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Author Biographies

Monier Abd El-Ghani was born on September 9th, 1955 in Cairo, Egypt. In 1976, he graduated in botany from the Faculty of Science, Cairo University (Egypt); from this institution he also received his MSc and PhD (taxonomy and flora) in 1981 and 1985, respectively. His MSc and PhD studies explored the vegetation structure and the biodiversity of alien plant species in the agroecosystems of the oases of the Western Desert of Egypt and the Faiyum region of the Nile land. His research interest in biodiversity in the arid regions of Egypt and Saudi Arabia resulted in the publication of 6 books and 72 articles in peer-reviewed (55) and national and local (13) journals. For two successive years (1997 and 1998), he obtained a research fellowship granted by the Alexander von Humboldt Foundation in Germany. In 2000, he was awarded the Encouragement State Prize in biological sciences from the Egyptian Academy of Scientific Research and Technology and, in 2003, the Cairo University Encouragement Prize in biological sciences (applied and theoretical). In April 2015, he was awarded his DSc from the Faculty of Science, Cairo University, in the field of plant taxonomy and flora, making him the first to get that degree in this field. In June 2015, he was awarded the State Prize for Excellence in Basic Sciences and, in 2015, the prestigious Georg Forster Research Prize from the Alexander von Humboldt Foundation in Germany.

Francisco Martín Huerta-Martínez is a biologist from the University of Guadalajara in Mexico. He obtained his MSc (botany) at Colegio de Postgraduados in Mexico State in 1995 and his PhD (botany) at the same institution in 2003. He is a professor at the University of Guadalajara in the Biological and Environmental Division with 27 years of experience in the Applied Ecology Department, where he teaches and does research about ecology.

His research interests are plant ecology, plant biodiversity and conservation, biotic interactions, ethnobotany, and forest ecology. He has published several national and international research papers and supervised four PhD theses, two MSc theses, and five undergraduate (biology) theses. From 2004 to 2010 he was a member of the National System of Researchers in Mexico. Currently, he is a member of the Ecological Society of America (ESA) and has participated in several of its annual meetings.

Hongyan Liu is a professor of vegetation ecology and Quaternary ecology at Peking University, China. He received his BS in physical geography and MS in environmental geoscience from Peking University and his PhD degree in botany from Hannover University, Germany. He has investigated the Inner Asian vegetation for over 20 years. His current research focuses on climate- and human-driven vegetation dynamics in the arid regions of Asia at different time scales and combines modern vegetation survey, tree-ring analysis, pollen analysis, and modelling. So far he has published about 80 papers in international journals. He is also the associate dean of research at the College of Urban and Environmental Sciences of Peking University.

Rahmatullah Qureshi obtained his MSc (Botany) in 1996 from the Shah Abdul Latif University, Khairpur (Mir's), Sindh, Pakistan. He joined as Research Associate in Shah Abdul Latif University, Khairpur (Mir's), Sindh, Pakistan, on September 25th, 1998 and got his PhD degree from the same university in 2005 in Taxonomy & Ethnobotany. He qualified Federal Public Service Commission for the post of Seed Certification Officer and joined the department on January 4th, 2002. He started his teaching career by joining the Department of Botany, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan, as Assistant Professor in 2007. Based on his research and teaching achievements, he has been promoted first to Associate Professor (BPS-19) in 2010 and then to TTS in the Department of Botany. His research interests include ethnobotany, plant biodiversity and conservation, phytosociology, biological activities of medicinal plants, and weed ecology. He has published over 155 research papers in prestigious peer-reviewed journals, two international books, and two invited international book chapters. So far, Dr. Qureshi has supervised 43 M.Phil. and 8 PhD theses (4 HEC awardees) and completed 12 research projects; 9 research theses (3 PhDs and 6 MPhil theses) are currently under his supervision. He won five research productivity awards from the Pakistan Council for Science and Technology (PCST) based on his publications, impact factor, number citations, etc. He has presented 45 abstracts at various national and international symposia, conferences, and workshops. Since 2011, he is a elected member of the executive council of the Pakistan Botanical Society as vice president (Punjab).

