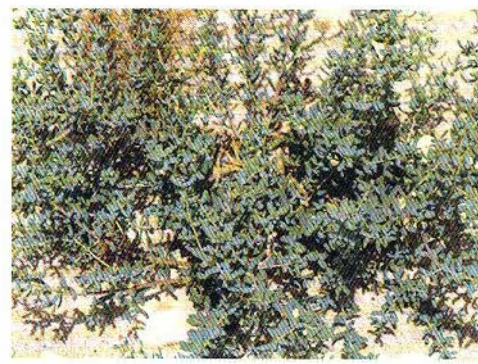


Halocnemum strobilaceum

Plate 64a. Common chenopods.


Salsola imbricata

Sueada aegyptica



Suaeda vermiculata

Salsola soda

Plate 64b. Common chenopods.

A multiseriate epidermis with sunken stomata, a hypodermis followed by layer of palisade cells are common features in stems of xerohalophytes. Water-storage parenchyma cells fill the central region and branches of vascular bundles as well as a central vascular cylinder have been reported in the stem of *Anabasis articulata* [Fisher *et al.*, (1997)].

"Suaedoid type" of leaf anatomy is characterized by the presence of a mesophyll made up of palisade parenchyma plus a chlorenchyma layer surrounding a central water storage tissue. The genus *Suaeda* comprises halophytic leaf succulents of saline, moist habitats. *Suaeda* species also comprise both C_3 and C_4 plants. The C_4 plants tend to have a cylindrical chlorenchyma sheath surrounding the central water-storage tissues.

This has been observed in the succulent leaves of *Salsola* and *Suaeda*. In *Arthrocnemum macrostachyum* there is a small central cylinder with anastomosing vascular bundles. Moreover, water storage tissues are common in the cortex and pith of succulent plants.

6.3.2 Fleshiness / Succulence

Plants living in deserts or on saline soils display certain morphological, anatomical and physiological characters to cope with salinity and/or aridity. Mostly, they develop water storage cells in their plant body hense resulting in fleshines. Water storage is a feature shared by many halophytes and succulence is a feature common in chenopods, mesenbryanthemums, etc. of saline habitats (Plate 65). Succulence indicates water storage tissue which might be in a system of canals or in water storage cells, hydathodes, or in cavities of various forms.

Plate 65. *Mesembryanthemum* sp. in bloom with succulent shoots.

Halophytes of saline soils have usually a uniseriate, thin-walled epidermis but their palisade cells and their parenchyma cells are large and store water e.g. *Salicornia* species; hence the fleshy appearance of the plant.

Chenopods coping with salinity and/or aridity are succulents. Succulence may be a feature of the whole plant or only confined to the stems and/or leaves. Succulence is also displayed in xerophytes and xero-halophytes such as *Salsola imbricata*, *Anabasis setifera* and *Zygophyllum qatarense*.

Occassionly succulence is portrayed only at the seed stage as in *Sclercephalus arabicus*, a common ephemeral with spiny fruits of stony grounds (Plate 66). Perhaps, this is an adaptation to cope with stress at its initial critical stage of development when moisture is vital for the plant's survival [Arid lands are characterized by erratic and scanty seasonal rains].

Plate 66. *Sclercephalus arabicus* habit.

Internally, water storage cells are clear and may occupy areas such as the central zone of stems or periery of leaves.

Water storage cells are large parenchyma cells filled with clear cell sap or mucilage and may be found in leaves, stems, or even roots (Plates 67 and 68). It is evident that water storage cells are a main feature of succulent halophytes

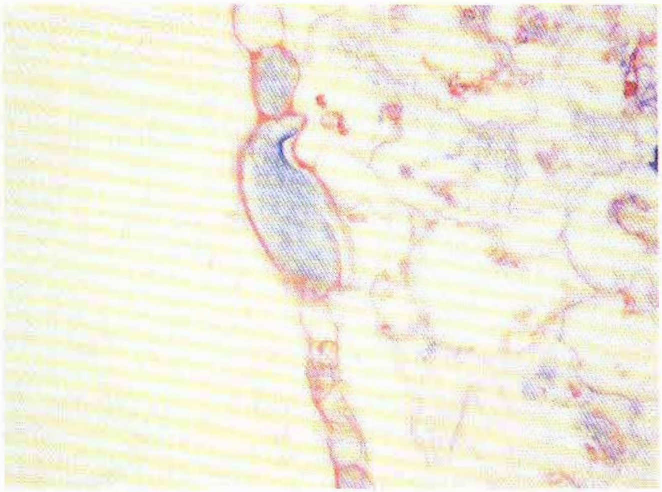


Plate 67. Mucilage vesicle cells in the epidermis T.S. *Sedum* leaf and water storage tissue.

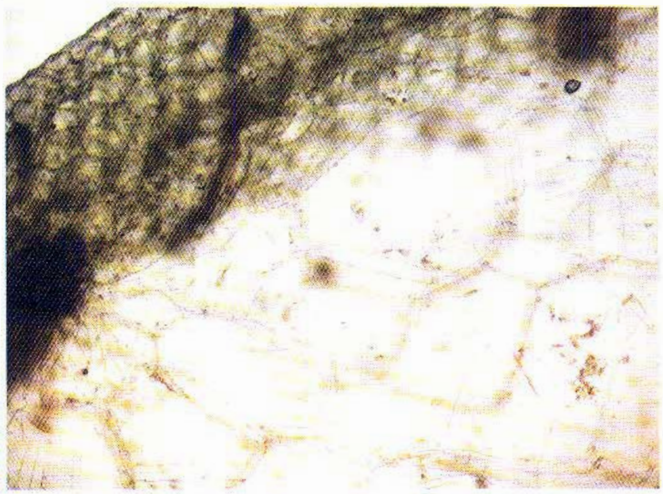


Plate 68. Water storage tissue in T.S. *Aloe leaf.*

6.3.3 Aerenchyma

These are "air cells" ie. structures that are occupied by air. They are a common feature of aquatic, and swamps plants. They are common in *Avicennia marina* (Plate 69) and also in typical aquatic plants such as *Nymphaea* and *Elodea* (Plate70). These supply the plant with the main element that is deficient in an aquatic medium i.e. air.

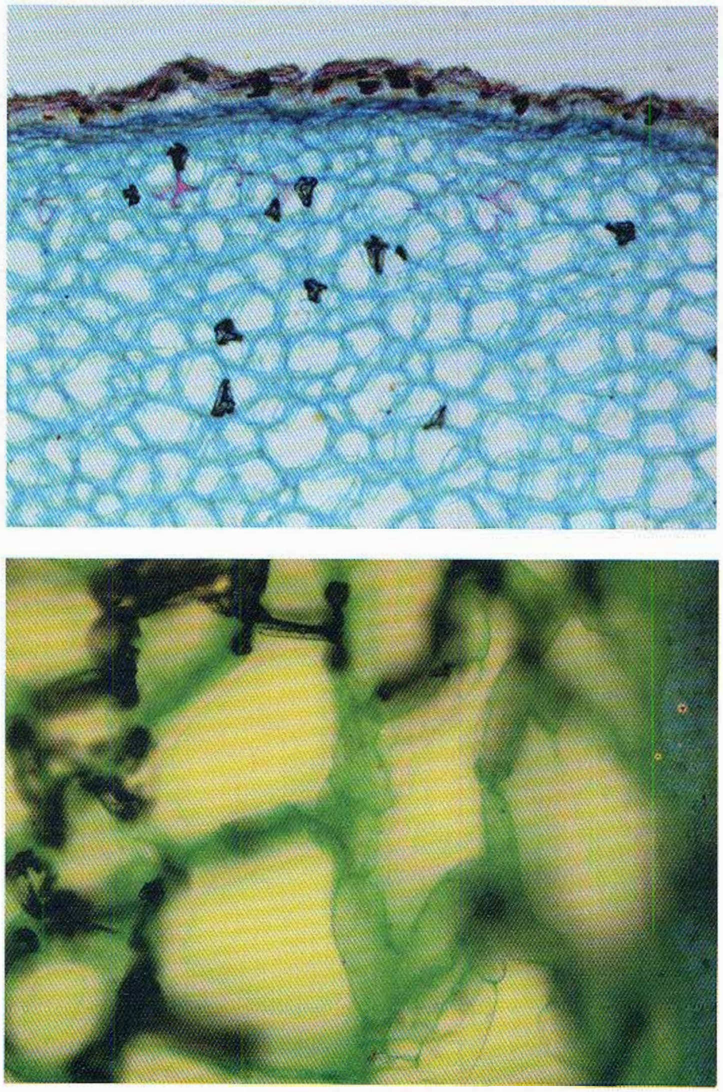
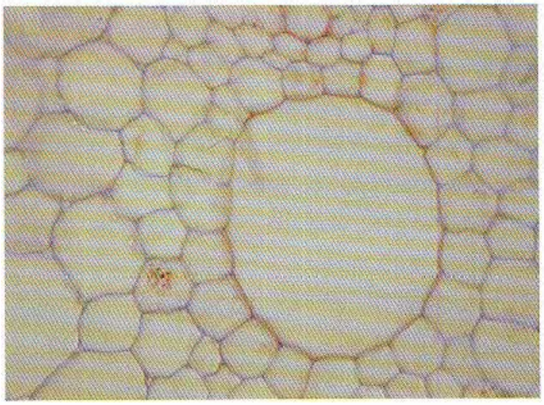
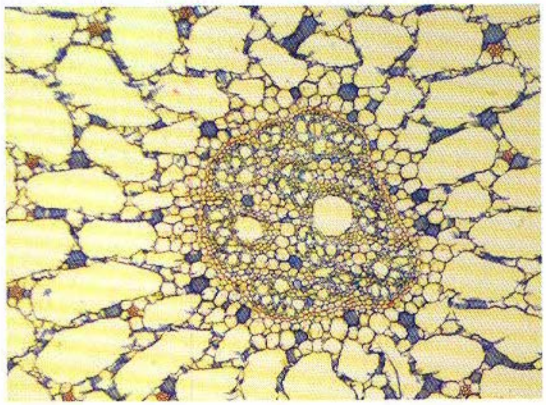


