Chapter 3
The Coastal Desert of Egypt

Abstract The coastal deserts in Egypt are found along the Mediterranean (east and west), the Red Sea, and the Gulfs of Suez and Aqaba in Sinai Peninsula. The variations in their floristic composition and vegetation structure are varied considerably. The association between the landform units and their floristic features showed significant differences. In the meanwhile, the biological spectrum and chorological analyses of the flora exhibited a general trend in both dominance and structure. Climatic variations, especially rainfall, between the different geographical areas play a profound role in the species distribution patterns. The relationships between the vegetation and the prevailing environmental characteristics indicated the importance of certain soil factors such as coarse and fine sediments, moisture content, electrical conductivity, pH, and organic matter. The distance from the sea and altitude were other significant factors in delimiting species distribution.

3.1 General

Deserts are large bands of dry lands along the tropics in both the Northern and Southern Hemispheres (Mares 1999; Middleton and Thomas 1997). Deserts cover around 25,500,000 km^2, approximately 20% of the land area of the world. The boundaries of these deserts, which are constantly changing due to various climatic and human factors, are likely to drift over the next century as human-induced global warming takes effect. The defining characteristic of world deserts is aridity. The current UNEP definition of desert is a moisture deficit under normal climatic conditions where P/PET <0.20, i.e. where rainfall is less than 20% of potential moisture loss through evaporation (Smith et al. 1997). The variation among deserts is probably greater than for any other biome, largely because deserts are so widely spaced on the planet and have arisen for very different reasons. North American continental deserts are far hotter and wetter than African and Middle Eastern deserts (Louw and Seely 1982). The Kalahari and Namib deserts in southern Africa mostly experience summer rainfall and are dominated by grasses, while the adjacent succulent Karoo desert experiences winter

The original version of this chapter was revised. An erratum to this chapter can be found at DOI 10.1007/978-3-319-59135-3_14

M.M. Abd El-Ghani et al., *Plant Responses to Hyperarid Desert Environments*,
DOI 10.1007/978-3-319-59135-3_3

rainfall and dominated by succulents. In contrast, Middle Eastern deserts experience winter rainfall and are dominated by annual forbs (mostly Asteraceae). The coastal Namibian and Chilean desert systems are driven by fog, while runoff from winter floods controls plant production in Middle Eastern deserts. Australian deserts are limited by phosphorus (Beadle 1981; Stafford Smith and Morton 1990), while nitrogen is the most limiting nutrient in other deserts (Ezcurra 2006).

Desert ecosystems of the world have in recent times been subjected increasingly to untested contacts with humans and their characteristic activities. Within the past 40 years, there has been heavy use of desert scrub communities for land reclamation, recreational purposes, military testing, and different construction projects, all of which have modified physical characteristics of soil and altered the composition of desert scrub vegetation and changing floristic composition.

In Egypt, the desert vegetation is by far the most important and characteristic type of natural plant life. It covers about 95% of the total area of the country and is mainly formed of xerophytic shrubs and subshrubs. Desert vegetation is composed of two sets of plants, ephemerals and perennials. The ephemerals are active only in the vernal aspect of the vegetation. The appearance of ephemerals and the duration of their life are dependent on the chance occurrence of rainy seasons. The perennial plant cover forms the permanent framework of the vegetation and is the best indicator of the habitat condition (Kassas and Imam 1954). Kassas (1966, 1971) added a third type termed *accidental vegetation*, where precipitation is so low and falls so irregularly that no permanent vegetation exists.

The remarkable variations in the flora and vegetation of its wadi ecosystem and the coastal flora along the Red Sea, the Eastern Desert was of extreme interest to botanists from the early beginnings of the last century such as Schweinfurth (1901), Hassib (1951), Kassas (1952, 1955, 1957 and 1966)Kassas and Batanouny (1984), Hassan (1987), Salama and Fayed (1990), Salama and El-Naggar (1991), Abd El-Ghani (1998), and Hassan (2003). Except that of Schweinfurth (1901) and Hassan (1987), most of the previous studies dealt with different ecological aspects, with less attention to the floristic features of this desert.

During last decades, most of the phytogeographic regions of Egypt (including the Eastern Desert) were affected by human activities such as cultivation of the deltaic part of wadis, the intensive collection of plant species for its values (medicinal, fuel, fibre, etc.), and establishment of new towns, roads, building factories, and quarries. These activities cause a destructive influence in the natural flora and change the distribution of plants in these areas. This means great changes in the distribution, presence, and extinction of the desert plants occurred.

A coastal plain is an area of flat, low-lying land adjacent to a seacoast. One of the world's largest coastal plains is located in eastern South America. The Mediterranean coast of Egypt (or the Northern coast of Egypt) extends for about 1,050 km from Rafah in the east on Sinai Peninsula to Sallum in the west on the Egyptian–Libyan border. It is one of the longest Mediterranean shores in North Africa. The city of Alexandria lies at the centre of the Mediterranean Egyptian coastline and has been the hub of sea travel between the Mediterranean Sea and the Nile Delta for over 2,300 years.

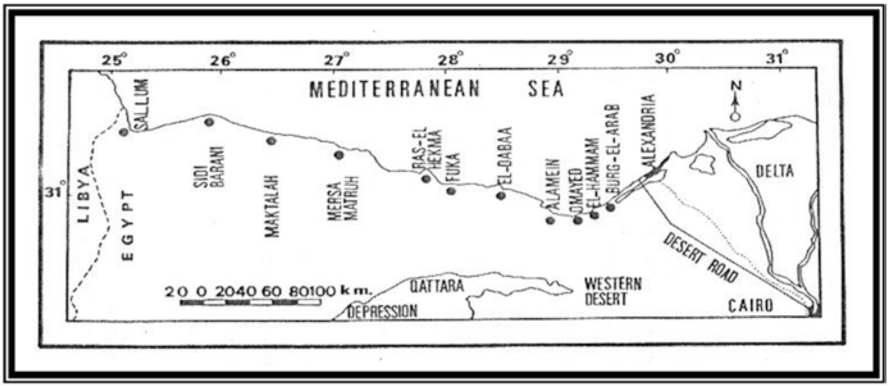

Fig. 3.1 Location map of the western Mediterranean coastal land of Egypt (after Hammouda 1982)

3.2 Surveyed Areas

3.2.1 The Western Mediterranean Coast (Sallum Area)

3.2.1.1 Association Between Floristic Compositions of Landform Units

The western section of the Mediterranean coastal plain of Egypt extends for about 500 km from Alexandria to Sallum on the Egyptian–Libyan border (Fig. 3.1). It is bounded on the north by the Mediterranean Sea and extends south for an average distance of 50 km, crossing the Northern Plateau (limestone). Physiographically, two main provinces can be distinguished: an eastern province between Alexandria and Ras El-Hikma and a western province between Ras El-Hikma and Sallum (Selim 1969). The southern tableland (Northern Plateau) is mainly covered by stones and gravel and extends southwards to the Qattara Depression. It increases gradually in level westwards and attains a maximum elevation of about 200 m above sea level at Sallum. Northwards it slopes gently to a coastal plain west of Mersa Matruh that varies in elevation from 10 to 30 m above sea level. Eastwards it decreases gradually in level until it loses its line of demarcation with the coastal plain.

Floristically, the Mediterranean coastal land of Egypt represents one of the richest phytogeographical territories of the country. El Hadidi and Hosni (2000) reported that 1,060 species or 51% of the total flora of Egypt are recorded from this territory. Three hundred and twenty-one species are confined in their distribution to a specific habitat and only known from this territory, of which more than two-thirds are typical Mediterranean chorotype. Four plant species are known to be endemic to this territory and not recorded elsewhere in the country; these include *Allium mareoticum* Bornm. & Gauba, *Echinops taeckholmianus* Amin, *Fumaria microstachys* Hausskn., and *Helianthemum sphaerocalyx* Gauba & Spach (Boulos 1995).

Since the 1950s, much attention has been paid to the western section of the Mediterranean coastal land. Extensive studies on the ecology, flora, biodiversity, phytosociology, and vegetation dynamics are carried out (see Zahran and Willis 1992 for literature). At least ten habitat types are recognized that belong to five vegetation types. These include the desert vegetation, the littoral salt marshes, the coastal dunes, the farmland vegetation, and the aquatic vegetation (for detailed information, see Zahran and Willis 1992; El Hadidi and Hosni 2000). Yet, not all parts of that section have been studied in the same intense way. Till the recent, less attention has been paid to the distant part of the western Mediterranean coast from Sidi Barrani to Sallum on the Egyptian–Libyan frontier. Therefore, floristic investigations were conducted to provide an analysis of the floristic composition associated with different landforms of the Sallum area.

This area represents the distant part of the western Mediterranean coastal land of Egypt, where the human activities through cultivation, grazing, and urbanization are much less pronounced than the other parts of the region. The study area (1,700 km^2) lies between 25° 09′–25° 35′E and 31° 32′–31° 15′N and extends for about 49 km from Buqbuq to Sallum on the Egyptian–Libyan frontier (Fig. 3.1). It is included in the semi-desert vegetation zone that is proposed by Bornkamm and Kehl (1990). The coastal plain is very narrow or, sometimes, lacking. Five main landform units can be distinguished in the study area (i.e. from the coast in the north to the fringes of the Diffa plateau in the south; Fig. 3.2): Sallum plateau (U_1), coastal saline depressions (U_2), inland sandy plains (U_3), inland rocky plains (U_4), and shallow wadis (U_5).

According to Ayyad and Ghabbour (1986), and recently by El Hadidi and Hosni (2000), the Sallum area lies within the northern arid province that runs parallel to the semiarid belt. Comparing climatic characteristics of four meteorological stations

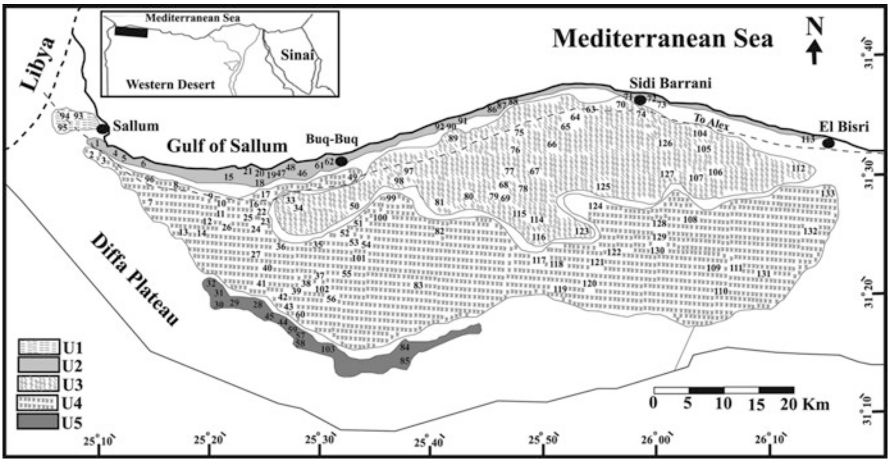

Fig. 3.2 Distribution of the 66 sampled sites in the five landform units of Sallum area. *U1* Sallum plateau, *U2* coastal saline depressions, *U3* inland sandy plains, *U4* inland rocky plains, and *U5* shallow wadis

Table 3.1 Long-term annual averages (Courtesy of the Egyptian Meteorological Authority) of some climatic factors of Sallum station in the study area and other three stations along the Mediterranean coast of Egypt

	Temperature (°C)	Relative humidity (RH%)		
Station	Minimum	Maximum	Rainfall (mm)	
Sallum	14.0	24.3	65.5	89.8
Sidi Barrani	15.5	23.3	69.7	149.8
Mersa Matruh	14.3	24.3	66.0	144.0
Alexandria	14.9	24.9	65.0	192.1

along the western section of the Mediterranean coast, Sallum station, the nearest to the study area, with other three is shown in Table 3.1. The wide variation in annual precipitation along the E–W direction on the Mediterranean coast (from Alexandria in the east to Sallum in the west) is remarkable.

Among the recent advances in geographical methodology and mapping is the technique of geographical information system (GIS) . The study of GIS has emerged in the last decades as an exciting multidisciplinary endeavour, spanning such areas as geography, cartography, remote sensing, image processing, the environmental sciences, and computer sciences. Within computing science, GIS is of special interest of fields such as databases graphics, systems engineering, and computational geometry, being not only a challenging application area but also providing foundational questions for these disciplines.

Floristic Composition

A total of 113 species (37 annuals and 76 perennials) belonging to 93 genera and 35 families are recorded. The largest families were Asteraceae and Fabaceae (16 for each), Chenopodiaceae (10), Poaceae (9), Brassicaceae (7), Caryophyllaceae (5), Liliaceae, and Zygophyllaceae (4 for each). They constituted about two-thirds (62.8%) of the recorded species and represent most of the floristic structure in the Mediterranean North African flora (Quézel 1978). Sixteen families are represented by only one species. The largest genera include *Astragalus* (7), *Lotus* and *Erodium* (3 for each), *Launaea, Atriplex, Silene, Medicago Limonium, Asparagus,* and *Asphodelus* (2 for each). Though floristic similarities prevail among the different sites of the study area, the floristic composition and vegetation structure show perceptible variations within each site.

Boulos (1975) cited 1,095 species recorded along the Mediterranean coastal region of Egypt. In the present study, the recorded species represent 10.3% of the total flora of the region. It is also noted that the generic index (113/93) is 1.2. Locally, this high ratio is in accordance with Zohary's (1973) observation "that a striking feature in Egypt's flora is the large number of genera in proportion to that of the species". The average global value is 13.6 (Good 1947). This low value in Egypt can be attributed to the lack of accumulation and differentiation centres in Egypt (Zohary 1973).

Biological Spectrum

The life-form spectrum of the Sallum area showed that the proportion of therophytes (32.7%) is higher than that of other life forms, while the proportions of chamaephytes (25.7%) and hemicryptophytes (22.1%) are noteworthy. High percentages of therophytes and hemicryptophytes coincide with the floristic characters of the arid zones in the Mediterranean Basin and in general for the floras of arid and semiarid zones (Migahid et al. 1971; Pignatti and Pignatti 1989; Bornkamm and Kehl 1985). The high contribution of annuals may be related to their short life cycles (sometimes a few weeks) that enable them to resist the instability of the arid desert ecosystem of the study area. They also have the ability to set seeds without the need for a visiting pollinator (Baker 1974), and this facilitates the continuity of their life cycles. It is to be noted here that Raunkiaer (1937) suggested a "therophyte climate" for the Mediterranean climate where a high percentage (>50% of the total species) of therophytes is noteworthy. Raven (1971) pointed out that several Mediterranean floras follow this trend: Cain (1950) in California, Hassib (1951) in Egypt, Zohary (1973) in Palestine, and Quézel (1978) in North Africa.

The distribution of the different life forms in the five landscape units is shown in Table 3.2. Clearly, the shallow wadies had the highest share of annuals. El-Ghareeb and Rezk (1989) provided evidence that therophytes acquire dominance in less saline and sandy habitats, whereas cryptophytes and chamaephyes in more saline habitats in the coastal areas of Egypt. On the other hand, Zahran (1982) concluded that chamaephytes are the most abundant life form in the halophytic vegetation of Egypt. The results of this study are in accordance with these findings. It is of interest to note that the proportions of cryptophytes, hemicryptophytes, and chamaephytes constitute the main bulk of the floristic structure in each of the five geomorphologic units. It ranges between 50% in the shallow wadis and 73.4% in the rocky plains, where they seem to play an important role in the process of sand accumulation and succession of vegetation in the study area. Plants of these three life forms have the ability to act as barriers to wind- and/or water-borne materials, which are then deposited around them. This enables such plants to produce adventi-

Table 3.2 Numbers and percentages of the life forms represented in the geomorphologic landscape units in the study area

	U_1		U_2		U_3		U_4		U_5	
Life forms	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Therophytes (TH)	5	20.8	11	23.9	7	24.1	10	24.4	28	41.2
Chamaephytes (CH)	8	33.4	15	32.6	9	31.1	17	41.5	13	19.1
Hemicryptophytes (H)	5	20.8	12	26.1	7	24.1	6	14.6	12	17.7
Cryptophytes (C)	4	16.7	5	10.9	2	6.9	3	7.3	9	13.2
Nano-Phanerophytes (NPh)	2	8.3	3	6.5	4	13.8	5	12.2	5	7.3
Parasites	–	–	–	–	–	–	–	–	1	1.5
Total number of species	24	46	29	41	68					

N Number of species recorded. U_1 Sallum plateau, U_2 coastal saline depressions, U_3 inland sandy plains, U_4 inland rocky plains, U_5 shallow wadis

Table 3.3 Pearson's product–moment correlations between the five landform units (U_1–U_5) of the Sallum area

Landform units	U_1	U_2	U_3	U_4
U_1				
U_2	0.27**			
U_3	0.29**	0.34**		
$-U_4$	0.19*	0.31**	0.31*	
U_5	−0.11	−0.39**	−0.35**	−0.18

Significant levels: **=$p < 0.01$, *=$p < 0.05$. See Table 3.2 for the abbreviations of the units

tious roots and aerial shoots from their buried organs and to replace them when they die. This has also been noted along the Mediterranean coast of Egypt (Batanouny 1973; Khedr 1993).

Pearson's product–moment correlations between the floristic compositions in the different landform units (U_1–U_5) were demonstrated in Table 3.3. Apart from the shallow wadis (H_5), positive significant differences between the other units were remarkable. The coastal saline depressions and the inland sandy plains showed negative correlations with the shallow wadis.

Chorological Affinities

Results of the chorological analysis (Table 3.4) revealed that 45.2% of the studied species were uniregional, of which 23% being native to the Saharo–Arabian chorotype. The typical Mediterranean was ranked second (21.3%), while the Sudano–Zambezian chorotype was very modestly represented. About 50.4% of the recorded species were biregional and pluriregional, extending their distribution all over the Saharo–Arabian, Sudano–Zambezian, Irano–Turanian, Mediterranean, and Euro–Siberian chorotypes. Being part of the Mediterranean region, the Mediterranean chorotype (uni, bi, and pluri) constituted 55.7% of the recorded species, whereas the Saharo–Arabian constituted 38.9%. Thus, they formed the major components (94.6%) of the floristic composition in this study. The biregional Mediterranean and Irano–Turanian chorotypes constituted the highest values (11.5%, 11.5%, and 9.7%, respectively). These results are in agreement with the findings of White (1993a, b), who claimed that the study area lies within the Mediterranean/Sahara regional transition zone, where the vegetation comprises floristic elements for both of the Mediterranean and Saharo–Arabian regions.

Distribution of the major chorotypes in the five landform units (Fig. 3.3) indicated the decrease in the numbers of the Mediterranean species in the Sallum plateau and Saline depressions and the increase of the Saharo–Arabian species in the inland rocky plains and the shallow wadis. This may be attributed to the fact that plants of the Saharo–Arabian region are good indicators for desert environmental conditions, while Mediterranean species stand for more mesic environment. A checklist of the included species occurring in the study area, together with their distribution in the different landform units and chorotypes, was shown in Table 3.5.