Chapter 1
Arid Deserts of the World: Origin, Distribution, and Features

Abstract It is not easy to define the word 'desert'. Botanicall, deserts could be defined as areas with little rainfall, and sparse vegetation made up of special plants having particular characteristics that enable them to avoid, resist, or tolerate harsh environments. Four major categories of derts are known: (1) subtropical deserts, (2) cool coastal deserts, (3) cold winter deserts, and (4) polar desert. Most arid deserts are found near the equator because of the plentiful daylight the location offers.The types of vegetation coincide with the pattern of the water resources othe habitat. As their diversity in landforms, soils, fauna, flora, water balances, and human activities, no particular definition of arid environments can be derived. However, the one binding element to all arid regions is aridity.

1.1 Historical

As quoted from El-Baz (1988): "The word *desert* originated as an ancient Egyptian hieroglyph pronounced *tesert* (Budge 1966), which means a place that was forsaken, or left behind. From this came the Latin verb *deserere*, to abandon. From the latter came *desertum*, a waste place, or wilderness, as *desertus* meaning abandoned or relinquished. This in itself implies that the desert had been a better place. In it, there was life – in some placed teeming life. There was much vegetation, grasses and trees, many animals and human beings. Then something happened, and the place became a wasteland; it was *deserted*".

1.2 Definitions and Features

It is not easy to define what is meant by the word "desert" for its difficulty and conflict. There are almost as many definitions of deserts and classification systems as there are deserts in the world. Most classifications rely on some combination of the number of days of rainfall, the total amount of annual rainfall, temperature, humidity, or other factors. The world's deserts occupy almost one-quarter of the Earth's land surface, which is approximately 75 million km^2. Meigs (1953) divided desert regions on Earth into three categories according to the amount of precipitation they received. In this now widely accepted system, extremely arid lands have at least 12 consecutive months without rainfall, arid lands have less than 250 mm of annual

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rainfall, and semiarid lands have a mean annual precipitation of between 250 and 500 mm. Arid and extremely arid lands are deserts, and semiarid grasslands generally are referred to as steppes.

Deserts are found across our planet along two fringes parallel to the equator at 25–35° latitude in both the Northern and Southern Hemispheres. Botanically, deserts could be defined as areas with sparse vegetation made up of special plants having particular characteristics that enable them to avoid, resist, or tolerate harsh environments. A paucity of trees is another common feature of deserts. Physically, they are large areas with a lot of bare soil and low vegetation cover. Deserts receive little rainfall; however, when rain does fall, the desert experiences a short period of great abundance. Plants and animals have developed very specific adaptations to make use of these infrequent short periods of great abundance. The general landmarks of the arid desert contain sand dunes, oases, and borders (outskirts). Sand dunes are areas of land where the only foot hold is from sand. The sediments are very small and were shaped by wind. Sandstorms occur frequently near sand dunes. An oasis is an area of plentiful vegetation and water surrounded by barren land. Oases usually form near sources of water visible at the surface. The border (outskirts) of arid desert is the perimeter, marking where the desert ends. The desert does not end abruptly; rather, the conditions become somewhat similar to those of semiarid desert and start to become much more hospitable with more vegetation and favourable temperatures. The soils are course, rocky, and shallow and have good drainage. There is less chemical erosion, causing coarse-textured soil. Wind blows most of the sand/soil, thus leaving heavier pieces behind. This causes areas where wind is common to contain only large pieces of sediments.

Usually, the surface streams formed by the little precipitation flow immediately after rainfall—unless the stream has a source of water outside of the desert. Streams that enter a desert usually suffer major water losses before they exit. Some of the water is lost to evaporation. Some is lost to transpiration (taken up by plants and then released to the atmosphere from the plants), and some is lost to infiltration (water entry into the soil of the stream channel).

1.3 Distribution of Deserts

The world's deserts are divided into four categories. Subtropical deserts are the hottest, with parched terrain and rapid evaporation (Batanouny 2001). Although cool coastal deserts are located within the same latitudes as subtropical deserts, the average temperature is much cooler because of frigid offshore ocean currents. Cold winter deserts are marked by stark temperature differences from season to season, ranging from 38 °C (100 °F) in the summer to −12 °C (10 °F) in the winter. Polar regions are also considered to be deserts because nearly all moisture in these areas is locked up in the form of ice.

Most arid deserts are found near the equator because of the plentiful daylight the location offers. The Sahara Desert is an example of an arid desert in Africa. Another example is the Rub' al Khali desert in Saudi Arabia famously known for its sand dunes, a prominent landmark of the arid desert (Table 1.1).