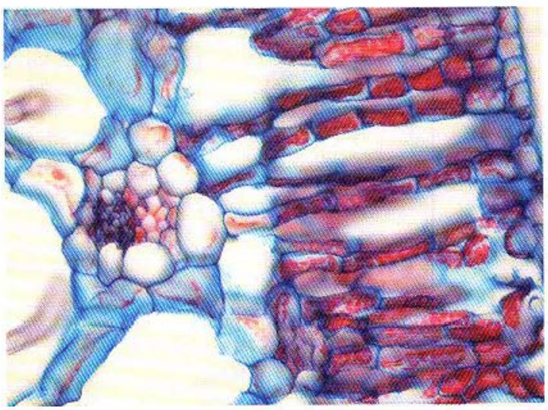
Plate 69. Aerenchyma cells in T.S. stem of *Avicennia marina.*



Elodea

Nymphaea





Nymphaea

Plate 70. Air spaces in the aquatic plants *Elodea* and *Nymphaea*.

6.3.4 Photosynthetic tissue

In typical xerophytes of semi-arid lands eg. *Hakea* and *Leptadenia pyrotechnica*, there are a number of morphological and anatomical features illustrative of adaptations to aridity. The leaves may be minute and deciduous and the branches are slender, green and photosynthetic as in *L. pyrotechnica*. *Nerium oleander* leaves are large and lanceolate and are always quoted as possessing typical anatomical features of xerophytic plants with the presence of crypts on the lower epidermis with sunken stomata (Plate 71).

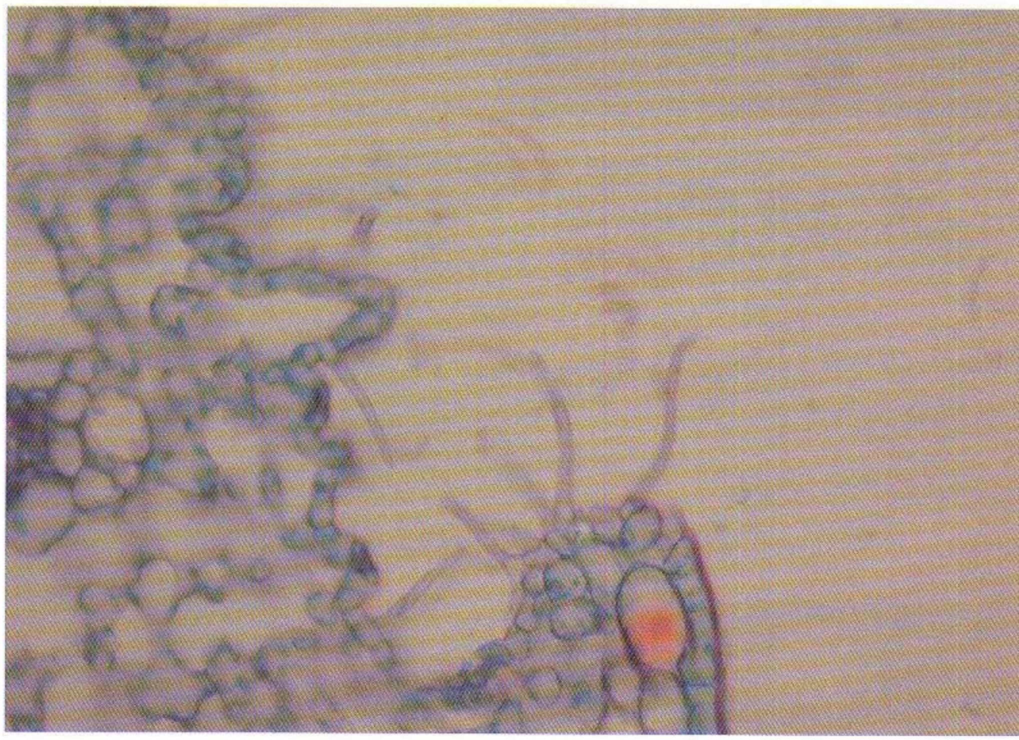


Plate 71. T.S. *Nerium* leaf showing crypts with sunken stomata.

Internaly, in *L. pyrotechnica* the epidermal layer is followed by a ring of collenchyma cells providing mechanical support to the slender branches and, a ring of chlorenchyma cells which are the seat of photosynthesis. Beyond these 3 layers of comparatively soft tissues, lies scattered fibre bundles within parenchyma tissue. Secondary growth is abnormal and is well illustrated by interxylary bundles of secondary phloem (Plate 72). The secondary xylem has a large number of xylem rays. The pith is narrow and the primary xylem is distinct. In *Hakea*, the palisade is formed on 3 layers (Plate 73).

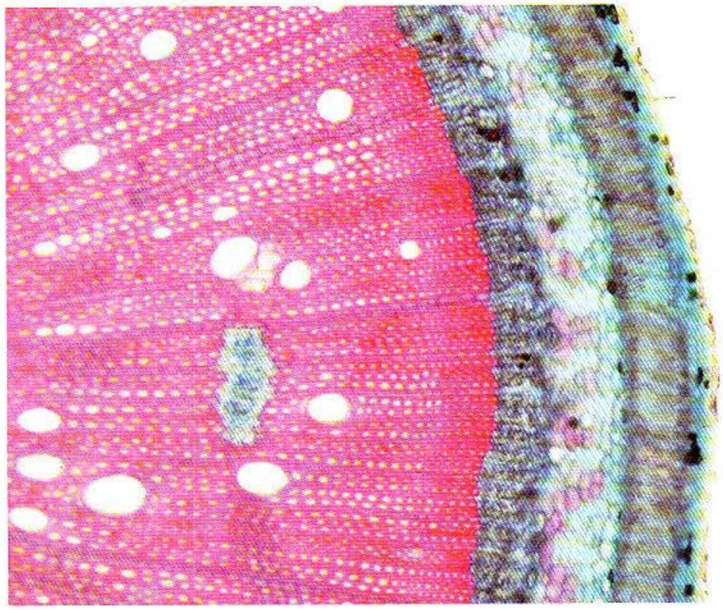


Plate 72. T.S. in *Leptadenia pyrotechnica* stem showing abnormal secondary growth with interxylary phloem and a chlorenchyma sheath on the cortical zone.

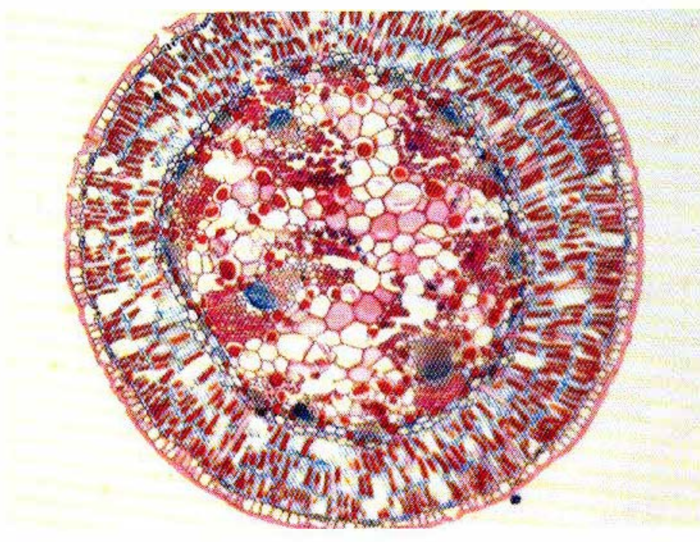


Plate 73. T.S. *Hakea* stemshowing thick zone of palisade tissue.

The examined chenopods are with various shades of green. *Anabasis setifera* is pale light green whereas *Arthrocnemum macrostachyum* is of a much deeper green colour. By colour one can distinguish between the two most common almost identical sabkha plants: *A. macrostachyum* and *Halocnemum strobilaceum*.

Most of the halophytes in this study have rudimentary leaves and usually they possess fleshy internodes. Internally the position of the chlorophyll containing cells differs (Plates 74 and 75).

