5 Plants of Sabkha Ecosystems of the Arabian Peninsula

Shahina A. Ghazanfar, Benno Böer, Abdul Wali Al Khulaidi, Ali El-Keblawy, and Sara Alateeqi

Abstract

Sabkhas are unique ecosystems that are highly saline and where specially adapted plants are able to grow, flower, and fruit. In general, saline environments are poor in species – for the Arabian Peninsula about 120 taxa are recorded as halophytes which constitute about 4% of the total flora of the Arabian Peninsula. Key halophytes of Arabia are nearly always perennial; predominant life-forms are somewhat succulent, semiwoody dwarf shrubs belonging to the families Amaranthaceae, Zygophyllaceae, and Plumbaginaceae and hemicryptophytes belonging to the Poaceae, Cyperaceae, and Juncaceae; annuals are exceptions. Coastal species are either obligate halophytes or salt-tolerant genera from unspecialized families, such as *Sporobolus* and *Aeluropus* (Poaceae), or salt-secreting species such as *Avicennia* (Acanthaceae) and *Limonium* (Plumbaginaceae). The submerged coastal vegetation, e.g., seagrasses, is one of the most important vegetation types of the Gulf coast and is of great importance to marine fauna. The north-south distribution of coastal species is more distinct on the Red Sea coast, with the border lying near Jeddah, than on the Persian Gulf coast where there is a broad transitional zone between Qatar and northern Oman. The east-west distribution of coastal species is not as distinct. The eastern elements are either restricted to the coasts around the Arabian Gulf or are Irano-Turanian species extending into the Gulf region. Several vicariant species groups of halophytes are represented in the Arabian Peninsula. Halophytes have developed strategies for seed germination such as high germination levels and fast germination speed. These traits are found in the sabkha plants of the Arabian Peninsula. Some halophytes have been investigated for their potential for phytoremediation in their ability to survive weathered oil-contaminated soils. They have been found to have a set of micoorganisms around their root system that are related to the degradation of oil in contaminated soils. Sabkha ecosystems are being degraded and altered throughout the Gulf countries as they appear to be nonproductive. Over the last two decades, there has been a growing concern in protecting and restoring mangroves, and programs do to so have seen

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promising results. But, on the whole, coastal and inland sabkhas are neglected, and these unique ecosystems require urgent protection.

Keywords
Annual · Arabia · Halophytes · Life-form · Perrenial · Sabkha

Introduction

Sabkhas are unique ecosystems that are highly saline and where specially adapted plants are able to grow. These plants, the true halophytes such as the mangroves, seagrasses, or some species of Amaranthaceae (in the former Chenopodiaceae), are able to complete their life cycle under saline conditions, where salt concentration is at least 200 mM NaCl (Flowers et al. 1986). Other halophytic plants growing on sabkhas depend on rain for their seed to germinate, but they can flower and fruit in saline habitats, and their seeds can survive saline conditions for considerable long periods of time. All halophytes need to regulate their cellular Na^+, Cl^-, and K^+ concentrations as they adjust to the external water potential. However, species differ in the succulence (water content per unit area of leaf; Flowers et al. 1986) and in the solutes accumulated. Detailed account of salinity tolerance in flowering plants is given in Flowers and Colmer (2008).

Nearly all terrestrial salt-tolerant plants belong to angiosperms (flowering plants), although a few are ferns (in families Pteridaceae and Ophioglossaceae) and several are marine algae. Worldwide, salt-tolerant flowering plants are found in about a third of the total plant families (Heywood et al. 2007), in about 500 genera of which about half belong to only 20 families (Table 5.1). Among monocotyledons, the Poaceae contain more halophytic genera than any other family (7% of the family); in Cyperaceae 14% of the genera are salt tolerant. Among the eudicots, Amaranthaceae (Chenopodioideae) have the highest proportion of halophytic genera followed by Asteraceae, Aizoaceae, Leguminosae, Apiaceae, Euphorbiaceae, Brassicaceae, Plantaginaceae, and Caryophyllaceae (Flowers et al. 1986) (Table 5.1).

Table 5.1 Families of flowering plants in which halophytic genera worldwide occur most frequently

Family	Percentage of halophytic genera
Chenopodiaceae	44
Aizoaceae	15
Cyperaceae	14
Caryophyllaceae	11
Poaceae	7
Arecaceae	6
Asteraceae	3
Fabaceae	3

Adapted from Flowers et al. (1986)

Sabkhas of the Arabian Peninsula

The Arabian Peninsula, including Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, Yemen, United Arab Emirates, and Yemen, lies between the Red Sea and the Persian Gulf (Fig. 5.1). It is covered mostly by sandy and gravelly plains with escarpment mountains in the southwest in Saudi Arabia, Yemen, and southern Oman and in the north in Oman and the UAE. Large areas of the Arabian Peninsula are covered by sand deserts which are (mostly) uninhabited. Over all the Arabian Peninsula is arid and lacks overground water. Few springs and oases exist which are used for subsistence agriculture. Climatically most areas in the plains and mountains receive, on average, beween 50 and 400 mm of precipitation a year (Fig. 5.2).

The Arabian Gulf coastal plain is a narrow strip bordering the northern part of the Arabian Peninsula. It is continuous with the depression in western and southern Iraq which constitutes the flood plain and deltas of the two rivers, Tigris R. and Euphrates R. (Chapman 1978). The southern part of the depression includes the western half of the Gulf and the Arabian Gulf coastal region. The low coastal flats extend to several kilometers inland and are periodically inundated by the sea. Coastal sabkhas are present along the coastline from Kuwait to the end of the Persian Gulf in Oman. Sabkha Maṭṭī, southwest of Qatar, is the largest of these with an area of about 6000 km^2

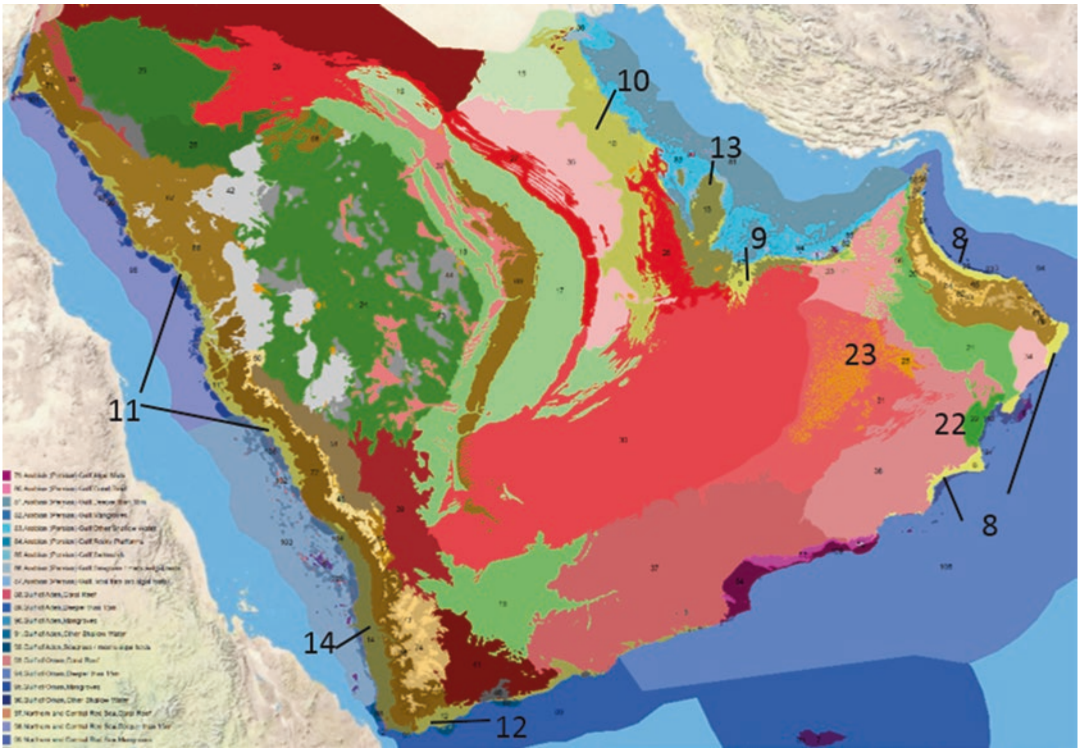

Fig. 5.1 Integrated terrestrial and marine habitat map of the Arabian Peninsula
Major coastal and inland sabkhas of the Arabian Peninsula: 8, Oman Coastal Plain; 9, Gulf Coastal and Sabkha Matti; 10, Northern Gulf Coastal Plain and Sabkha; 11, Red Sea Coastal Plain and Sabkha; 12, Southern Coastal Plain; 13, Southern Gulf Coastal Plain; 14, Tihama Coastal Plain; 22, Inland Sabkha Huqf; 23, Inland Sabkha Umm as Samim.
Source: Abu Dhabi Global Environment Data Information (AGEDI 2013). Reproduced with permission

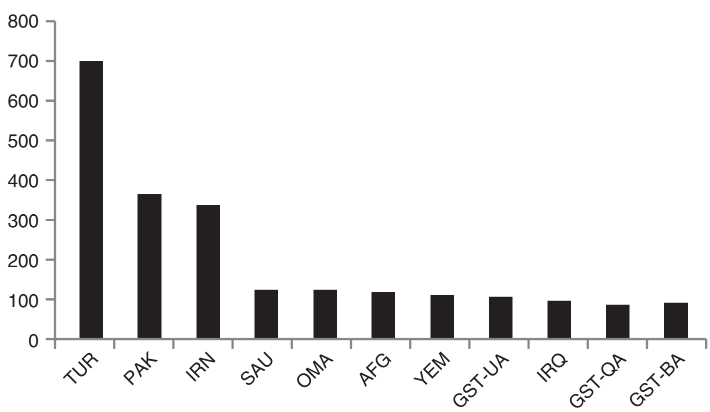

Fig. 5.2 Number of halophytic species in countries of SW Asia. TUR Turkey; PAK Pakistan; IRN Iran; SAU Saudi Arabia; OMA Oman; AFG Afghanistan; YEM Yemen; GST-UA United Arab Emirates; IRQ Iraq; GST-QA Qatar; GST-BA Bahrain. (Data from published sources – see references)

(Chapman 1978) (Fig. 5.1). It is characterized by a thin crust of salt (halite) and a mat of algae underlain by sand, silt, or clay, with a layer of gypsum about 50 cm below the surface. Coastal sabkhas have probably formed because of postglacial flooding of the Arabian Gulf which cut the supply of sand to dunes further south, and deflation removed the sand to the water table, which evaporated due to the increasing aridity over the past 5000 years (Glennie 1987). Coastal sabkhas are frequently flooded during storms and spring tide.