Table 1.1 Types of deserts, together with their location, area and topography, and characteristics (http://www.infoplease.com)

Desert	Location	Area (km^2)	Topography and characteristics
Subtropical deserts			
Sahara	Morocco, Western Sahara, Algeria, Tunisia, Libya, Egypt, Mauritania, Mali, Niger, Chad, Ethiopia, Eritrea, Somalia	9,064,958	70% gravel plains, sand, and dunes. Contrary to popular belief, the desert is only 30% sand. This world's largest nonpolar desert gets its name from the Arabic word *Sahra*, meaning desert
Arabian	Saudi Arabia, Kuwait, Qatar, United Arab Emirates, Oman, Yemen	2,589,988	Gravel plains, rocky highlands; one-fourth is the Rub' al Khali ("Empty Quarter"), the world's largest expanse of unbroken sand
Kalahari	Botswana, South Africa, Namibia	569,797	Sand sheets, longitudinal dunes
Australian desert			
Gibson	Australia (southern portion of the Western Desert)	310,798	Sandhills, gravels, grasses. These three regions of desert are collectively referred to as the Great Western Desert—otherwise known as the "Outback". It contains Ayers Rock, or Uluru, one of the world's largest monoliths
Great Sandy	Australia (northern portion of the Western Desert)	388,498	
Great Victoria	Australia (southernmost portion of the Western Desert)	647,497	
Simpson and Sturt Stony	Australia (eastern half of the continent)	145,039	Simpson's straight, parallel sand dunes are the longest in the world—up to 125 mi. It encompasses the Stewart Stony Desert, named for the Australian explorer
Mojave	United States: Arizona, Colorado, Nevada, Utah, California	139,859	Mountain chains, dry alkaline lake beds, calcium carbonate dunes
Sonoran	United States: Arizona, California; Mexico	310,798	Basins and plains bordered by mountain ridges; home to the saguaro cactus
Chihuahuan	Mexico; Southwestern United States	453,247	Shrub desert; largest in North America
Thar	India, Pakistan	453,247	Rocky sand and sand dunes
Cool coastal deserts			
Namib	Angola, Namibia, South Africa	33,669	Gravel plains
Atacama	Chile	139,859	Salt basins, sand, lava; world's driest desert

(continued)

Table 1.1 (continued)

Desert	Location	Area (km^2)	Topography and characteristics
Cold winter deserts			
Great Basin	United States: Nevada, Oregon, Utah	492,097	Mountain ridges, valleys, 1% sand dunes
Colorado Plateau	United States: Arizona, Colorado, New Mexico, Utah, Wyoming	336,698	Sedimentary rock, mesas, and plateaus—includes the Grand Canyon and is also called the "Painted Desert" because of the spectacular colours in its rocks and canyons
Patagonian	Argentina	673,396	Gravel plains, plateaus, basalt sheets
Kara-Kum	Uzbekistan, Turkmenistan	349,648	90% grey-layered sand—name means "black sand"
Kyzyl-Kum	Uzbekistan, Turkmenistan, Kazakhstan	297,848	Sands, rock—name means "red sand"
Iranian	Iran	258,998	Salt, gravel, rock
Taklamakan	China	271,948	Sand, dunes, gravel
Gobi	China, Mongolia	1,294,994	Stony, sandy soil, steppes (dry grasslands)
Polar			
Arctic	United States, Canada, Greenland, Iceland, Norway, Sweden, Finland, Russia	11,654,946	Snow, glaciers, tundra
Antarctic	Antarctica	14,244,934	Ice, snow, bedrock

1.4 Meaning and Causes of Aridity

Arid environments are extremely diverse in terms of their landforms, soils, fauna, flora, water balances, and human activities. Because of this diversity, no practical definition of arid environments can be derived. However, the one binding element to all arid regions is aridity. Aridity is usually expressed as a function of rainfall and temperature. A useful "representation" of aridity is the following climatic aridity index: p/ETP (where p = precipitation, ETP = potential evapotranspiration), calculated by method of Penman, taking into account atmospheric humidity, solar radiation, and wind (Kassas and Batanouny 1984).

Three arid zones can be delineated by this index: namely, hyperarid, arid, and semiarid. Of the total land area of the world, the hyperarid zone covers 4.2%, the arid zone 14.6%, and the semiarid zone 12.2%. Therefore, almost one-third of the total area of the world is arid land. Also, arid conditions are found in the subhumid zone (aridity index, 0.50–0.75). The term "arid zone" is used here to collectively represent the hyperarid, arid, semiarid, and subhumid zones.