Table 3.4 Chorotype analysis of the species examined as numbers (N) and percentages (%) of the total species recorded

Chorotypes	N	(%)
Monoregional		
Mediterranean	24	21.3
Saharo–Arabian	26	23.0
Sudano–Zambezian	1	0.9
	51	45.2
Biregional		
Mediterranean+Saharo–Arabian	13	11.5
Mediterranean+Irano–Turanian	13	11.5
Saharo–Arabian+Irano–Turanian	11	9.7
Saharo–Arabian+Sudano–Zambezian	5	4.4
	42	37.1
Pluriregional		
Med+Sah–Arab+Iran–Tur	4	3.5
Med+Iran–Tur+Eur–Sib	6	5.3
Med+Sah–Arab+Sud–Zam	3	2.7
Sah–Arab+Sud–Zam+Iran–Tur	2	1.8
	15	13.3
Cosmopolitan	4	3.5
Paleotropic	1	0.9
Total	113	100

Sah–Arab Saharo–Arabian, *Med* Mediterranean, *Iran–Tur* Irano–Turanian, *Eur–Sib* Euro–Siberian, *Sud–Zam* Sudano–Zambezian

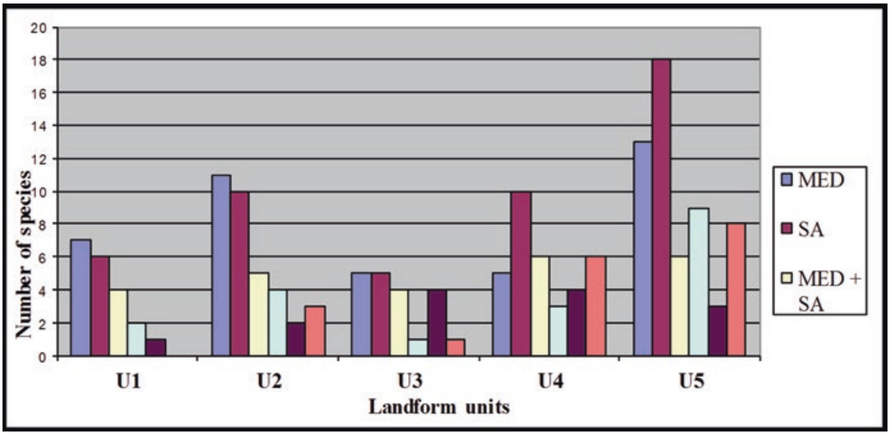

Fig. 3.3 Distribution of the major chorotypes in the five landform units of the Sallum area

Table 3.5 Distribution of plant species recorded in the Sallum area, together with their life forms and chorotypes in the five landform units (U_1–U_5). For abbreviations of life form and landform units, see Table 3.2

Family	Species	Life form	U_1	U_2	U_3	U_4	U_5	Chorotype	`P (%)
			4	17	14	22	9		
Amaryllidaceae	*Pancratium maritimum* L.	G	–	–	–	–	+	MED	20
Apiaceae	*Bupleurum lancifolium* Hornem.	Th	–	–	–	+	–	MED+IT	20
	Deverra tortuosa (Desf.) DC.	Ch	+	+	+	+	+	SA	100
Asclepiadaceae	*Periploca angustifolia* Labill.	NPh	–	–	–	+	+	SA+SZ	40
Asteraceae	*Anthemis microsperma* Boiss.& Kotschy	Th	–	–	–	–	+	MED	20
	Artemisia judaica L.	Ch	+	–	–	–	–	SA	20
	Atractylis carduus (Frossk.) C.Chr.	H	–	–	–	+	–	MED+SA	20
	Carduncellus mareoticus (Delile) Hanelt	Th	+	+	+	–	–	SA	60
	Carthamus glaucus M.Bieb.	Th	+	+	+	+	+	MED	100
	Centaurea glomerata Vahl	Th	–	–	+	–	–	SA	20
	Echinops sipnosus L.	H	+	+	–	+	–	IT	60
	Hyoseris lucida L.	G	–	–	–	–	+	MED	20
	Hyoseris scabra L.	G	–	–	–	–	+	MED	20
	Koelpinia linearis Pall.	Th	–	–	–	–	+	SA+IT	20
	Launaea nudicaulis (L.) Hook.f.	H	–	+	+	–	–	SA+SZ+IT	40
	Launaea spinosa (Forssk.) Sch.Bip. ex Kuntze.	H	–	+	+	–	–	SA	40
	Phagnalon barbeyanum Asch. & Schweinf.	Ch	–	–	–	–	+	SA	20
	Reichardia tingitana (L.) Roth.	Th	–	–	–	–	+	SA+IT	20
	Scorzonera undulata Vahl	G	–	–	–	–	+	MED+IT	20
	Varthemia candicans (Delile) Boiss.	H	–	–	–	–	+	MED+IT	20
Boraginaceae	*Arnebia decumbens* (Vent) Coss. & Kralik	Th	–	–	–	–	+	SA+IT	20
	Echiochilon fruticosum Desf.	Ch	–	+	–	+	–	SA	40
	Heliotropium lasiocarpum Fisch. & C. A. Mey.	Ch	–	–	+	+	–	MED+IT+ES	40

(continued)

Table 3.5 (continued)

Family	Species	Life form	U_1	U_2	U_3	U_4	U_5	Chorotype	`P (%)
			4	17	14	22	9		
Brassicaceae	*Brassica tournefortii* Gouan	Th	–	–	–	–	+	MED+SA	20
	Carrichtera annua (L.) DC.	Th	–	–	–	–	+	SA	20
	Enarthrocarpus lyratus (Forssk.) DC.	Th	–	–	–	–	+	MED	20
	Erucaria microcarpa Boiss.	Ch	–	–	–	+	–	MED+IT	20
	Farsetia aegyptia Turra	Ch	–	–	+	+	+	SA+SZ	60
	Sisymbrium irio L.	Th	–	–	–	–	+	MED+SA+IT	20
	Zilla spinosa L.	Ch	–	–	–	+	–	SA	20
Caryophyllaceae	*Herniaria hemistemon* J. Gay	H	+	–	+	+	–	SA	60
	Gymnocarpos decander Forssk.	Ch	–	–	+	+	–	MED+SA	40
	Paronychia arabica (L.) DC.	Th	–	–	–	–	+	SA	20
	Silene succulenta Forssk.	H	–	–	–	–	+	MED	20
	Silene vivianii Steud.	Th	–	–	–	–	+	SA	20
Chenopodiaceae	*Anabasis articulata* (Forssk.) Moq.	Ch	+	+	+	+	+	SA+IT	100
	Arthrocnemum macrostachyum (Moric.) K. Koch	Ch	–	+	–	–	–	MED+SA	20
	Atriplex halimus L.	NPh	+	+	+	+	+	MED+SA	100
	Atriplex portulacoides L.	Ch	+	+	+	+	+	COSM	100
	Bassia muricata (L.) Asch.	Th	–	+	–	–	–	SA+IT	20
	Halocnemum strobilaceum (Pall.) M. Bieb.	Ch	–	+	–	–	–	MED+SA+IT	20
	Haloxylon salicorincum (Moq.) Bunge ex Boiss.	Ch	+	+	+	+	+	SZ	100
	Noaea mucronata (Forssk.) Asch. & Schweinf.	Ch	–	–	–	+	–	MED+IT	20
	Salsola kali L.	Th	–	+	+	+	–	PAL	60
	Suaeda pruinosa Lange	Ch	–	+	+	+	–	MED	60
Cistaceae	*Helianthemum lippii* (L.) Dum. Cours.	Ch	+	+	+	+	–	SA+SZ	80
Convolvulaceae	*Convolvulus arvensis* L.	H	–	–	+	–	–	COMS	20

Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.	H	–	–	–	+	+	SA	40
Euphorbiaceae	*Euphorbia retusa* Forssk.	H	+	–	–	–	+	SA	40
	Euphorbia dendroides L.	Ch	+	–	–	–	–	MED	20
Fabaceae	*Argyrolobium uniflorum* (Decne.) Jaub. & Spach	Ch	–	–	–	–	+	MED+SA+SZ	20
	Astragalus caprinus L.	H	–	+	–	+	+	SA	60
	Astragalus hamosus L.	Th	–	+	–	+	+	MED+IT	60
	Astragalus hispidulus DC.	Th	–	+	–	+	+	SA	60
	Astragalus peregrinus Vahl	Th	–	+	–	+	+	SA	60
	Astragalus schimperi Boiss.	Th	–	+	–	+	+	SA	60
	Astragalus sieberi DC.	Ch	–	+	–	+	+	SA	60
	Astragalus spinosus (Forssk.) Muschl.	Ch	–	+	–	+	+	SA+IT	60
	Lotus angustissimus L.	Th	–	+	+	–	–	MED+ES	40
	Lotus creticus L.	H	–	+	+	–	–	MED	40
	Lotus polyphllos E.D.Clarke	H	–	+	+	–	–	MED	40
	Medicago coronata (L.) Bartal.	Th	–	–	–	–	+	MED+IT	20
	Medicago laciniata (L.) Mill.	Th	–	–	–	–	+	SA	20
	Ononis vaginals Vahl	Ch	–	–	–	–	+	SA+IT	20
	Retama raetam (Forssk.)Webb & Berthel.	NPh	–	–	–	+	+	MED+SA+IT	40
	Trigonella stellata Forssk.	TH	–	–	–	–	+	SA+IT	20
Frankeniaceae	*Frankenia revoluta* Forssk.	H	–	+	–	–	–	MED+IT+ES	20
Geraniaceae	*Erodium crassifolium* L'Hér.	G	–	–	–	–	+	SA	20
	Erodium laciniatum (Cav.) Willd.	Th	+	–	–	–	–	MED	20
	Erodium pulverulentum (Boiss.) Batt.	Th	–	–	–	–	+	SA	20
Globulariaceae	*Globularia arabica* Jaub. & Spach	Ch	–	–	–	+	–	MED+SA	20
Juncaceae	*Juncus acutus* L.	HH	–	–	–	–	+	COSM	20
	Juncus rigidus Desf.	HH	–	–	–	–	+	MED+IT+ES	20

(continued)

Table 3.5 (continued)

Family	Species	Life form	U_1 4	U_2 17	U_3 14	U_4 22	U_5 9	Chorotype	`P (%)
Lamiaceae	*Ajuga iva* (L.) Schreb.	H	–	–	–	–	+	MED	20
	Marrubium alysson L.	Th	–	–	–	–	+	MED+SA	20
	Salvia lanigera Poir.	H	+	–	+	–	–	MED+SA	40
Liliaceae	*Asparagus aphyllus* L.	Ch	+	+	–	–	–	MED	40
	Asparagus stipularis Forssk.	G	+	+	–	–	–	MED+SA	40
	Asphodelus ramosus L.	G	+	+	+	+	–	MED	80
	Asphodelus tenuifolius Cav.	Th	+	+	+	+	–	MED+SA+SZ	80
Iridaceae	*Gynandriris sisyrinchium* (L.) Parl.	G	–	–	–	–	+	MED	20
Malvaceae	*Malva parviflora* L.	Th	–	–	–	–	+	MED	20
Neuradaceae	*Neurada procumbens* L.	Th	–	–	–	–	+	SA	20
Plantaginaceae	*Plantago albicans* L.	H	–	–	–	–	+	MED+SA	20
Plumbaginaceae	*Limoniastrum monopetalum* (L.) Boiss.	Ch	–	+	–	–	–	MED	20
	Limonium narbonense Mill.	H	–	+	–	–	–	MED	20
	Limonium pruinosum (L.) Chaz.	H	–	+	–	–	–	SA	20
Poaceae	*Aeluropus* sp.	G	–	–	–	–	+	MED+IT	20
	Ammophila arenaria (L.) Link	G	–	+	–	–	–	MED	20
	Cynodon dactylon (L.) Pers.	G	–	–	+	–	–	COSM	20
	Cutandia memphitica (Spreng.) K. Richt.	Th	–	–	–	–	+	MED+SA+IT	20
	Hordeum murinum L. subsp. *leporinum* (Link) Arcang.	Th	–	+	+	+	–	MED+IT	60
	Lygeum spartum Loefl. ex L.	G	+	+	–	+	–	MED	60
	Schismus barbatus (L.) Thell.	Th	–	–	–	–	+	SA+IT	20
	Sporobolus spicatus (Vahl) Kunth	G	–	+	–	+	–	MED+SA+SZ	40
	Stipa parviflora Desf.	H	–	–	–	–	+	MED+IT	20
Resedaceae	*Reseda alba* L.	Th	–	–	–	–	+	MED+IT	20

Rubiaceae	*Galium* sp.	Th	–	–	–	–	+	MED+IT+ES	20
	Crucianella maritima L.	H	–	+	–	–	+	MED	40
Rutaceae	*Haplophyllum tuberculatum* (Forssk.) A.D. Juss.	H	–	–	–	–	+	SA	20
Santalaceae	*Thesium humile* Vahl	P	–	–	–	–	+	MED	20
Scrophulariaceae	*Kickxia aegyptiaca* (L.) Nábelek	Ch	–	–	–	–	+	SA	20
	Verbascum letourneuxii Asch. & Schweinf.	H	+	–	–	+	–	MED	40
Solanaceae	*Hyoscyamus muticus* L.	H	–	+	–	–	+	SA+IT+SZ	40
	Lycium shawii Roem. & Schult.	NPh	–	–	+	+	+	SA+SZ	60
Tamaricaceae	*Reaumuria hirtella* Jaub. & Spach	Ch	–	+	–	–	–	MED+IT	20
Thymelaeaceae	*Thymelaea hirsuta* (L.) Endl.	NPh	+	=	+	+	+	MED+SA	100
Zygophyllaceae	*Fagonia microphylla* Pomel	Ch	–	–	–	–	+	SA+IT	20
	Peganum harmala L.	H	+	+	–	–	+	MED+SA+IT	60
	Zygophyllum album L.f.	Ch	–	+	–	+	–	MED+SA	40
	Nitraria retusa (Forssk.) Asch.	NPh	–	+	+	–	–	SA+SZ	40
	Peganum harmala L.	H	+	+	–	–	+	MED+SA+IT	60

+, present; –, absent; *MED* Mediterranean, *SA* Saharo–Arabian, *IT* Irano–Turanian, *SZ* Sudano–Zambezian chorotypes, *G* geophyte, *HH* hydrophyte helophyte

Species Distribution Patterns (Figs. 3.4, 3.5, 3.6, 3.7, and 3.8)

Nine of the recorded species were ubiquitous, have a wide ecological range of distribution, and represented in all the five landform units. Psammophytes (e.g. *Deverra tortuosa, Thymelaea hirsuta, Haloxylon salicornicum, Anabasis articulata*) and halophytes (e.g. *Atriplex halimus, Atriplex portulacoides*) have the highest presence values (P = 100%). On the other hand, *Carthamus glaucus* showed the highest presence estimate among annuals (P = 100%). Sixty-one species or about 53.9% of the recorded flora demonstrated a certain degree of consistency, where they exclusively recorded in or confined to a certain landform unit and do not penetrate elsewhere. In the Sallum plateau, *Euphorbia dendroides* and *Artemisia judaica* were recorded. The former species is considered by El Hadidi et al. (1992) as one of the endangered species known from Sallum area and represents its westernmost range of distribution. It is a very rare species that confined to the Marmarica district of the Mediterranean coastal land of Egypt (El Hadidi and Fayed 1978). El-Garf (2003) reported that wadi Halazeen (west of Mersa Matruh) is a less known natural habitat that supports a dense growth of *Euphorbia dendroides*. Urgent conservation measures should be taken for this species in its natural habitat.

In the coastal saline depressions, where halophytic vegetation dominates, nine species were recorded. *Arthrocnemum macrostachyum, Halocnemum strobilaceum, Frankenia revoluta, Ammophila arenaria,* and *Limoniastrum monopetalum* were the dominants. These species comprised the common salt marsh plant communities in the western Mediterranean region of Egypt (Shaltout and El-Ghareeb 1992). Heavy deposition of sand and the active formation of hummocks by the sand binding character of the dominant plants may contribute to the instability of its environment.

Forty-one species were confined to the shallow wadis, of which 21 were annuals. This landform is known to be the richest among the others. It represents one of the major physiographic features of the western Mediterranean desert of Egypt, with peculiar physical and biological features including a characteristic plant cover. Some of these wadis are vegetationally and floristically rich and used mainly as rangelands (Kamal 1988). The phytosociology and vegetation analyses of some of these wadis were the subject of El Hadidi and Ayyad (1975) and extended by El-Kady and Sadek (1992) and Kamal and El-Kady (1993). Among the recorded species, *Anthemis microsperma, Brassica tournefortii, Malva parviflora, Trigonella stellata, Cutandia memphitica,* and *Reichardia tingitana* were included.

Three species from the inland sandy plains and other six from the inland rocky plains were recorded. The latter landform unit favours the growth of certain chasmophytes, e.g. *Globularia arabica* and *Noaea mucronata*. Three species are common in both landform units*:* *Herniaria hemistemon*, *Heliotropium lasiocarpum*, and *Gymnocarpos decanter*.

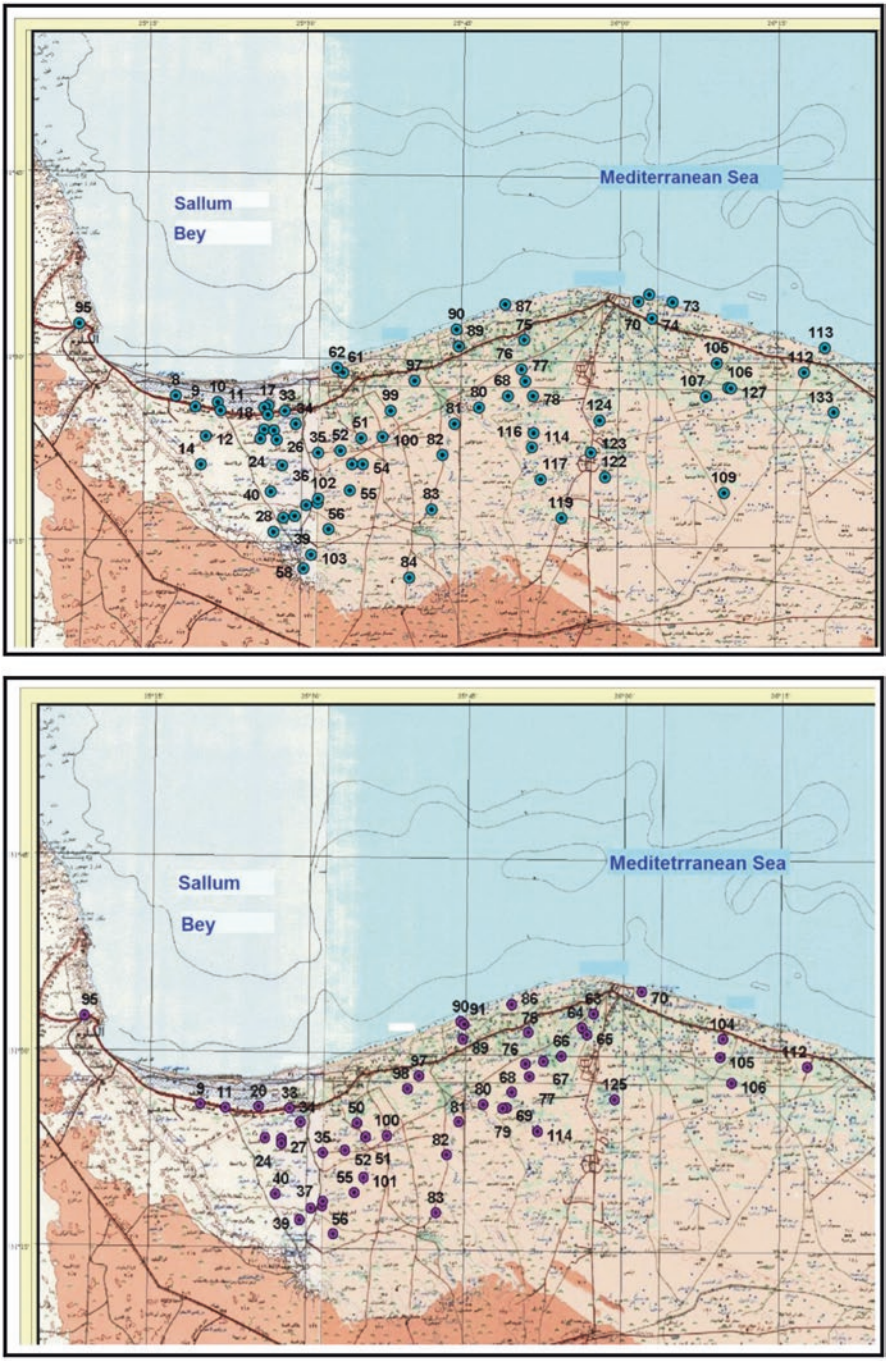

Fig. 3.4 Distribution map of *Thymelaea hirsuta* (*up*) and *Asphodelus ramosus* (*down*)

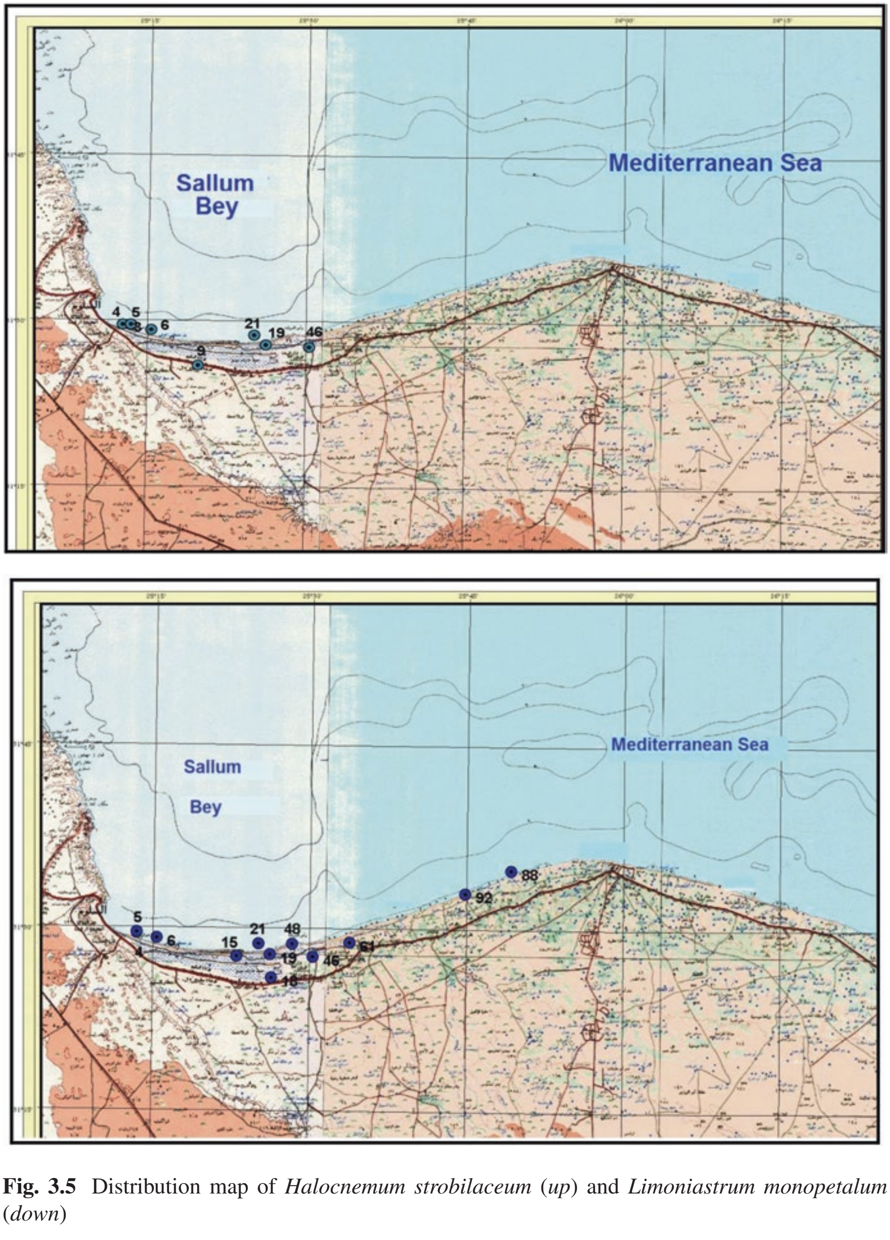

Fig. 3.5 Distribution map of *Halocnemum strobilaceum* (*up*) and *Limoniastrum monopetalum* (*down*)