Coastal sabkhas are also present in the coastal region of central Oman. On the eastern coast lies the Barr al Hikman Peninsula which is a flat featureless highly saline plain from sea level to about 20 m asl and low sandy coastal dunes. Formed as a result of a fall in sea level, it is unique in its quaternary sediments (the largest in the Arabian Peninsula) with alluvial sandy gravel overlain with a thin layer of shifting aeolian sand (Glennie 1987; Gubba and Glennie 1998). This and other low, flat coastal landscapes are composed of layers of sand, silt, mud, and salt to a depth of several meters. Evaporation brings up salts which form a crust on the surface. The sabkhas become firm during dry weather and are often covered with mud polygons.

Inland sabkhas in the Arabian Peninsula are present where wadis flow and terminate and whose drainage is frequently blocked by constantly shifting dunes and where former lakes existed. Two large inland sabkhas in the northern part of the Peninsula are Sabkha Maṭṭī in the UAE which also extends southward into Saudi Arabia and Umm as Samim, a large inland salt plain in western Oman (Fig. 5.1). Umm as Samim is fed by a few wadis originating in the western Hajar mountain range of northern Oman. It consists of a main zone of salt crust, including heaved crust. Fresh salt is continually precipitated as a result of evaporation, and the expansion breaks the surface into polygonal plates bounded by rims of fresh salt. Vegetation present around the fringes and runnels leading to the sabkha is highly salt tolerant.

The Red Sea coastal plain consists of a narrow coralline plain and inland eroded bedrock covered with alluvial sand and gravel.

Climate

The climate of the Arabian Peninsula ranges from hyperarid to semiarid and is markedly influenced by topography. The hyperarid areas receive <100 mm rainfall, the arid areas 100–250 mm rainfall, the semiarid plains and foothills 250–500 mm rainfall, and mountains and summits >500 mm average rainfall. The western mountains influence rainfall along the Red Sea coast and coasts, and the Zagros Mountains of western Iran play an important part in rainfall over the extreme east of the Peninsula. Winter is the rainfall period for the north, the eastern coast, and coastal areas of northern Oman of the Peninsula which receive about 50% of rainfall and then the remainder coming in the spring months. Spring rain is also received by Central Oman and landward areas of the southern mountains. The southern regions receive summer rainfall, this being entirely due to the influence of the southwest monsoon. (Fisher and Membery (1998) give a detailed account of the climate of the Arabian Peninsula; Fig. 5.3).

Distribution and Biogeography of the Halophytic Flora of the Arabian Peninsula

A fair amount of literature exists on halophytes of the countries of SW Asia including the Arabian Peninsula, and a number of papers are present on the physiology and germination studies of halophytes (Böer 2004; Flowers 1986 and references therein; Flowers and Comer 2008 and references therein, Ghazanfar 2011 and references therein). More recently, several studies have concentrated on the phylogeny of halophytes mainly in the Family Chenopodiaceae leading to revised classifications and changes in the nomenclature of species (Akhani et al. 2007; Kadereit et al. 2006, 2006a, 2007; Kadereit and Freitag 2011;

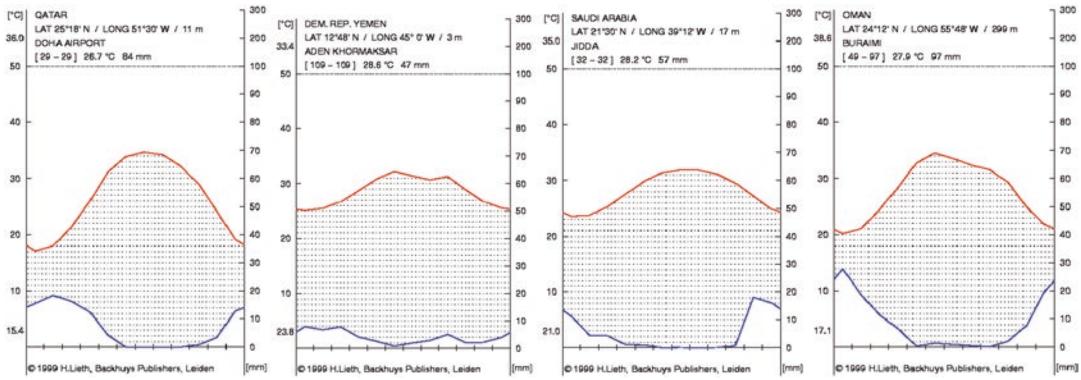

Fig. 5.3 Climate diagrams of countries of the Arabian Peninsula. Doha (Qatar), Aden (Yemen), Jeddah (Saudi Arabia), Buraimi (Oman)

Table 5.2 Number of halophytic taxa in plant families in the Arabian Peninsula

Family	No. halophytic species	Family	No. halophytic species
Acanthaceae	1	Juncaceae	2
Aizoaceae	4	Liliaceae	1
Apocynaceae	2	Mimosaceae	2
Arecaceae	1	Najadaceae	1
Asteraceae	2	Orobanchaceae	1
Boraginaceae	2	Plumbaginaceae	6
Chenopodiaceae	41	Poaceae	17
Caryophyllacae	8	Portulacaceae	1
Ceratophyllaceae	1	Potamogetonaceae	1
Convolvulaceae	2	Rhizophoraceae	2
Cymodoceaceae	3	Ruppiaceae	1
Cynomoriaceae	1	Salvadoraceae	1
Cyperaceae	4	Tamaricaceae	3
Fabaceae	5	Typhaceae	1
Frankeniaceae	1	Zygophyllaceae	11
Hydrocharitaceae	2		

From Ghazanfar (2011)

Sukhorukov et al. 2016). The following section is adapted from halophytes of SW Asia by Ghazanfar et al. (2014).

In general, saline and arid environments are poor in species. Of the total 415 plant families (APG III 2009 and update APG IV 2016), halophytes of SW Asia are recorded in 68 families (117 plant families worldwide as recorded by Aronson 1989). The majority of halophytes belong to the families Chenopodiaceae, Poaceae, Fabaceae, Asteraceae, and Cyperaceae. Chenopodiaceae has the largest number of species and genera of all families only exceeded by Poaceae which has more genera (but fewer species) than Chenopodiaceae (Table 5.1). These data are in accordance with that found for halophytes of the world (Flowers et al. 1986; Table 5.2).

Floristically, the Arabian Peninsula mainly falls within the Saharo-Sindian and Irano-Turanian floristic regions (Leonard 1981–89; Zohary 1973), to which the majority of the halophytic communities belong.

Halophytes can be obligate or facultative. Whereas obligate halophytes survive only in saline habitats, facultative halophytes grow equally well in saline and nonsaline habitats.

Important and frequent halophytes in the sabkha ecosystems of the Arabian Peninsula are mostly perennial hemicryptophytes, succulents, subshrubs, and stoloniferous perennial herbs. The most salt-tolerant obligate halophytes in the Arabian Peninsula include *Arthrocnemum macrostachyum*, *Caroxylon* spp., *Cyperus aucheri*, *Halocnemum strobilaceum*, *Halopeplis perfoliata*, *Limonium* spp., *Salicornia perennans* (=*Salicornia europaea* sensu auctt.), *Seidlitzia rosmarinus*, *Suaeda* spp., *Tamarix* spp., and *Tetraena* spp.; grasses and sedges include *Aeluropus lagopoides*, *Juncus rigidus*, *Odyssea mucronata*, *Sporobolus spicatus*, *S. consimilis*, *Urochondra setulosa*, and mangroves *Avicennia marina*. The most important facultative halophytes include *Salsola drummondii*, *Suaeda vermiculata*, *Suaeda aegyptiaca*, *Anabasis setifera*, and *Tetraena qatarense*.

About 120 taxa are recorded as halophytes in the Arabian Peninsula (see Appendix). This constitutes about 4% of the total flora of the Arabian Peninsula (±3500 taxa) (Ghazanfar et al. 2014), third in the world after Turkey, Iran, and Pakistan (Tables 5.1 and 5.2; Fig. 5.2). Halophytes in SW Asia constitute about half the number of halophyte taxa (and families) recorded for the world by Aronson (1989).

Not surprisingly the majority of halophytes belong to the families Amaranthaceae, Poaceae, Zygophyllaceae, Fabaceae, and Plumbaginaceae. Table 5.1 shows the distribution of halophytic taxa and their families in the Arabian Peninsula (see Abbas 2002; Abed 2002; Al-Gifri and Gabali 2002; Al-Turki et al. 2000; Barth 2002; Böer and Al Hajiri 2002; Böer and Gliddon 1998; Brown et al. 2008; Ghazanfar 2002, 2003, 2006, 2007, 2011, 2015; Omar et al. 2002).

Key species in saline habitats of Arabia are nearly always perennial. The predominant life-forms are succulent, semiwoody dwarf shrubs belonging to the families Amaranthaceae, Zygophyllaceae, and Plumbaginaceae and hemicryptophytes with runners and spiny leaves belonging to the families Poaceae and Juncaceae. Annual succulents such as *Bienertia cycloptera* and *Tetraena simplex* are exceptions. Coastal species are either obligate halophytes like the representatives of the families Amaranthaceae, Frankeniaceae, and Plumbaginaceae or salt-tolerant genera from unspecialized families, such as *Sporobolus* and *Aeluropus* (Poaceae) or salt-secreting species such as *Avicennia* (Acanthaceae) and *Limonium* (Plumbaginaceae). The most common coastal and salt-tolerant species are *Arthrocnemum macrostachyum*, *Halocnemum strobilaceum*, *Halopeplis perfoliata*, *Caroxylon* spp., and *Suaeda* spp., (Amaranthaceae); *Aeluropus lagopoides*, *Odyssea mucronata*, *Sporobolus spicatus*, and *S. consimilis* (Poaceae); *Juncus rigidus* (Juncaceae); *Tetraena* spp. (Zygophyllaceae); *Limonium* spp. (Plumbaginaceae); and *Avicennia marina* (Acanthaceae) (Deil 1998; Ghazanfar et al. 2014 and references therein).