The hyperarid zone (aridity index, 0.03) comprises dryland areas without vegetation, with the exception of a few scattered shrubs. True nomadic pastoralism is frequently practiced. Annual rainfall is low, rarely exceeding 100 mm. The rains are infrequent, irregular, and unpredictable in both space and time, sometimes rainless for several years.

The arid zone (aridity index, 0.03–0.20) is characterized by pastoralism and no farming except with irrigation. For the most part, the native vegetation is sparse, being comprised of annual and perennial grasses and other herbaceous vegetation and shrubs and small trees. There is high rainfall variability, with annual amounts ranging between 100 and 300 mm.

The semiarid zone (aridity index, 0.20–0.50) can support rain-fed agriculture with more or less sustained levels of production. Sedentary livestock production also occurs. Native vegetation is represented by a variety of species, such as grasses and grass-like plants, fortes and half-shrubs, and trees. Annual precipitation varies from 300–600 to 700–800 mm, with summer rains, and from 200–250 to 450–500 mm with winter rains.

Aridity results from the presence of dry, descending air. Therefore, aridity is found mostly in places where anticyclonic conditions are persistent (Evenari et al. 1971), as is the case in the regions lying under the anticyclones of the subtropics. The influence of subtropical anticyclones on rainfall increases with the presence of cool surfaces. Arid conditions also occur in the ward side of major mountain ranges that disrupt the structure of cyclones passing over them, creating "rain shadow" effects. Rainfall is also hindered by the presence of greatly heated land surfaces; as a consequence, large areas of dry climate exist far from the sea.

1.5 Arid Zone Climate and Vegetation

The arid zone is characterized by excessive heat and inadequate, variable precipitation; however, contrasts in climate occur. In general, these climatic variances result from differences in temperature, in the rainy season, and in the degree of aridity. Three major types of climate are distinguished when describing the arid zone: the Mediterranean climate, the tropical climate, and the continental climate (Shmida 1985). In the Mediterranean climate, the rainy season ~~is~~ during autumn and winter. Summers are hot with no rains, while winter temperatures are mild. In the tropical climate, rainfall occurs during the summer. The greater the distance from the equator, the shorter the rainy season (Fig. 1.1).

Winters are long and dry. In the continental climate, the rainfall is distributed evenly throughout the year, although there is a tendency towards greater summer precipitation.

The vegetation cover in arid zones is scarce. Nevertheless, three plant forms can be distinguished: (1) ephemeral annuals, (2) succulent perennials, and (3) non-succulent perennials (Zahran and Willis 1992).

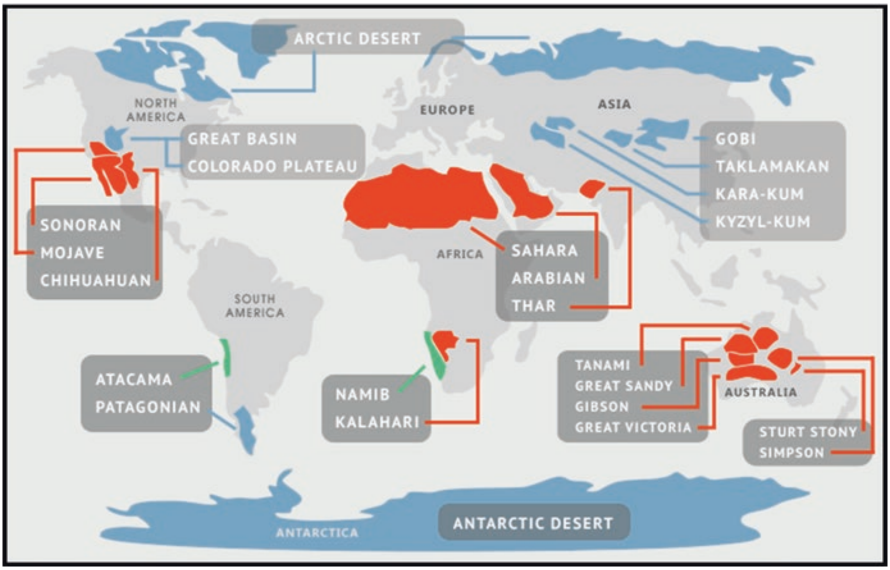

Fig. 1.1 Deserts of the world (http://www.cdn.whatarethe7continents.com)

Ephemeral annuals, which appear after rains, complete their life cycle during a short season (±8 weeks). Their growth is restricted to a short wet period. Ephemerals do not have the xeromorphic features of perennials. In general, ephemerals are small in size, have shallow roots, and their physiological adaptation consistent with their active growth. Ephemerals live through the dry season, which may last a number of years, in the form of seeds. At times, ephemerals can form dense stands and provide some forage.