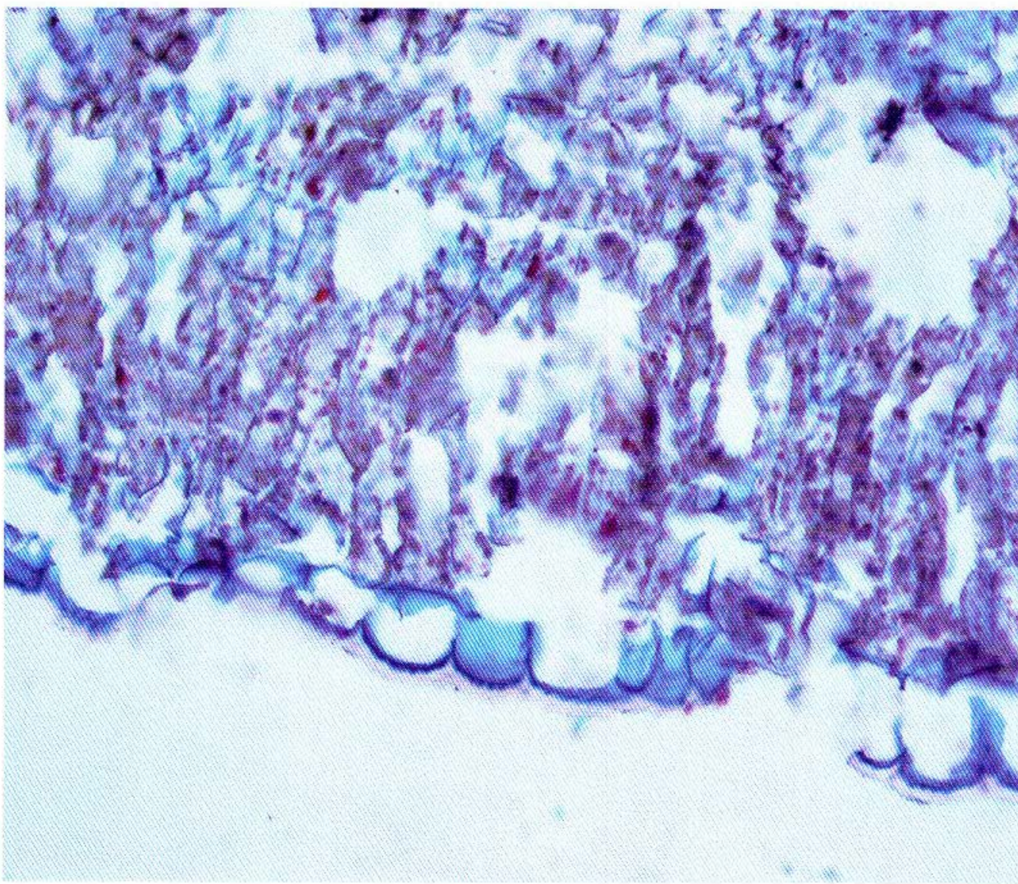


Plate 74. T.S. *Anabasis setifera* leaf with wide zone of mesophyll.

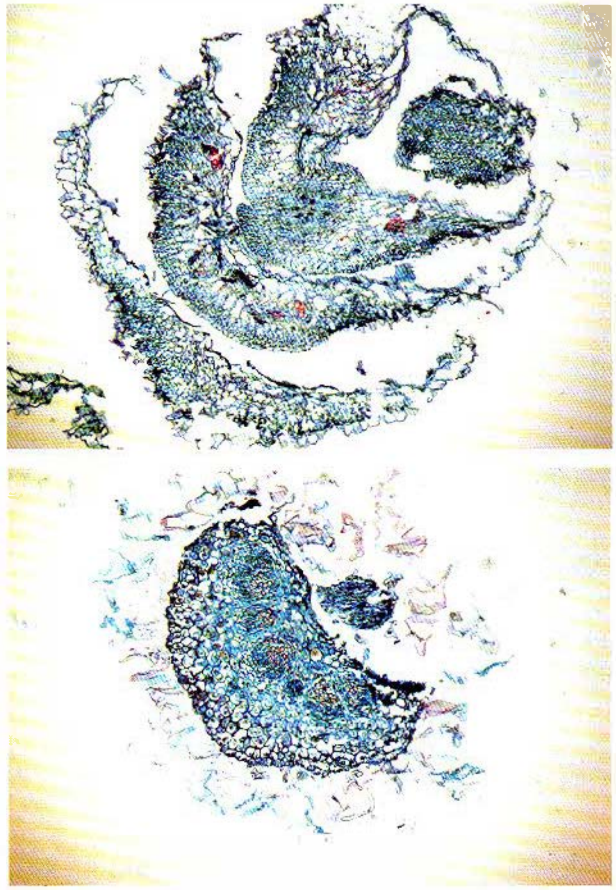


Plate 75. T.S. in *Salsola imbricata* showing congested rudimentary leaves clasping a central axis (above) and T.S. in *Anabasis setifera* leaf (below).

6.3.5 Pneumatophores

Mangroves are tropical and require climatic conditions appropriate for an evergrowing state. The distribution of mangroves will therefore depend on the locations of hospitable shores. Most mangroves species have a wide range of distribution but no particular speices is pantropical in its distribution. Mangroves have always occupied tidal habitats in the Tropics and have retained constant biological adaptation.

Tomlinson (1986) has categorized the known mangroves species into two groups based on their geographical distribution (latitudinal and longitudinal). These he termed the Eastern Group and the Western Group.

The genus *Avicennia* is represented by 8 speices 5 of which belong to the Eastern group (*Avicennia alba*, *A. eucalyptifolia*, *A. lanata*, *A. marina* and *A. officinalis*). *Avicennia bicolor*, *A. germinans* and *A. schaveriana* belong to the Western group. ***Avicennia marina*** is the local mangrove species and is widespread over the whole of the longitudinal and the latitudinal ranges specified for the Eastern Group. It is widespread on the Arabian Gulf coastline and on the coastlines of some Gulf islands. Plants such as mangroves living in sea waters tend to develop aerial roots with lenticels for gaseous exchange. Externaly. pneumabophores are upright, corky and spongy; internally, they are made up of arenchyma cells with air filling their spaces (Plate 76).

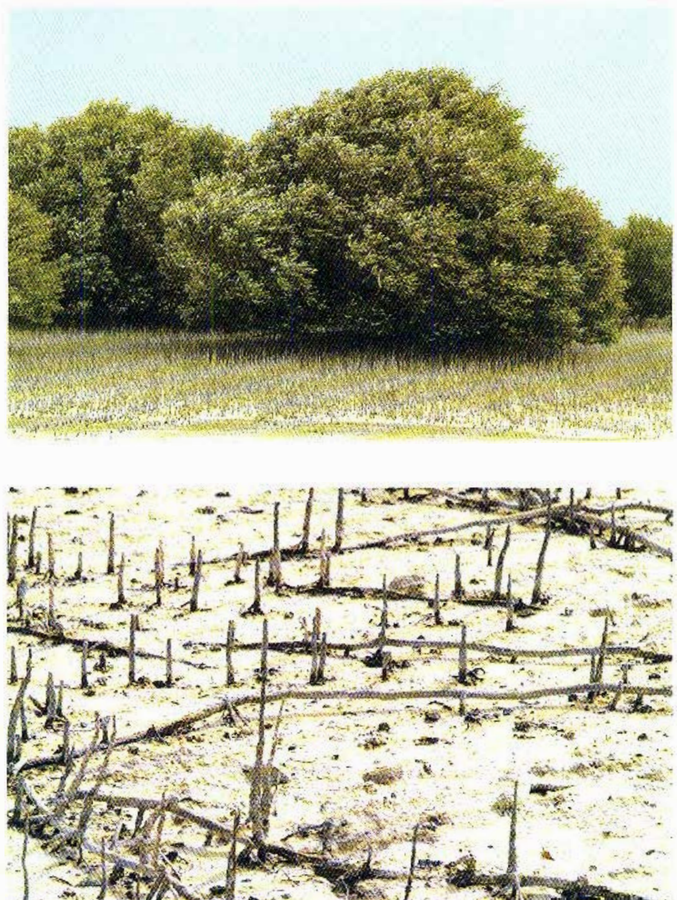


Plate 76. Pneumatophores in *Avicennia marina* [Note cable network of the aerial roots].

6.3.6 Salt glands and crystals

Plants of saline habitats also tend to develop a sound excretory system to rid the plant of excess salts. Salt glands are not uncommon on leaf surfaces of salt tolerant plants. *Avicennia*, *Atriplex*, *Limonium* and *Tamarix* possess salt glands. Visible salt crystals are common on leaves of *Limonium axillare* (Plate 77).

Plate 77. Salt glands on *Avicennia marina* (above) and salt on leaves of *Limonium axillare* (below).

In *Tamarix* leaves, the salt glands are of a group of secretory cells which lie in a depression in the epidermis surrounded by collecting cells. Yet another common feature is the presence of vesiculate hairs in *Atriplex*.

Aquatic plants and halophytes tend to have various inclusions such as mucilage, crystals, sclereids, etc. Crystals include raphides and druses. Chemical analysis of chenopods has proved the occurrence of free oxalates in most species (Plates 78 and 79).