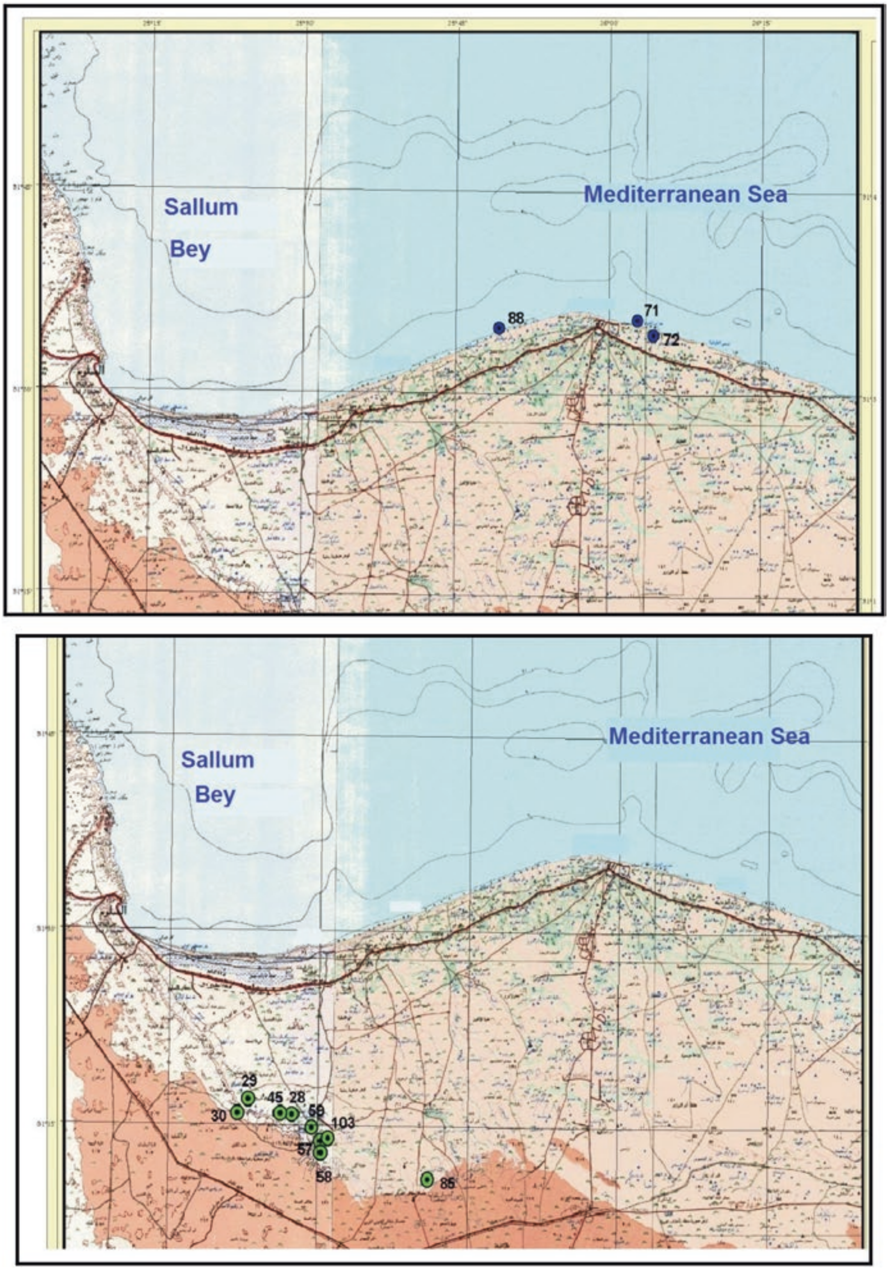

Fig. 3.6 Distribution map of *Pancratium maritimum* (*up*) and *Retama raetam* (*down*)

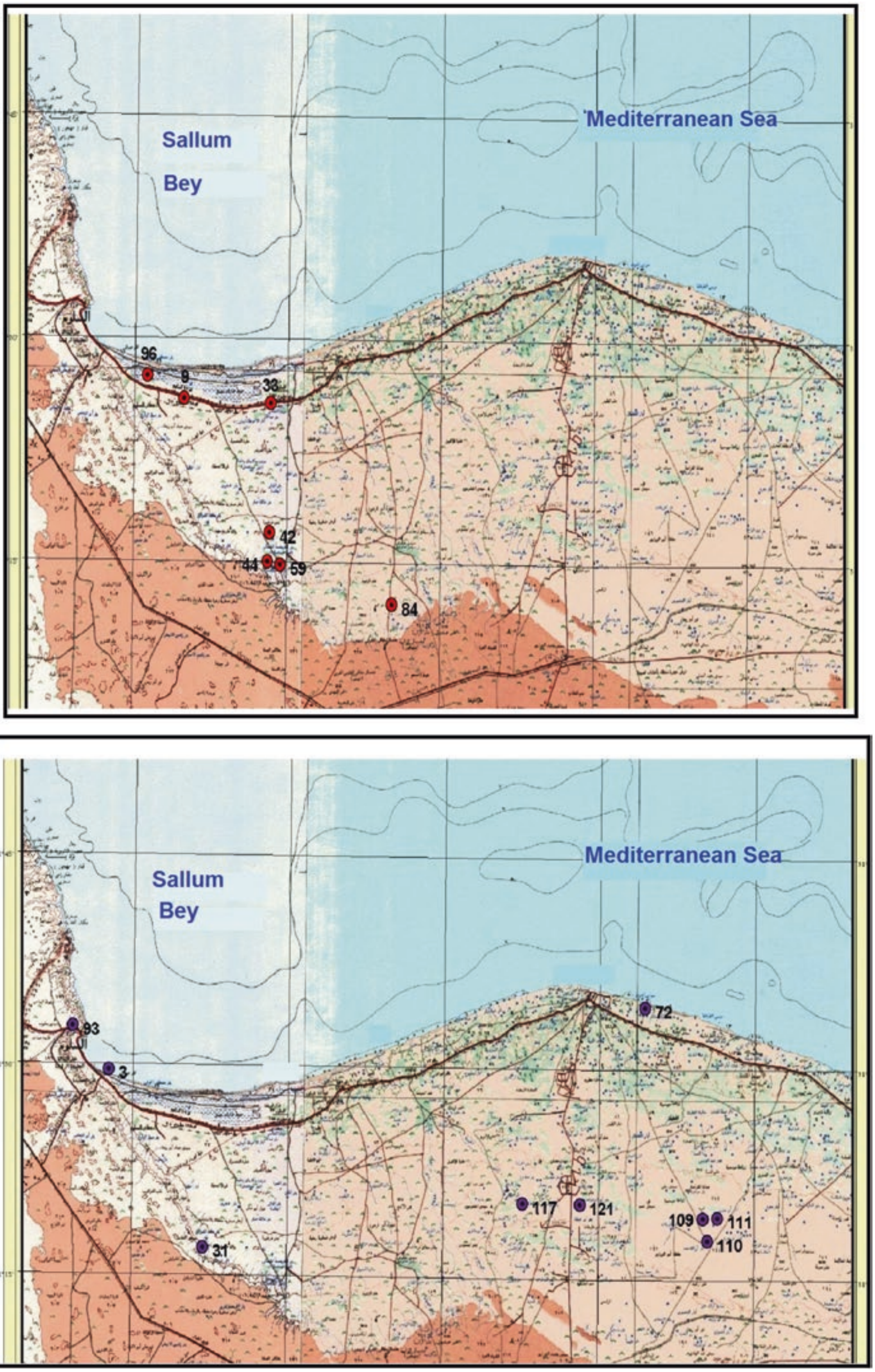

Fig. 3.7 Distribution map of *Periploca angustifolia* (*up*) and *Peganum harmala* (*down*)

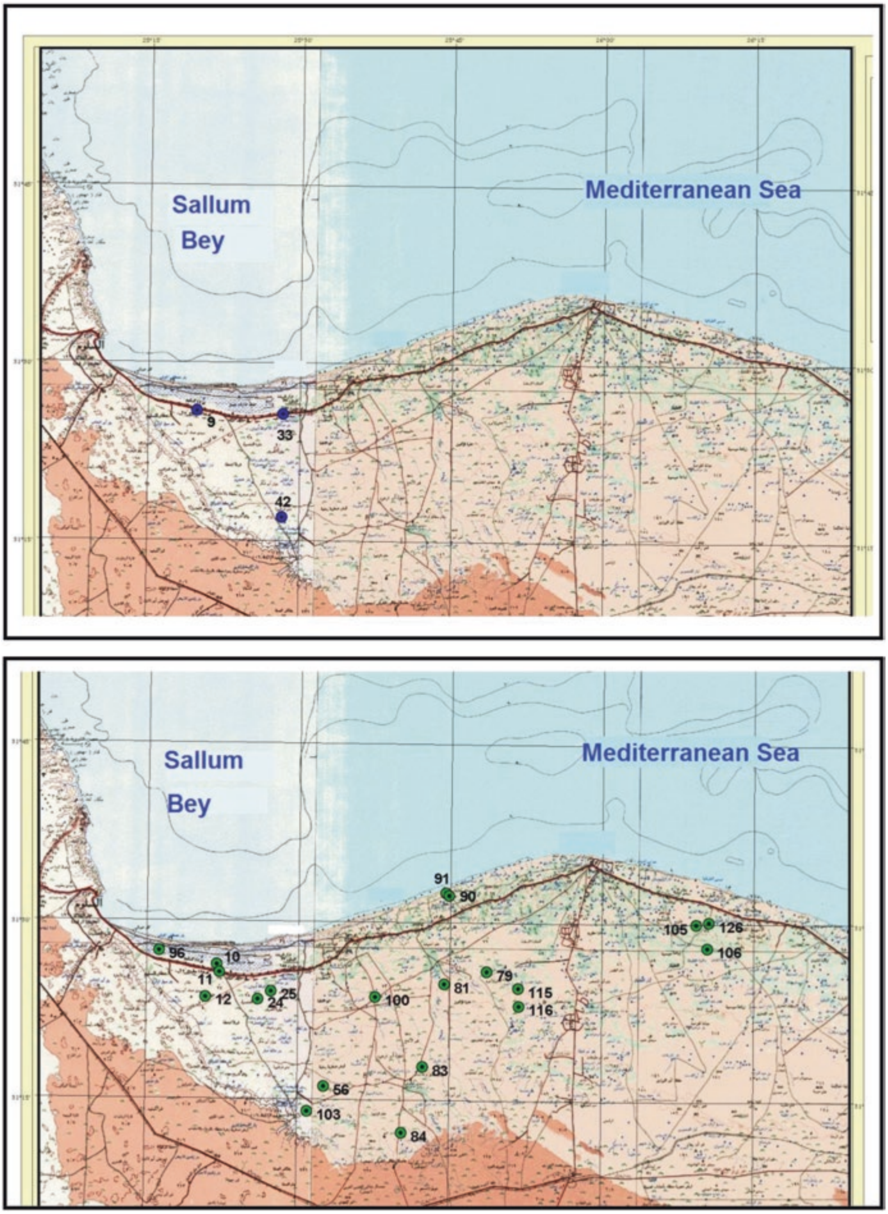

Fig. 3.8 Distribution map of (*up*) and *Globularia arabica* (*up*) and *Gymnocarpos decanter* (*down*)

3.2.1.2 Vegetation Analysis and Environmental Relationships

Classification of the Vegetation

The application of TWINSPAN on the relative importance values (IV) of the 55 perennial species recorded in 53 sampled stands helped to distinguish five vegetation groups (Fig. 3.9, Table 3.6). These groups were named after their leading dominant species (those have the highest relative IV) as follows: (A) *Haloxylon salicornicum,* (B) *Haloxylon salicornicum–Thymelaea hirsuta,* (C) *Thymelaea hirsuta–Anabasis articulata,* (D) *Haloxylon salicornicum–Atriplex portulacoides,* and (E) *Salsola tetrandra–Limoniastrum monopetalum.* Each of these groups could easily be linked to a habitat type: foot of the Diffa plateau, sand plains, nonsaline depressions, saline depressions, and the coastal salt marshes, respectively. Table 3.7 summarizes the mean values and the standard deviations of the measured soil variables and the diversity indices in the five groups derived from TWINSPAN.

The first TWINSPAN dichotomy differentiated the 53 stands into two main groups according to pH, EC, Na^+, K^+, and Mg^{++} ($p = 0.0001$). Group E (12 stands) dominated by *Salsola tetrandra–Limoniastrum monopetalum*, which inhabited the coastal saline depression, was separated on the right side of the dendrogram, while the left side is still heterogeneous (Fig. 3.9). At the second hierarchical level, the inland dry group of stands (41) was split into two subgroups related to pH, EC, organic matter, Na^+, and altitude ($p = 0.0001$). Here, another distinct group (A; 9 stands) dominated by *Haloxylon salicornicum* found on the gravel plains at the foot of Diffa plateau was also separated. Description of each group will be given below.

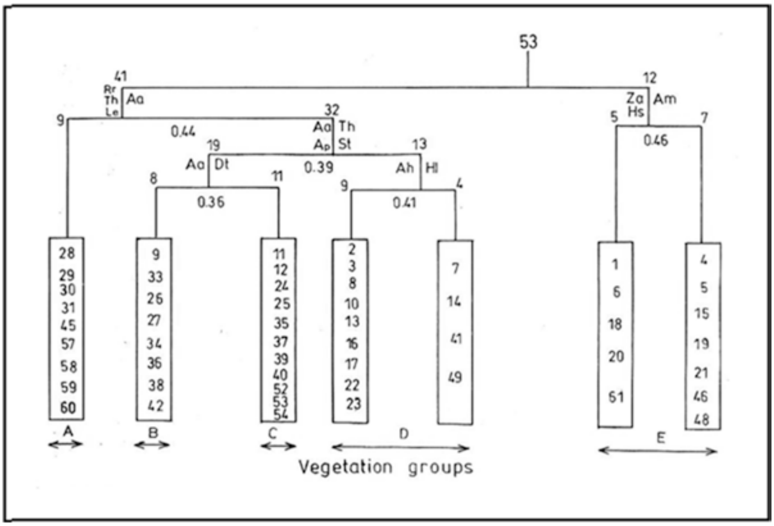

Fig. 3.9 TWINSPAN dendrogram of the 53 studied stands of the Sallum area based on their importance values. A–E are the five vegetation groups

Table 3.6 Species composition of the 53 stands in the six transects, arranged in order of occurrence in the five TWINSPAN groups (A–E). The mean importance value (out of 300) rounded to the nearest integer is given in each group

	TWINSPAN group				
Species	A	B	C	D	E
Group size	9	8	11	13	12
Total number of recorded species	14	17	16	27	19
Haloxylon salicornicum	155	78	36	94	6
Retama raetam	49	–	–	–	–
Astragalus sieberi	4	–	8	1	1
Carthamus glaucus	5	2	–	10	
Hyoscyamus muticus	8	2	1	–	–
Lycium shawii	17	–	1	4	
Farsetia aegyptiaca	9	–	1	–	–
Periploca angustifolia	7	16	–	–	–
Citrullus colocynthis	7	–	–	–	–
Euphorbia retusa	10	–	–	–	–
Marrubium alysson	6	–	–	–	–
Thymelaea hirsuta	5	75	100	25	7
Deverra tortuosa	–	50	2	26	7
Lygeum spartum	–	1	–	–	15
Globularia arabica	–	10	–	–	–
Zilla spinosa	–	15	–	–	–
Anabasis articulata	5	15	82	26	–
Asphodelus ramosus	–	24	46	–	–
Carduncellus mareoticus	–	–	1	3	–
Echinops spinosus	–	–	2	1	–
Gymnocarpos decanter	–	–	7	–	–
Atriplex halimus	–	–	3	64	31
Helianthemum lippii	–	–	–	4	–
Nitraria retusa	–	–	–	3	–
Noaea mucronata	–	–	–	2	–
Verbascum letourneuxii	–	–	–	2	–
Salsola tetrandra	–	1	3	26	66
Limoniastrum monopetalum	–	–	–	–	65
Halocnemum strobilaceum	–	–	–	1	69
Suaeda maritima	–	1	1	1	13
Arthrocnemum macrostachyum	–	–	–	1	15
Sporobolus spicatus	–	–	–	1	9
Zygophyllum album	–	–	–	2	14
Frankenia revoluta	–	–	–	–	8
Limonium pruinosum	–	–	–	–	8

Table 3.7 Mean values and standard deviations (±) of the soil variables in the stands representing the vegetation groups obtained by TWINSPAN

Soil variables		Mean ± SD	TWINSPAN vegetation groups					F-ratio
			A	B	C	D	E	
Sand	(%)	99.9 ± 0.08	99.7 ± 0.02	99.9 ± 0.04	99.8 ± 0.07	99.8 ± 0.07	99.9 ± 0.1	2.1
Silt		0.07 ± 0.07	0.01 ± 0.02	0.07 ± 0.03	0.08 ± 0.06	0.1 ± 0.06	0.07 ± 0.09	2.5
Clay		0.02 ± 0.02	0.01 ± 0.03	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.04 ± 0.03	3.8*
MC		3.4 ± 4.6	3.16 ± 3.4	2.12 ± 0.09	2.2 ± 1.70	2.5 ± 1.6	6.7 ± 8.3	2.2
OM		0.2 ± 0.01	0.08 ± 0.09	0.19 ± 0.13	0.2 ± 0.14	0.3 ± 0.14	0.2 ± 0.2	3.9*
CO_3		5.8 ± 2.4	6.9 ± 2.2	5.7 ± 2.30	4.5 ± 1.90	6.0 ± 2.1	5.9 ± 3.1	1.3
pH		9.1 ± .03	9.2 ± 0.4	9.2 ± 0.15	9.4 ± 0.20	9.3 ± 0.2	8.7 ± 0.1	7.0*
EC		1.1 ± 1.80	3.6 ± 0.03	0.45 ± 0.10	0.4 ± 0.06	0.6 ± 0.2	3.3 ± 3.0	8.9*
Alt		25.6 ± 27.3	62.0 ± 28.2	31.0 ± 21.8	21 ± 15.3	23.1 ± 21.4	2.0 ± 12.7	12.1*
Na^+	(meq/l)	0.4 ± 0.080	0.04 ± 0.01	0.11 ±± 0.08	0.08 ± 0.03	0.2 ± 0.15	1.5 ± 1.1	15.7*
K^+		0.06 ± 0.05	0.03 ± 0.007	0.04 ± 0.02	0.04 ± 0.01	0.06 ± 0.02	0.12 ± 0.07	8.4*
Mg^{++}		0.01 ± 0.006	.005 ± 0.009	0.008 ± 0.003	0.008 ± 0.003	0.009 ± 0.004	0.02 ± 0.008	7.3*
SD		1.83 ± 0.07	1.5 ± 0.06	1.70 ± 0.07	1.6 ± 0.6	2.2 ± 0.5	1.9 ± 0 3	2.4
SR		6.0 ± 2.6	1.9 ± 1.6	6.0 ± 2.4	5.2 ± 1.8	7.1 ± 2.9	6.5 ± 3.4	1.4

MC moisture content, *OM* organic matter, *EC* electric conductivity, *Alt* altitude, *SD* species diversity, *SR* species richness.
* differences significant at $p < 0.05$

Group A. *Haloxylon salicornicum* **Group**

The nine stands of this group were sampled from the foot of the Diffa plateau. On the highly elevated and gravely calcareous soil with moderate moisture content and the least amounts of organic matter and salinity (Table 3.6), sand sheets of *Haloxylon salicornicum* were found. It was differentiated by the growth of shrubs of *Retama raetam*, *Lycium europaeum*, and *Farsetia aegyptia* and occupied parts of the drainage channels of the southern stretches where surface deposits were deeper. This group had the largest share (23) of annuals. Shortly after rainfall, the soil surface supporting the sites of this group was covered with a dense vegetation of annual species, especially *Schismus barbatus, Anthemis microsperma, Reichardia tingitana, Brassica tournefortii, Medicago laciniata, Cutandia memphitica, Erodium pulverulentum, Malva parviflora,* and *Astragalus hamosus.*

Group B. *Haloxylon salicornicum–Thymelaea hirsuta* **Group**

The landscape of this group was characterized by a combination of *Haloxylon salicornicum* and *Thymelaea hirsuta* found on the sand plains with deep loose soil and the lowest levels of moisture content. It represents a transitional zone between the nonsaline and saline depression vegetation groups. This group was differentiated by a number of woody species such as *Periploca angustifolia, Deverra tortuosa, Globularia arabica,* and *Zilla spinosa*. The herb layer was relatively sparse and characterized by *Hordeum leporinum, Asphodelus tenuifolius, Bupleurum lancifolium,* and *Astragalus peregrinus*. The most common xerophytic species in the Egyptian Desert, Sinai, and the neighbouring arid environments were included in this group (Zohary 1973; Batanouny 1979a; Salama and Fayed 1990; Abd El-Ghani and Amer 2003) .