Succulent perennials are able to accumulate and store water (that may be consumed during periods of drought); this is because of the proliferation and enlargement of the parenchymal tissue of the stems and leaves and their physiological feature of low rates of transpiration. Cacti are typical succulent perennials.

Non-succulent perennials comprise the majority of plants in the arid zone. These are hardy plants, including grasses, woody herbs, shrubs, and trees that withstand the stress of the arid zone environment. Many non-succulent perennials have "hard" seeds that do not readily germinate, under natural desert conditions. The hard seeds have coats, which must be softened by water, scarified mechanically by sand surfaces of the desert, by the activity of microorganisms, etc. before they will germinate.

1.6 Vegetation Types

Walter (1963) wrote: "If the runoff in a region with 25 mm precipitation is 80%, and the area in which the water accumulates constitutes 4% of the total area, that area will receive an amount of water corresponding to a rainfall of approximately

500 mm". This shows how much water the main channels of the wadi can receive. Where there are no wadis, the accumulation of sheet runoff in depressions is of great importance in enriching water revenues.

The types of vegetation coincide with the pattern of the water resources of the habitat. This can be considered to be a communal adaptation to the changing environmental conditions (Batanouny 2001). Three main vegetation types can be distinguished: (1) The *accidental* type (Kassas and Batanouny 1984) is found in those areas where rainfall is not an annually recurring incident, e.g. in the Great Sahara. (2) The *restricted* type (Walter 1963), or mode contractee (Monod 1954), occurs in arid areas where rainfall, though low and variable, is an annually recurring phenomenon. This type is the result of runoff and the accumulation of water at lower elevations. The vegetation is confined to rather restricted areas (wadis, runnels, and depressions with relatively adequate water supply). (3) The *diffuse* type results in vegetation that is more or less evenly distributed (rainfall desert; Zohary 1962). This type occurs in areas with considerable rainfall (>100 mm).

It is not only the water resources of a particular habitat that are controlled by the local topography but also the physical and chemical attributes of the soil (Batanouny 1973), and the soil thickness and its texture are evidently affected by it. A slight depression of a few centimetres in the ground level will lead to the accumulation of a thin veneer of soil carried with the water running into it. Hence, a relatively suitable habitat for plant growth is created despite the harsh conditions of the desert (Batanouny and Hilli 1973).

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Part I
Egypt: The Land of Three Deserts

Chapter 2
The Desert of Egypt

Abstract Egypt is part of Sahara of North Africa in the hyperarid regions, with a hot and almost rainless climate. The Egyptian deserts are among the most arid parts of the world. Therefore, desert vegetation covers vast areas formed mainly of xerophytic shrubs and subshrubs. Egypt includes three deserts: (1) the Eastern, (2) the Western, and (3) Sinai. The Nile land, with its valley and delta, forms the fertile arable lands. Five major habitats can be distinguished: (1) the aquatic habitat, (2) the swampy habitat, (3) the canal bank habitat, (4) the cultivated lands, (5) the northern lakes, (6) the artificial lakes, and (7) the Nile islands. The Mediterranean coastal land of Egypt extends for about 970 km between Sallum on the Egyptian–Libyan border eastwards and Rafah on the Egyptian–Palestinian border. The Red Sea coastal lands include series of high mountains; the highest peak is of Gebel Elba in its southern part.