The submerged coastal vegetation of the Arabian Peninsula, especially that of the Gulf, has been well studied owing to the rapid coastal development. The submerged seagrass beds are one of the most important vegetation types and highly productive ecosystems of great importance to the marine fauna especially the marine turtles, shrimps, and numerous species of fish and are highly important carbon sinks. Sheppard et al. (1992) report five species of seagrasses from the Gulf, *Halodule uninervis*, *H. wrightii*, *Halophila stipulacea*, *H. ovalis*, and *Syringodium isoetifolium*. *Ruppia maritima* is also reported in several coastal lagoons (Mandaville 1990). *Halodule uninervis*, *Halophila stipulacea*, and *H. ovalis* are most widespread and the most common.

Biogeographical limits of the coastal and saline vegetation of the Arabian Peninsula have been adapted from Deil (1998). Biogeographically Vesey-Fitzgerald (1957) was the first to recognize the difference between the salt marsh flora on either side of the Tropic of Cancer, and Freitag (1991) showed that the tropical and extra-tropical distribution of the halophytic coastal species of the Chenopodiaceae is similar to that of the non-halophytic species.

Halopeplis perfoliata is an example of a species with a typical circum-Arabian distribution in the Nubo-Sindian zone of the Sahara-Sindian phytochorion. *Arthrocnemum macrostachyum* is a bi-regional species with a Sahara-Sindian/

Mediterranean distribution. *Halocnemum strobilaceum* is a pluri-regional species occurring in the Mediterranean/Saharo-Sindian/Irano-Turanian phytochoria with a distinct southern distributional boundary. *Salsola schweinfurthii* is a Saharo-Arabian species, and *Seidlitzia rosmarinus* has a Saharo-Sindian and Irano-Turanian distribution, not occurring south of Jeddah or Musandam. *Suaeda monoica* is a tropical Saharo-Sindian species commonly distributed in Sudan and Eritrea and with its northernmost limit on the Diimaniyat Islands off the coast of Muscat (Ghazanfar 1992); it is replaced by *Nitraria retusa* further north (Freitag 1991; Kassas and Zahran 1967). The distributional limits of *Seidlitzia rosmarinus* delimit to a large extent the extra-tropical from tropical coastal vegetation complexes. It occurs in seasonally wet inland saline habitats, often replacing the *Halocnemum* community on drier habitats, and usually forming a community of its own, which in the Irano-Turanian region includes several halophytic annuals. *Arthrocnemum macrostachyum* is replaced by the truly tropical *Halosarcia indica* in southeast Pakistan and western India and by *Halopeplis perfoliata* in the southern coasts of the Arabian Peninsula. *Odyssea mucronata* is not distributed north of Jeddah, and similarly *Limonium axillare* is replaced by *L. pruinosum* north of the Tropic of Cancer. Other extra-tropical taxa include *Cornulaca ehrenbergii*, *Gymnocarpos decander*, *Anabasis setifera*, and *Halopyrum mucronatum*.

The north-south distribution of coastal species is more distinct on the Red Sea coast, with the border lying near Jeddah, than on the Arabian Gulf Coast where there is a broad transitional zone lying between Qatar and northern Oman. The east-west distribution of coastal species is not as distinct as that of the north-south distribution. The eastern elements are either restricted to the coasts around the Arabian Gulf (e.g., *Salsola drummondii*) or are Irano-Turanian species extending into the Gulf region (e.g., *Bienertia cycloptera* and *Seidlitzia rosmarinus*). Some east-west species are closely related vicariants, such as *Salsola drummondii* restricted to eastern Arabia and extending eastward to India and *S. schweinfurthii* distributed mainly from eastern Saudi Arabia to Jordan, with an outlier recorded from Oman (Miller and Cope 1996).

There are several vicariant groups of halophytic species in the Arabian Peninsula. These include species in the genera *Cornulaca*, with *C. monacantha* distributed from southwest Asia eastward to Pakistan (Boulos 1992) and *C. aucheri* distributed in the eastern regions of the Peninsula, Iraq, Iran, and southwest Pakistan; *Salsola*, with *Caroxylon vermiculatum* (=*Salsola chaudharyi*, treated as *Salsola villosa* in Miller and Cope 1996) in central Saudi Arabia (Botschantzev 1984) and *S. omanensis* in the coastal plains of Dhofar (Boulos 1991); and *Suaeda* (Freitag 1991) with *Suaeda moschata* restricted to the Barr al Hikman Peninsula and Hallaniyat Islands in Oman (Scott 1981). Other examples include the *Cyperus conglomeratus* complex (*C. aucheri*, *C. conglomeratus*; Kukkonen 1991) and the *Limonium axillare* group (*L. axillare*, *L. stocksii*, *L. carnosum*, and *L.* cf. *stocksii*). East-west and littoral-inland vicariance is well illustrated in the genus *Tetraena* section Mediterranean, with *T. coccineum* mainly distributed in the northern coasts of the Red Sea, *T. qatarense* in the Arabian Gulf and Gulf of Oman (Boulos 1987), *T. hamiense* in the southwestern corner of the Arabian Peninsula, *T. mandavillei* in the southern Rub' al Khali and Hadhramaut, and *T. migahidii* in the Nafud (El-Hadidi 1977, 1980). *Sevada schimperi*, a monotypic genus within Chenopodiaceae, is endemic to the coastal habitats around Bab al Mandab, Yemen (Freitag 1989).

Terrestral Sabkha Vegetation and Plant Communities

Vegetation, plant communities, and the zonation of plants of coastal and inland sabkhas have been well described for all countries of the Arabian Peninsula in varied detail. A summary of the vegetation of the coastal and inland sabkhas of the countries is given here with references to the studies made for each country (adapted from Deil 1998). Detailed accounts of vegetation types are also given in Barth (2002).

Saudi Arabia

Refs: Coastal vegetation of the Red Sea coast (El-Shourbagy et al. 1987; Chaudhary 1998); around springs (El-Sheikh and Youssef 1981; El-Sheikh et al. 1985); eastern coast (Mandaville 1990); Shaltout et al. (1997); Arabian Gulf coast in the vicinity of Jubail (Böer 1994, 1996; Böer and Warnken 1992).

The coastal regions have extensive stands of *Suaeda monoica*, *S. fruticosa*, and *S. vermiculata*. Where some freshwater is available, *Tamarix nilotica* and thickets of *Salvadora persica* can be found. The littoral salt marsh communities on the Red Sea coast north of Jeddah consist of *Avicennia marina* in the first zone followed by a *Halopeplis perfoliata* zone in the moist but not waterlogged soil fringing the shoreline. On soft aeolian deposits overlaying mudflats, *Aeluropus massauensis* occurs in the third zone, and on coarse soils where the water table is below 1.5 m, a *Tetraena coccineum* or a *Limonium axillare-Suaeda pruinosa* zone is present. Mangroves are also found on the west coast and the Farasan Islands consisting of *Avicennia marina* and *Rhizophora mucronata*, while on the east coast, only *A. marina* is found.

Sabkhas are also present around springs. The vegetation of sabkhas around Al Khari springs southeast of Riyadh and that of Al Qassim in the Nefud consist of *Seidlitzia rosmarinus* where water is present at depths of 35–75 cm and salinity of 50,000 μS; a *Tetraena decumbens-Caroxylon imbricatum* community is found where the water is at a depth of 60–120 cm and salinity 500 μS.

The inland sandy saline plains have *Caroxylon* spp. and *Hammada salicornica*, associated with *Acacia tortilis*.

Yemen

Refs: Yemen coastal vegetation (Al Khulaidi et al. 2010; Al Khulaidi 2013); Tihama Coast (El-Demerdash et al. 1995); Gulf of Aden (Al-Gifri and Gabali 2002; Kürschner et al. 1998), Hadhramaut coast at Felek, east of Mukalla (Kürschner et al. 1998).

The coastal plains of Yemen show a number of vegetation types: mangrove (*Avicennia marina*) swamp occurs along the Red Sea coastal fringe, mainly north of the wadi Siham outlet; isolated swamps are also seen south Al Mukha, north Yakhtol (southern Tihama), and around Bir Ali (west of Al Mukalla). Occasionally other plants such as *Aeluropus lagopoides*, *Suaeda* spp., and others may occur with the mangroves. These form a transition to other vegetation types found further inland. A *Suaeda vermiculata* shrubland is found along the coast on flat, often bare muddy ground and covers from shoreline to about 5 km inland. *Suaeda vermiculata* and *Aeluropus lagopoides* are the most common species in this sabkha.

Northward from Wadi Siham the *Avicennia marina* zone is followed by a *Limonium cylindrifolium-Suaeda fruticosa-Limonium axillare* community which forms hummocks. A sterile sabkha is present, after which raised beaches above the high tide level are covered by *Atriplex farinosa*, *Tetraena hamiense*, *Aeluropus lagopoides*, and *Halopyrum mucronatum*. Sand dunes toward the seaward side are colonized by *Suaeda monoica* and *Caroxylon spinescens* and the inland dunes by *Odyssea mucronata*, *Jatropha pelargoniifolia*, and *Leptadenia pyrotechnica*.

The southwestern corner of the Arabian Peninsula is characterized by *Odyssea mucronata*, endemic to this part of Arabia. *O. mucronata* is a clump-forming, spiny, rhizomatous perennial which colonizes semimobile dunes and flat sandy areas. Depending on the depth of sand, an *Odyssea mucronata-Suaeda monoica* community can be distinguished on flat sandy layers overlying saline silts and an *Odyssea mucronata-Panicum turgidum* community on deeper sand.

The Hadhramaut coast is situated in the transition zone from the southeastern to the southwestern vegetation type. This is seen from the *Cyperus conglomeratus/C. aucheri* associations, where the Omano-Makranian element (Kürschner 1986), *Coelachyrum piercei*, and the Eritreo-Arabian element *Odyssea mucronata* are common members. The coastal vegetation shows a strong phytogeographical relationship with the coasts of northeast Africa. The species zones are (1) coastal dunes colonized by sedges and grasses (*Cyperus aucheri*, *Halopyrum mucronatum*, *Odyssea mucronata*, *Coelachyrum piercei*, and *Panicum turgidum*); (2) sandy-salty depressions colonized by the endemic *Urochondra setulosa* association, with the codominant *Arthrophytum macrostachyum*, *Limonium cylindrifolium*, and *Crotalaria saltiana*; (3) clayey-salty, relatively wet areas colonized by monospecific stands of *Arthrophytum macrostachyum*; (4) sandy coastal plains colonized by the endemic *Anabasis ehrenbergii*-*Pulicaria hadramautica*-*Tetraena hamiense* association; and (5) the karstic limestone plateau colonized by *Stipagrostis paradisea*, *Commiphora gileadensis*, and *Euphorbia rubriseminalis*.