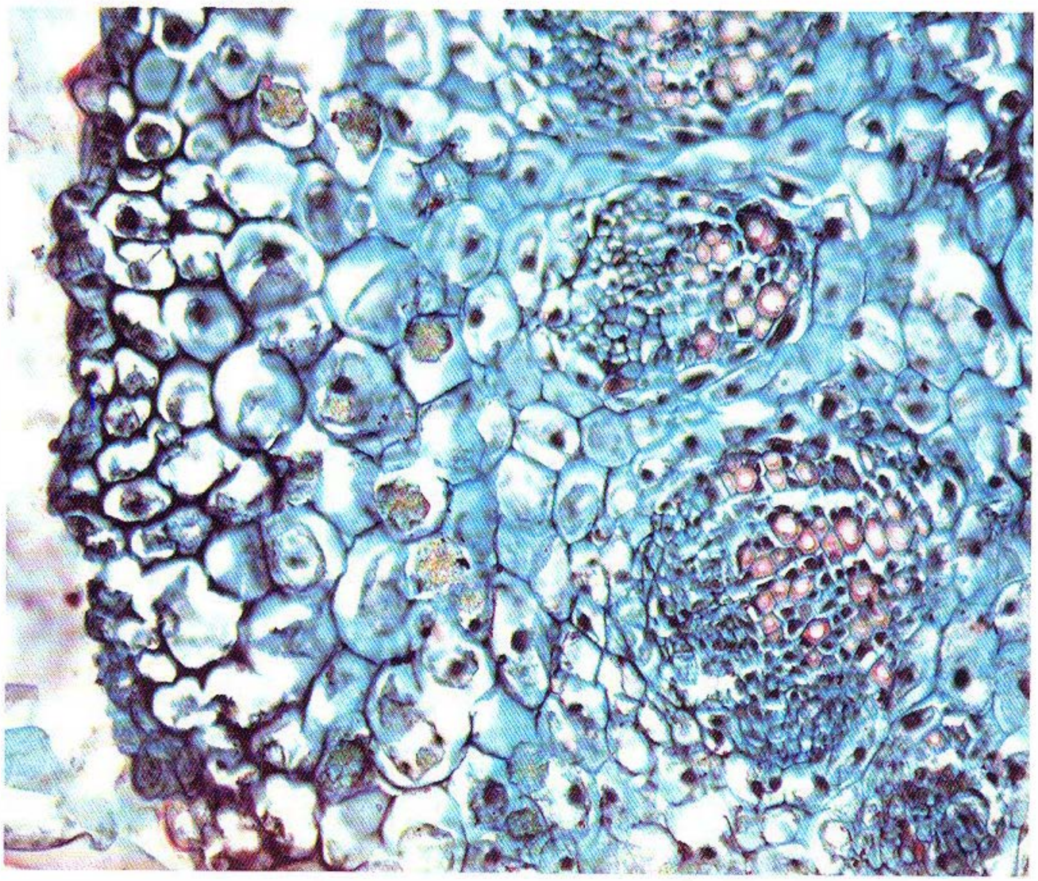


Plate 78. Crystals (Druses) in *Anabasis setifera* T.S. leaf.

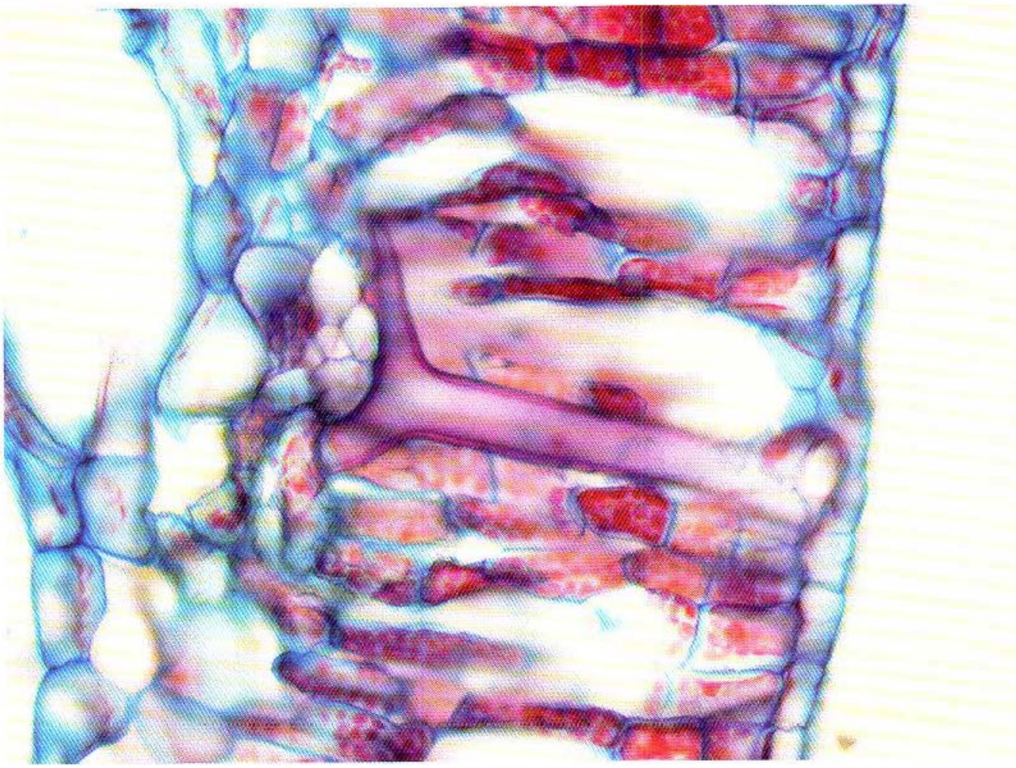


Plate 79. Bone-shaped sclereids in an aquatic plant (*Nymphaea* leaf).

7 Physiological Aspects of Selected Halophytes and Xerophytes

7.1 Introduction

Scientific evidence of solute accumulation and the role of proline in well documented and has been discussed in Chapter1. The methodology of the study has been outlined in Chapter 3.

7.2 Solute Accumulation

Plants normally accumulate soluble organic solutes (such as proline, glycinebetaine, sugars, etc.,) in response to a number of different environmental factors such as drought, chilling temperatures and salinity (Stewart and Lee, 1974; Paleg and Aspinall, 1981, McCue and Hanson, 1990, Nilsen and Orcutt, 1996; Delauney and Verma, 1993, Orcutt and Nilsen, 2000).

7.3 Results and Discussions

7.3.1 Proline

Proline has been recognized as an important compatible solute playing various roles in the physiology and biochemistry of plants under stress such as:

- Contributing to the processes of osmoregulation: It is thought that proline plays a vital role in plant cytoplasmic osmotic adjustment in response to osmotic stresses (Wyn Jones *et al.*, 1977).
- Maintaining turgor and hydration: Aspinall and Paleg (1981) suggested that proline is believed to play a role in the hydration processes of cellular microstructures and plasma membranes. This process is vital in the maintenance of cell turgidity since it interacts with hydrophobic surface residues on the proteins leading to the increase of hydrophilic surfaces of the associated molecules, thereby stabilizing these compounds under salinity and drought.
- Protection of enzyme activity and cellular structures: It has been suggested that proline protects plasma membranes and proteins against the adverse effects of high concentrations of inorganic ions and temperature extremes (Pollard and Wyn

Jones, 1979; Paleg *et al.*, 1981; Nash *et al.*, 1982; Paleg *et al.*, 1984; Brady *et al.*, 1984; Gibson *et al.*, 1984; Smirnoff and Stewart, 1985; Manetas *et al.*, 1986; Santarius, 1992; Santoro *et al.*, 1992; Samaras *et al.*, 1995; Liu and Zhu, 1997). Proline function as a protective element may be via the enzymes in the cytoplasm (Brock, 1981). Proline may also tend to be excluded from the hydration sphere of proteins and stabilizes folded protein structures (Low, 1985). Moreover, proline influences protein solvation and it may function as a hydroxyl radical scavenger as well as a stabilizing membrane by interacting with phospholipids, (Rudolph *et al.*, 1986; Smirnoff and Cumbes, 1989).

- Source of amino groups and energy: The concentration of proline falls rapidly once stress is relieved, and can be readily utilized as a source of amino groups and energy. Proline is oxidized rapidly in the mitochondria to glutamate in turgid tissues during which NADH is produced at the final stage of oxidation (i.e. to show proline oxidation). Energy is released in the form of ATP when electrons are passed from NADH to O_2 through the electron transport chain on the cristae of mitochondria. Glutamate, on the other hand, produced during proline oxidation can be converted to α–ketoglutaric acid giving its amino group by the transamination processes, which can enter the Krebs cycle. This is supported by the rapid evolution of CO_2 following re-watering of stressed plants (Aspinall and Paleg, 1981).
- Sink for nitrogen: Proline accumulation during stress conditions can be considered as a sink for the nitrogenous compounds derived from net loss of protein. Protein degradation is enhanced and protein synthesis is inhibited leading for such accumulation (Dhindsa and Cleland, 1975; Rao and Nainawattee, 1980).

7.3.1.1 Proline accumulation

In the study carried out, the plants under investigation showed different abilities to accumulate proline (Table 9). For example, *Ochradenus baccatus* (xerophyte) accumulated more proline than all other plants followed by *Zygophyllum qatarense* (xero-halophyte), *Limonium axillare* and *Suaeda vermiculata* (halophytes). *Avicennia marina* (a mangrove), on the other hand, had the lowest proline concentration among all investigated plants. Variability in proline accumulation in the plants studied can be attributed to various factors including :

- The different metabolic responses of the plants under study to the environmental factors facing them in their habitats.