2.1 Location and Physiographic Features

Egypt is part of Sahara of North Africa and occupies the northeastern corner of Africa and the Sinai Peninsula, covering a total area of over 1 million km^2 (about 1,019,600 km^2) in the hyperarid regions. The Mediterranean Sea bound it to the north, Sudan to the south, Libya to the west, and the Gulf of Aqaba and the Red Sea to the east (Said 1962). It is situated between latitudes 22° and 32° north and lies for the most part in the temperate zone with less than a quarter of its area south of the Tropic of Cancer. Most of landmass is below 500 m above sea level, which limits potential diversity. About 95% of Egypt land is desert; the Western Desert constitutes one of the most extreme arid desert habitats in the world (Fig. 2.1). Generally, the Nile Valley divides Egypt into two geomorphological regions: the eastern dissected plateau and the western flat expanse which form an extension of the Libyan Desert. Although the land to the east of the Nile forms one geomorphological region, it is divided geographically into the Eastern Desert and the Peninsula of Sinai, separated by the Gulf of Suez. Three areas of Egyptian desert may therefore be distinguished: the Eastern Desert, the Western Desert, and the Sinai Peninsula. The whole country forms part of the great desert belt that stretches from the Atlantic across the whole of North Africa through Arabia. It is a cross-road territory with its Mediterranean front connecting it with Europe with which it has had biotic

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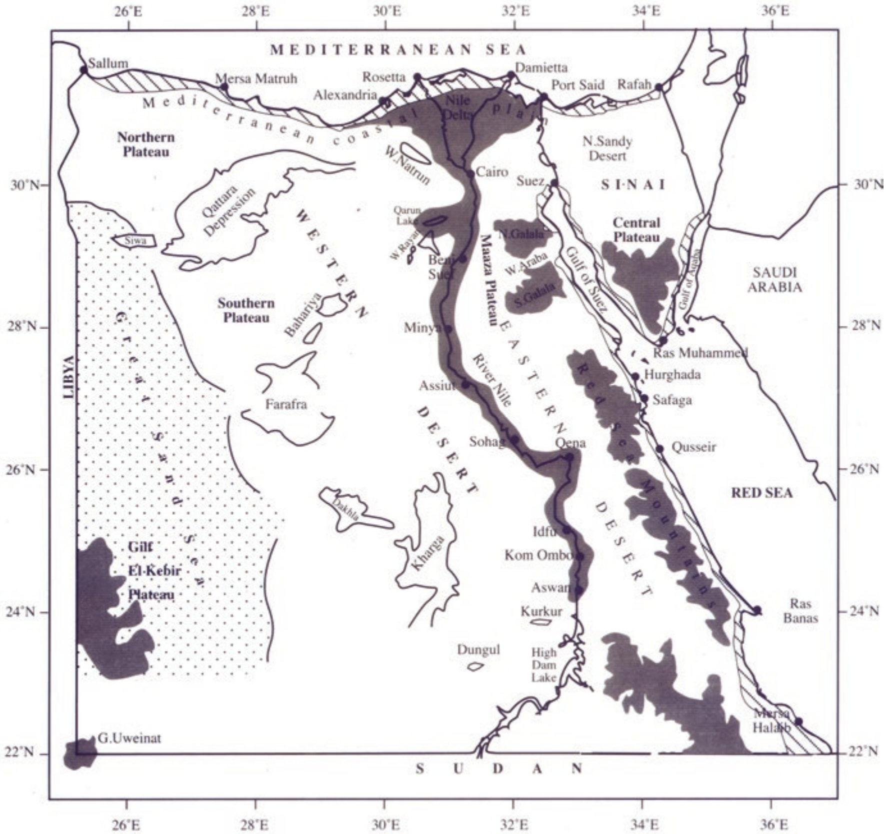

Fig. 2.1 Map of Egypt

exchanges during the glacials and the interglacials, and today we know that routes of migratory birds converge through Egypt. Two highway corridors join Egypt with tropical Africa and beyond: the Nile Valley and the basin of the Red Sea. The Sinai Peninsula is the bridge between Africa and Asia.

Egypt is characterized by a hot and almost rainless climate. The average annual rainfall over the whole country is only about 10 mm. Even along the narrow northern strip of the Mediterranean coastal land where most of the rain occurs, the average annual rainfall is usually less than 200 mm, and the amount decreases very rapidly inland (southwards). The scanty rainfall accounts for the fact that the greater part of the country is barren and desolate desert.

The Egyptian deserts are among the most arid parts of the world. The rainfall does not exceed 10 mm/annum in most parts of the country. The highest rainfall is that along the Mediterranean coast with an average of 150 mm/annum. This amount decreases rapidly as one proceeds southwards till it reaches 30 mm at Cairo. Further to the south, rain decreases reaching 3 mm or even less.