Oman

Refs: Coastal, inland sabkha, and saline and brackish water vegetation (Ghazanfar 1992, 1993, 1995, 1998, 1999, 2002, 2006); coastal vegetation of the islands of Masirah and Shagaf (Ghazanfar and Rappenhöner 1994); vegetation of the Qurm Nature Reserve near Muscat (Kürschner 1986); inland sabkha Umm as Samim (Heathcote and King 1998).

The coastal vegetation in the northern Oman can be classified into four plant communities: (1) a *Limonium stocksii*-*Tetraena qatarense* community in northern Oman where the coasts are mainly sandy and interspersed with rocky limestone headlands; (2) a *Limonium sarcophyllum*-*Suaeda aegyptiaca* community characteristic of rocky shores with narrow beach areas and a wide spray zone; (3) an *Atriplex*-*Suaeda* community characteristic of the vegetation of offshore islands, flat sandy beaches, and coastal sabkhas (dominant and associated species are *Atriplex coriacea*, *A. farinosum*, *A. leucoclada*, *Arthrocnemum macrostachyum*, *Suaeda aegyptiaca*, *S. vermiculata*, *S. monoica*, *S. moschata*, and *Halocnemum strobilaceum*) and a *Limonium axillare*-*Sporobolus*-*Urochondra* community characteristic of the vegetation of the southern coasts, with *Limonium axillare*, *Urochondra setulosa*, and *Sporobolus* spp. associated with several other species depending on coastal geomorphology; and (4) coastal lagoons with *Sporobolus virginicus*, *S. iocladus*, and *Paspalum vaginatum* as the main bordering species and *Phragmites australis* and *Typha* spp. forming the bordering reeds. In addition, *Avicennia marina* occurs throughout coastal Oman in discontinuous patches and over a wide range of water salinities.

On the Barr al Hikman Peninsula and the offshore island of Masirah, *Avicennia marina* is present in sheltered lagoons, a halophytic shrub community dominated by *Atriplex farinosa* and *Suaeda moschata* occurs on low coastal dunes which receive salt spray, and a *Halopyrum mucronatum*-*Urochondra setulosa* community occurs on more or less stabilized dunes. An *Arthrocnemum macrostachyum*-*Suaeda vermiculata* community occurs on the saline, silt plains and a *Limonium stocksii*-*Cyperus auheri*-*Sphaerocoma aucheri* community on shallow sands.

The inland sabkha, Umm as Samīm, is the largest in the Arabian Peninsula. It lies in northwest Oman bordering the sand desert of the Rub' al Khali and covers an area of *c*. 5000 km^2. Much of the sabkha is too saline to support any vegetation, but plants exist on the edges. The fringing vegetation of Umm as Samim is very sparse since rainfall is scanty (<50 mm per year) and temperatures high. The few species present are *Aeluropus lagopoides*, *Cornulaca monacantha*, *Hammada salicornica*, *Salsola* cf. *drummondii*, *Suaeda aegyptiaca*, and *Tetraena qatarense.* Therophytes consist of *Tetraena simplex* and *Tribulus longipetalus*.

United Arab Emirates

Refs: Coastal and sabkha flora (Böer 2002); coastal vegetation near Dubai (Deil and Müller-Hohenstein 1996); coastal vegetation and conservation (Brown et al. 2008); biogeography (Böer and Saenger 2006).

A transect through the coastal dunes and sabkha in the UAE shows the typical dry haloseries within the Omano-Makranian region of the Arabian Gulf; four plant communities are present associated in the *Limonium stocksii*-*Tetraena qatarense* vegetation complex: (1) the seaward dunes colonized by the *Cornulaca monacantha*-*Sphaerocoma aucheri* community (the Salsolo-Suaedetalia of Knapp 968); (2) the landward dunes colonized by *Halopyrum mucronatum* (stabilizing the sand), *Atriplex leucoclada*, and *Suaeda aegyptiaca*; (3) salty depressions which may be temporarily inundated with seawater colonized by *Halopeplis perfoliata*; and (4) an ephemeral, salt-tolerant *Frankenia pulverulenta*-*Tetraena simplex* plant community growing in depressions with sandy overlays. The landward dunes, away from the influence of salt spray, are also dominated by *Cornulaca monacantha* and *Sphaerocoma aucheri*. They are associated here with glycophytic (i.e., non-halophytic) dune species such as *Panicum turgidum*, *Crotalaria persica*, *Lotus garcinii*, *Taverniera spartea*, and *Indigofera intricata*. Similar is as well the halophytic vegetation of Qatar which along a transect from the mangrove zone to the sabkha plain shows a distinct floristic and edaphic gradient with the following zonation: (1) *Avicennia marina*, (2) *Arthrocnemum macrostachyum*, (3) *Halocnemum strobilaceum*, and (4) *Juncus rigidus*-*Aeluropus lagopoides*. Associated species are *Tetraena qatarense*, *Halopeplis perfoliata*, and *Anabasis setifera*.

The vegetation of the Arabian Gulf coast in the vicinity of Jubail is similar to that of Bahrain. The zonation of species within the intertidal zone from the sea landward is given as follows: (1) *Avicennia marina*, (2) *Salicornia perennans*, (3) *Arthrocnemum macrostachyum*, (4) *Halocnemum strobilaceum*, (5) *Halopeplis perfoliata* (>2 m and above the intertidal zone), (6) *Limonium axillare* (>2 m and above the intertidal zone), and (7) *Tetraena qatarense* (>2 m and above the intertidal zone). The outer fringe consists of the *Seidlitzia rosmarinus* community on small dunes followed by *Rhanterium epapposum*, *Hammada salicornica*, *Panicum turgidum*, and *Calligonum comosum* on nonsaline sands.

Bahrain

Refs: Abbas 2002; Abbas and El-Oqlah 1992.

Sabkhas and coastal lowlands represent about 40% of the area of Bahrain. These are the western and northeastern coastal plains, and the southwest and south sabkhas, all of which support halophytic vegetation. In the western coastal plain, four plant communities can be distinguished: *Aeluropus lagopoides* community, *Tetraena qatarense* community, *Halopeplis perfoliata* community, and *Sporobolus ioclados* community. These are to large extent interconnected with each other. The northeastern coast supports the mangrove, *Avicennia marina*, in the intertidal zone followed landward by *Arthrocnemum macrostachyum* and inland by *Suaeda vermiculata*. *Cressa cretica* is found in small scattered depressions, and more inland from the mangroves, *Halocnemum strobilaceum* dominates on a reclaimed area that used to be part of the mangrove swamp.

The southwest sabkha is a large salt pan and subject to tidal inundation. Algal mats dominate this coastal sabkha, and where the salinity decreases, *T. qatarense* and *Cyperus aucheri* are present on small sand dunes. The south sabkha is more diverse with *H. perfoliata* in very saline soils associated with few *H. strobilaceum*, *A. macrostachyum*, and *Seidlitzia rosmarinus*.

Qatar

Refs: Halophytic vegetation (Abdel-Razik 1991; Abdel-Razik and Ismail 1990; Babikir 1984; Batanouny 1981; Batanouny and Turki 1983; Babikir and Kürschner 1992; Böer and Hajiri 2002.

The major sabkha vegetation zones can be best described along a transect from the mangroves to the sabkha plain which show distinct floristic gradient: (1) *Avicennia marina*, (2) *Arthrocnemum macrostachyum*, (3) *Halocnemum strobilaceum*, and (4) *Juncus rigidus*-*Aeluropus lagopoides*. Associated species are *Tetraena qatarense*, *Halopeplis perfoliata*, and *Anabasis setifera*. In a coastal littoral plain in southwestern Qatar around the Gulf of Salwa, seven interconnected halophytic plant communities form a mosaic. These are the following:

1. The *Halopeplis perfoliata* community on sandy beaches along the Gulf shore and surrounding depressions, not inundated by the sea.

2. The *Halocnemum strobilaceum* community, which colonizes the depressions.
3. The *Halopyrum mucronatum*-*Sporobolus consimilis* community on calcareous sands.
4. *Limonium axillare*, *Suaeda vermiculata*, and *Cistanche tubulosa* forming sandy mounds.
5. The *Tetraena qatarense* community growing in shallow depressions and runnels on coarse-textured soils, associated with *Cornulaca monacantha*, *Robbairea delileana*, and *Stipagrostis*.
6. Inland, *Panicum turgidum* and *Pennisetum divisum* tussocks are present on fine sand and A*nabasis setifera* on coarse sand.
7. The *Suaeda vermiculata* community on fine-textured soils but restricted to the southwestern area.

In northwestern Qatar (ad Dakhira), an *Avicennia marina* association is present in the supralittoral border followed by an ephemeral halophytic community, the *Salicornia perennans*-*Suaeda maritima* association, in the intertidal zone. An *Arthrocnemum macrostachyum* association is present in the supra-tidal area with *Halopeplis perfoliata* sometimes associated with it. The *Aeluropus lagopoides*-*Tamarix passerinoides* association is present on dunes and the *Caroxylon cyclophyllum*-*Panicum turgidum*-*Anabasis setifera* association on windblown, sandy accumulations at the foot of limestone cliffs. The limestone plateau itself is colonized by a xeromorphic, very open dwarf shrubland of *Tetraena qatarense*, *Helianthemum lippii*, and *Lycium shawii*.

Kuwait

Refs: Coastal vegetation (Omar et al. 2002; Omar 2007); coastal vegetation and zonation (Halwagy and Halwagy 1977; Halwagy et al. 1982; Halwagy 1986).

In Kuwait, *Salicornia perennans* (=*Salicornia europaea*) grows on low, frequently inundated mud banks or along creeks, sometimes associated with *Aeluropus lagopoides* and *Bienertia sinuspersici* (=*Bienertia cycloptera*) or with *Juncus rigidus* on the fringes of creeks. A *Halocnemum strobilaceum* community occupies the lower marshes along the shoreline with the seaward edge inundated very frequently by tides. A *Seidlitzia rosmarinus* community occurs further inland, followed by *Nitraria retusa* above the high tide mark dominating the middle marshes, and finally the *Tetraena qatarense* community on elevated, coarse sandy sites on the landward edge of the marsh. The salt marshes are fringed by non-halophytic communities such as the *Cyperus aucheri* community, the *Rhanterium epapposum*-*Convolvulus oxyphyllus*-*Stipagrostis plumosa* community, and the *Hammada salicornica* community, the latter covering most of the territory of Kuwait.