Group C. *Thymelaea hirsuta–Anabasis articulata* **Group**

This vegetation group dominated the nonsaline depressions with soils of the highest pH values and the lowest levels of carbonate content. Other physical soil properties were comparable to those of group B. While *Gymnocarpos decandrum, Asphodelus ramosus*, and *Astragalus siberii* dominated the shrub layer, the herb layer showed the lowest share of annuals (viz. *Centaurea glomerata, Lotus angustissimus, Asphodelus tenuifolius*, and *Hordeum leporinum*) .

Group D. *Haloxylon salicornicum–Atriplex portulacoides* **Group**

This was the largest group of stands (13) and the most diversified among the other vegetation groups. It inhabited the saline depressions on fertile soils that are rich in their fine sediment contents (silt and clay). Relatively high soil salinity favoured the growth of some salt-tolerant species as *Atriplex portulacoides, Salsola tetrandra,* and *Nitraria retusa.* The shrub layer was characterized by the growth of *Carthamus glaucus, Anabasis articulata, Carduncellus mareoticus,* and *Deverra tortuosa.* Other species showed certain degree of fidelity since they did not penetrate to other vegetation groups: such as *Helianthemum lippii, Noaea mucronata,* and *Verbascum letourneuxii.* Few annual species *Bassia muricata, Astragalus hamosus, Centaurea glomerata,* and *Asphodelus tenuifolius* were recorded.

Group E. *Salsola tetrandra–Limoniastrum monopetalum*
On muddy fertile saline soil with high Na^+, K^+, and Mg^{++}, the coastal salt marshes with vegetation characterized by the complex *Halocnemum strobilaceum, Salsola tetrandra*, and *Limoniastrum monopetalum* were found, indicating the saline nature of this group (12 stands). Notably, several halophytic species were recorded such as *Suaeda maritima, Arthrocnemum macrostachyum, Zygophyllum album, Frankenia hirsuta,* and *Limonium pruinosum.* The herb layer was modestly represented and included among others *Brassica tournefortii, Centaurea glomerata, Astragalus hispidulus,* and *Hordeum leporinum.*

Soil Characteristics of the Vegetation Groups

Environmental characteristics of the five vegetation groups were summarized in Table 3.7. Of the measured parameters, clay, organic matter, pH, electric conductivity, altitude, Na^+, K^+, and Mg^{++} showed highly significant differences between groups. It can be noted that clay, moisture content, electric conductivity, K^+, and Mg^{++} displayed relatively high values on coastal salt marshes (group E), organic matter on the saline depressions (group D), and total carbonates and altitude on the foot of Diffa plateau (group A). A remarkable decrease in salinity gradient from the coastal salt marshes (group E) to the foot of Diffa plateau (group A) is also noticeable.

Ordination of Stands

Figure 3.10 showed the ordination results of the DCA analysis of the floristic data set. The 53 stands were plotted along axes 1 and 2 and tend to cluster into five groups that resulted from TWINSPAN analysis described above. The stands were spread out 6.4 SD units along the first axis (eigenvalue = 0.81), expressing the high floristic variations among vegetation groups and indicating a complete turnover in species composition that took place (Hill 1973). This diagram displayed graphically that group B was transitional in its composition between the other groups. Stands of group E were separated towards and the positive end of DCA axis 1, while those of groups A and C were separated out along the other end. DCA axis 2 with an eigenvalue of 0.53 and a gradient length of 3.86 SD is less important. The species–environment correlation (Table 3.8) was also high: 0.83 and 0.55 for DCA axis 1 and 2 showing that the species data were related to the measured environmental variables. The significant correlations of soil variables with the first three DCA axes revealed greater correlations along axis 1 than the higher-order axis. DCA axis 1 showed significant correlations with altitude, EC, K^+, moisture content, and clay, which can be interpreted as an altitude–soil salinity gradient. As axis 2 was significantly correlated with total carbonates and altitude, which was interpreted as an altitude–carbonate gradient.

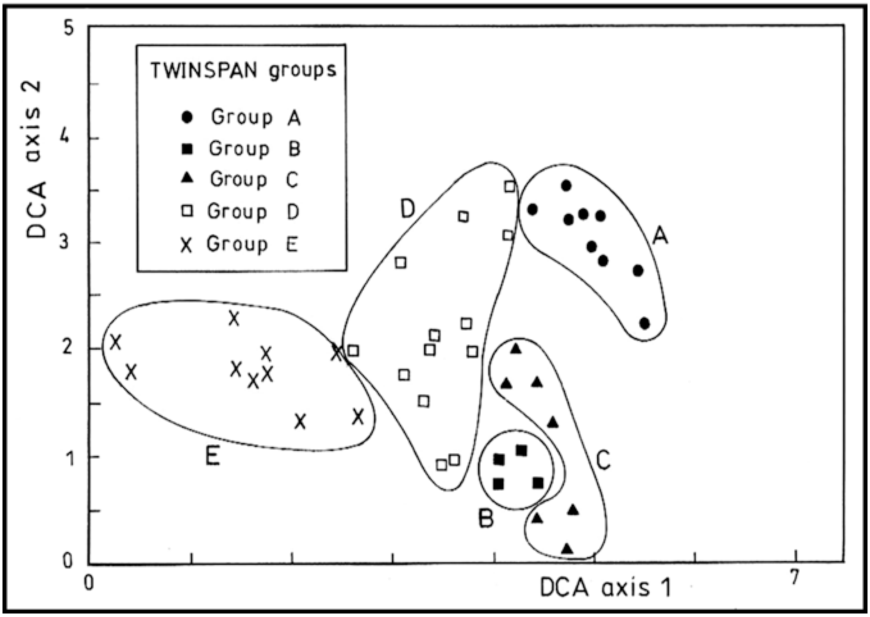

Fig. 3.10 DCA ordination diagram for the 53 stands on the first two axes with the TWINSPAN groups superimposed

Table 3.8 Comparison of the results of ordination for the first three axes of DCA and CCA. Intra-set correlations of the soil variables, together with eigenvalues and species–environment correlation coefficients. For soil factors abbreviations and units, see Table 3.7

	DCA axis			CCA axis		
Soil variables	1	2	3	1	2	3
Eigenvalues	0.81	0.55	0.32	0.65	0.38	0.33
Species–environment correlation	0.83	0.55	0.70	0.93	0.85	0.78
Silt	−0.24	−0.15	0.09	0.3	−0.001	0.02
Clay	−0.59*	−0.03	0.01	0.74*	0.04	0.03
MC	−0.60*	0.01	−0.21	0.71*	−0.1	−0.27
OM	−0.32	−0.1	0.04	0.37	−0.08	0.18
CO_3	−0.11	0.39*	−0.21	−0.2	0.10	−0.32
pH	0.51	−0.22	0.32	−0.57*	−0.22*	0.41*
EC	−0.71*	0.04	−0.05	0.86*	−0.15	−0.09
K^+	−0.67*	0.12	−0.1	0.80*	0.12	−0.13
Mg^{++}	−0.51*	0.02	−0.42	0.41	0.65*	−0.18
Altitude	0.56*	0.32*	−0.05	−0.50*	−0.38*	−0.34*

* Differences significant at $p < 0.05$

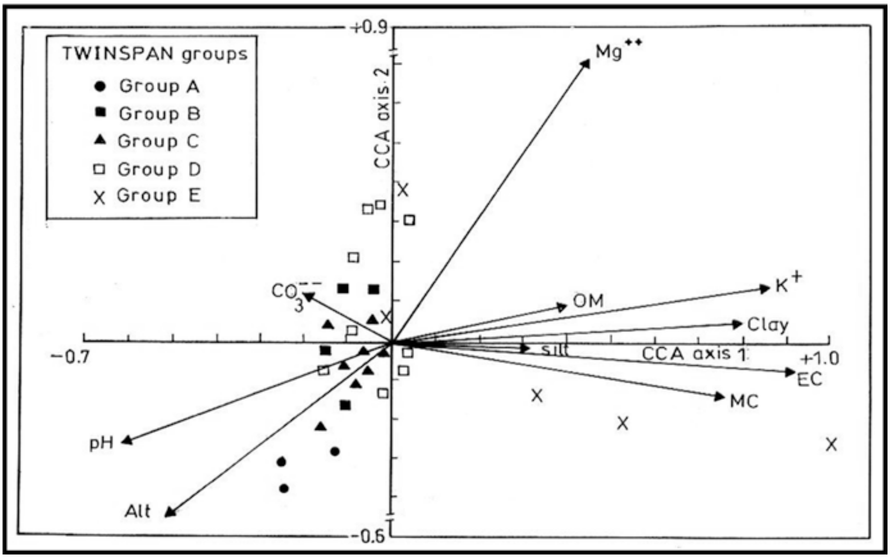

Fig. 3.11 CCA biplot of axes 1 and 2 showing the distribution of the 53 stands with their TWINSPAN groups and soil variables

Environment–Vegetation–Diversity Relationships

The successive decrease of the eigenvalues of the first three CCA axes (Table 3.8) suggests a well-structured data set. These eigenvalues were somewhat lower than for the DCA axes, indicating that important explanatory stand variables were not measured and included in the analysis or some of the variations were not explained by environmental variables (Franklin and Merlin 1992; McDonald et al. 1996). However, the species–environment correlations were higher for the first three canonical axes, explaining 67.3% of the cumulative variance. These results suggested a strong association between vegetation and the measured soil parameters presented in the biplot (Jongman et al. 1987). From the intra-set correlation of the soil factors with the first three axes of CCA shown in Table 3.8, it can be noted that CCA axis 1 was correlated to clay, moisture content, pH, EC, K^+, and altitude. This fact becomes more clearly in the biplot (Fig. 3.11). A test for significance with an unrestricted Monte Carlo permutation test (99 permutations) found the F-ratio for the eigenvalue of axis 1 and the trace statistics to be significant ($p < 0.001$), indicating that observed patterns did not arise by chance. CCA axis 2 was clearly related to pH, Mg^{++}, and altitude.

3.3 Concluding Remarks

1. The plant life was restricted to microenvironments (as in wadis, runnels, and depressions) where runoff water collects and provides sufficient moisture for plant growth. This was described by Monod (1954) as végétation contracté,

runoff desert (sensu Zohary 1962), and restricted desert (sensu Walter 1963). The vegetation was characterized by sparseness of plant cover (does not exceed 5% on the average; Kassas 1966), a limited number of plant species (12 on the average in each stand), and paucity of trees (5% of the recorded species). Therophytes, chamaephytes, and hemicryptophytes constituted the mean bulk (80.1%) of the recorded species. High percentages of therophytes and hemicryptophytes coincide with the floristic characters of the arid zones in the Mediterranean Basin and in general for the floras of arid and semiarid zones (Migahid et al. 1971; Bornkamm and Kehl 1985; Pignatti and Pignatti 1989).

2. According to White and Léonard (1991), this area lies in the Mediterranean–Sahara regional transition zone that includes the coastal land along the Mediterranean Sea. Chorological analysis of species showed the decrease in the numbers of the Mediterranean species and increase of the Saharo–Arabian species along N–S direction form the seashore inwards till the fringes of Diffa plateau. This may be attributed to the fact that plants of the Saharo–Arabian region are good indicators for desert environmental conditions, while Mediterranean species stand for more mesic environment. Being part of the Mediterranean region, the Mediterranean chorotype (uni, bi, and pluri) constituted more than 50% of the total flora, while the Saharo–Arabian chorotype constituted 38.9%. This result is in agreement with the findings of White (1993), where the vegetation comprises floristic elements of both Mediterranean and Saharo–Arabian regions.
3. Phytosociological investigations indicated that *Haloxylon salicornicum*, *Thymelaea hirsuta*, and *Anabasis articulata* dominated the vegetation. The next important species were *Atriplex portulacoides*, *Salsola tetrandra*, *Deverra tortuosa*, *Asphodelus ramosus*, and *Halocnemum strobilaceum*; each exerted a local dominance in certain stands than in others. Nevertheless, these species were so overlapping in their phytosociological behaviour that no distinct association could be recognized, and accordingly, the vegetation may be considered as a continuum that could be a part of a larger vegetational gradient in the Western Desert of Egypt. This, however, does not preclude the possibility of classifying it into different vegetation groups.
4. The vegetation of the Sallum area was differentiated into two main parts: coastal dominated by halophytic plant communities and inland desert dominated by xerophytic ones. The application of TWINSPAN revealed the separation of five distinct vegetation groups named after their dominant species as follows: *Haloxylon salicornicum* (A), *Haloxylon salicornicum–Thymelaea hirsuta* (B), *Thymelaea hirsuta–Anabasis articulata* (C), *Haloxylon salicornicum–Atriplex portulacoides* (D), and *Halocnemum strobilaceum–Salsola tetrandra–Limoniastrum monopetalum* (E). Most of these species have repeatedly been recorded as abundant in ecological studies of specific habitats in the western Mediterranean coastal land of Egypt (Tadros and Atta 1958; Migahid et al. 1971; Ayyad and El-Ghareeb 1982; Shaltout and El-Ghareeb 1992; Zahran et al. 1996), and variations in their abundances have also been related to edaphically and topographic variations (Abdel-Razik et al. 1984; El-Ghareeb and Hassan 1989;

El-Kady and Sadek 1992). The floristic composition, therefore, represents most of the floristic structure in the Mediterranean North-African flora (Quézel 1978).

5. The vegetation groups that resulted from TWINSPAN may be related to the Salsolion tetrandrae of habitats with soils derived from chalky rocks and marls and rich in lime and soluble salts (Zohary 1973) and the Anabasion articulatae arenarium, Hammada-Anbasion articulatae, and Thymelaeion hirsutae (Tadros and Atta 1958) of less saline habitats. The associations belonging to these alliances with their characteristic species have been described by Maire and Weiller (1947), Killian and Lemée (1948), Braun-Blanquet (1949), Simmoneau (1954), and Navikoff (1961) in North Africa and by Tielbörger (1997) in Sinai and in the Negev Desert of Israel. However, Bornkamm and Kehl (1990) suggested one new order, Pituranthetalia tortuosi, to comprise all the plant communities of the Western Desert of Egypt. Consequently, the vegetation of this area represents a transition from the western communities in North Africa to those characteristics of eastern Mediterranean. Ayyad and El-Ghareeb (1982) and El-Ghareeb (1990) have reported similar conclusion in the salt marsh vegetation along the western Mediterranean coast of Egypt.
6. Both DCA and CCA assessed the soil–vegetation relationships. The results of CCA analysis showed well the relative positions of species and sites along the most important ecological gradients. Both ordination techniques clearly indicated that fine soil sediments, moisture content, pH, electric conductivity, altitude, and relative concentrations of K^+ and Mg^{++} were the most important parameters for the distribution of the vegetation pattern in this area. The role of these factors in delimiting plant communities in the Western Desert has been stressed by many authors, among others Ayyad (1976) and Kamal and El-Kady (1993). The percentage of surface sediments of different size classes determines the spatial distribution of soil moisture (Yair and Danin 1980), as shown for other desert ecosystems in Egypt by Sharaf El Din and Shaltout (1985) and Abd El-Ghani (1998, 2000a) and in Saudi Arabia by El-Demerdash et al. (1994).
7. The distribution of species in saline and marshy habitat which relates to salinity in many arid regions has been discussed by several authors, Kassas (1957), Ungar (1968), and Maryam et al. (1995), among others. Ungar (1974) indicated that the distribution of halophytes in the United States is mainly dependent on the salinity gradient, while local climate, topography, soil moisture, and biotic factors are less important. Ragonese and Covas (1947) described the interrelation of the salinity gradient and vegetation in the northern Argentinian salt marshes. Abu-Ziada (1980) and Abd El-Ghani (2000b) also noted strong relationships between the vegetation pattern and the soil moisture–salinity gradients in the oases of the Western Desert of Egypt. When studying the salt marsh communities of the western Mediterranean coastal desert, Ayyad and El-Ghareeb (1982) pointed out that salinity, the concentration of different ions, and the periodical variation in the water table determine the distribution of species and the differences between communities. They also conclude that the salt marsh vegetation in this part of the country represents a transition from the western communities in North Africa and those characteristics of the Eastern Mediterranean region. In their account of the northern and eastern Mediterranean coastal salt marshes, Zahran et al. (1996)

demonstrated the distribution of some halophytic species as best correlated along a gradient of a dozen of soil variables, the most important are salinity, moisture content, soil texture, organic matter, and calcium carbonate. In this area, the gradient in soil salinity and its variation from one habitat to another is the primary determinant of the plant community composition.

3.3.1 The Eastern Mediterranean Coast (El-Arish-Rafah Area)

It is located between El Arish (31° 10′N, 33° 48′E) and Rafah (31° 17′N, 34° 15′E) and extends for about 45 km along the northeastern Mediterranean coast of Sinai (Fig. 3.12). The area was chosen for its high environmental diversity. It represents the easternmost part of the international coastal highway that links Egypt with the countries of North Africa in the west and those of the eastern Mediterranean in the east. The natural vegetation is very sparse. A semi-steppe type of vegetation characterizes the study area. Kassas (1952) reported the major dominant landforms (littoral dunes, inland dunes, and salt marshes), but Danin (1983) listed further floristic subdivisions and brief habitat descriptions. The coastal belt of the sand dunes represents one of the salient features of the investigated area. The dunes of north Sinai absorb and store rainwater, the lowlands between them being a permanent source of fresh water that can be tapped by digging shallow wells. As a result of population pressure, the demand for fresh-water supplies was accordingly increased. Thus, water from the Nile is now transferred to Sinai Peninsula through El Salam Canal.

Desert reclamation and agricultural processes were practiced in the study area. Date palm plantations and irrigated gardens are other conspicuous features along part of the seashore. In many instances, the land was ploughed and cultivated after the first rain of a season.

Cultivation of barley, maize, tomato, sesame, grapes, peaches, pomegranates, olives, figs, and watermelons was achieved. Nevertheless, spreader dykes were also conducted for cultivation of beans and wheat, and other cereals were carried out just upstream of the dykes. Large-scale forestation with tamarisk (*Tamarix aphylla*) and *Acacia saligna* was carried out, mainly along roads traversing the dunes, to arrest sand dune encroachment (Weinstein and Schiller 1979).

According to UNESCO-FAO (1963), the climate of the study area is attenuated subdesertic. Recent records of climatic data for Rafah were incomplete and insufficient. Available records of the mean annual rainfall decrease in the east–west direction. It reached *c.* 304 mm year $^{-1}$ at Rafah and 96.8 mm at El Arish. The gradient in the annual rainfall is obvious, which was associated with an inverse evaporation gradient, indicating the increase of aridity from west of the study area to its east. Average daily maxima of the hottest month were 38.6 °C at El Arish and 31.5 °C at Rafah, while average daily minima of the coldest month were 7.3 °C and 7.8 °C, respectively. Frost may occur in January and February at El Arish, and fog and dew were also common and probably contribute much to the total sum of plant-available moisture. Average maximum relative humidity at El Arish was 70%, and the average minimum was 32%.

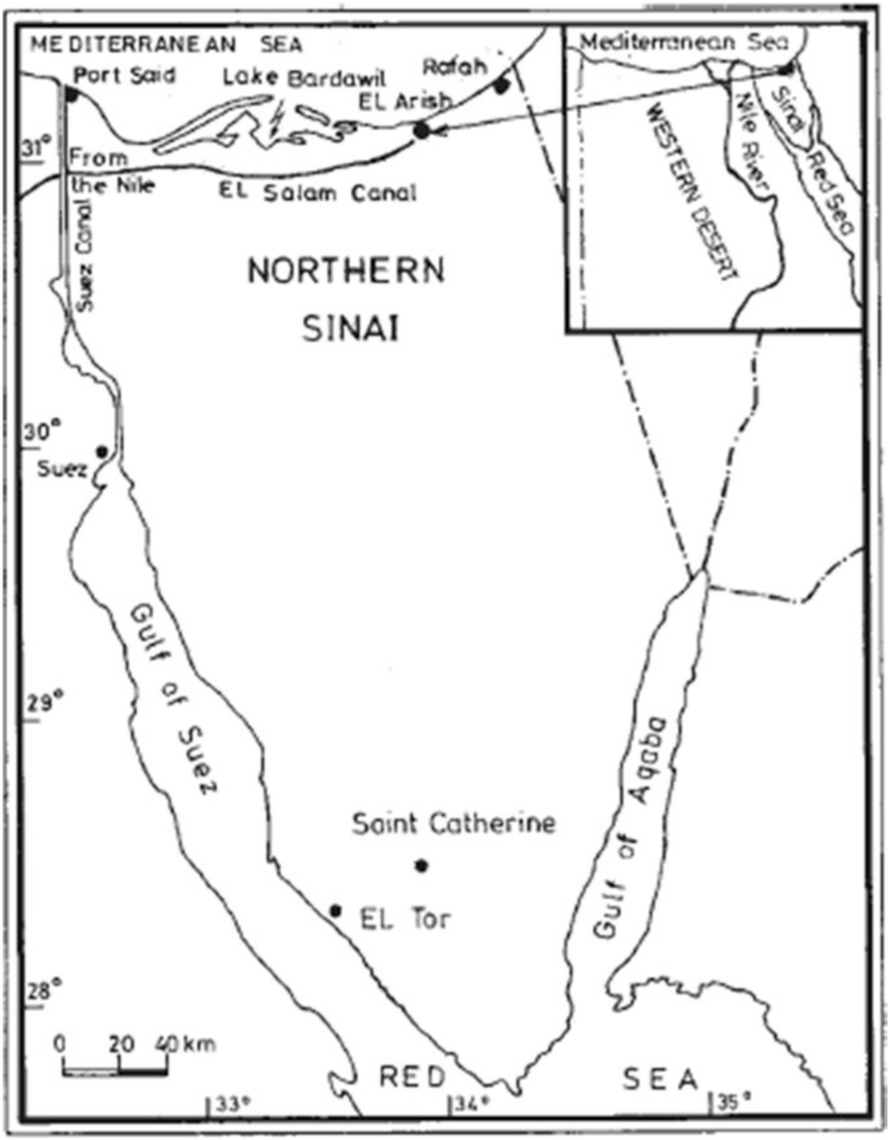

Fig. 3.12 Location map showing El-Arish-Rafah area

3.4 Floristic Relations

In total, 78 species from 31 families of the vascular plans were found, of which 24 annuals and 54 perennials. There is a gradual increase in the total number of recorded species from 27 in the coastal plain to 43 in the sand dunes. The floristic similarities between the recognized four landforms (Table 3.9) showed significant

Table 3.9 Sørensen's coefficient of floristic similarity (CCs) between the different landform units in the study area

Landform unit	C	S	M	D
C				
S	–0.43*			
M	0.47**	0.005		
D	0.28	0.46**	0.30	
Total number of species	27	41	28	43
% of alien weed species	12.5	19.1	15.7	26.6

S sand plains, *C* coastal plain, *M* saline depressions, *D* sand dunes
$^{**}p < 0.01$, $^{*}p < 0.05$

positive correlations between saline depressions and the coastal plain in one hand and between the sand plains and sand dunes in the other. The coastal and sand plains were negatively correlated with each other. Regarding species richness, the floristic composition in the recognized landforms showed remarkable differences. Chamaephytes were the predominant life form and constituted 32% of the recorded flora, followed by therophytes (31%) and hemicryptophytes (17%). In this context, chamaephytes, hemicryptophytes, and cryptophytes altogether constituted the main bulk of the floristic structure of each of the recognized landform unit. It ranged from 49% and 51% in sand dunes and sand plains to 61% and 67% in the coastal plain and saline depressions, respectively.