- The energy constraints that may result in a substantial amount of energy required for active transport and the extrusion of ions, as well as, the accumulation of organic solutes such as proline, glycinebetaine, sugars and other organic solutes (Yeo, 1983; Yasseen, 1992).
- The plants under investigation are well adapted to drought and salinity and do not need to accumulate much proline.

Lutts *et al.*, 1999 mention that the accumulation of proline seems to be a symptom of injury rather than an indicator of salinity resistance. In fact, there is no correlation between the proline content obtained and the salt and drought resistance of different plant species (Levitt, 1980; Yasseen, 1992).

It has been found that high proline concentrations occurred in salt-sensitive rather than in salt-tolerant species. This, according to Wyn Jones and Storey (1978), Tal *et al.* (1979) and Yasseen (1983) was supported by comparisons between closely related genotypes. However, this conclusion seems in clear contradiction to that of Stewart and Lee (1974) who had suggested that the capacity to accumulate proline is correlated with salt resistance in halophytes.

Techniques to evaluate salt resistance under different environmental conditions are still not perfected which may be the reasons behind contradictory conclusions in the evaluation of salt resistance of halophytes (Moftah and Michel, 1987; Liu and Zhu, 1997).

However, other cytoplasmic and/or compatible solutes, may accumulate substantially in halophytes due to salinity and may play the same role as proline. These solutes include glycinebetaine, polyols, and other methylated organic osmolytes, (Greenway and Munns, 1980; Yancey *et al.*, 1982; McCue and Hanson, 1990; Delauney and Verma, 1993 Orcutt and Nilsen, 2000).

7.3.2 Soluble nitrogen and sugar compounds

Such compounds play various functions in plant metabolism under stress as well as contributing to the osmotic adjustment depending on the growth stage, composition of the medium and environmental conditions (Munns and Weir, 1981; Morgan, 1984; Riazi *et al.*, 1985; Timpa *et al.*, 1986; Al-Hadi *et al.*, 1997; Al-Hadi *et al*, 1999). It has been reported that sugars could contribute between 30-50% of the osmotic adjustment in leaves of glycophytes. A comparison of the contribution of sucrose, reducing sugars,

Na^+, and Cl^- to the osmotic potential of various halophytes indicated that organic materials played a secondary role (Flowers *et al.*, 1977). In fact, there are three main reasons for the accumulation of sugars under stress conditions: (1) disturbances in the balance between photosynthesis which produces sugars with the processes of their utilization, (2) variation in the stomatal resistance under osmotic stress which affects the accumulation through CO_2 fixation in photosynthesis and, (3) disturbances in the metabolism of carbohydrates (Yasseen, 1992).

Although, information is scanty on the sugar content in halophytes under saline environments, sugars could be the solutes that contribute to the osmotic adjustment in some families with halophytes such as the Chenopodiaceae and the Gramineae (Albert and Popp, 1977; Gorham *et al.* 1980; Paliwal *et al.*, 1993). Further, some studies have indicated that sugars may be considered as compatible osmolytes under salt conditions in many halophytes (Gorham *et al.*, 1985).

Tables 10 and 11 show total soluble sugars (TSS) and total soluble nitrogen (TSN) in the shoot and the root system of the plant species studied. More soluble sugar is found in the shoots of *Suaeda vermiculata* followed by *Heliotropium bacciferum*, *Arthrocnemum macrostachyum*, *Pulicaria crispa*, *Pulicaria gnaphalodes*, *Limonium axillare*, with the least concentrations of soluble sugar in *Aeluropus lagopoides*, and *Anabasis setifera*.

TSN contents on the other hand, were considerably lower than those of TSS in the shoot system of all plant species investigated with marked differences in their contents. *Sporobolus spicatus* had the highest values with *Zygophyllum qatarense*, *Limonium axillare*, *Arthrocnemum macrostachyum*, *Suaeda vermiculata*, *Halocnemum strobilaceum*, *Pulicaria crispa*, *Heliotropium bacciferum* in decreasing amounts respectively. The lowest concentration was detected in *Avicennia marina*.

Qatari soils have been reported to be poor in nitrates particularly sabkha soils (Ashore *et al.*, 1991). The low nitrogen content in sandy soils of all areas investigated explains the reduction of available soluble nitrogen in plant tissues. Moreover, it has been shown that the carbon skeletons of soluble nitrogen compounds may be converted to organic acids by a series of biochemical reactions leading to soluble sugars such as sucrose (Alhadi *et al.*, 1997, Taiz and Zeiger, 1998). Similar results were obtained from the root system of plants with high concentrations of soluble sugar and nitrogen in their shoot system. This reflects the general trend of carbon and nitrogen metabolism that might have occurred in these plants. Therefore, it is feasable that these plants could be considered as a possible source of sugar and nitrogen in local animal fodder.

7.3.3 Ionic Contents

Adaptation of plants to salinity may be associated with different mechanisms of uptake, translocation, accumulation and utilization of ions present in high concentrations in the root environment. Exclusion, inclusion, excretion, extrusion, and dilution mechanisms for extra ions have been suggested as explanations of salt resistance in many plant species. The data in Tables 12 and 13 show the ion composition in the shoot and root system of the plant species in the areas investigated (*Zygophyllum qatarense*, *Halopeplis perfoliata*, *Suaeda vermiculata*, *Seidlitzia rosmarinus*, *Limonium axillare*, *Salsola imbricata*, *Anabasis setifera*, *Arthrocnemum macrostachyum*, *Suaeda aegyptiaca*, *Halocnemum strobilaceum* and, *Aeluropus lagopoides*). Most plants accumulated higher concentrations of Na^+, Cl^-, and Ca^{2+}, and lower concentrations of K^+ and Mg^{2+}. It seems that plants absorb ions that are abundant in their growth medium (Table 7), playing a significant role in the osmotic adjustment between plant tissues and their environment. It has been reported that Na^+, K^+, and Cl^- are the main ions playing a vital role in achieving osmotic adjustment in halophytes under saline conditions. This is acheived by lowering the solute potential thereby lowering the water potential of plant tissues (Flowers and Yeo, 1986).

7.3.3.1 Na^+ and Cl^- ions: The effect of Na^+ and Cl^- ions in the soil on the growth and macronutrients in plants living in highly saline environment is interesting because their amounts in the soil extracts could affect the macronutrient concentration by two ways:

- The concentrations of major macronutrients (such as K^+, Ca^{2+}, and Mg^{2+}) in the water soil extracts were similar but showed differential accumulation in plant tissues. These cations become deficient in saline soils attributed to the interference of Na^+ ions.
- Na^+ and Cl^- ions inhibit H^+-ATPase of plasma membranes and consequently inhibit the protein transporters leading to nutrient imbalance. It has been reported that antiporters of various kinds work in conjunction with the H^+-ATPase pumps that regulate the electrochemical balance of the cytoplasm. Salt resistance may be correlated with the activity of these pumps and antiporters (Fukuda *et al.*, 1998; Orcutt and Nilsen, 2000).

Survival of halophytes, particularly chenopods on highly saline soils (Na^+, Cl^-) is invariably accompanied by high ion content. These plants are unique in their ability to accumulate concentrations of salts equaling or exceeding those of seawater in their leaves without causing toxic effects or damage to their active metabolic systems. These ions are sequestered in vacuoles leaving relatively low ion content in the cytoplasm. Organic solutes are accumulated in the cytoplasm to contribute to the osmotic equilibrium across the tonoplast (Greenway and Munns, 1980; Gorham *et al.*, 1985). It is reasonable to accept that these plants have adaptive characteristics, which contribute to their avoidance of high concentrations of ions in their leaves. Adaptive features include salt glands and salt bladders and an increase in leaf volume associated with succulence (Longstreth and Nobel, 1979; Greenway and Munns, 1980).

The ion distribution within the halophytic plants have been reviewed (Flowers, 1975; Flowers *et al.*, 1977; Flowers, 1985; Flowers *et al.*, 1986; Flowers and Yeo, 1986; Cheeseman, 1988; Al - Hilal, 1997; Hasegawa *et al.*, 2000). On average more than 90 % of Na^+ in halophytes was detected in the shoot, and at least 80 % was detected in the leaves. This, contrasts with glycophytes which exclude excessive ions from their leaves. Evidence has been obtained from the preferential transport of Na^+ over K^+ to the shoot of *Suaeda maritima*, while most of the Na^+ absorbed in the roots of *Suaeda monoica* was eventually exported to the shoot. A similar mechanism seems to operate in halophytic plants in this study.

7.3.3.2 Ca^{2+} ions: are accumulated in plant tissues play various functions:

- Maintaining the internal membrane structure of plants exposed to high concentrations of Na^+, and Cl^- (Orcutt and Nilsen, 2000).
- Regulating ion homeostasis by affecting ion channels and antiporters. For example, Ca^{2+} blocks the uptake of K^+ in the guard cells leading to the closure of the stomata as an adaptation mechanism under salt stress (Nilsen and Orcutt, 1996; Orcutt and Nilsen, 2000).
- Activating some enzymes such as ATPase and some proteins by accelerating protein formation (Mengel and Kirkby, 1978, Taiz and Zeiger, 1998).
- Increasing the plasticity of plant tissues and controls cell membrane permeability (Taiz and Zeiger, 1998; Orcutt and Nilsen, 2000).