Intertidal Vegetation

Mangroves

Mangroves occur throughout the coasts of the Arabian Peninsula, bordering bays and creeks, some offshore islands, and on several sea lagoons. Of the three recorded species, *Avicennia marina* is by far the commonest and most abundant (Frey and Kürschner 1989; Sheppard et al. 1992), being tolerant of low air temperatures (12 °C) and high water salinities (40–50%) (Böer 1996; Sheppard et al. 1992). The distribution of mangroves indicates that cold winter temperatures rather than salinity limit their northernmost extent, and mangroves may formerly have been more common in the Gulf and Red Sea than they are at present (Sheppard et al. 1992, and references therein).

Avicennia marina, originally described from Al Luhayyah on the Red Sea coast of Yemen, occurs southward from latitude 26°N along the Red Sea coast and in the Gulfs of Aden and Oman. The northernmost populations of *A. marina* are recorded from *c*. 27°N in the Jubail Marine Wildlife Sanctuary on the Arabian Gulf coast of Saudi Arabia (Böer and Warnken 1992) and the Gulf of Suez and Sinai coast in the Gulf of Eilat (Danin 1983). Dense stands of this species occur on Mahout Island in Gubbat Al Hashish in central Oman, where the trees are up to 4 m in height and where the mangroves sustain shrimp, crab, and other fisheries of commercial importance (Fouda and Al-Muharrami 1996). *Rhizophora mucronata* is known from Gizan (south of Jeddah) and the Farasan Islands (El-Demerdash 1996) and from the Gulf of Aqaba and Bahrain and an isolated stand of about 200 trees on Jazeerat Al Mubarraz in Abu Dhabi. *Bruguiera gymnorhiza* has been recorded from the offshore islands near Hodeida (Zahran 1975), though its presence there is unconfirmed (Sheppard et al. 1992). In the last decade, attempts have been made for the restoration of *Avicennia marina* especially in the UAE (El Amry 1998; de Soyza et al. 2002), and attempts on restoration coupled with conservation, sustainable use, and as carbon sinks and the UAE have resulted in positive results (Bhat et al. 2004; Böer 1996; Böer et al. 2014).

Salt Marshes

Only a handful of perennial species are found in the intertidal zone of the coasts of the Arabian Peninsula.

On coastal flats such as those found in Bahrain, Kuwait, Qatar, and Oman, the dominant (and forming monospecific stands) are *Salicornia perennans* and *Arthorcnemum macrostachyum*. *Salicornia perennans* reproduces mainly by vegetative growth in Kuwait (Brown in obs.). *Atriplex farinosa* and *A. leucoclada* are also found, associated with *Suaeda* spp. (*S. monoica*, *S. moschata*) in Oman. South of UAE, *Salicornia perennans* is not found on the southern coasts of Arabian Peninsula. On rocky and pebbly shores, such as those found in northern and southern Oman, a *Limonium sarcophyllum*-*Suaeda aegyptiaca* (northern Oman) and a *Limonium axillare*-*Sporobolus*-*Urochondra* (southern Oman) community is found. *Limonium cylindrifolium* with the endemic *Urochondra setulosa* and codominant *Arthrophytum macrostachyum* community is found in saline depressions on Yemen coasts.

Sub-tidal Vegetation

Seagrasses

About 11 species of seagrasses have been recorded from the Arabian Peninsula. Their distribution is controlled by a complex of environmental factors which include substrate, depth, temperature, salinity, and light penetration (Sheppard et al. 1992). Shallow coastal bays (<10 m deep) often have well-developed seagrass beds, such as along the shallow southeast coasts of Bahrain, where the species are restricted to shallow waters with good light penetration. Relatively dense seagrass beds occur in central and southern Oman (Jupp et al. 1996) and the Gulf of Aden. Four species are recorded from southeast Arabia and the Gulf (Jupp et al. 1996, Sheppard et al. 1992), with most communities dominated by the smaller-bodied species *Halodule uninervis*, *Halophila ovalis*, and *H. stipulacea*. The larger *Syringodium isoetifolium* occurs in the Gulf but is relatively rare. In contrast, several larger-bodied and wide-leaved seagrasses such as *Thalassadedron ciliatum*, *Thalassia hemprichii*, *Cymodocea rotunda*, and *C. serrulata* occur in the Red Sea (Aleem 1979, Jupp et al. 1996). It has been suggested that the effects of seasonal upwelling along the southeastern coasts of the Arabian Peninsula, which causes large fluctuations in sea temperature, are responsible for the impoverished seagrass beds (Basson et al. 1977; De Clerck and Coppejans 1994) and the occurrence of only small-bodied hardy species (Jupp et al. 1996).

Seed Dispersal and Germination Strategies in Halophytes

Halophytes of arid and hyperarid deserts of the Gulf regions are facing several natural stresses such as high temperatures, salinity, and drought. The scarcity of rainfall received in many years in Arab Gulf region (Böer 1997) coupled with high evaporation due to high temperatures, especially during summer, resulted in the formation of what are called sabkha ecosystems or hypersaline salt marshes (Khan and Gul 2006). In order to enhance survival and fitness in such stressful environments, halophytes developed complementary sets of adaptation and survival strategies during different stages of their life cycle (Gutterman 1994; El-Keblawy 2004). The success of halophytes in highly saline soils is greatly dependent on their success in germination and seedling establishment, which are the most sensitive stages in a plant life (El-Keblawy 2013; El-Keblawy and Bhatt 2015; El-Keblawy et al. 2015). In addition, other factors such as seed morphology, mass, wing size, and persistence can all greatly affect the seed dispersal, dormancy, and germination behavior and consequently affect fitness of many desert halophytes (El-Keblawy et al. 2014, 2016a; El-Keblawy and Bhatt 2015; Xing et al. 2013).

Dispersal and Seed Bank

Seeds are either stored in the soil (i.e., soil seed bank) or retained above ground on maternal plants until they are released (i.e., aerial seed bank) (Gunster 1992). Seeds of halophytes are usually stored in saline soils and consequently exposed to salinity stress (Aziz and Khan 1996; El-Keblawy 2014). Persistent seed banks of halophytes carry seeds over a predictable dry or hypersaline period after which germination occurs. As seeds of many of the halophytes could not germinate in salinity level more than seawater salinity, germination usually happens when saline habitats receive effective rainfalls that dilute soil salinity (El-Keblawy 2014). Still, seeds of some halophytes are very sensitive to salinity and cannot germinate above 300 mM NaCl (Khan and Gul 2006). Such plants retain their seeds on the plant canopy as aerial seed bank (El-Keblawy and Bhatt 2015). Retention of seeds in the aerial seed bank may protect them from the lethal effects of salt in the soil. El-Keblawy and Bhatt (2015) compared salinity tolerance in two species with aerial seed bank (*Halocnemum strobilaceum* and *Halopeplis perfoliata*). They found that *H. strobilaceum*, which has a short-term aerial seed bank (less than 9 months), is more tolerant to salinity, but *H. perfoliata*, which has a long-term aerial seed bank (more than 17 months), is less salt tolerant. This result suggests that aerial seed bank protects salt-sensitive seeds from effects of high soil salinity (El-Keblawy and Bhatt 2015). The maintenance of aerial seed bank as a strategy to avoid detrimental soil salinity effects in less tolerant species is especially important during summer, when soil salinity increases.

The distribution of different plant species is the result of their strategies of seed dispersal, dormancy, and germination behavior (Kos et al. 2012). Under the unpredictable heterogeneous environments, such as saline habitats of arid deserts, plants develop multiple strategies through producing offspring that differ in time and place of germination and tolerance to environmental stresses (Baskin and Baskin 1998; El-Keblawy 2003). Fruits of many halophytic plants have winged perianths that help their dispersal and determine the proper place of seed storage and time of germination (Wei et al. 2008; Xing et al. 2013). In the Arabian Peninsula, fruits of many desert halophytes, such as *Hammada salicornica*, *Haloxylon persicum*, *Salsola drummondii*, and *Caroxylon imbricatum*, have winged perianths that help them to disperse and also regulate their dormancy and seed bank dynamics (El-Keblawy 2013). However, seeds of other halophytes, such as *Halopeplis perfoliata* and *Halocnemum strobilaceum*, do not have any dispersal structures and consequently have the chance to bury in the soils (El-Keblawy and Bhatt 2015; El-Keblawy et al. 2015). Still, some other halophytes, such as *Anabasis setifera*, produce nonpersistent wings that could help fruits in dispersal but usually disintegrate within few months after seed landing. The dispersal structures of the last group should help fruit dispersal, but their degradation could help seeds to bury in the salty soil (El-Keblawy et al. 2016a, b). The presence of winged perianths has been considered as an important trait that helps seed to disperse and regulate dormancy and seed bank dynamics (El-Keblawy 2014).

Fruits with winged perianths are able to explore habitats away from their maternal sites. In addition, as winged fruits usually land over soil surface, they face diurnal fluctuations in temperatures and are exposed to intense light during storage (Zalamea et al. 2015). The diurnal soil surface temperature during the summer in the UAE fluctuates between 20 and 60 °C for more than 4 h between noon and midnight (El-Keblawy and Al-Hamadi 2009). Several studies have reported that diurnal fluctuations resulted in breaking seed dormancy of some halophytes, such as *Sporobolus ioclados*, *Diplachne fusca*, *Limonium axillare*, *Halocnemum strobilaceum*, and *Halopeplis perfoliata* (El-Keblawy 2013; Morgan and Myers 1989). However, exposure of seeds to diurnal fluctuation in natural conditions under the very high temperatures of the Arabian Peninsula causes seed death in other halophytes, such as *Caroxylon imbricatum* (El-Keblawy et al. 2007) and *Hammada salicornica* (El-Keblawy and Al-Shamsi 2008). Seeds of plants that have winged perianths usually have a transient seed bank, but those without wings form persistent transient seed bank (El-Keblawy 2013).