None of the 78 species occurs at all the 63 studied stands. There were few highly frequent species and very many that were infrequent. Only 2 species (*Echinops spinosus* and *Zygophyllum album*) had a frequency of more than 50%, and 35 species (about 65% of the total) had a frequency more than 10%. This is similar to the distribution of frequencies reported for roadside vegetation in California (Frenkel 1970) and New Zealand (Ullmann et al. 1995). Some of the recorded species have wide ecological and sociological range of distribution such as *Cornulaca monacantha* and *Cyperus capitatus*, with 75 records and the highest occurrence among perennials (24%), while *Mesembryanthemum crystallinum* recorded in 119 sample plots and showed the highest occurrence among annuals (38%).

The results revealed that 37 species (55.2% of the total) demonstrated a certain degree of consistency, where they exclusively recorded in or confined to a certain landform unit and do not penetrate elsewhere. These species were distributed as follows: 11 in the sand plains (e.g. *Panicum turgidum, Fagonia arabica,* and *Convolvulus lanatus*), 3 in the coastal plain (e.g. *Agathophora alopecuroides, Solanum elaeagnifolium*, and *Euphorbia paralias*), 13 in the saline depressions (e.g. *Arthrocnemum macrostachyum, Juncus rigidus, Halocnemum strobilaceum*, and *Suaeda aegyptiaca*), and 10 in the sand dunes (e.g. *Cynodon dactylon, Bassia indica, Chenopodium murale, Amaranthus graecizans,* and *Rumex pictus*).

3.5 Vegetation Classification

Classification of the presence–absence data set of 78 species recorded in 63 stands using the TWINSPAN analysis yielded 18 vegetation groups (VG) at level 6 of the hierarchy (Fig. 3.13; Table 3.10). These groups could be categorized at level 3 of the classification into seven major vegetation types (VT) . These types were named after the first and second dominant species as follows: (I) *Artemisia monosperma* in the sand dunes; (II) *Artemisia monosperma–Echinops spinosus* in the sand plains, coastal plain, and sand dunes; (III) *Cyperus capitatus–Ammophila arenaria* in the sand dunes; (IV) *Ammophila arenaria–Pancratium maritimum* in the coastal plain; (V) *Zygophyllum album*; (VI) *Arthrocnemum macrostachyum*; and (VII) *Arthrocnemum macrostachyum–Zygophyllum album* in the saline depressions. One-way ANOVA test showed significant differences (F-ratio = 8.8; $p = 0.001$) between the recognized landforms and the evolved vegetation types. The total number of recorded species and species richness of the seven vegetation types (VT) differs between stands (Table 3.10). While VT (II) had the highest total number of species (56), VT (III) and (V) had the lowest (13 and 14, respectively). The highest species richness of 16.7 ± 4.8 was found in VT (II), but the lowest (6.9 ± 2.2) was in VT (IV).

Characteristics of the vegetation groups showed that 17 out of the 18 groups occurred only in one landform, while VG (7) dominated by *Artemisia monosperma* was represented in the sand plains and the sand dunes. Whereas the vegetation groups of *Ammophila arenaria–Pancratium maritimum* and *Echinops spinosus–*

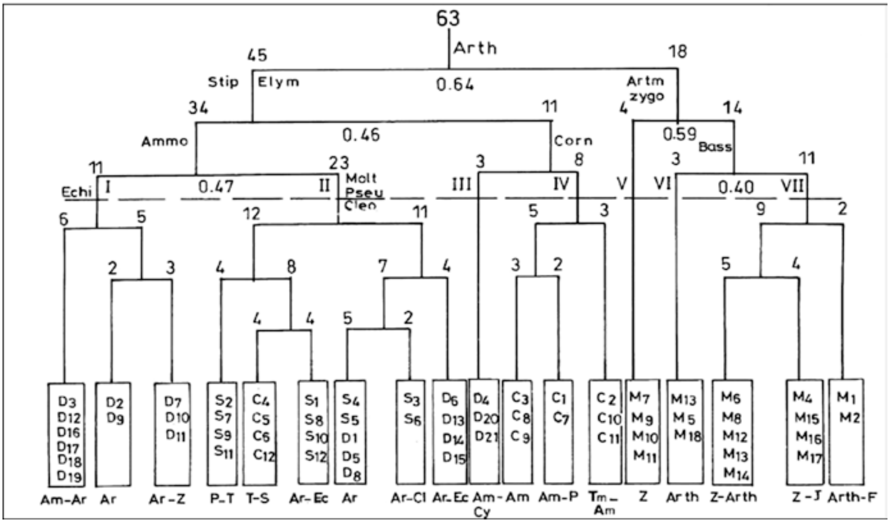

Fig. 3.13 The dendrogram resulting from TWINSPAN analysis of 63 stands of the study area. The *broken line* denotes the level at which the dendrogram yields seven vegetation types (I–VII). Indicator species and vegetation group abbreviations are shown in the Appendix

Table 3.10 Characteristics of the seven vegetation types (VT) and 18 vegetation groups (VG) derived after the application of TWINSPAN. For landform unit abbreviations, see Table 3.9

VT	VG	Characteristic species	Species richness	P%	N	Landform units			
						C	S	M	D
I	1	*Artemisia monosperma*	5.2	100	6				6
		Ammophila arenaria		75					
	2	*Artemisia monosperma*	12.0	100	2				2
	3	*Artemisia monosperma*	6.0	100	3				3
		Zygophyllum album		100					
II	4	*Panicum turgidum*	7.2	100	4		4		
		Thymelaea hirsuta		100					
	5	*Silene succulenta*	8.0	75	4	4			
		Thymelaea hirsuta		50					
	6	*Artemisia monosperma*	12.0	100	4		4		
		Echinops spinosus		100					
	7	*Artemisia monosperma*	15.8	80	5		2		3
	8	*Artemisia monosperma*	12.5	100	2		2		
				100					
		Cleome amblyocarpa							
	9	*Echinops spinosus*	16.2	100	4				4
		Artemisia monosperma		75					
III	10	*Cyperus capitatus*	12.3	100	3				3
				67					
		Ammophila arenaria							
IV	11	*Ammophila arenaria*	12.7	100	3	3			
	12	*Ammophila arenaria*	16.5	100	2	2			
		Pancratium maritimum		100					
	13	*Ammophila arenaria*	13.0	100	3	3			
		Tamarix nilotica		67					
V	14	*Zygophyllum album*	8.7	100	4			4	
VI	15	*Arthrocnemum macrostachyum*	9.7	100	3			3	
VII	16	*Arthrocnemum macrostachyum*	6.4	100	5			5	
		Zygophyllum album		100					
	17	*Zygophyllum album*	8.2	100	4			4	
		Juncus rigidus		80					
	18	*Arthrocnemum macrostachyum*	6.0	100	2			2	
		Frankenia hirsuta		100					

N number of stands recorded

Artemisia monosperma have the highest species richness (16.5 ± 1.5 and 16.2 ± 2.4, respectively species), those of *Artemisia monosperma–Ammophila arenaria* (5.2 ± 1.7), *Artemisia monosperma–Zygophyllum album*, and *Arthrocnemum macrostachyum–Frankenia hirsuta* (6.0 ± 2.0 for each) had the lowest.

3.5.1 Abbreviations of Indicator Species

Species	Abbreviation
Ammophila arenaria (L.) Link	Ammo
Arthrocnemum macrostachyum (Moric.) K.Koch	Arth
Bassia indica (Wight) A.J. Scott	Bass
Cleome amblyocarpa Barratte & Murb.	Cleo
Cornulaca monacantha Delile	Corn
Echinops spinosus L.	Echi
Elymus farctus (Viv.) Runemark ex Melderis	Elym
*Moltkiopsis ciliata (*Forssk.) I.M. Johnst.	Molt
Pseudorlaya pumila (L.) Grande	Pseu
Stipagrostis scoparia (Trin. & Rupr.) de Winter	Stip
*Zygophyllum album L.*f.	Zygo

3.5.1.1 Abbreviations of Vegetation Groups (VG)

Landform unit abbreviations: C, coastal plain; S, sand plain; M, saline depressions; and D, sand dunes

(VG)	Species	Abbreviations
1	*Ammophila arenaria–Artemisia monosperma*	Am–Ar
2	*Artemisia monosperma*	Ar
3	*Artemisia monosperma–Zygophyllum album*	Ar–Z
4	*Pancratium maritimum–Thymelaea hirsuta*	P–T
5	*Thymelaea hirsuta–Silene succulenta*	T–S
6	*Artemisia monosperma–Echinops spinosus*	Ar–Ec
7	*Artemisia monosperma*	Ar
8	*Artemisia monosperma–Cleome amblyocarpa*	Ar–Cl
9	*Artemisia monosperma–Echinops spinosus*	Ar–Ec
10	*Ammophila arenaria–Cyperus capitatus*	Am–Cy
11	*Ammophila arenaria*	Am
12	*Ammophila arenaria–Pancratium maritimum*	Am–P
13	*Ammophila arenaria–Tamarix nilotica*	Tm–Am
14	*Zygophyllum album*	Z
15	*Arthrocnemum macrostachyum*	Arth
16	*Zygophyllum album–Arthrocnemum macrostachyum*	Z–Arth
17	*Zygophyllum album–Juncus rigidus*	Z–J
18	*Arthrocnemum macrostachyum–Frankenia hirsuta*	Arth–F

A Detrended Correspondence Analysis (DCA) ordination plot of the 63 stands on axes 1 and 2 (Fig. 3.14), with the 7 TWINSPAN vegetation types, was superim-

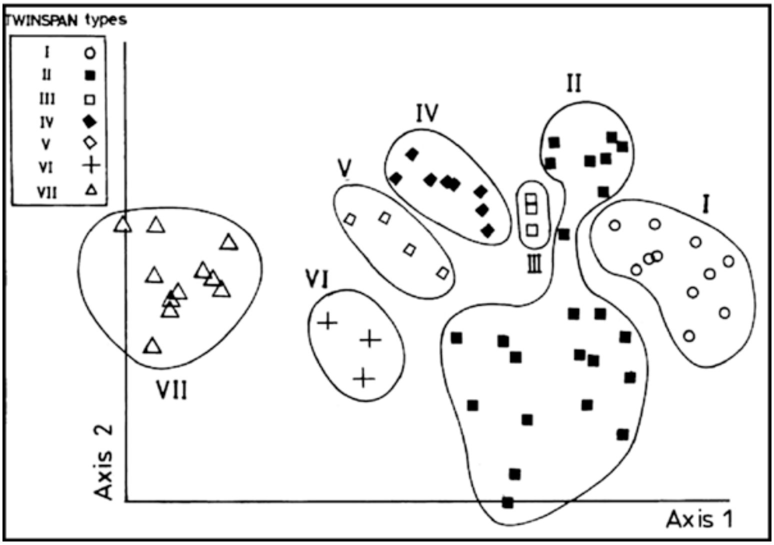

Fig. 3.14 Ordination diagram of Detrended Correspondence Analysis (DCA) of 63 stands, with their TWINSPAN vegetation types

posed. The stands were spread out at 5.3 SD units of the first axis (eigenvalue = 0.71), expressing the high floristic variation among the vegetation types and indicating a complete turnover in species composition that took place (Hill 1979). Stands of VT (I) were separated towards the positive end of DCA axis 1, while those of VT (VII) were separated out along the other end. DCA axis 2 with eigenvalue of 0.39 and a gradient length of 3.11 was less important. The species–environment correlation was high: 0.96 and 0.67 for DCA axes 1 and 2, showing that the species data were strongly related to the measured environmental variables. A well-defined gradient in soil salinity ($r = -0.92$) was found on axis 1, reflected in the species composition from stands with high to stands with low saline content. The vegetation types (V), (VI), and (VII) of the saline depressions appeared on the left side of axis 1, while those of other landforms appeared on the right side. Plot scores of DCA axis 2 were positively correlated ($r = 0.61$) with landform, indicating a gradient from coastal plain on the seashore to sand dunes inwards in the desert.

3.6 Vegetation–Environment Relationships

The soil variables of the stands comprising the seven vegetation types differ significantly according to the one-way ANOVA (Table 3.11). The soil of VT (I) had the highest content of sand, but the lowest content of clay, $CaCO_3$, and total soluble salts. The soil of VT (II) had the highest content of $CaCO_3$, while the soil of stands which

Table 3.11 Mean values, standard deviation (± SD), and ANOVA F-values of the environmental variables and species richness in the stands representing the seven vegetation types (I–VII) obtained by TWINSPAN

Environmental variables		Total mean	TWINSPAN vegetation types							F-ratio
			I	II	III	IV	V	VI	VII	
			(*n*–11)	(*n*–23)	(*n*–3)	(*n*–8)	(*n*–4)	(*n*–3)	(*n*–11)	
Sand	(%)	93.7 ± 4.1	96.9 ± 0.9	95.8 ± 3.1	96.8 ± 0.9	87.6 ± 2.1	93.8 ± 1.6	91.9 ± 5.1	91.1 ± 3.5	12.7*
Silt	(%)	2.7 ± 2.6	1.0 ± 0.4	1.0 ± 1.3	0.9 ± 0.4	4.5 ± 1.8	2.4 ± 0.5	4.7 ± 5.5	4.8 ± 3.9	4.7*
Clay	(%)	3.6 ± 2.5	2.1 ± 0.7	2.7 ± 2.1	2.3 ± 0.9	7.9 ± 1.8	3.8 ± 1.1	3.4 ± 2.7	4.1 ± 1.9	10.4*
$CaCO_3$	(%)	1.9 ± 0.6	1.1 ± 0.2	2.8 ± 0.3	1.8 ± 0.2	2.6 ± 0.1	1.6 ± 0.009	1.2 ± 0.006	1.1 ± 0.007	59.6*
pH		7.8 ± 0.3	7.7 ± 0.4	7.8 ± 0.3	7.8 ± 0.5	7.9 ± 0.4	7.7 ± 0.3	7.9 ± 0.2	7.8 ± 0.3	0.6
TSS		1.1 ± 1.5	0.8 ± 0.01	2.1 ± 0.01	7.2 ± 0.1	7.3 ± 0.2	18.1 ± 0.1	24.5 ±± 0.3	41.9 ± 1.0	106.8*
Alt		25.5 ± 3.6	27.7 ± 10.3	30.4 ± 15.5	36.7 ± 11.5	8.1 ± 9.9	23.7 ± 4.8	20.0 ± 10.0	24.4 ± 6.1	4.1*
DFS		107.7 ± 85.3	179.1 ± 98.5	98.3 ± 94.9	193.3 ± 11.5	21.9 ± 8.4	117.5 ± 25.0	76.7 ± 15.3	100.0 ± 31.6	4.3*
Species richness		10.2 ± 4.3	13.6 ± 2.7	16.7 ± 4.8	12.7 ± 0.6	6.9 ±± 2.2	8.7 ± 2.2	9.7 ± 2.1	7.1 ± 1.5	6.5*
Total number of species		19 ± 3.5	18	56	13	24	14	17	22	42.4*

TSS total soluble salts, *Alt* altitude, *DFS* distance from seashore
$^*p < 0.01$

constitute VT (III) had the lowest silt content (0.9%), the farthest from the seashore (193.3 m) and at the highest altitudes (36.7 m above sea level). The soil of VT (IV) occupies the lowest altitude (8.1 m above sea level) that was very close to the seashore (DFS = 21.9 m) and rich in clay content (7.9%). The soils of VT (V), (VI), and (VII) have the highest values of salinity (18.1, 24.5, and 41.9 meq/l, respectively) .

The species–environment correlations were higher for the first three canonical axes, explaining 72.4% of the cumulative variance (Table 3.12). These results suggest a strong association between vegetation and the measured environmental parameters presented in the biplot (Jongman et al. 1987). From the intra-set correlations of the environmental variables and the first three axes of CCA, it can be inferred that CCA axis 1 was positively correlated with salinity and negatively with altitude, while CCA axis 2 was defined by landforms, distance from the seashore, altitude,` and clay. This fact becomes evident in the ordination biplot (Fig. 3.15). Contributions of salinity, landforms, altitude, and clay, which were selected by the forward selection option in the program CANOCO, to the variation in species data, were 36.8%, 17.2%, 14.4%, and 6.9%, respectively. A test for significance with an unrestricted Monte Carlo permutation test found the F-ratio for the eigenvalue of CCA axis 1 and the trace statistics to be significant ($p = 0.01$), indicating that the observed patterns did not arise by chance. The ordination diagram produced by CCA in Fig. 3.15 showed that the pattern of ordination was similar to that of the floristic DCA (Fig. 3.14), with most of the stands remaining in their respective TWINSPAN vegetation types. Clearly, vegetation types (V), (VI), and (VII) were highly associated with soil salinity, those of VT (I) and (III) with altitude and the distance from the seashore, and those of VT (II) and (IV) with clay and lime content.

Table 3.12 Comparison of the results of ordination for the first three axes of DCA and CCA. Intra-set correlations of the environmental variables, together with eigenvalues and species–environment correlation coefficients

		DCA axis			CCA axis		
		1	2	3	1	2	3
Eigenvalues		0.71	0.39	0.30	0.67	0.30	0.29
Species–environment correlation coefficients		0.96	0.67	0.51	0.97	0.92	0.83
Sand	↕ (%)	−0.07	0.08	0.04	0.09	0.15	0.004
Silt		−0.30	−0.06	−0.09	0.30	−0.10	−0.13
Clay		−0.12	0.10	0.11	0.04	−0.27*	−0.47*
$CaCO_3$		−0.002	0.03	−0.03	−0.06	−0.31*	−0.34
pH		−0.12	0.01	0.10	−0.09	−0.20	−0.30
Total soluble salts (TSS) (meq/l)		−0.92*	−0.10	0.01	0.97*	0.06	0.07
Landform (LF)		−0.005	0.61*	0.32	0.05	0.95*	−0.28
Altitude (ALT) (m)		0.32	0.06	−0.16	−0.24*	0.48*	0.74*
Distance from seashore (DFS) (m)		0.25	0.41*	−0.001	−0.18	0.78*	0.30

* Differences significant at $p< 0.05$

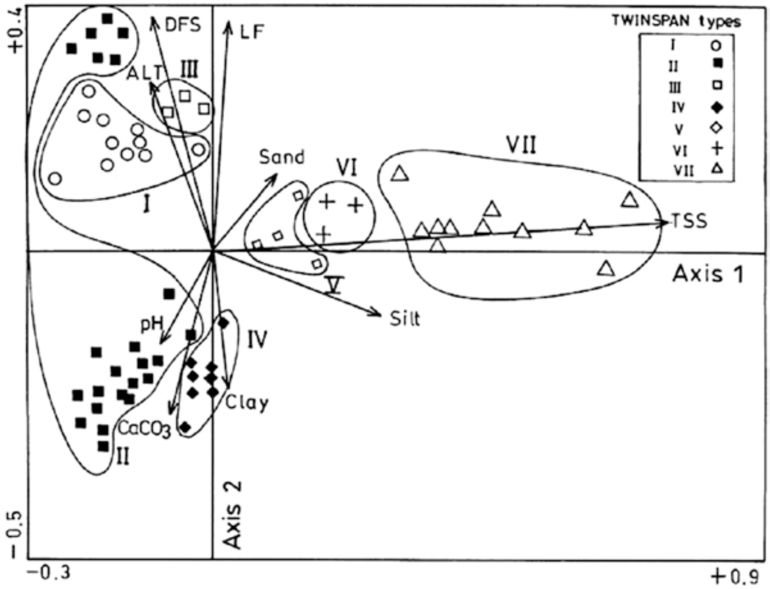

Fig. 3.15 Ordination biplot yielded by canonical correspondence analysis (CCA) of the 63 stands with their TWINSPAN vegetation types and soil variables

3.7 Diversity Versus Environment

The effects of environmental variables on the species richness were shown in Table 3.13. The results showed that species richness was significantly correlated with the first axis (salinity–altitude gradient) of CCA ordination, but was unrelated to the second axis (landform $CaCO_3$ gradient). Whereas soil salinity exhibited high significant negative correlation with species richness ($p = 0.001$), landforms were positively correlated with it ($p = 0.001$).