7.3.3.3 Mg2+ ions: concentrations in the plant tissues of investigated were lower than those recommended by Chapman and Pratt (1961) for normal growth.

Tables 12 and 13 show that some plants contained acceptable concentrations of magnesium in their shoot and root systems (Pulicaria crispa, Limonium axillare, Suaeda aegyptiaca, Cocculus pendulus, Arthrocnemum macrostachyum, Aeluropus lagopoides, Haloxylon strobilaceum Heliotropium bacciferum). Magnesium is an important element attaining a central position in the chlorophyll molecule, thereby affecting the concentrations of chlorophylls a and b in the green plant tissues.

7.3.3.4 **Trace element content:** particularly Fe, Cu, Zn, Co, Ni, Cr, and Cd measured in the shoot and root systems of plants investigated (Tables 14 and 15) were of acceptable concentrations compared the recommended values reported by Chapman and Pratt (1961)for normal plant growth. However, Fe was the main element accumulated in the plant investigated with Ni, Cu, Zn, Cr, Co, and Cd in lower values respectively.

7.3.3.5 **Photosynthetic Pigments:** namely chlorophyls a and b and carotenoids, measured in leaves of the plants investigated are shown in Table (16). The results show considerable variation in their pigments contents. The highest value of the total photosynthetic pigments was found in Aeluropus lagopoides (Gramineae) and decreased progressively in Ochradenus baccatus, Sporobolus spicatus, Avicennia marina, Pulicaria crispa, Pulicatia gnaphalodes, Ziziphus nummularia, Heliotropium bacciferum and Capparis spinosa.

On the other hand, *Halopeplis perfoliata, Seidlitzia rosmarinus, Zygophyllum qatarense* showed the lowest content of the total photosynthetic pigments among the studied species. In general the results revealed that the concentrations of photosynthetic pigments, in halophytes and xerophytes in the present study were less than those reported for many glycophytes (Bengston *et al.*, 1978; Alhadi *et al.*, 1999; Yasseen, 2001). The reduction in the chlorophyll content in selected halophytes in saline soils has been reported by Levitt, (1980) who attributed it to the inhibition of the pigments biosynthesis, equally the degradation of synthesized pigments by increasing the activity of chlorophyllase enzyme (Svitsev *et al.*, 1973) as well as, damaging the photosynthetic apparatus (Yasseen, 1983). Moreover, Cl^- accumulation in plant tissues could reduce the photosynthetic pigments (Mengel and Kirkby, 1978).

Table 10. Proline content of leaves, plant water content, soil water content and ECe of the soil in the studied areas

Species	Proline content µg / g. Fw	Plant water content (%)	Soil water content (% of FC)*	ECe of the soil (dS m-1)
Avicennia marina	11 - 37	66 - 69	Saturated Soil	Seawater
Heliotropium bacciferum	151 -192	69 - 76	9 – 10	5 - 72
Capparis spinosa	131 – 302	62 - 68	9 – 12	4 - 5
Anabasis setifera	21 – 54	72 - 76	12 – 43	71 - 198
Arthrocnemum macrostachyum	10 – 112	81 - 89	24 – 48	27 - 198
Halocnemum strobilaceum	19 – 73	71 - 80	34 – 61	12 - 198
Halopeplis perfoliata	56 – 281	78 - 88	34 – 50	12 - 178
Haloxylon salicornicum	91 – 119	70 -78	9- 12	80 - 90
Salsola imbricata	38 – 82	80 - 81	11 – 16	150 - 195
Salsola soda	132 – 185	83 - 89	43 – 71	> 200
Salicornia europaea	55 – 172	80 - 87	43 – 71	> 200
Seidlitzia rosmarinus	161 – 327	84 - 88	14 – 30	52 - 81
Suaeda aegyptiaca	80 – 317	86 - 88	11 – 16	150 - 195
Suaeda vermiculata	96 – 409	77 - 82	8 – 43	32 - 142
Pulicaria crispa	25 – 32	59 -66	5 - 8	4 - 6
Pulicaria gnaphalodes	32 – 119	59 - 66	5 – 8	4 - 6
Aeluropus lagopoides	241 – 253	70 - 72	40 – 66	45 - 50
Sporobolus spicatus	40 -147	58 - 66	32 – 44	107 - 128
Cocculus pendulus	34 -51	60 -69	9 – 12	4 - 5
Limonium axillare	103 – 810	64 - 72	32 – 43	12 - 198
Ochradenus baccatus	1277 – 1347	68 - 71	4 – 12	7 - 8
Ziziphus nummularia	87 – 97	62 - 67	9 – 12	4 - 5
Zygophyllum qatarense	419 - 1136	81 - 87	10 – 46	12 - 187

* FC : Field Capacity

Table 11. Total soluble sugar and total soluble nitrogen in the shoot system of the plant species studied.

Species	TSS mgg-1 DW	TSN µgg-1 DW	Soil water content (% of FC)*	ECe of the soil (dS m-1)
Avicennia marina	2.2 – 6.0	40 – 63	Saturated Soil	Seawater
Heliotropium bacciferum	10.6 – 16.6	73 – 140	9 – 10	5 – 72
Capparis spinosa	--------------	---------	9 – 12	4 – 5
Anabasis setifera	1.6 – 2.0	81 – 92	12 – 43	71 – 198
Arthrocnemum macrostachyum	4.0 – 14.1	79 – 165	24 – 48	27 – 198
Halocnemum strobilaceum	1.8 – 2.5	48 – 146	34 – 61	12 – 198
Halopeplis perfoliata	2.9 – 3.5	46 – 88	34 – 50	12 – 178
Haloxylon salicornicum	--------------	-------------	9 – 12	80 – 90
Salsola imbricata	1.6 – 3.1	77 – 128	11 – 16	150 – 195
Salsola soda	--------------	-------------	43 – 71	> 200
Salicornia europaea	--------------	-------------	43 – 71	> 200
Seidlitzia rosmarinus	2.8 – 4.7	77 – 119	14 – 30	52 – 81
Suaeda aegyptiaca	3.9 – 4.3	100 – 119	11 – 16	150 – 195
Suaeda vermiculata	6.7 – 19.8	104 – 161	8 – 43	32 – 142
Pulicaria crispa	8.8 – 9.9	127 – 144	5 – 8	4 – 6
Pulicaria gnaphalodes	6.3 – 7.2	63 – 92	5 – 8	4 – 6
Aeluropus lagopoides	1.5 – 1.7	84 – 126	40 – 66	45 – 50
Sporobolus spicatus	3.3 – 3.4	195 – 236	32 – 44	107 – 128
Cocculus pendulus	--------------	-------------	9 – 12	4 – 5
Limonium axillare	4.7 – 8.0	67 – 169	32 – 43	12 – 198
Ochradenus baccatus	2.9 – 3.5	92 – 109	4 – 12	7 – 8
Ziziphus nummularia	--------------	-------------	9 – 12	4 – 5
Zygophyllum qatarense	2.9 – 4.3	85 – 190	10 – 46	12 – 187

* FC : Field Capacity ------------- : No data

TSS : Total Soluble Sugars TSN: Total Soluble Nitrogen

Table 12. Total soluble sugar and total soluble nitrogen in the root system of the species studied.

Species	TSS mgg-1 DW	TSN µgg-1 DW	Soil water content (% of FC)*	ECe of the soil (dS m-1)
Avicennia marina	--------------	-----------	Saturated Soil	Seawater
Heliotropium bacciferum	14.3 – 18.8	149 – 178	9 – 10	5 – 72
Capparis spinosa	------------	--------------	9 – 12	4 – 5
Anabasis setifera	2.3 – 2.9	81 – 104	12 – 43	71 – 198
Arthrocnemum macrostachyum	5.3 – 12.0	67 – 102	24 – 48	27 – 198
Halocnemum strobilaceum	3.1 – 4.9	21 – 132	34 – 61	12 – 198
Halopeplis perfoliata	1.1 – 1.8	52 – 90	34 – 50	12 – 178
Haloxylon salicornicum	------------	------------	9 – 12	80 – 90
Salsola imbricata	1.9 – 5.4	49 – 100	11 – 16	150 – 195
Salsola soda	------------	------------	43 – 71	> 200
Salicornia europaea	------------	------------	43 – 71	> 200
Seidlitzia rosmarinus	1.4 – 2.8	75 – 113	14 – 30	52 – 81
Suaeda aegyptiaca	1.2 – 3.1	48 – 71	11 – 16	150 – 195
Suaeda vermiculata	3.4 – 11.8	110 – 197	8 – 43	32 – 142
Pulicaria crispa	7.7 – 9.5	81 – 155	5 – 8	4 – 6
Pulicaria gnaphalodes	3.3 – 3.5	81 – 127	5 – 8	4 – 6
Aeluropus lagopoides	0.9 – 1.5	125 – 172	40 – 66	45 – 50
Sporobolus spicatus	1.0 – 2.1	91 – 114	32 – 44	107 – 128
Cocculus pendulus	------------	------------	9 – 12	4 – 5
Limonium axillare	7.9 – 10.1	69 – 119	32 – 43	12 – 198
Ochradenus baccatus	------------	------------	4 – 12	7 – 8
Ziziphus nummularia	------------	------------	9 – 12	4 – 5
Zygophyllum qatarense	2.3 – 4.8	54 – 115	10 – 46	12 – 187

* FC : Field Capacity TSS : Total Soluble Sugars TSN : Total Soluble Nitrogen

----------: No data

Note the values of TSN for *Avicennia marina*, *Ochradenus baccatus*, and *Zygophyllum qatarense* places *O. baccatus* instead of *Z. qatarense* as of intermediate values, whereas in proline *O. baccatus* had the highest contents. This might be due to an inherent character in the plant related to its metabolism and should be further investigated.