Salinity and Tolerance During Germination

Survival of halophyte seeds in the belowground seed banks depends on their capacity for salt tolerance at the germination stage, their ability to tolerate hypersaline conditions during storage in the soil, and/or their ability to avoid salinity (Kozlowski and Pallardy 2002; Ungar 2001). Several studies have concluded that seeds of a few halophytes, such as *Salicornia rubra* (Khan et al. 2000), *Salicornia pacifica* (Khan and Weber 1986), *Salicornia herbacea* (Chapman 1960), *Halocnemum strobilaceum* (Qu et al. 2008; El-Keblawy and Bhatt 2015), and *Salsola drummondii* and *Suaeda vermiculata* (El-Keblawy, unpublished data), can germinate at salinities above that of seawater (*c*. 500 mM NaCl). Conversely, seeds of other halophytes, including *Halopeplis perfoliata* (Mahmoud et al. 1983; El-Keblawy et al. 2015), *Salicornia brachystachya*, and *Salicornia dolistachya* (Huiskes et al. 1985), cannot tolerate seawater at germination stage.

The absence of perianth structures provide halophytes a greater chance to bury in very saline soils. These seeds are exposed to very high salt concentrations, especially during summer, when water evaporates leaving a salt crust near and on the soil surface. The small buried seeds of halophytes have to survive these hypersaline conditions and be able to germinate once the salinity level is reduced, which usually happens after heavy rainfall (El-Keblawy 2004). The ability of halophyte seeds to maintain their viability after an extended period of exposure to salinity has been recorded in several species (see Khan and Gul 2006).

Khan and Gul (2006) reviewed the germination recovery of salt-treated seeds of many halophytes of the Great Basin desert and found substantial recovery in distilled water of seeds treated with up to 600 mM NaCl in *Halogeton glomeratus*, *Sarcobatus vermiculatus*, *Suaeda moquinii*, and *Triglochin maritima*. Similarly, high salinity did not permanently injure seeds, and germination is fully recovered when seeds were transferred to distilled water in many halophytes of subtropical regions, such as *Atriplex patula* (Ungar 2001); *Suaeda fruticosa* (Khan and Ungar 1997); *Arthrocnemum macrostachyum*, *Sarcocornia fruticosa*, and *Salicornia ramoissim* (Pujol et al. 2000); *Salicornia rubra* (Khan et al. 2000); and *Limonium stocksii* (Zia and Khan 2004). Khan and Gul (2006) indicated that species from temperate area (e.g., Great Basin desert) tolerated higher salinities and were able to recover their germination than those from subtropical region, such as the Arabian Peninsula and Pakistan. Such data indicates that seeds of the Great Basin halophytes can tolerate higher salinity when present in the seed bank. The ability of seeds of many halophytes to maintain their viability during exposure to high salinity levels and to recover their germination after transfer to distilled water indicates that the effect of NaCl is more likely to be a reversible osmotic inhibition of germination, rather than ion specific toxicity (El-Keblawy and Al-Shamsi 2008).

The germination recovery of salt-treated seeds of several halophytes is dependent on the temperature regime of incubation. In several halophytes including *Salsola imbricata* (El-Keblawy et al. 2007), *Salsola vermiculata* (Guma et al. 2010), *Hammada salicornica* (El-Keblawy and Al-Shamsi 2008), and *Limonium stocksii* (Zia and Khan 2004), recovery was seen to be higher at lower temperatures and consistent with greater rainfall in Arab Gulf regions. The recovery was greater at moderate temperatures, compared to lower and higher temperatures, in other halophytes such as *Urochondra setulosa* (Gulzar et al. 2001) and *Puccinellia nuttalliana* (Macke and Ungar 1971). Seeds of *Aeluropus lagopoides* exposed to higher salinity recovered quickly at warmer compared to moderate and lower temperatures (Gulzar and Khan 2001).

Fast Germination of Halophytes

Several species of halophytes in subtropical regions produce seeds that germinate very fast and to high levels immediately after maturation. Typically, the time of maturation of these seeds coincides with the onset of rainfall and cooler temperatures, which are favorable for seed germination and seedling recruitment. However, seeds of these species die within few month of dispersal (i.e., form a transient seed bank). For example, fresh seeds of both *Caroxylon imbricatum* and *Hammada salicornica* have high germination levels and germination speed. However, room temperature and warm storage for 9 months resulted in complete death of the seeds (El-Keblawy 2014). Similarly, Khan (1990) and Zaman and Khan (1992) studied temporal dynamics of seed bank of four perennial halophytes (*Cressa cretica*, *Haloxylon stocksii*, *Caroxylon imbricatum*, and *Sporobolus ioclados*) and found that the high germination observed for fresh seeds was gradually reduced with time until they finally died in few months after dispersal. In addition, seeds of *Aeluropus lagopoides* were not dormant and showed 100% germination at the optimal temperature at the time of seed maturation and maintained a transient seed bank (Gulzar and Khan 2001).

Parsons (2012) reviewed the speed of germination and concluded that there are a group of plants, especially those from arid or saline habitats that germinate in less than 24 h from imbibition. A total of 20 species were recorded from the Amaranthaceae (15 of them are from the subfamily Salsoloideae), which most of them are known to survive saline habitats. Seeds of the Salsoloideae contain fully differentiated spiral embryos that immediately uncoil and rupture the thin seed coat once water imbibition takes place (Parsons 2012). The fast germination has been reported for many halophytes of subtropical climate of the Arab Gulf region and East Asia. These include *Hammada salicornica*, *Haloxylon recurvum* (Sharma and Sen 1989), *Limonium axillare* (Mahmoud et al. 1983) and *L. stocksii* (Zia and Khan 2004), *Caroxylon imbricatum* (El-Keblawy et al. 2007), and *H. salicornica* (El-Keblawy and Al-Shamsi 2008). Fast germination has been considered as a strategy to utilize the brief period of water availability and ensure rapid seedling growth early in the growing season. Earlier emergence usually produces more vigorous seedlings that are characterized by greater competitive advantages, compared with late-emerged seedlings. Similarly, halophyte seeds stored in saline soils recover their germination shortly after rainfall. The fast germination after rainfall confers seedling longer growing period for establishment, before salinity increases with evaporation (El-Keblawy et al. 2016b).

Halophytes in Bioremediation

Phytoremediation and phytovolatization are very useful tools to clean up polluted environments. These techniques require suitable plants that can extract metals from soil that they either accumulate them or volatize them through their foliage (Padmavathiamma et al. 2014). In the Arabian Peninsula, among the halophytes, *Phragmites australis* has been used extensively to clean contaminated wastewater as it absorbs large amounts of water, preventing the spread of contaminated wastewater into adjacent uncontaminated areas. *Phragmites australis* has also been used to treat oil production water (OPWs) in Oman, with significant reduction of the concentration of toxic heavy metals (80%) and total hydrocarbons (96%). The quality of treated water conformed to Omani wastewater standards for agricultural reuse (Mahruki et al. 2006).

Prosopis cineraria, *Acacia senegal*, and *Acacia nilotica* were used in a study to stimulate microbial degradation of soil pollutants in desert soil that was contaminated with 2.5–2.6% crude petroleum oil (Mathur et al. 2010). The rhizosphere of these plants was tested for their abilities to degrade the pollutants. The results showed that a highest reduction (26%) of total petroleum hydrocarbons (TPHs) was observed in the rhizosphere soil of *P. cineraria*, a facultative halophytic tree in the Arabian Peninsula, as compared to 15.6% and 12.8% reduction in the rhizosphere soil of *A. senegal* and *A. nilotica*, respectively. The results clearly revealed the efficiency of *P. cineraria* for phytoremediation of TPHs in a contaminated desert soil when compared to the other two legume trees (Mathur et al. 2010).

Tamarix aphylla has also been used as a vegetation filter to “clean” soils polluted with heavy metals around petrochemical and detergent factories (Al-Taisan 2009).

Among the Amaranthaceae, Chenopodioideae, *Hammada salicornica* was studied by Al-Ateeqi (2014) to test its tolerance for weathered oil-contaminated soils as a potential phytoremediator on polluted Kuwait soils. In chenopods, the rhizosphere mainly supports the existence of bacteria but not so much fungi, yet some species are known to do so (Gawronski and Gawronska 2007), and apparently *Hammada* is one of them. In the rhizosphere of *H. salicornica*, few species of bacteria and fungi were found (Al-Ateeqi 2014). Both species of bacteria, *Inquilinus* sp. and *Streptomyces*, were present in the rhizosphere of *H. salicornia* growing on oil-contaminated soil in Kuwait. *Inquilinus* sp. is related to petroleum degradation (Tuan et al. 2011), and *Streptomyces* is known to consume n-octadecane, kerosene, n-hexadecane, and crude oil as a sole carbon source (Tuan et al. 2011). Another species of bacteria, *Rhodococcus*, is also related with oil degradation (Auffret et al. 2009). Several other species such as *Agrobacterium tumefaciens*, *Nocardia cyriacigeorgica*, *Sphingopyxis* sp., and *Gordonia lacunae*/*Gordonia terrae* (Nolvak et al. 2012; Steliga 2012) are all related with oil degradation.

For the presence of fungi in the rhizosphere of *Hammada*, Steliga (2012) talks in general about the usefulness of the *Penicillium* as a species that would be good for preparation of bioremediation strategies which would enhance the result of cleaning up contaminants. *Penicillium simplicissimum* has been found in the *Hammada* rhizosphere as well.

Hammada salicornica has been investigated by Brown and Porembsky (2000) as one of the plants that had survived in an oil-contaminated area on the northern side of Kuwait Bay. In their study, they found that where as tar-like oil tracks remained largely unvegetated 7 years after oil release, a number of *Hammada* shrubs survived oil contamination mainly due to the presence of phytogenic hillocks (*nebkhas*) around their bases. These phytogenic hillocks provided “safe sites” for a number of plant species. This also applied to blowouts, former phytogenic hillocks on the oil tracks that had been subjected to severe sand deflation in recent years. Laboratory studies showed that the seed bank under the oil tracks had been completely damaged but a number of seedlings emerged from soil samples on the phytogenic hillocks and blowouts, even though their numbers were lower.

Phragmites australis, *Tamarix aphylla*, *Prosopis cineraria*, and *Hammada salicornica* are seen as useful halophytes that have great potential in phytoremediation; the latter two can tolerate weathered oil contamination and have a set of micoorganisms around their root system that are related to the degradation of oil in contaminated soils (Al-Ateeqi 2014; Mathur et al. 2010).

Conservation of Sabkha Ecosystems

Sabkha ecosystems are unique ecosystems which support plants that are not only specialized in their physiology and morphology but have also developed strategies in their life cycles and seed dispersal and have potential as bioremediators for water and contaminated soils. These sandy and saline ecosystems with their specialized flora and fauna are living laboratories that offer unique opportunities for research into salinity tolerance and best survival of plants in arid and hyperarid environments.