3.8 Concluding Remarks

1. The examined the vegetation–environment relationships in the different landforms along the roadside verges between El Arish and Rafah on the northeastern Mediterranean coast of Sinai. Both DCA and CCA were applied to assess the species distribution and the prevailing environmental conditions. The results of CCA showed well the relative positions of species and stands along the most important ecological gradients. Both ordination techniques indicated that soil salinity, calcareous sediments, soil texture, landform, altitude, and distance from seashore were the most important factors for the distribution of the vegetation pattern along the road verges in the study area. The distribution of the vegetation

Table 3.13 Spearman rank correlations between species richness and stand scores of the first two axes of CCA and the environmental variables

Variables	Correlation	*P*
Axis 1	0.68	0.001*
Axis 2	0.06	0.78
Sand	0.07	0.56
Silt	−0.13	0.32
Clay	0.01	0.92
$CaCO_3$	−0.01	0.90
pH	0.20	0.11
TSS	–0.31	0.001*
ALT	–0.35	0.79
DFS	0.02	0.88
Landform	0.65	0.001*

$^{*}p < 0.01$ (for abbreviations, see Table 3.12)

types reflects these relations, with VT (V–VII) being typical of the saline silty stands, VT (I and III) and partly VT (II) showing a gradient of increasing altitude and distance from seashore, and VT (IV) and mostly VT (II) being found on more $CaCO_3$ and clay contents.

2. The 18 groups identified by TWINSPAN were considered to represent seven vegetation types, each of definite floristic and environmental characteristics. Most of the characteristic species of the identified vegetation types were salt-tolerant species, indicating the saline nature of the study area. The application of DCA to the same set of data supports the distinction between these types. Some of the identified vegetation types have very much in common with that recorded along the western Mediterranean coastal land (Shaltout and El-Ghareeb 1992), in south Sinai region (El-Ghareeb and Shabana 1990; Abd El-Ghani and Amer 2003), in some wadis of the Eastern (Fossati et al. 1998) and Western Desert (Bornkamm and Kehl 1985; Abd El-Ghani 2000a), and in the Negev Desert of Israel (Olsvig-Whittaker et al. 1983; Tielbörger 1997). Due to the specific environment of the study area, many species with a nitrophilous (e.g. *Cynodon dactylon*, *Cakile maritima*, and *Phragmites australis*), psammophilous (e.g. *Echinops spinosus*, *Cornulaca monacantha*, *Cyperus capitatus*, and *Artemisia monosperma*), halophilous (e.g. *Arthrocnemum macrostachyum*, *Halocnemum strobilaceum*, *Agathophora alopecuroides*, *Juncus rigidus*, and *Frankenia hirsuta*), and psammohalophilous (e.g. *Zygophyllum album*, *Ammophila arenaria*, and *Tamarix nilotica*) occurred in the distinguished vegetation types.
3. It has been emphasized that roadside zonation was based on structural criteria, such as vegetation height, density, and dominance structure of plant communities rather than on floristic composition only (Kopecký 1978), features that were beyond the focus of this study. The arrangement of the seven major vegetation types followed a general pattern in zones parallel to the roadway. Each type has indicator species with varying degrees of overlap between types. The zonation of these physiognomic vegetation types (VT I–VII) from the roadside inwards can be characterized according to the landform unit on which it occurred as follows:

   (a) Coastal plain; at the inner edge of the road verge and exposed to salt spray. Vegetation composition in this landform was dominated with *Ammophila* *arenaria–Pancratium maritimum* (VT IV) found very close to the seashore on the low-lying stands rich in fine sediments. Less frequent species include *Elymus farctus* and *Silene succulenta*.

(b) Saline depressions; located on the outermost zone of the outer road verge that were relatively influenced by seawater and forming wet salt marshes. They dominated with *Zygophyllum album*, *Arthrocnemum macrostachyum*, and *Arthrocnemum macrostachyum–Zygophyllum album* (VT V, VI, and VII, respectively). High salinity of this landform favours the growth of some salt-tolerant species as *Frankenia hirsuta*, *Juncus rigidus*, *Agathophora alopecuroides*, and *Cyperus laevigatus*. Low species richness in the vegetation types of the coastal plain and saline depressions may be related to their high soil salinity. Our results indicated that species richness was negatively correlated with soil salinity and positively correlated with landform units. Such salinity stress on species diversity in the study area and related areas was reported (Moustafa and Klopatek 1995; Shaltout et al. 1997) .

(c) Sand plains: followed the saline depressions and away from the direct influence of the sea. The vegetation structure of this vegetation type occurred in two facies: (1) the farthest from the seashore and inhabiting the deep sandy soil stands with low content of $CaCO_3$. It is dominated with *Panicum turgidum* and *Thymelaea hirsuta* (2), the nearest to the seashore found on high soil contents of $CaCO_3$, pH, and fine sediments. It represents the typical vegetation type that dominated with *Artemisia monosperma–Echinops spinosus* (VT II). The relatively high species diversity of VT (II) may be explained in terms of the theory of substrate heterogeneity (Mellinger and McNaughton 1975), as this landform can be considered as ecotonal area that embraces the characteristics of both coastal plain and sand dunes. High species diversity due to substrate heterogeneity and local topographic variations in some Mediterranean plant communities was also confirmed (among others Kutiel et al. 1979, Behhouhou et al. 2001, Al-Sodany et al. 2003) .

(d) Sand dunes: represents the innermost zone of the outer road verge away from any influence of the sea and characterized with *Artemisia monosperma* (VT I), *Artemisia monosperma–Echinops spinosus* (VT II), and *Cyperus capitatus–Ammophila arenaria* (VT III). The vegetation composition of the coastal sand dunes in the present study has very much in common with those in Israel (Barbour et al. 1981; Tielbörger 1997) and in the western Mediterranean coast of Egypt (Ayyad 1973). The coastal sand dune system was a prominent feature in this study. However, its vegetation has been disturbed through grazing and over-exploitation for fuelwood, construction, and being burnt to clear the way for cultivation. Consequently, the high species diversity and the highest share of alien weeds of vegetation types (I) and (III) characterized sand dune vegetation in the study area may be related to the high disturbance of their substrates as a result of agriculture practising, farming processes, and other excessive human disturbances.

3.8.1 A Coastal Plain in South Sinai (El-Qaa Plain)

El-Qaa plain (33° 20′–34° 10′E and 27° 47′ – 28° 41′N) occupies the southwestern corner of Sinai Peninsula (Zahran and Willis 2009). It is a depression of about 1,125 km², extending for about 100 km along the southern section of the eastern coast of the Gulf of Suez (Fig. 3.16). To the east, it is bounded by the outskirts of the

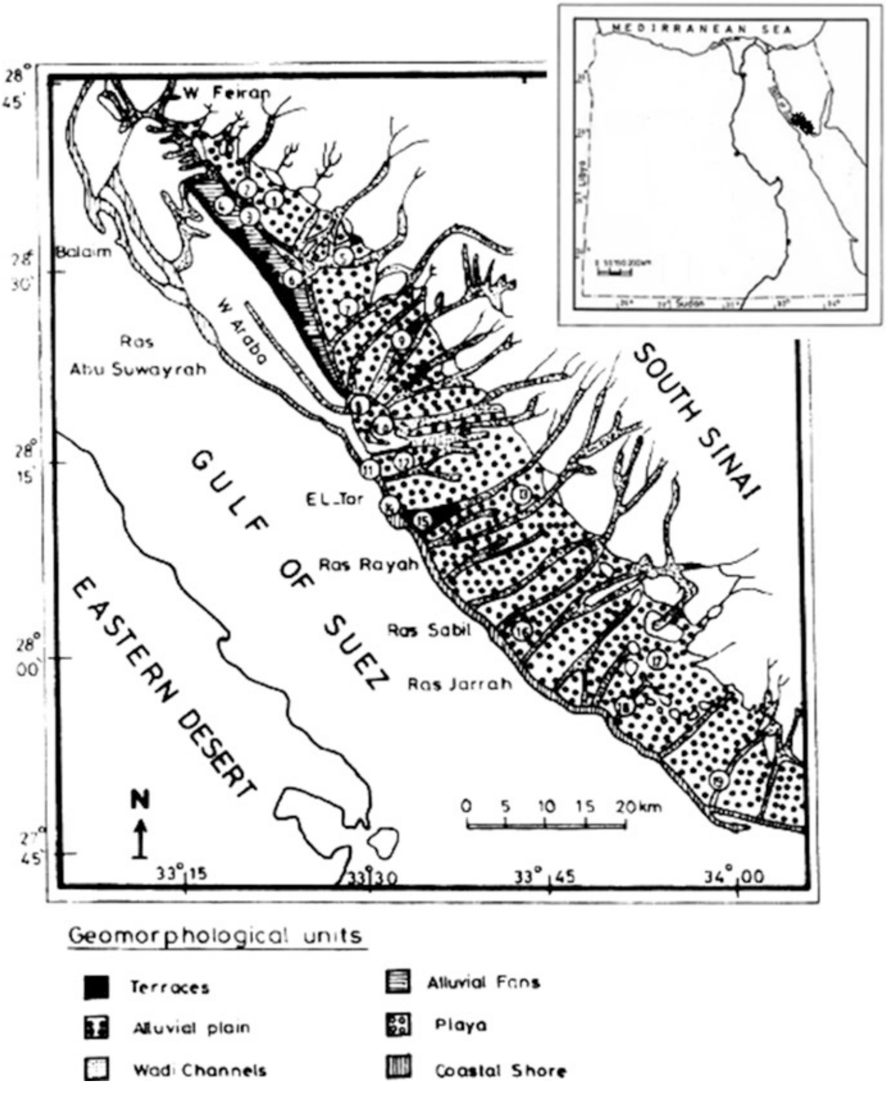

Fig. 3.16 Location map of El-Qaa plain showing the distribution of the studied sites (1–19) within the six geomorphologic units. A, b, and c are three climatic stations at El-Arish, Suez, and El-Tor, respectively

rugged montane area of south Sinai and to the north by wadi Feiran. The plain rises up to 200 m above sea level (ASL) , sloping gently towards the south east of the Peninsula. It is characterized by young tertiary and quaternary alluvial sediments, sandstone, gypsum, and limestone. Much of the alluvial sediments originate from the hills to the east. Alluvial fans derived from magmatic and metamorphic parent rocks are common in the southern part of Sinai Massif. Limestone derived from local weathering and transported by wind mixes with the alluvium or forms individual dunes (Danin 1983). The plain is divided into six geomorphologic units: terraces, alluvial plains, wadi channels, alluvial fans, playas, and coastal shore. The climate of El-Qaa plain does not differ greatly from that of southern Sinai, which is hot, with low rainfall and high relative humidity. Ayyad et al. (1983) considered the area to be one of the driest parts of Egypt. It belongs to the hyperarid bioclimatic province with precipitation less than 30 mm year^{-1}. Comparing climatic characteristics of three meteorological stations in Sinai Peninsula, El-Tor station, the nearest to El-Qaa plain, with the other two is shown in Table 3.14. Obviously, a rainfall gradient along the N–S direction (from El-Arish in the north to El-Tor in the south) can be detected.

Zahran and Willis (2009) reported that scanty rainfall on the mountains is one of the main water resources in southern Sinai, which runs over the slopes and collects in narrow deep wadis forming perpetual streams and rivulets. In rainy years, the excess water percolates and is stored in rock crevices. It may be obtained by digging wells within an average water table ranging between 17–25 m in old wells and 35–40 m in the new ones. Since permanent watercourses are devoid, cultivation therefore depends on groundwater supplies that are extracted by motor-driven pumps. Agriculture is mainly practised in the middle sector of El-Qaa plain near El-Tor City on the Red Sea coast, where parts of the plain are recently cultivated. Among the main cultivated plants are wheat (*Triticum aestivum*), alfa-alfa (*Medicago sativa*), maize (*Zea mays*), date palm (*Phoenix dactylifera*), and various vegetables. The lack of good drainage system has resulted in the salinization of several cultivated parts of the plain.

Table 3.14 Climatic characteristics (average 1975–1985; Meteorological authority 1989) of three stations: El-Tor (within the study area), Suez to the north, and El-Arish (on the Mediterranean coast) for comparison

	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
Station	Max	Min	Max	Min	
El-Arish	25.6	12.2	70	32	180
Suez	30.6	17.4	51	29	16.3
El-Tor	38.3	10.5	58	22	10.4

3.9 Floristic Relations

In total, 203 species representing 129 genera and 29 families are collected and identified in this study. Grasses constitute only 9% of the recorded species, while the woody perennials (shrubs and subshrubs) are highly dominated (46%). The largest families are Asteraceae (n = 24), Fabaceae (n = 23), Chenopodiaceae (n = 19), Poaceae (n = 18), and Zygophyllaceae (n = 11), representing 12%, 11%, 9%, 8%, and 5% of the total flora, respectively. The best represented genera are *Astragalus* (7), *Fagonia* (6), *Stipagrostis* (5), *Atriplex, Lotus, Plantago,* and *Zygophyllum* (4 for each).

None of the 203 species occurs at all the 19 sites. Some of the recorded species have a wide ecological and sociological range of distribution, e.g. *Deverra tortuosa* and *Zygophyllum coccineum*, with ten records and the highest species occurrence (P = 53%), while *Zygophyllum simplex* recorded in seven sites and showed the highest occurrence among annuals (P = 37%). One hundred fifty-six species or 77% of the total recorded species demonstrated a certain degree of fidelity, where they exclusively recorded in or confined to a certain geomorphologic unit and do not penetrate elsewhere. These species are distributed as follows: 20 in the terraces (e.g. *Stachys aegyptiaca, Varthemia montana, Otostegia fruticosa, and Launaea spinosa*), 47 in the alluvial plains (e.g. *Anabasis setifera, Echiochilon fruticosum, Asteriscus graveolens, Traganum nudatum, Limonium axillare, and Salsola schweinfurthii*), 62 in the wadi channels (e.g. *Pulicaria arabica, Teucrium leucocladum, Cleome droserifolia, Gymnocarpos decanter, Salvia aegyptiaca, Blepharis ciliaris, and Haplophyllum tuberculatum*), 7 in the alluvial fans (e.g. *Astragalus camelorum, Launaea tenuiloba, and Pulicaria crispa*), and 20 in the coastal shore and playas (e.g. *Haloxylon salicornicum, Salsola tetrandra, Haloxylon persicum*, *Juncus rigidus*, *and Suaeda vermiculata*). Floristic composition in the different geomorphologic landscape units showed differences in species richness. The highest mean species richness of 19.7 ± 1.7 is recorded in the wadi channels, whereas the lowest species richness values are recorded in the coastal shore and playas (6.0 ± 1.4) and in the alluvial fans (mean of 8.4 ± 1.6 species). Terraces and alluvial plains demonstrated intermediate species richness value of 14.8 ± 2.5 and 14.3 ± 1.5, respectively. Therophytes are the predominant life form and constituted 50% of the total flora, followed by chamaephytes (26%), hemicryptophytes (21%), and phanerophytes (18%). Apart from the playas and the coastal shore, preponderance of therophytes upon the other life forms in the geomorphologic units is remarkable (Fig. 3.17).

Results of the total chorological analysis of the surveyed flora presented in Table 3.15 revealed that 46% of the studied species are uniregional, of which 41% being native to the Saharo–Arabian chorotype. Typical Mediterranean and Sudano–Zambezian chorotypes are very modestly represented. About 50% of the recorded species are biregional and pluriregional, extending their distribution all over the Saharo–Arabian, Sudano–Zambezian, Irano–Turanian, and Mediterranean chorotypes. The biregional Saharo–Arabian and Mediterranean, the Saharo–Arabian and Irano–Turanian, and the Saharo–Arabian and Sudano–Zambezian chorotypes constituted the highest values (13%, 12%, and 11%, respectively), while Cosmopolitan and endemic taxa rarely occurred.

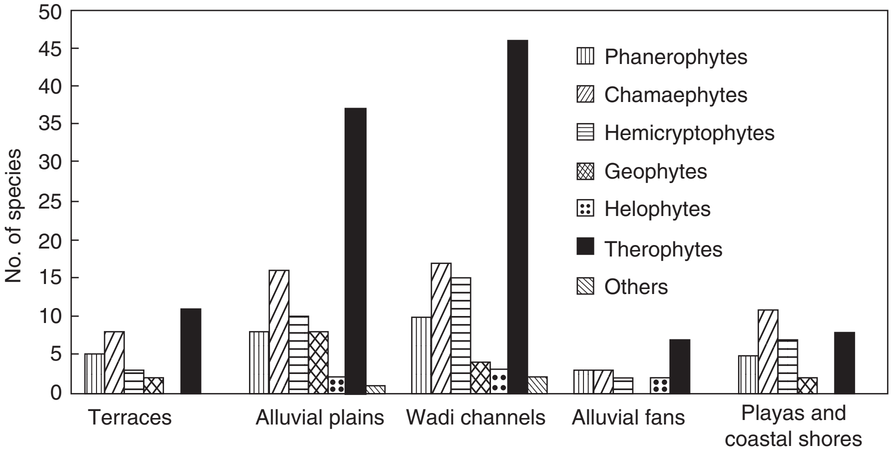

Fig. 3.17 Life-form spectrum within each geomorphologic unit of El-Qaa plain. *Ph* phanerophytes, *CH* chamaephytes, *Hc* hemicryptophytes, *G* geophytes, *He* helophytes, and *Th* therophytes

Table 3.15 Chorotype analysis of the species examined as numbers and percentages of the total species recorded

Chorotypes	No. of species	(%)
Monoregional		
Mediterranean	4	2
Irano–Turanian	2	1
Saharo–Arabian	83	41
Sudano–Zambezian	4	2
	93	46
Biregional		
Mediterranean+Saharo–Arabian	27	13
Saharo–Arabian+Sudano–Zambezian	23	11.4
Saharo–Arabian+Irano–Turanian	24	12
Mediterranean+Euro–Siberian	1	3
Mediterranean+Irano–Turanian	6	0.5
Others	2	1
	83	40.9
Pluriregional		
Sah–Arab +Med+Iran–Tur	7	3.5
Sah–Arab +Med+Eur–Sib	2	1
Sah–Arab+Sud–Zam+Iran–Tur	3	1.4
Sah–Arab+Sud–Zam+Med	4	2
Others	3	1.4
	19	9.3
Paleotropic	3	1.4
Pantropic	3	1.4
Cosmopolitan	1	0.5
Endemic	1	0.5
	8	3.8
Total	203	100

Sah–Arab Saharo–Arabian, *Med* Mediterranean, *Iran–Tur* Irano–Turanian, *Eur–Sib* Euro–Siberian, *Sud–Zam* Sudano–Zambezian

3.9.1 Classification of the Vegetation

The TWINSPAN classification of the 19 sites resulted in five site groups (A–E, Table 3.16, Fig. 3.18), each of which could easily be linked to a geomorphologic unit presented in Fig. 17. Each site group will be referred here to as TWINSPAN vegetation group and named after the leading dominant species that exerts local

Table 3.16 Synoptic table of the indicator and preferential species of the five TWINSPAN groups (A–E) with their presence estimates

	TWINSPAN groups				
Species	A	B	C	D	E
Total number of species	29	82	97	17	33
Mean species richness	14.8 ± 2.5	14.3 ± 1.5*	19.7 ± 1.7*	6.4 ± 1.6*	8.0 ± 1.4
Number of sites	1	7	5	2	4
Calotropis procera	○	–	–	–	–
Capparis spinosa var. *spinosa*	●	–	–	–	–
Chrozophora oblongifolia	○	–	–	–	–
Devera triradiata	○	–	–	–	–
Echinops glaberrimus	○	–	–	–	–
Launaea spinosa	○	–	–	–	–
Anabasis setifera	–	○	–	–	–
Convolvulus lanatus	–	●	–	–	–
Cornulaca monacantha	–	●	–	–	–
Deverra tortuosa	–	○	–	–	–
Fagonia indica	–	○	–	–	–
Panicum turgidum	–	○	–	–	–
Salvia deseri	–	○	–	–	–
Stipagrostis scoparia	–	○	○	–	–
Cotula cinerea	–	–	●	–	–
Filago desertorum	–	–	●	–	–
Launaea nudicaulis	–	–	●	–	–
Artemisia judaica	–	–	○	–	–
Heliotropium digynum	–	–	○	–	–
Oligomeris linifolia	–	–	○	–	–
Salvia aegyptiaca	–	–	○	–	–
Trigonella stellata	–	–	○	–	–
Ziziphus spina-christi	–	–	○	○	–
Acacia raddiana subsp. *raddiana*	–	–	–	●	–
Leptadenia pyrotechnica	–	–	–	●	–
Anastatica hierochuntica	–	–	–	○	–
Launaea tenuiloba	–	–	–	○	–
Phoenix dactylifera	–	–	–	○	○
Nitraria retusa	–	–	–	–	●

(continued)

Table 3.16 (continued)

Species	TWINSPAN groups				
	A	B	C	D	E
Tamarix nilotica	–	–	–	–	●
Zygophyllum album	–	○	–	–	●
Bassia muricata	–	–	–	–	○
Halocnemum strobilaceum	–	–	–	–	○
Haloxylon salicornicum	–	–	–	–	○
Opophytum forsskaoli	–	–	○	–	○
Suaeda monoica	–	–	–	–	○
Zilla spinosa	–	○	–	–	○

● above 50%, *O* less than 50%, – absence. *A* terraces, *B* alluvial plains, *C* wadi channels, *D* alluvial fans, *E* playas and coastal shore
*, $P < 0.01$; **, $p < 0.001$

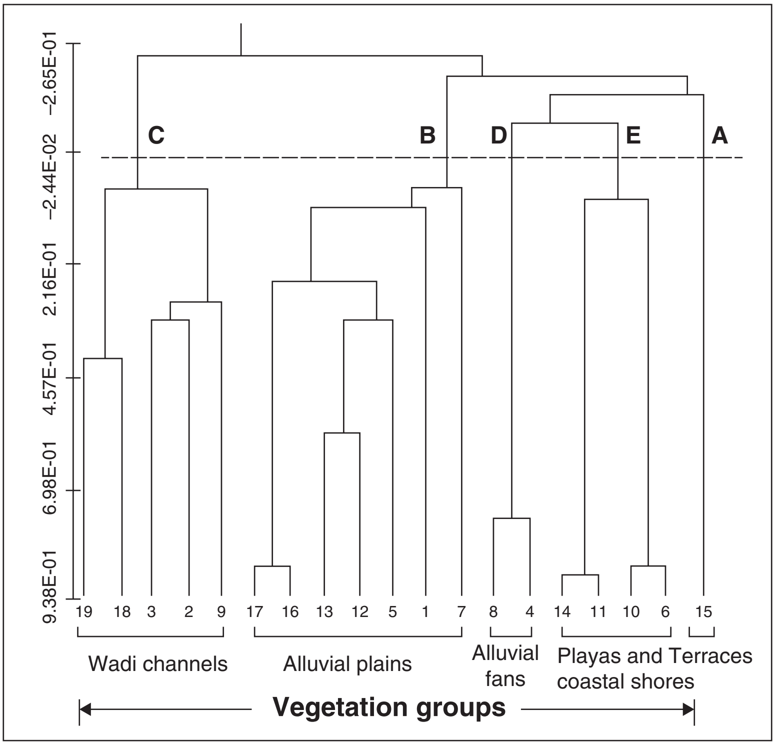

Fig. 3.18 TWINSPAN classification of the 19 sites of EL-Qaa plain. A–E are the five separated vegetation groups

dominance or is distinctly important in a certain group of sites. Sørensen's coefficients of floristic similarity (CCs) between the five vegetation groups are generally low (Table 3.17). Among the significant relations are those between groups A, B, and C and between groups B and E. However, groups D and E have the lowest similarities with other groups.