Table 13. Ionic composition (mg / g DW) of shoots of the studied plant species.

Species	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	ECe of the soil (dS m-1)
Avicennia marina	15 - 40 *	2.8- 4.4*	51 - 52*	0.43- 0.53*	43-53*	Seawater
Heliotropium bacciferum	18 – 61	4.1 - 6.6	21- 42	0.30 - 1.70	4 -24	5 – 72
Capparis spinosa	49- 66	6.9 - 8.3	24 - 26	10.5 - 10.8	0.5-1.5	4 – 5
Anabasis setifera	26 – 125	6.4 - 9.7	10 – 21	0.44 - 1.20	1.5 - 67	71 – 198
Arthrocnemum macrostachyum	26 – 84	2.2 - 7.2	14 -50	0.20 - 2.22	15 - 156	27 – 198
Halocnemum strobilaceum	33 – 92	2.0 - 9.1	15 – 59	0.35 - 1.36	16 - 62	12 – 198
Halopeplis perfoliata	34 – 223	2.8 - 9.1	21 – 39	0.42 - 0.97	14 - 212	12 – 178
Haloxylon salicornicum	68 – 112	7.4 -18.4	13 – 34	0.81 – 1.78	0.5 -1.0	80 – 90
Salsola imbricata	30 – 126	5.5 -10.8	19 – 29	0.55 – 1.22	11-102	150 – 195
Salsola soda	68 – 88	6.3 - 8.3	16 – 21	0.90 – 1.07	31 - 35	> 200
Salicornia europaea	22 – 68	4.0 - 6.6	16 – 19	1.08 – 1.38	3 - 6	> 200
Seidlitzia rosmarinus	45 – 150	3.7-10.5	19 – 33	0.44 – 0.88	37 - 49	52 – 81
Suaeda aegyptiaca	23 – 97	3.3-10.5	13 – 30	0.55 – 2.92	31 - 116	150 – 195
Suaeda vermiculata	31 – 211	7.2 -13.3	18 – 46	0.28 – 0.89	13 - 36	32 – 142
Pulicaria crispa	40 – 50	5.2 -12.0	30 – 42	2.28 – 6.44	3 - 5	4 – 6
Pulicaria gnaphalodes	25 – 49	8.0 -10.8	28 – 37	0.66 – 0.77	3 - 5	4 – 6
Aeluropus lagopoides	34 – 70	6.9 - 12.9	22 – 54	0.53 – 1.91	19 - 65	45 – 50

Table 13 Contd. Ionic composition (mg / g DW) of shoots of the studied plant species.

Species	Na+	K+	Ca2+	Mg2+	Cl-	ECe of the soil (dS m-1)
Sporobolus spicatus	76 – 88	9.4 -13.2	27 – 39	0.72 – 1.25	6 - 7	107 – 128
Cocculus pendulus	57 – 99	3.2-12.3	20 – 28	1.07 – 2.26	1.5- 2.0	4 – 5
Limonium axillare	59 – 143	4.2-10.5	21 – 58	0.27 – 5.33	19 - 30	12 – 198
Ochradenus baccatus	25 – 32	4.5 - 5.2	48 – 51	0.42 – 0.48	9 - 10	7 – 8
Ziziphus nummularia	42 – 60	4.1 - 6.6	19 - 23	1.02 – 1.05	1.5 - 3.5	4 – 5
Zygophyllum qatarense	50 – 225	2.6 - 7.4	14 – 47	0.27 – 1.13	14 - 94	12 – 187

* These data for leaves: For stems: 52 – 142 mg / g DW Na^+; 2.8 – 4.0 mg / g DW K^+; 46 – 51 mg / g DW Ca^{2+}; 0.53 – 0.73 mg / g DW Mg; 43– 53 mg / g DW Cl^-

Table 14. Ionic composition (mg / g DW) of roots of the studied plant species.

Species	Na+	K+	Ca2+	Mg2+	Cl-	ECe of the soil (dS m-1)
Avicennia marina	----------	----------	----------	----------	---------	Seawater
Heliotropium bacciferum	20 – 81	6.9 - 8.3	18 – 31	0.41-4.59	3 – 6	5 – 72
Capparis spinosa	----------	----------	----------	----------	---------	4 – 5
Anabasis setifera	28 – 51	4.8-16.4	19 – 29	0.29-0.75	3 – 6	71 – 198
Arthrocnemum macrostachyum	26 – 146	2.5 - 8.0	16 – 29	0.27-1.13	8 – 19	27 – 198
Halocnemum strobilaceum	22 – 83	1.9 - 7.0	13 – 54	0.40-1.46	6 – 53	12 – 198
Halopeplis perfoliata	25 – 197	2.8-10.2	13 – 34	0.23-1.44	12 - 62	12 – 178
Haloxylon salicornicum	---------	----------	----------	----------	---------	80 – 90
Salsola imbricata	45 – 118	3.3-10.8	20 – 30	0.54-1.34	12 - 101	150 – 195
Salsola soda	----------	-------	----------	----------	---------	> 200

Table 14 Contd. Ionic composition (mg / g DW) of roots of the studied plant species.

Species	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	ECe of the soil ($dS\ m^{-1}$)
Salicornia europaea	----------	----------	----------	----------	----------	> 200
Seidlitzia rosmarinus	14 – 114	3.6-12.2	19 – 33	0.44-0.94	12 – 97	52 – 81
Suaeda aegyptiaca	34 – 118	3.3-11.1	17 – 30	0.28-4.15	12 – 70	150 – 195
Suaeda vermiculata	40 – 101	5.4 -13.3	20 – 34	0.66-1.69	5 – 13	32 – 142
Pulicaria crispa	39 – 92	4.2 - 7.9	24 – 29	1.64-2.73	2 – 5	4 – 6
Pulicaria gnaphalodes	51 – 99	7.9-14.1	17 – 28	1.83-3.58	3 – 6	4 – 6
Aeluropus lagopoides	50 – 178	6.6-13.4	29 – 32	0.50-1.08	6 – 62	45 – 50
Sporobolus spicatus	101-241	9.9-19.1	35 – 44	0.83-2.04	18 – 20	107 – 128
Cocculus pendulus	----------	----------	----------	----------	----------	4 – 5
Limonium axillare	55 – 108	4.2-10.5	17 – 35	0.27-1.28	2 – 22	12 – 198
Ochradenus baccatus	----------	----------	----------	----------	----------	7 – 8
Ziziphus nummularia	----------	----------	----------	----------	----------	4 – 5
Zygophyllum qatarense	26 – 88	2.1 – 6.4	11 – 41	0.18-0.88	6 – 30	12 – 187

Table 15. Trace elements content (μg / g DW) of shoots of the plant species studied.

Species	Fe	Cu	Zn	Co	Ni	Cr	Cd
Avicennia marina	8.48 - 10.36*	0.716 - 0.867*	0.665 -0.733*	0.018 -0.046*	0.795 - 1.833*	0.550 -0.611*	< 0.0004*
Heliotropium bacciferum	7.20 - 14.68	0.517 - 1.143	0.402 - 0.717	0.031 -0.051	0.595 - 5.000	0.567 - 1.983	< 0.0013
Capparis spinosa	11.90 - 12.22	0.777 - 1.175	0.925 - 1.050	0.014 -0.024	1.075 - 1.350	1.075 - 1.307	< 0.0016
Anabasis setifera	9.90 - 14.42	0.117 - 4.222	0.067 - 2.099	0.013 – 0.020	0.330 - 3.333	0.665 - 2.133	< 0.0025
Arthrocnemum macrostachyum	6.28 - 14.20	0.283 - 1.050	0.173 -1.033	0.009 – 0.037	0.533 - 1.600	0.533 -0.987	< 0.0011
Halocnemum strobilaceum	3.55 - 16.51	0.150 - 5.574	0.075 - 1.802	0.011 –0.075	0.647 - 4.124	0.687 - 2.300	< 0.0350

Table 15 Contd. Trace elements content (μg / g DW) of shoots of the plant species.