The coastal areas on the Arabian Peninsula are being transformed rapidly for amenity and resort building. Sabkha ecosystems are being degraded and altered throughout the Gulf countries as they appear to be nonproductive. Only a few coastal areas in the Arabian Peninsula are designated as nature areas and are protected. These protected areas are designated mainly for the protection of birds (e.g., Bar al Hikman, Oman), turtles (e.g., Ras al Had, Oman), and marine fauna (Aspinall 1995, 1996a, b; Baldwin 1996; Baldwin and Kiyumi 1999), which provide a degree of protection to the plants as well; a few are designated solely for the protection of mangroves (e.g., Qurm Nature Reserve, Oman; Khor Kalba, Sharjah; Bul Syayeef, Abu Dhabi; Ras Ghanada, Abu Dhabi). However, in the last two decades, there has been a growing concern in protecting and restoring mangroves, and programs do to so have seen promising results.

It is our wish and hope that sabkha ecosystems get the same protection as other unique ecosystems in the Arabian Peninsula.

Appendix: Halophytes of the Arabian Peninsula. Accepted Names in Bold; Synonyms in *Italics*

AIZOACEAE

Mesembryanthemum nodiflorum L., Sp. Pl. 480 (1753).

Syn. *Chlorophytum nodiflorum* L. (1753).

Sesuvium sesuvioides (Fenzl) Verdc., Kew Bull. 1957, 349 (1957).

Basionym. *Diplochonium sesuvioides* Fenzl (1839).

Sesuvium portulacastrum Syst. Nat., ed. 10. 2: 1058 (1759).

Trianthema triquetra Willd., Ges. Naturf. Fr. Berlin Neue Schriften 4: 181 (1803).

Zaleya pentandra (L.) Jeffery, Kew Bull. 14 (2): 238 (1960).

Syn. *Trianthema pentandra* L. (1767).

APOCYNACEAE: ASCLEPIADOIDEAE

Pentatropis nivalis (J.F.Gmel). D.V.Field & J.R.I.Wood, Kew Bull. 38(2): 215 (1983).

Basionym. *Asclepias nivalis* J.F.Gmel. (1791).

ASTERACEAE

Pluchea dioscorides DC., Prodr. 5: 450 (1836).

Pulicaria hadramautica Edinb. J. Bot. 50(1): 79 (1993).

ACANTHACEAE

Avicennia marina Vierh., Denkschr. Kaiserl. Akad. Wiss. Wien. Math.-Naturwiss. Kl. lxxi. 435 (1907).

BORAGINACEAE

Heliotropium bacciferum Forssk., Fl. Aegypt.-Arab. 38 (1775) sensu lato.

Syn. *Heliotropium undulatum* Vahl var. *ramosissimum* Lehm. (1831); *H. ramosissimum* (Lehm.) DC. (1845); *H. kotschyi* Bunge (1869) nom. Nud.; *H. tuberculosum* (Boiss.) Boiss. (1879); *H. persicum* auct.: Boiss. (1879), non Lam. (1789); *H. lignosum* Bornm. (1937) nomen nudum; *H. fartakense* O.Schwartz (1939); *H. bacciferum* Forssk. subsp. *lignosum* (Vatke) Kazmi var. *fartakense* (O.Schwartz) Kazmi (1970).

AMARANTHACEAE: CHENOPODIOIDEAE

Agathophora iraqensis Botsch., in Bot. Zhurn. 62(10): 1451 (1977).

Syn. *Halogeton alopecuroides* Moq., Chenop. Monogr. Enum. 161 (1840).

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

Syn. *Salsola setifera* (Moq.) Akhani (2007) nom. Illegit.

Arthrocnemum macrostachyum (Moric.) K.Koch, Hort. Dendrol. 96, no. 3 (1853).

Basionym. *Salicornia glauca* Delile (1813) non Stocks (1812); *Salicornia macrostachya* Moric (1820);

Arthrocnemem glaucum (Delile) Ung.-Sternb. (1876).

Atriplex farinosa Forssk., Fl. Aegypt.-Arab. 123 (1775).

Syn. *A. hastata* Forssk. (1775) non Linn.

Atriplex stocksii Boiss., Diagn. Pl. Or. Nov. ser. 2(4): 73 (1859).

Atriplex griffithii Moq. var. **stocksii** (Boiss.) Boiss., Fl. Or. (1879).

Syn. *A. sokotranum* Vierh. (1903); *A griffithii* Moq. subsp. *stocksii* (Boiss.) Boulos (1991).

Atriplex leucoclada Boiss., Diagn. Pl. Or. Nov. ser. 2 (12): 95 (1853) var. **inamoena** (Allen) Zohary, Fl. Palest. 1: 147 (1966).

Syn. *A. inamoena* Allen (1939).

Bassia muricata (L.) Asch., Beitr. Fl. Aethiop. 1: 289 (1867).

Syn. *Salsola muricata* L. (1767); *Kochia muricata* (L.) Schrad. (1809).

Bassia eriophora (Schrad.) Asch., Beitr.. Fl. Aethiop. 187 (1867).

Syn. *Kochia eriophora* Scghrad. (1909).

Bienertia cycloptera Bunge, Trudy Imp. S.-Petersb. Bot. Sada vi, ii, 425 (1879) & Boiss., Fl. Or. 4: 945 (1879).

Caroxylon cyclophyllum (Baker) Akhani & E.H.Roalson, Int. J. Pl. Sci. 168(6): 947 (2007).

Basionym. *Salsola cyclophylla* Baker (1894).

Caroxylon imbricatum (Forssk.) Moq., Prodr. (DC.) 13(2): 177 (1849).

Basionym. *Salsola imbricata* Forssk. (1775); *Chenopodium baryosmon* Schult. ex Roem. & Schult. (1820); *Salsola baryosma* (Roem. & Schult.) Dandy (1950); *Caroxylon imbricatum* (Forssk.) Akhani & E.H.Roalson (2007) nom. superfl. Later homonym.

Caroxylon spinescens (Moq.) Akhani & E.H.Roalson, Int. J. Pl. Sci. 168(6): 948 (2007).

Basionym. *Salsola spinescens* Moq. (1849).

Caroxylon villosum (Schult.) Akhani & E.H.Roalson, Int. J. Pl. Sci. 168(6): 948 (2007).

Basionym. *Salsola villosa* Schult. (1820).

Cornulaca aucheri Moq., Chenopodium Monogr. Enum. 163 (1840).

Syn. *Cornulaca leucacantha* Charif & Aellen (1950).

Cornulaca monacantha Delile, Fl. Aegypt., Ill. 206, t 22, f.3 (1814).

Halocnemum strobilaceum (Pallas) M.Bieb., Fl. Taur.-Caucas. 3: 3 (1819).

Basionym. *Salicornia strobilacea* Pallas (1771).

Halopeplis perfoliata (Forssk.) Bunge ex Schweinf. & Aschers, Fl. Aethiop. 289, nomen; et ex Ung.-Sternb. in Atti. Congr. Bot. Firenze, 874,329 (1876).

Basionym. *Salicornia perfoliata* Forssk. (1775).

Halothamnus bottae Jaub. & Spach, Ill. Pl. Orient. 2: 50, t. 136 (1845).

Syn. *Caroxylon bottae* (Jaub. & Spach) Moq. (1849); *Salsola bottae* (Jaub. & Spach) Boiss. (1879).

Haloxylon persicum Bunge ex Boiss. & Bushe, Nouv. Mém. Soc. Imp. Naturalistes Moscou 12: 189 (1860).

Hammada salicornica (Moq.) Iljin (1948).

Syn. *Haloxylon salicornicum* (Moq.) Bunge ex Boiss., (1879); *Caroxylon salicornicum* Moq. (1849); *Hammada elegans* (Bunge) Botsch (1964).

Kaviria rubescens (Franch.) Akhani, Int. J. Pl. Sci. 168(6): 948 (2007).

Basionym. *Salsola rubescens* Franch., Sert. Somal. 60 (1882); *Salola hadramautica* Baker (1894); *Salsola leucophyla* Baker (1894).

Salicornia perennans Willd., Sp. Pl. 1: 24 (1797).

Syn. *Salicornia europaea* auctt. Non L., Sp. Pl. 3 (1753).

Salsola drummondii Ulbr., Nat. Pflanzenfam. 2, 16C: 256 (1934).
Syn. *Salsola obpyrifolia* Botsch & Akhani (1989).
Salsola schweinfurthii Solms-Laub., Bot. Zeit. 59: 173 (1901).
Suaeda aegyptiaca (Hasselq.) Zohary, J. Linn. Soc. Bot. 55: 635 (1957).
Basionym. *Chenopodium aegyptiacum* Hasselq. (1757).
Syn. *Suaeda hortensis* Forssk. ex J.F.Gmel. (1791); *Suaeda baccata* Forss. Ex J.F. Gmelin (1791); *Schanginia hortensis* (Forssk. ex Gmelin) Moq. (1840); *S. aegyptiaca* (Hasselq.) Aellen (1964).
Seidlitzia rosmarinus Ehrenb. ex Boiss., Fl. Or. 4: 951 (1879).
Syn. *Salsola rosmarinus* (Ehrenb. ex Boiss.) Akhani (2007).
Suaeda moschata A.J.Scott, Kew Bull. 36(3) 558 (1981).
Suaeda monoica Forssk. ex J.F.Gmel., Syst. Nat. ed. 1791: 2, 503 (1791).
Sevada schimperi Moq. in DC., Prodr. 13(2): 154 (1849).

CERATOPHYLLACEAE
Ceratophyllum demersum L., Sp. Pl. 992 (1753).

CARYOPHYLLACEAE
Herniaria maskatensis Bornm., Mitth. Thuring. Bot. Vereins 6: 51 (1894).
Polycarpaea spicata Wight & Arn. in Ann. Nat. Hist. ser. 1 (3): 91 (1831).
Polycarpaea jazirensis R.A. Clement, Edinb. J. Bot. 51(1): 53–54 (1994).
Sphaerocoma aucheri Boiss., Fl. Or. 1: 739 (1867).
Xerotia arabica Oliver in Hk., Icon. Pl. 24, t. 2359 (1895).
Polycarpon succulentum J. Gay in Rev. Bot. Bull. Mens. 2: 372 (1846).
Spergularia diandra (Guss.) Heldr. et Sart. in Heldr., Herb. Graec. Norm. no. 492 (1855).
Syn. *Arenaria diandra* Guss. (1827).
Spergularia marina (L.) Gris., Spic. 1: 213 (1843).
Syn. *Arenaria rubra* L. var. *marina* L. (1753).