Group A. ***Capparis spinosa*** **var.** ***spinosa*** **Group**

The four plots in this group are sampled from one site (15) that was accessible to us. On highly saline, gravel, and fertile soils with the lowest amount of calcium carbonate (Table 3.18), terraces of *Capparis spinosa* var. *spinosa* are found. Apart from *Calotropis procera,* shrubs and subshrubs of *Gomphocarpus sinaicus, Varthemea montana*, *Launaea spinosa, Stachys aegyptiaca, Echinops glaberrimus*, and *Deverra triradiata* are also recorded. The herb layer is relatively sparse and characterized by *Euphorbia granulata*, *Hyparrhenia hirta, Andrachne hispida, Stipa capensis, Anchusa hispida*, and *Plantago afra*.

Group B. ***Cornulaca monacantha–Convolvulus lanatus*** **Group**

This group is characterized by a combination of *Cornulaca monacantha* and *Convolvulus lanatus* found on the alluvial plains, somewhat fertile, with high soil

Table 3.17 Sørensen's coefficient of floristic similarity (CCs) between the TWINSPAN vegetation groups

Vegetation group	A	B	C	D
A				
B	−0.15*			
C	−0.30**	−0.25**		
D	−0.02	−0.02	−0.002	
E	−0.11	−0.19	−0.13	0.05

* $p < 0.05$; ** $p < 0.01$. See text for vegetation groups A–E

Table 3.18 Mean values, standard deviation errors, and ANOVA F-values of the soil variables in the sites representing the five vegetation groups obtained by TWINSPAN

Soil variables		TWINSPAN groups					F-ratio	*P*
		A	B	C	D	E		
pH		7.5 ± 0.3	7.8 ± 0.1	8.4 ± 0.1	7.9 ± 0.2	8.2 ± 0.1	4.77	0.01
EC (mS cm^{-1})		9.8 ± 49.0	47.0 ± 1.8	2.0 ± 22.0	31.9 ± 34.6	64.8 ± 24.5	1.37	0.29
$CaCO_3$	↑	2.15 ± 13.9	12.0 ± 5.2	14.6 ± 6.2	25.0 ± 9.8	39.9 ± 6.9	3.30	0.04
OM		0.3 ± 0.3	0.2 ± 0.1	0.06 ± 0.1	0.06 ± 0.2	0.5 ± 0.1	1.52	0.25
Gypsum	(%)	1.1 ± 2.3	3.2 ± 0.9	0.4 ± 1.0	1.9 ± 1.6	2.4 ± 1.7	1.10	0.39
Sand		38.1 ± 13.9	68.7 ± 5.3	58.8 ± 6.2	66.9 ± 9.9	54.0 ± 7.0	1.57	0.24
Gravel		59.2 ± 11.2	22.2 ± 4.2	34.4 ± 4.9	32.7 ± 7.9	8.3 ± 0.08	6.70	0.003
Silt + clay	↓	2.4 ± 14.0	8.3 ± 5.3	6.8 ± 6.3	6.6 ± 9.9	40.5 ± 7.0	4.54	0.01
SP		23.0 ± 5.3	20.9 ± 2.0	20.4 ± 2.4	22.0 ± 3.7	35.2 ± 2.6	5.84	0.006

EC electrical conductivity, *$CaCO_3$* calcium carbonate, *OM* organic matter, *SP* soil saturation content of sand and gypsum. It is differentiated by a number of woody species (*Artemisia monosperma, Halogeton alopecuroides, Salsola schweinfurthii, Anabasis setifera, Farsetia aegyptiaca, Zygophyllum dumosum, Deverra tortuosa, Heliotropium arbainense, and Acacia tortilis* subsp. *tortilis*) and herbs (*Trigonella stellata, Rumex vesicarius, Diplotaxis acris, Lotus glinoides, and Morettia parviflora*). This vegetation group includes the most common xerophytic species in the Egyptian Deserts, Sinai, and in the neighbouring arid environments as well (Zohary 1973; Batanouny 1979a; Abd El-Ghani 1998). It is noteworthy that due to the relatively high soil salinity, some salt-tolerant and moist-loving species are recorded and include *Halopeplis perfoliata, Spergularia diandra, Limonium axillare, Limoniastrum pruinosum,* and *Atriplex dimorphestegia*. Since the alluvial plains form the main geomorphologic landscape unit in El-Qaa plain, this vegetation group includes the most widespread species in the study area.

Group C. *Cotula cinerea–Filago desertorum–Launaea nudicaulis* **Group**
This is the largest group of sample plots (30) and the most diversified among the other vegetation groups. It inhabits the wadi channels on the alkaline soils (pH=8.4) with the lowest levels of soil salinity, gypsum, and organic matter. *Ziziphus spina-christi* is the only tree species recorded, whereas *Cassia italica, Iphiona scabra, Hyoscyamus muticus, Pulicaria arabica, Convolvulus hystrix,* and *Artemisia judaica* constitute the shrub and subshrub layer. This group had the largest share (46) of annual species. Shortly after rainfall, the soil surface supporting the sites of this group is covered with a dense vegetation of annual species, especially *Trigonella stellata, Oligomeris linifolia, Parietaria alsinifolia, Sonchus oleraceus, Silene villosa, Aristida adscensionis, Plantago ciliata, Schismus arabicus, Medicago laciniata,* and *Matthiola livida.*

Group D. *Acacia tortilis subsp. raddiana–Leptadenia pyrotechnica* **Group**
This group dominates the highly elevated alluvial fans with comparable physical soil properties to those of group C. The nine sample plots studied in this group are characterized by the growth of *Acacia tortilis* subsp. *raddiana* and *Leptadenia pyrotechnica*. In addition, *Ziziphus spina-christi, Tamarix nilotica, Tamarix aphylla,* and *Phoenix dactylifera* are occasionally recorded. The shrub and subshrub layer comprise *Ficus pseudo-sycomorus, Launaea tenuiloba, Pulicaria crispa,* and *Deverra tortuosa*. The lowest number of annuals is recorded in this group, of which *Astragalus camelorum, Anastatica hierochuntica, Ifloga spicata, Zygophyllum simplex,* and *Filago desertorum* are occurred.

Group E. *Nitraria retusa–Tamarix nilotica–Zygophyllum album* **Group**
On muddy fertile sites with high calcium carbonate and saline soils, the coastal shore and playas with vegetation characterized by the complex *Nitraria retusa, Tamarix nilotica,* and *Zygophyllum album* are found, indicating the saline nature of this geomorphologic landscape unit. It represents the least diversified among the other recognized groups. Notably, several halophytic species are recorded, e.g. *Suaeda monoica*, *Halocnemum strobilaceum*, *Haloxylon persicum*, *Atriplex halimus*, and *Reaumuria negavensis*. The herb layer is modestly represented and includes *Frankenia pulverulenta, Cressa cretica, Spergularia marina,* and *Lotus peregrinus,* among others.

3.10 Soil Characteristics of the Vegetation Groups

Soil characteristics of each of the five vegetation groups are summarized in Table 3.18. Of the measured soil parameters, pH, calcium carbonate, gravel, fine soil fraction, and soil saturation show highly significant differences between groups. It can be also noted that soil saturation and calcium carbonate attain their highest levels in the group of playas and coastal shore, the electric conductivity, and gypsum on the terraces and on the alluvial plains.

3.11 Ordination of Stands

Figure 3.19 shows the ordination results of the DCA analysis of the floristic data set. The 19 site scores are plotted along axes 1 and 2 and tend to cluster into five groups that resulted from TWINSPAN analysis described above. The sites are spread out 7.34 SD units along the first axis (eigenvalue = 0.82), expressing the high floristic variation among vegetation groups and indicating a complete turnover in species composition that took place (Hill 1979). The ordination diagram displays graphically that site groups C and D are transitional in their composition between the other groups. Sites of group E are separated towards the positive end of DCA axis 1, while those of groups A and B are separated out along the other end. DCA axis 2 with an eigenvalue of 0.65 and a gradient length of 5.46 is less important. The species–environment correlation is also high: 0.93 and 0.84 for DCA axes 1 and 2 showing that the species data are strongly related to the measured environmental variables. Significant correlations of soil variables with the first three DCA axes revealed greater correlations along axis 1 than the higher-order axes. DCA axis 1 showed significant positive correlations with $CaCO_3$, pH, soil saturation, and organic matter

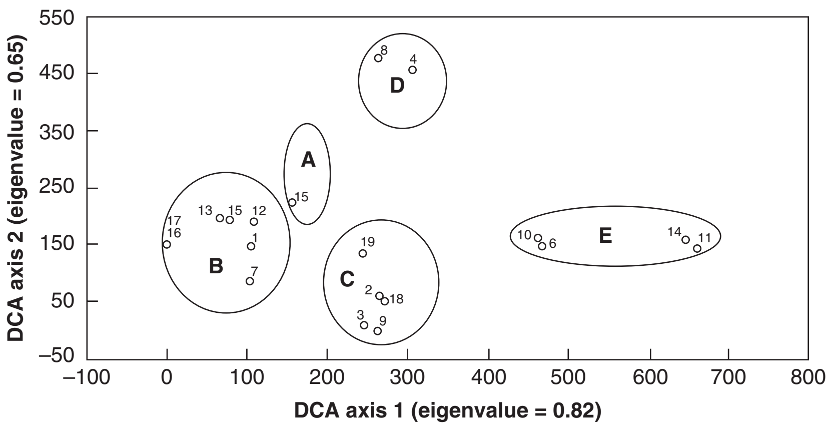

Fig. 3.19 The floristic DCA ordination of the 19 sites with the TWINSPAN groups superimposed

(Table 3.18). We interpreted DCA axis 1 as a calcium carbonate–soil saturation gradient. Axis 2 is significantly correlated with pH, electric conductivity, and gypsum. We interpreted axis 2 as an electric conductivity–gypsum gradient.

3.12 Vegetation and Soil Factors

The eigenvalues (Table 3.19) are somewhat lower than for the DCA axes, indicating that important explanatory site variables are not measured and included in the analysis or some of the variation is not explained by environmental variables (Franklin and Merlin 1992; McDonald et al. 1996). However, the species–environment correlations are higher for the first three canonical axes, explaining 67% of the cumulative variance. These results suggest a strong association between vegetation and the measured soil parameters presented in the biplot (Jongman et al. 1987). From the intra-set correlations of the soil factors with the first three axes of CCA, it can be noted that CCA axis 1 is correlated to soil reaction, calcium carbonate, organic matter, and soil saturation (Fig. 3.20). A test for significance with an unrestricted Monte Carlo permutation test (99 permutations) found the F-ratio for the eigenvalue of axis 1 and the trace statistics to be significant ($P < 0.001$), indicating that observed patterns did not arise by chance. It is worthwhile to note that the results of DCA demonstrated patterns very similar to those of CCA, suggesting that there might be no other important environmental variables missed in sampling. CCA axis 2 is clearly related to pH, gypsum, organic matter, soil salinity, and gravel. As a result of the significant differences between groups in relation to certain soil factors, their species and space have been arranged along axes 1 and 2 of the CCA scatter diagram.

Table 3.19 Comparison of the results of ordination for the first three axes of DCA and CCA. Intra-set correlations of the soil variables, together with eigenvalues and species–environment correlation coefficients

Soil variables		CCA axis 1	CCA axis 2	CCA axis 3	DCA axis 1	DCA axis 2	DCA axis 3
Eigenvalues		0.75	0.52	0.36	0.82	0.65	0.46
Species–environment correlations		0.96	0.94	0.83	0.93	0.84	0.68
pH		0.59*	0.57**	−0.0005	0.64***	0.43*	0.5**
EC (MS cm^{-1})		0.08	−0.67***	0.2	0.05	−0.4*	0.007
$CaCO_3$	(%)	0.71***	−0.3	−0.18	0.72***	−0.17	−0.4*
Gypsum	(%)	−0.1	−0.47**	−0.3	−0.16	−0.23*	-0.18
OM	(%)	0.46**	−0.58**	0.19	0.43*	−0.16	−0.14
Gravel	(%)	−0.2	0.66***	0.73***	−0.35*	−0.02	0.51**
Sand	(%)	−0.16	−0.33	−0.53	−0.03	−0.17	−0.25
Silt + clay	(%)	0.39	−0.27	−0.26	0.47*	0.04	−0.35
SP		0.51**	−0.43	−0.01	0.57**	0.09	−0.43*

*** = $p < 0.001$, ** = $p < 0.01$. For abbreviations, see Table 3.18

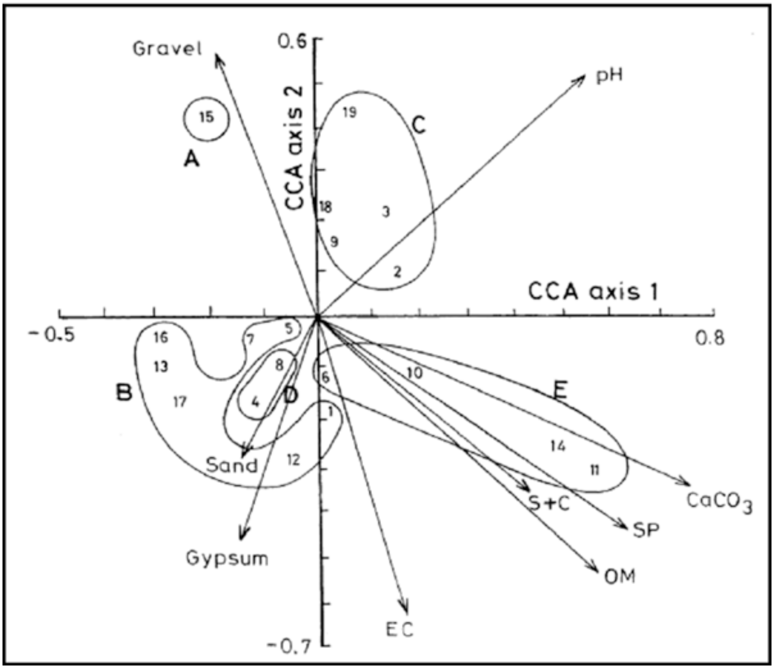

Fig. 3.20 CCA ordination biplot of the first two axes showing the distribution of the 19 sites with their TWINSPAN groups (A–E) and the examined soil variables

3.13 Concluding Remarks

1. The present study examined the environmental correlates of species distribution in different geomorphologic units of El-Qaa plain along the southwestern coast of the Gulf of Suez, southern Sinai. Both DCA and CCA assess the soil–vegetation relationships. The results of CCA analysis showed well the relative positions of species and sites along the most important ecological gradients. Both ordination techniques clearly indicated that soil surface sediments, calcium carbonate, soil reaction, organic matter, and soil saturation percentage are the most important factors for the distribution of the vegetation pattern in El-Qaa plain. The soil texture gradient that exists from the upland terraces to fine-textured flats in the alluvial plains and wadi channels in arid desert environments resulted in gradients of available soil moisture. The organic matter content plays an important role as a key element in soil fertility, as shown for other desert ecosystems in Egypt by Sharaf El Din and Shaltout (1985) and Abd El-Ghani (1998, 2000b) and in Saudi Arabia by El-Demerdash et al. (1994).
2. The plant life in the study area is restricted to microenvironments (as in wadis, runnels, and depressions) where runoff water collects and provides sufficient moisture for plant growth. This is described by Monod (1954) as végétation con-

tracté, runoff desert (Zohary 1962), and restricted desert (Walter 1963). The vegetation is characterized by sparseness of plant cover (does not exceed 5% on the average; Kassas 1966), a limited number of plant species (16 on the average in each site), and paucity of trees (5% of the recorded species). The vegetation structure is relatively simple, in which the species have to withstand the harsh environmental conditions. This is not only reflected by the preponderance of annuals but also by the presence of several highly adapted, drought-resistant species (Abdel-Razik et al. 1984). Monodominant plots in the study area are not as common as those dominated by more than one species. Monotypic stands dominated by *Artemisia judaica* are recorded in wadi El-Sheikh of south Sinai (El-Ghareeb and Shabana 1990), whereas in gorges of Gebel Uweinat and in Gilf Kebir (SW corner of Egypt) are dominated by *Cornulaca monacantha* and *Zygophyllum coccineum* (Boulos 1982; Bornkamm 1986).

3. The importance of the study area from a phytogeographical point of view may be due to its position on the Sinai Peninsula, which is located in the intersection of the four phytogeographic regions: Mediterranean, Irano–Turanian, Sudano–Zambezian, and the Saharo–Arabian region. This may reflect the relatively rich floristic diversity of the Sinai Peninsula. Chorological analysis of the floristic data revealed that the Saharo–Arabian chorotype (46%) forms the major component of the floristic structure along El-Qaa plain. This is in accordance with the results obtained by Danin and Plitman (1987) on the phytogeographical analysis of the flora of Israel and Sinai. The presence of the monoregional Saharo–Arabian chorotype in a higher percentage than the interregional chorotypes (bi- and pluriregionals) is not in accordance with Zohary (1973). The Saharo–Arabian chorotype decreased northwards and replaced by Mediterranean and Irano–Turanian chorotype (Hegazy and Amer 2001; Danin and Plitman 1987). This may be attributed to the fact that plants of the Saharo–Arabian species are good indicators for desert environmental conditions, while Mediterranean species stand for more mesic environment. The low percentage of the endemic species is remarkable. Wickens (1977) and Boulos (1997) mentioned that the Saharo–Arabian region is characterized by the presence of few endemic species and genera and absence of endemic families. Most of the endemic species in Sinai is confined to the mountain region (El Hadidi 1967).
4. Spatial distribution of plant species and communities over a small geographic area in desert ecosystems is related to heterogeneous topography and landform pattern (Kassas and Batanouny 1984). The heterogeneity of local topography, edaphic factors, and microclimatic conditions leads to variation of the distributional behaviour of the plant associations of the study area. In terms of classification, the vegetation that characterizes the study area can be divided into five vegetation groups. Most of the identified vegetation groups have very much in common with that recorded in some wadis of the Eastern Desert (Kassas and Zahran 1965; Abd El-Ghani 1998), Western Desert (Bornkamm and Kehl 1990; Abd El-Ghani 2000a, b), along the eastern (El-Demerdash et al. 1994) and western Mediterranean region (Ayyad and El-Ghareeb 1982), in south Sinai

region (El-Ghareeb and Shabana 1990; Moustafa and Zaghloul 1996; El-Kady et al. 1998), and in northwestern Negev, Israel (Tielbörger 1997). The members of each pair of groups are, in some cases, linked together by having one of the dominant species in common. Group E comprises a number of salt-tolerant species, e.g. *Tamarix nilotica*, *Zygophyllum album*, and *Nitraria retusa*, occupying the playas and the coastal shores. According to Kassas and Girgis (1965), the growth of the desert scrub *Nitraria retusa* represents the highest tolerance to soil salinity conditions and a penultimate stage in the successional development. The plant reaches its northernmost limit of distribution around Qara Oasis on the southwestern edge of Qattara Depression (Abd El-Ghani 1992) as well as in Bahariya Oasis (Abd El-Ghani 1981). *Suaeda monoica* is among the tropical species which extends northwards to south Sinai. It grows in a pure community or mixed with *Nitraria retusa* forming sand hillocks in littoral and inland salinized parts in the studied area. The presence of *Suaeda monoica* in El-Qaa plain forms a tropical corridor that represents the extreme northern limit of the species distribution in Egypt (Hegazy and Amer 2001). Further studies on the biogeography and conservation biology of the aforementioned plants in the country are strongly recommended. Group A includes *Capparis spinosa* var. *spinosa* that occupied the terraces. Since the alluvial plains form the main geomorphologic landscape unit in El-Qaa plain, group B includes the most widespread species in the study area. It is dominated by the xero-psammophytes *Cornulaca monacantha*, *Convolvulus lanatus*, and *Deverra tortuosa*, inhabited the alluvial dry nonsaline plains where infiltration is higher and water accumulated in deeper layers. This group of species is more widely distributed in Egypt and neighbouring countries (Batanouny 1979b; Zahran and Willis 1992; Frankenburg and Klaus 1980). Calculation of Søensen's coefficient of floristic similarity (CC) between the TWINSPAN groups indicates significant differences of the species compositional changes between the wadi channels and both the terraces and the alluvial plains. This may be related to the comparable soil characters of these landforms.