Species	Fe	Cu	Zn	Co	Ni	Cr	Cd
Halopeplis perfoliata	6.28 - 16.22	0.200 - 13.746	0.075 -1.067	0.014 – 0.051	0.505 - 5.666	0.378 - 5.333	< 0.0180
Haloxylon salicornicum	13.58 - 29.97	2.583 - 9.624	1.130 - 2.704	0.009 –0.023	1.255 - 2.186	1.193 - 2.044	< 0.0060
Salsola imbricata	3.87 - 10.30	0.150 - 0.597	0.050 - 1.092	0.001 - 0.050	2.081 - 6.095	1.163 - 3.572	< 0.0020
Salsola soda	10.82 - 16.34	1.299 - 1899	1.424 - 2.374	0.024 – 0.026	2.473 - 5.247	0.989 - 9.693	< 0.0012
Salicornia europaea	15.80 - 16.52	1.075 - 2.999	1.350 - 1.774	0.009 - 0.018	1.107 - 1.829	0.945 - 1.052	< 0.0065
Seidlitzia rosmarinus	7.43 - 16.38	0.223 - 3.273	0.067 - 0.203	0.005 –0.013	0.432 -1.961	0.482 - 1.385	0.0000
Suaeda aegyptiaca	2.32 - 11.17	0.125 - 9.169	0.287 - 2.074	0.010 - 0.047	1.207 - 4.297	0.793 – 11.842	< 00200
Suaeda vermiculata	7.20 - 31.56	0.275 - 3.400	0.453 - 2.959	0.007 – 0.098	0.646 - 7.325	0.263 - 3.575	< 0.0650
Pulicaria crispa	16.35 - 30.16	1.131 - 1.308	0.616 - 1.130	0.043 - 0.065	1.981 - 5.329	2.161 - 2.353	< 0.0008
Pulicaria gnaphalodes	15.13 - 22.85	0.401 - 1.181	0.511 - 0.628	0.080 –0.085	2.783 - 3.525	1.550 - 2.428	0.0000
Aeluropus lagopoides	7.58 - 33.74	0.965 - 7.607	0.660 - 1.601	0.018 –0. 109	1.353 8.249	0990 - 4.821	< 0.0350
Sporobolus spicatus	16.53 - 20.93	0.323 - 4.282	0.715 - 0.966	0.039 –0.042	6.350 - 13.426	2.135 - 2.949	< 0.0160
Cocculus pendulus	9.40 -25.11	1.375 - 2.913	1.100 -2.358	0.017 - 0.029	1.300 - 2.034	1.100 - 2.187	< 0.0015
Limonium axillare	6.47 - 15.00	0.417 - 1.110	0.550 - 1.234	0.016 - 0.051	0.795 - 3.667	0.275 - 1.368	< 0.0010
Ochradenus baccatus	7.20 - 10.83	0.517 - 0.633	0.612 - 0.717	0024 -0.034	4.233 - 5.667	0.717 - 1.072	0.0012
Ziziphus nummularia	13.57 - 18.71	2.432 - 3.500	1.300 - 2.025	0.018 - 0.019	1.415 - 1.857	1.095 - 1.348	< 0.0028
Zygophyllum qatarense	6.30 - 13.44	0.125 - 2.666	0.453 -1.154	0.002 - 0.041	0.616 – 23.216	0.367 - 1.657	< 0.0011

* Data given is for leaves, for stems: 7.95 – 10.70 μg / g DW Fe, 0.533 - 0.633 μg / g DW Cu, 0.535 – 0.793 μg / g Dw Zn, 0.017 – 0.018 μg / g DW Co, 0.766 – 1.483 μg / g DW Ni, 0.380 – 0.535 μg / g DW Cr, < 0.0180 μg / g DW Cd.

Specie	Fe	Cu	Zn	Co	Ni	Cr	Cd
Avicennia marina	----------	----------	----------	--------	--------	---------	---------
Heliotropium bacciferum	11.82 - 18.28	0.807 - 1.240	0.402 - 0.658	0.012 - 0.024	1.022 - 2.080	0.758 - 2.193	< 0.0055
Capparis spinosa	----------	----------	----------	--------	--------	---------	---------
Anabasis setifera	8.92 - 17.58	0.265 - 3.550	0.338 - 1.250	0.010 - 0.021	2.425 - 6.725	1.750 - 3.750	< 0.0015
Arthrocnemum macrostachyum	5.70 - 18.50	0.443 - 1.013	0.425 - 1.049	0.009 - 0.020	0.783 - 3.499	0.616 - 1.268	< 0.0035
Halocnemum strobilaceum	7.60 - 14.67	0.517 - 4.075	0.462 - 1.150	0.010 - 0.027	0.628 - 4.072	0.398 - 2.261	< 0.0400
Halopeplis perfoliata	6.03 - 18.14	0.200 - 4.872	0.518 - 1.187	0.013 - 0.051	0.795 - 5.225	0.550 - 1.959	< 0.1000
Haloxylon salicornicum	----------	----------	----------	--------	--------	---------	---------
Salsola imbricata	8.20 - 14.70	0.100 - 0.665	0.362 - 0.975	0.002 - 0.171	0.997 - 3.325	1.078 - 2.724	< 0.1000
Salsola soda	----------	----------	----------	--------	--------	---------	---------
Salicornia europaea	----------	----------	----------	--------	--------	---------	---------
Seidlitzia rosmarinus	10.20 - 19.15	0.375 - 3.928	0.508 - 0.912	0.007 - 0.019	0.800 - 1.877	0.480 - 1.278	< 0.0200
Suaeda aegyptiaca	8.08 - 12.63	0.100 - 0.930	0.452 - 0.975	0.012 - 0.171	1.717 - 4.350	1.092 - 2.724	< 0.1000
Suaeda vermiculata	8.47 - 16.15	0.255 - 3.400	0.275 - 0.942	0.010 - 0.078	1.328 - 12.325	0.630 - 3.400	< 0.0400
Pulicaria crispa	14.48 - 17.35	1.122 - 1.265	0.555 - 0.615	0.020 - 0.036	1.258 - 3.475	0.890 - 2.090	< 0.0010

Table 16 Contd. Trace elements contents (μg / g DW) of roots of the plant species studied.

Species	Fe	Cu	Zn	Co	Ni	Cr	Cd
Pulicaria gnaphalodes	8.80 - 14.55	0.752 - 1.005	0.498 - 0.805	0.024 - 0.030	1.700 - 2.067	0.872 - 1.613	< 0.0160
Aeluropus lagopoides	15.09 - 18.83	0.175 - 1.227	0.115 - 0.851	0.006 - 0.059	1.059 - 5.913	0.695 - 3.028	< 0.0300
Sporobolus spicatus	23.67 - 31.94	0.340 - 0.658	0.765 - 0.986	0.040 - 0.215	1.856 - 4.875	2.135 - 6.924	< 0.0040
Cocculus pendulus	----------	----------	----------	--------	--------	---------	---------
Limonium axillare	7.36 - 19.59	0.367 - 1.112	0.600 - 1.345	0.015 - 0.067	0.793 - 3.133	0.567 - 2.112	< 0.0006
Ochradenus baccatus	----------	----------	----------	--------	--------	---------	---------
Ziziphus nummularia	----------	----------	----------	--------	--------	---------	---------
Zygophyllum qatarense	7.20 - 16.64	0.125 - 1.967	0.250 - 1.139	0.009 - 0.050	0.795 -5.398	0.533 -2.157	< 0.0017

---------- : No data

Table 17. Total photosynthetic pigments content in the leaves of the species studied.

Species	Photosynthetic pigments μg g-1 Fw				Soil water content (% of FC)*	ECe of the soil (dS m-1)
	A	B	C	Total		
Avicennia marina	441	226	142	809	Saturated Soil	Seawater
Heliotropium bacciferum	270	138	118	526	9 – 10	5 – 72
Capparis spinosa	289	159	78	526	9 – 12	4 – 5
Anabasis setifera	114	48	44	206	12 – 43	71 – 198
Arthrocnemum macrostachyum	139	78	87	303	24 – 48	27 – 198
Halocnemum strobilaceum	94	47	49	190	34 – 61	12 – 198
Halopeplis perfoliata	82	45	50	177	34 – 50	12 – 178

Table 17 Contd. Total photosynthetic pigments content in the leaves of the species studied.

Species	Photosynthetic pigments μg g-1 Fw A	B	C	Total	Soil water content (% of FC)*	ECe of the soil (dS m-1)
Haloxylon salicornicum	119	53	67	239	9 – 12	80–90
Salsola imbricata	132	56	44	232	11 – 16	150– 195
Salsola soda	159	80	71	310	43–71	> 200
Salicornia europaea	160	97	59	316	43 – 71	> 200
Seidlitzia rosmarinus	61	31	30	122	14 – 30	52 – 81
Suaeda aegyptiaca	113	56	39	208	11 – 16	150 – 195
Suaeda vermiculata	114	66	53	233	8 – 43	32 – 142
Pulicaria crispa	345	211	83	639	5 – 8	4 – 6
Pulicaria gnaphalodes	307	200	94	601	5 – 8	4 – 6
Aeluropus lagopoides	733	301	133	1167	40–66	45–50
Sporobolus spicatus	455	208	151	814	32 – 44	107 – 128
Cocculus pendulus	110	62	52	224	9 – 12	4 – 5
Limonium axillare	172	81	64	317	32 – 43	12 – 198
*Ochradenus baccatus***	639	314	139	1092	4 – 12	7 – 8
Ziziphus nummularia	326	175	77	576	9 – 12	4 – 5
Zygophyllum qatarense	84	38	33	155	10 – 46	12 – 187

* FC Field Capacity, ** Total Photosynthetic Pigments in stems 428 $\mu g\ g^{-1}$ Fw

A Chlorophyll a, B Chlorophyll b, C Carotenoids

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