CONVOLVULACEAE
Cressa cretica L. Sp. Pl. 223 (1753).
Ipomoea pes-caprae (L.) R.Br., Narr. Exped. R. Zaire 477 (1818).
Basionym. *Convolvulus pes-caprae* L. (1753).

CYMODOCEACEAE
Halodule uninervis Boiss., Fl. Or. 5: 24 (1882).
Syringodium isoetifolium (Asch.) Dandy, J. Bot. 77: 116 (1939).
Thalassodendron ciliatum (Forssk.) Hartog, Verh. Kon. Ned. Akad. Wet., Afd. Nat. Sect. 2, 59(1): 88 (1970).

CYNOMORIACEAE
Cynomorium coccineum L., Sp. Pl. 2: 970 (1753).

CYPERACEAE
Cyperus arenarius Salzm. Ex Steud., Syn. Pl. Glumac. 2(7): 46 (1854) publ. (1855).
Cyperus conglomeratus Vahl, Enum. Pl. 2, 334 (1805).
Cyperus laevigatus L., Mant. 179 (1771).
Schoenoplectus littoralis Palla, Sitz. Zool.-Bot. Ges.Wien. 38: 49 (1888).

FABACEAE
Alhagi graecorum Boiss., Diagn. Pl. Or. Ser. 1, 9: 114 (1848).
Syn. *A. maurorum* DC. (1825) non Medik.
Lotus garcinii DC., Prodr. 2: 212 (1825).
Taverniera lappacea (Forssk.) DC., Prodr. 2: 339 (1852).
Basionym. *Hedysarum lappaceum* Forssk. (1775).
Taverniera spartea (Burm.f.) DC., Prodr. 2: 339 (1852).
Basionym. *Hedysarum spartium* Burm.f. (1768).

Crotalaria saltiaina T.Anders., Bot. Rep. T. 648 (1812).

FRANKENIACEAE

Frankenia pulverulenta L., Sp. Pl. 332 (1753).

HYDROCHARITACEAE

Halophila ovalis (R.Br.) Hook.f., Bot. Antart. Voy. III, 2: 45 (1858).

Halophila stipulacea Asch., Sitz. Ges. Naturf. Freunde Berlin 3(1867).

Najas flexilis (Willd.) Rostk. & W.L.E.Schmidt, Fl. Sedin. 382 (1824).

Najas graminea Delile Descript. Egypte, Hist. Nat. 2: 282 (1813).

Najas marina L., Sp. Pl. 2: 1015 (1753).

JUNCACEAE.

Juncus rigidus Desf., Fl. Atlant. 1: 312 (1798).

Juncus acutus L., Sp. Pl. 1: 325 (1753).

LILIACEAE

Dipcadi biflorum Ghaz., Kew Bull. 51(4): 805 (1996).

MIMOSACEAE

Acacia tortilis (Forssk.) Hayne, Arzneigew. 10: I, t. 31 (1827).

Basionym. *Mimosa tortilis* Forssk. (1775).

Prosopis cineraria (L.) Druce, Rep. Bot. Soc. Exch. Cl. Brit. Isles 1913, 3: 422 (1914).

Basionym. *Mimosa cineraria* L. (1753).

OROBANCHACEAE

Cistanche phelypaea (L.) Cout., Fl. Portugal: 571 (1913).

Basionym. *Lathraea phelypaea* L. (1753).

Syn. *Orobanche tinctoria* Forssk. (1775); *Phelypaea tubulosa* Schrenk (1840); *Cistanche tubulosa* (Schrenk) Hook.f. (1884); *Cistanche tinctoria* (Forssk.) Beck (1904).

PLUMBAGINACEAE

Limonium axillare (Forssk.) Kuntze, Rev. Gen. Pl. 2: 395 (1891).

Syn. *Statice axillaris* Forssk. (1775).

Limonium carnosum (Boiss.) O. Kuntze, Rev. Gen. Pl. 2: 395 (1891).

Syn. *Statice carnosum* Boiss. (1879).

Limonium cylindrifolium Verdc. ex Cufod., Bull. Jard. Bot. Natl. Belg. 30 (Suppl.) 661 (1960).

Limonium milleri Ghaz. & J.R.Edm., Edinb.J. Bot. 60(1): 15 (2003).

Limonium sarcophyllum Ghaz. & J.R.Edm., Edinb.J. Bot. 60(1): 13 (2003).

Limonium stocksii (Boiss.) Kuntze, Rev. Gen. Pl. 2: 396 (1891).

Syn. *Statice arabicum* Jaub. & Spach (1844); *S. stocksii* Boiss. in DC. (1848); Boiss. (1879).

POACEAE

Aeluropus lagopoides (L.) Trin. Ex Thwaites, Enum. Pl. Zeyl.: 374 (1864).

Syn. *Aeluropus littoralis* auct. non (Gouan) Parl.

Aristida abnormis Chiov., Pirotta, Fl. Eritrea 48 (1903).

Arundo donax L., Sp. Pl., 1: 81 (1753).

Echinochloa crusgalli (L.) P.Beauv., Ess. Agrostogr.: 53: 161 (1812).

Basionym. *Panicum crusgalli* L. (1753).

Halopyrum mucronatum (L.) Stapf, Hook.f., Icon. Pl. 25: t. 2448 (1896).

Basionym. *Uniola mucronatum* L. (1762).

Panicum antidotale Retz., Observ. Bot. (Retzius) iv. 17 (1786).

Panicum turgidum Forssk., Fl. Aegypt.-Arab. 18 (1775).

Paspalidum desertorum (A.Rich.) Stapf, Fl. Trop. Afr. 9(4): 585 (1920).

Basionym. *Panicum desertorum* A. Rich. (1850).

Paspalum distichum L., Syst. Nat. Ed. 10, 2: 855 (1759).

Paspalum vaginatum Sw., Prodr.: 21 (1788).

Phragmites australis (Cav.) Trin. ex Steud., Nomencl. Bot. Ed. 2, 2: 324 (1841).

Syn. *P. communis* Trin. (1820); *Arundo donax* Forrsk., (1775) non L.

Sporobolus consimilis Fresen., Mus. Senckenberg. 2: 140 (1837).

Sporobolus helvolus (Trin.) T.Durand & Schinz., Consp. Fl. Afric. 5: 820 (1895).
Basionym. *Vilfa helvola* Trin. (1837).
Sporobolus ioclades (Nees ex Trin.) Nees, Fl. Afric. Austr. Ill. 1: 161 (1841).
Syn. *S. arabicus* Boiss., (1853); *S. jemenicus* Pilg. Ex Schwartz (1939); *S. kentrophyllus* (K.Schum.) Calyton (1997).
Sporobolus spicatus (Vahl.) Kunth, Revis. Gramin. 1: 67 (1829).
Syn. *Agrostis virginica* Forssk. (1775).
Sporobolus virginicus (L.) Kunth, Revis. Gramin. 1: 67 (1829).
Urochondra setulosa (Trin.) C.E.Hubb., Hook., Icon. Pl. 35: t. 3457 (1947).
Basionym. *Vilfa setulosa* Trin. (1840).

PORTULACCACEAE
Portulaca oleracea L., Sp. Pl. 445 (1753).

POTAMOGETONACEAE
Potamogeton pectinatus L., Sp. Pl. 127 (1753).

RHIZOPHORACEAE
Rhizophora mucronata Lam., Encycl. 6(1): 189 (1804).
Bruguiera gymnorrhiza (L.) Sav., Ecycl. 4: 696 (1798).

RUPPIACEAE
Ruppia maritima L., Sp. Pl. 1: 127 (1753).

SALVADORACEAE
Salvadora persica L., Sp. Pl. 1: 122 (1753).

TAMARICACEAE
Tamarix mascatensis Bunge, Tentamen 60 (1852).
Tamarix aphylla (L.) G. Karsten, Deutsch. Fl.: 641 (1882).
Syn. *Thuja aphylla* L. (1755) p.p.; *Tamarix orientalis* Forssk. (1775); *T. articulata* Vahl (1791), nom. illegit.
Tamarix aucheriana (Decne.) Baum, Monogr. Rev. Tamarix: 148 (1978).
Syn. *Trichaurus aucherianus* Decne. ex Walpers (1843); *T. passerinoides*, Boiss. (1867), non Del. ex Desv.

TYPHACEAE
Typha domingensis Pers., Syn. Pl. 2(2): 532 (1807).

ZANNICHELLIACEAE
Zannichellia palustris L., Sp. Pl. 969 (1753).

ZYGOPHYLLACEAE
Fagonia indica Burm.f., Fl. Indica 102, t. 34, f.1 (1768).
Fagonia luntii Bak., Kew Bull. 1894: 330 (1894).
Fagonia ovalifolia Hadidi, Fl. Iran. 98: 2, t.1, (1972).
Fagonia schweinfurthii (Hadidi) Hadidi, Oester. Bot. Z. 121: 272 (1973).
Syn. *Fagonia arabica* Edgeworth & Hook. F. (1874) non L.; *F. indica* Burm.f. var. *schweinfurthii* Hadidi (1972).
Nitraria retusa Asch., Verh. Biot. Prov. Barndenberg 18: 94 (1876).
Tetraena alba (L.f.) Beier & Thulin, Pl. Syst. Evol. 240: 35 (2003).
Basionym. *Zygophyllum album* L.f. (1762).
Tetraena hamiensis (Schweinf.) Beier & Thulin, Pl. Syst. Evol. 240: 35 (2003).
Basionym. *Zygophyllum hamiensis* Schweinf. (1899).
Tetraeana qatarensis (Hadidi) Beier & Thulin, Pl. Syst. Evol. 240(1–4): 36 (2003).
Basionym. *Zygophyllum qatarense* Hadidi (1978); *Z. coccineum* auct., non Linn.; *Z. smithii* Hadidi, nom. nud.; *Z. hamiensis* var. *qatarense* (Hadidi) Jac. Thomas & Chaudhary (2001).
Tetraena simplex (L.) Beier & Thulin, Pl. Syst. Evol. 240: 36 (2003).
Basionym. *Zygophyllum simplex* L. (1767).
Tribulus arabicus Hosni, Bot. Not. 130: 261. (1977).
Syn. *T. omanensis* Hosni (1978).

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