5. Under the conditions of low and irregular rainfall which prevail in the study area, local topography is one of the overriding factors controlling sedimentation and water redistribution within the local landscape (Zohary 1962). Therefore, topographic variations usually translate into high habitat heterogeneity and corresponding species diversity (Kassas and El-Abyad 1962). In extreme conditions notably high aridity and high salinity, Danin (1976) summarized that low diversities of vascular plants are expected in extreme deserts, high Arctic and high alpine habitats, salt marshes, and mangrove swamps. The present study reveals that the lowland wadi channels (group C) that receive considerable amounts of runoff water have the highest species richness (19.7 species ±1.7). The agricultural processes practised in this area may also contribute to the high share of annuals recorded. The highly salinized soil with deep fine sediments (group E) dominated by *Tamarix nilotica*, *Zygophyllum album*, and *Nitraria retusa* have the lowest species richness (6.0 species ±1.6).

Photo Gallery

Photo 3.1 *Euphorbia dendroides* growing on Sallum Pateaux along the Egyptian–Libyan borders

Photo 3.2 The limestone plateaux along the Mediterranean western coastal desert showing sparse vegetation

Photo 3.3 Shrubs of *Thymelaea hirsuta* dominating the desert vegetation in Sallum area

Photo 3.4 *Cistanche phelypaea*; a desert parasite in the Sallum area

Photo 3.5 Vigor growth of *Chrysanthemum coronarium* growing in the limestone plateaux of the Sallum area

Photo 3.6 Inland desert vegetation of *Haloxylon salicornicum* in the Sallum area. Note the coastal sand dunes in the background

References

Abd El-Ghani MM (1981) Preliminary studies on the vegetation of Bahariya Oasis, Egypt. Unpublished M. Sc. Thesis, Cairo University. 309 pp

Abd El-Ghani MM (1992) Flora and vegetation of Qara Oasis, Egypt. Phytocoenologia 21(1–2):1–14

Abd El-Ghani MM (1998) Environmental correlates of species distribution in arid desert ecosystems of eastern Egypt. J Arid Environ 38:297–313

Abd El-Ghani MM (2000a) Vegetation composition of Egyptian inland salt marshes. Bot Bull Acad Sin 41:305–314

Abd El-Ghani MM (2000b) Floristics and environmental relations in two extreme desert zones of western Egypt. Glob Ecol Biogeogr 9:499–516

Abd El-Ghani MM, Amer WM (2003) Soil-vegetation relationships in a coastal desert plain of southern Sinai. J Arid Environ 55:607–628

Abdel-Razik M, Abdel-Aziz M, Ayyad M (1984) Environmental gradients and species distribution in a transect at Omayed (Egypt). J Arid Environ 7:337–352

Abu-Ziada MEA (1980) Ecological studies on the flora of Kharga and Dakhla Oases of the Western Desert of Egypt. Ph.D. Thesis, Faculty of Science, Mansoura Univ. 342 pp

Al-Sodany YM, Shahata MN, Shaltout KH (2003) Vegetation along an elevation gradient in Al-Jabal Al-Akhdar, Libya. Ecol Mediterr 29:35–47

Ayyad MA (1973) Vegetation and environment of the western Mediterranean coastal land of Egypt. I. The habitat of sand dunes. J Ecol 61:509–523

Ayyad M (1976) The vegetation and environment of the western Mediterranean coastal land of Egypt. II. The habitat of non-saline depressions. J Ecol 62:439–456

Ayyad M, Abdel-Razik M, Mehanna A (1983) Climatic and vegetational gradients in the Mediterranean Desert of Egypt. Pre-report of the Mediterranean Bioclimatology Symposium, Montpellier (France)

Ayyad M, El-Ghareeb R (1982) Salt marsh vegetation of the western Mediterranean desert of Egypt. Vegetatio 49:3–19

Ayyad M, Ghabbour SI (1986) Hot deserts of Egypt and the Sudan. In: Evenari M, Noy-Meir L, Goodall DW (eds) Ecosystems of the world 12B. Elsevier, Amsterdam, pp 149–202

Baker HG (1974) The evolution of weeds. Annu Rev Ecol Syst 5:1–24

Barbour MG, Shmida A, Johnson AF, Holton B (1981) Comparison of coastal dune scrub in Israel and California: physiognomy, association patterns, species richness and phytogeography. Isr J Bot 30:181–198

Batanouny KH (1973) Habitat features and vegetation of deserts and semi-deserts of Egypt. Vegetatio 27:181–199

Batanouny KH (1979a) The desert vegetation in Egypt. Cairo University African studies review. Spec Publ 1:9–37

Batanouny KH (1979b) Vegetation along Jeddah-Mecca road: pattern and process affected by human impact. J Arid Environ 2:21–30

Beadle HCW (1981) The vegetation of Australia. Gustav Fischer, Stuttgart

Behhouhou SS, Dargie TCD, Gilbert OL (2001) Vegetation associations in the Great Western erg and the Saoura valley, Algeria. Phytocoenologia 31:311–324

Bornkamm R (1986) Flora and vegetation of some small oases in S-Egypt. Phytocoenologia 14(2):275–284

Bornkamm R, Kehl H (1985) Pflanzengeographische zonen in der Marmarika (Nordwest-Ägypten). Flora 176:141–151

Bornkamm R, Kehl H (1990) The plant communities of the western desert of Egypt. Phytocoenologia 19(2):149–231

Boulos L (1975) The Mediterranean element in the flora of Egypt and Libya. Coll. Int. Centre de la Recherche Scientifique, Montpellier, pp 119–124

Boulos L (1982) Flora of Gebel Uweinat and some neighbouring regions of southwestern Egypt. Candollea 37:257–276
Boulos L (1995) Flora of Egypt. Checklist. Al Hadara Publishing, Cairo, 283 pp
Boulos L (1997) Endemic flora of the Middle East and North Africa. In: Barakat HN, Hegazy AK (eds) Reviews in ecology: desert conservation and development. Metropole, Cairo, pp 229–245. 331pp
Braun-Blanquet J (1949) Premier apercu phytosocilogique du Sahara Tunisien. Mém Ser Soc Hist Nat Afr 2:1–16
Cain SA (1950) Life-forms and phytoclimate. Bot Rev 16:1–32
Danin A (1976) Plant species diversity under desert conditions. I. Annual species diversity in the Dead Sea valley. Oecologia 22:251–259
Danin A (1983) Desert vegetation of Israel and Sinai. Cana Publishing House, Jerusalem. 148 pp
Danin A, Plitman U (1987) Revision of the plant geographical territories of Israel and Sinai. Plant Syst Evol 156:43–53
El Garf IA (2003) Studies on the shallow wadies of the Mareotis sector of the Mediterranean coastal land of Egypt. I. Floristic features of wady Halazeen. Bull Fac Sci Assiut Univ 32(1-D):61–71
El Hadidi MN (1967) Observations on the flora of Sinai mountain region. Bull Soc Geogr Egypte 40:123–155
El Hadidi MN, Ayyad MA (1975) Floristic and ecological features of Wadi Habis (Egypt). La flore Basin Méditterr: Essai Systématique Synthétique, Colleques Internatinaux du CNRS 235:247–258
El Hadidi MN, Fayed AA (1978) Studies on the genus euphorbia L. in Egypt. II. Systematic treatment. Taeckholmia 9:9–57
El Hadidi MN, Hosni HA (2000) Flora Aegyptiaca. Volume 1, Part 1. Cairo University Herbarium and The Palm Press, Egypt, Palm Press, Cairo
El Hadidi MN, Abd El-Ghani MM, Fahmy AG (1992) The plant red data book of Egypt. I. Woody perennials. Palm Press and Cairo University Herbarium, Cairo, Palm Press, Cairo
El-Demerdash MA, Hegazy AK, Zilay AM (1994) Distribution of the plant communities in Tihamah coastal plains of Jazan region, Saudi Arabia. Vegetatio 112:141–151
El-Ghareeb R (1990) A phytosociological study of Zygophyllum album L. in the western Mediterranean coast of Egypt. J Univ Kuwait (Sci) 17:143–155
El-Ghareeb R, Hassan IA (1989) A phytosociological study on the inland desert plateau of the Western Mediterranean Desert of Egypt at El-Hammam. J Arid Environ 17:13–21
El-Ghareeb R, Rezk RM (1989) A preliminary study on the vegetation of the coastal land at Bousseli (Egypt). J Univ Kuwait (Sci) 16:115–127
El-Ghareeb R, Shabana MA (1990) Vegetation-environmental relationships in the bed of Wadi El-Sheikh of southern Sinai. Vegetatio 90:145–157
El-Kady HF, Sadek L (1992) On the phytosociology of wadi Um Ashtan in the western desert of Egypt. Feddes Repertorium 103(3–4):269–277
El-Kady H, Heneidy S, El-Demerdash M (1998) Vegetation analysis of the northern Aqaba Gulf coastal land of Egypt. J Union Arab Biol 6(B):319–328
Ezcurra E (2006) Global deserts outlook. United Nations Environment Program, Nairobi
Fossati J, Pautou G, Peltier JP (1998) Wadi vegetation of the North-Eastern desert of Egypt. Feddes Repertorium 109:313–327
Frankenburg P, Klaus D (1980) Atlas der Pflanzenwelt des Nordafrikanischen Trockenraums. Arbeiteilung Geographie Institut, vol A133. Universität Bonn, Germany, pp 1–237
Franklin J, Merlin M (1992) Species-environment patterns of forest vegetation on the uplifted reef limestone of Atiu, Managia, Ma'uke and Miti'aro, Cook Islands. J Veg Sci 3:3–14
Frenkel RE (1970) Ruderal vegetation along some California roadsides. University of California Press, Berkeley
Good R (1947) Geography of the flowering plnats, 1st edn. Longmans, London
Hammouda, SA (1982): A study of the vegetation environmental relationships of the Western Mediterranean Desert of Egypt. M.Sc. Thesis. Alex. University, Egypt

Hassan AA (2003) Habitat and plant species diversity along the Red Sea coast in Egypt. M.Sc. Thesis, Fac. Sci., Cairo Univ., Egypt

Hassan LM (1987) Studies on the flora of the Eastern desert, Egypt. Ph. D. Thesis, Cairo University

Hassib M (1951) Distribution of plant communities in Egypt. Bull Sci Fouad I Univ 29:59–261

Hegazy AK, Amer WM (2001) Altitudinal and latitudinal diversity of the flora on the Eastern and Western sides of the Red Sea. 3rd IUPAC – International Conference on Biodiversity. 3–8 November 2001. Antalya, Turkey

Hill MO (1973) Diversity and evenness: a unifying notation and its consequences. Ecology 54:427–432

Hill MO (1979) TWINSPAN – a FORTRAN program for arranging multivariate data in an ordered two-way table of classification of individuals and attributes. Cornell University, Ithaca. 90 pp

Jongman RH, ter Braak CJF, van Tongeren OFG (1987) Data analysis in community and landscape ecology. Pudoc (Wageningen), The Netherlands. 299 pp

Kamal S (1988) A study of vegetation and land use in the western Mediterranean desert of Egypt. Ph.D. Thesis, Faculty of Science, Alexandria University

Kamal SA, El-Kady HF (1993) Vegetation analysis of some wadis in the Egyptian Mediterranean desert. Feddes Repertorium 104(7–8):537–545

Kassas M (1952) Habitat and plant communities in the Egyptian desert. I. Introduction. J Ecol 40:342–351

Kassas M (1957) On the ecology of the Red Sea coastal land. J Ecol 45:187–203

Kassas M (1966) Plant life in deserts. In: Hills ES (ed) Arid lands. UNESCO, London, pp 145–180. 461 pp

Kassas M (1971) Die Pflanzenwelt. 2.Teil, Pflanzenleben in der östlichen Sahara. In: Schiffers H (ed) Die Sahara und ihre Randgebiete. I. Physiogeographie, Afrika-Studien, vol 60. Weltforum-Verlag, München, pp 477–497. 674 pp

Kassas M, Batanouny KH (1984) Plant ecology. In: Cloudsley-Thompson JJ (ed) Sahara desert. Pergamon Press, Oxford, pp 77–90. 348 pp

Kassas M, El-Abyad MS (1962) On the phytosociology of the desert vegetation of Egypt. Ann Arid Zone 1:54–83

Kassas M, Girgis WA (1965) Habitat and plant communities in the Egyptian desert. IV. The units of a desert ecosystem. J Ecol 53:715–728

Kassas M, Imam M (1954) Habitats and plant communities in the Egyptian deserts. III. The wadi bed ecosystem. J Ecol 42:424–441

Kassas M, Zahran MA (1965) Studies on the ecology of the red sea coastal land. II. The district from El-Galala El-Qibliya to Hurghada. Bulletin de la Société de Géographie D'Egypte 38:155–173

Khedr AA (1993) Ecological studies on some halophytes, xerophytes and psammophytes with particular reference to their environmental adaptations. Ph. D. Thesis, Mansoura University

Killian C, Lemée G (1948) Étude sociologique, morphologique et écologique de quelques halophytes sahariens. Rev Génétique Bot 55:376–402

Kopecký K (1978) Die Strassenbegleitenden Rasengesellschaften im Gebrige Orlické und seinem Vorlande. Vegetace ČSSR, A-10. Academia Praha, Praha

Kutiel P, Danin A, Orshan G (1979) Vegetation of the sandy soils near Caesarea, Israel. I. Plant communities, environment and succession. Isr J Bot 28:20–35

Louw GN, Seely MK (1982) Ecology of desert organisms. Longmans, London

Maire R, Weiller M (1947) Remarque sur la flore et la végétation de la Tripolitaine et de la Cyrenaique septentrionales. Recueil Trav Inst Bot Montpellier France 3:1–17

Mares MA (1999) Encyclopedia of deserts. University of Oklahoma Press, Norman

Maryam H, Ismail S, Alaa F, Ahmed R (1995) Studies on growth and salt regulation in some halophytes as influenced by edaphic and climatic conditions. Pak J Bot 27:151–163

McDonald DJ, Cowling RM, Boucher C (1996) Vegetation-environment relationships on a species-rich coastal mountain range in the fynobs biome (South Africa). Vegetatio 123:165–182

Mellinger MV, McNaughton SJ (1975) Structure and function successional vascular plant communities in Central New York. Ecol Monogr 45:161–182

Middleton NJ, Thomas DSG (1997) World atlas of desertifi cation, 2nd edn. Edward Arnold, London

Migahid AM, Batanouny KH, Zaki MAF (1971) Phytosociological and ecological study of a sector in the Mediterranean coastal region in Egypt. Vegetatio 23:113–134

Monod T (1954) Mode contracte' et diffus de la vegetation Saharienne. In: Cloudsley-Thompson JL (ed) Biology of desert. Institute of Biology, London, pp 35–44. 224 pp

Moustafa AA, Klopatek JM (1995) Vegetation and landforms of the Saint Catherine area, southern Sinai, Egypt. J Arid Environ 30:385–395

Moustafa AA, Zaghloul MS (1996) Environment and vegetation in the montane Saint Catherine, south Sinai, Egypt. J Arid Environ 34:331–349

Navikoff G (1961) Contribution a l'étude des relations entre le sol et la végétation halophile de la Tunisie. Ann Inst Nat Rech Agronomique Tunis 34:90–114

Olsvig-Whittaker L, Shachak M, Yair A (1983) Vegetation patterns related to environmental factors in a Negev Desert watershed. Vegetatio 54:153–165

Pignatti E, Pignatti S (1989) Life forms and phytogeographical affinities of the Canarian flora. Flora 183:87–95

Quézel P (1978) Analysis of the flora of Mediterranean and Saharan Africa. Ann Mo Bot Gard 65:479–534

Ragonese A, Covas G (1947) The halophilous flora of southern Santa Fe province (Argentina). Darwin 7:40–496

Raunkiaer C (1937) The plant life forms and statistical plant geography. Clarendon Press, Oxford

Raven P (1971) Relationship between Mediterranean floras. In: Davis PH et al (eds) Plant life in south-west Asis. Botanical Society of Edinburgh, Edinburgh, pp 119–134

Salama, FM, El-Naggar, SM (1991) Phytosociology of wadi system west of Qusseir province. Feddes Repert. 102, 453-468.

Salama FM, Fayed AA (1990) Phytosociological study on the deltaic part and the principal channel of wadi Qena, Egypt. Feddes Repertorium 101(1–2):89–96

Schweinfurth G (1901) The flora of the desert surrounding Helwan, In Helwan and the Egyptian Desert (Ed. W.P. May). London

Selim AA (1969) Geology of El-Salum Area, western Mediterranean coastal zone, U.A.R. Ph.D. Thesis, Alexandria University

Shaltout KH, El-Ghareeb R (1992) Diversity of the salt marsh plant communities in the western Mediterranean region of Egypt. J Univ Kuwait (Sci) 19:75–84

Shaltout KH, El-Halawany EF, El-Garawany MM (1997) Coastal lowland vegetation of eastern Saudi Arabia. Biodivers Conserv 6:1027–1070

Simmoneau P (1954) La végétation de sols salés d'Oranie. Les groupements á Atriplex dans les plaines sublittorales Ann Agron 2:226–257

Smith SD, Anderson JE, Monson RK (1997) Physiological ecology of North American desert plants. Springer, Berlin

Stafford Smith DM, Morton SR (1990) A framework for the ecology of arid Australia. J Arid Environ 18:255–278

Stahr K, Bornkamm R, Gauer A, Kehl H (1985) Veränderung von Boden und Vegetation am Übergang von Halbwüste zur Vollwüste zwischen Mittelmeer und Quattare Depression in Ägypten. Geoökodynamik 6:99–120

Tadros TM, Atta BM (1958) Further contribution to the sociology and ecology of halophilous communities of Mareotis (Egypt). Vegetatio 8:137–160

Tielbörger K (1997) The vegetation of linear desert dunes in the north-western Negev, Israel. Flora 192:261–278

Ullmann I, Bannister P, Wilson JB (1995) The vegetation of roadside verges with respect to environmental gradients in southern New Zealand. J Veg Sci 6:131–142

UNESCO-FAO (1963) Carte bioclimatique de la zone mediterranéenne. Arid Zone Res 21

Ungar IA (1968) Species-soilrelationships on the Great Slat Plains of northern Oklahoma. Am Midl Nat 80:392–406

Ungar I (1974) Halophyte communities of Park county, Colorado. Bull Torrey Bot Club 101:145–152

Walter H (1963) Water supply of desert plants. In: Rutter AJ, Whitehead EH (eds) The water relations of plants. Blackwell, London, pp 199–205. 394 pp

Weinstein A, Schiller G (1979) Afforestation and tree planting in Sinai. II. Northeastern Sinai. La-Yaaran 29:13–16. (Hebrew), 32 (English)

White F (1993a) Long distance dispersal and the origins of the afromontane flora Sonderb. Naturwissschaft Vereins Hamburg 7:87–116

White F (1993b) The AETFAT chorological classification of Africa: history, methods and applications. Bull Jardin Bot Nat Belg 62:225–281

White F, Léonard J (1991) Phytogeographical links between Africa and southwest Asia. Flora et Vegetatio Mundi 9:229–246

Wickens GE (1977) Some of the phytogeographical problems associated with Egypt. Publications Cairo University Herbarium 7&8:223–230

Yair A, Danin A (1980) Spatial variation as related to the soil moisture regime over an arid limestone hillside, northern Negev, Israel. Oecologia 47:83–88

Zahran MA (1982) Ecology of the halophytic vegetation. In: DN Sen, KS Rajpurhit (eds) Contribution to the ecology of halophytes. Tasks Veg Sci 2:3–20

Zahran MA, Willis AJ (1992) The vegetation of Egypt. Chapman & Hall, London. 424pp

Zahran MA, Willis AJ (2009) The vegetation of Egypt. Vol. 2. Plant and vegetation. Springer Science and Business Media B.V, London. 437pp

Zahran MA, Murphy KJ, Mashaly IA, Khedr AA (1996) On the ecology of some halophytes and psammophytes in the Mediterranean coast of Egypt. Verh Ges Ökol 25:133–146

Zohary M (1962) Plant life in Palestine. Ronald Press, New York. 262 pp

Zohary M (1973) Geobotanical foundations of the Middle East. Volumes 1 & 2. Gustav Fischer Verlag, Stuttgart