In Egypt, desert vegetation is by far the most important and characteristic type of the natural plant life. It covers vast areas and is formed mainly of xerophytic shrubs and subshrubs. Monod (1954) recognized two types of desert vegetation, namely contracted and diffuse. Both types refer to permanent vegetation which can be accompanied by ephemeral (or annual) plant growth depending on the amount of precipitation in a given year. Kassas (1966, 1971) added a third type as "accidental vegetation" where precipitation is so low and falls so irregularly that no permanent vegetation exists. It occurs mainly as contracted patches in runnels, shallow depressions, hollows, wadis, and on old dunes with coarse sand. Accidental vegetation consists of species which are able to perform an annual life cycle: potential annuals (Haines 1951), or potential perennials (Bornkamm 1987), but can likewise continue growing as long as water persists in the soil. Thomas (1988) identified these plants as those with episodic growth strategies linked to immediate water availability. Recently, Springuel (1997) classified the accidental vegetation in south-eastern Egypt into three groups: (i) runoff-dependent vegetation in the main *wadi* channels, (ii) run-on-dependent vegetation of playa formation, and (iii) rain-dependent vegetation on levelled plains of sand sheets.

2.2 General Features of Phytogeographical Divisions

2.2.1 The Western Desert

The Western Desert covers two-thirds of Egypt (about 681,000 km^2) as it extends from the Mediterranean coast to the Sudanese border for about 1,073 km and from the Libyan border to the Nile Valley for about 600–850 km. Precipitation decreases from 150 mm at the coast to practically zero in the south, and southwest Egypt is known as the driest part of the globe. Well-marked drainage systems (wadis) comparable to those of the Eastern Desert are not found (Zahran and Willis 2009). Another salient feature, resulting from arid conditions, is the uniformity of the surface as compared with other parts of North Africa.

2.2.2 The Eastern Desert

The Eastern Desert of Egypt occupies about 223,000 km^2, i.e. 21% of the total area of Egypt. It is characterized by two main ecological units, the Red Sea costal land and the inland desert with its wadis. According to Zahran and Willis (2009), the latter can be divided into four main geomorphological and ecological regions: (1) Cairo–Suez Desert, (2) Limestone Desert, (3) Sandstone Desert, and (4) Nubian Desert.

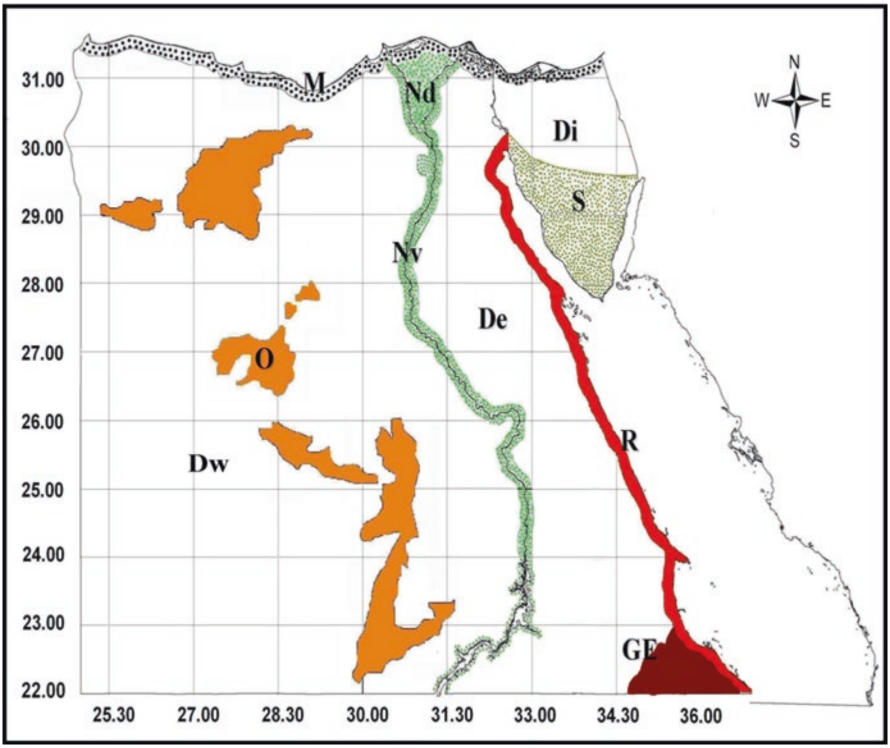

Fig. 2.2 Phytogeographical divisions of Egypt (after Wickens 1977). *M* Mediterranean, *Nd* Nile Delta, *Nv* Nile Valley, *De* Eastern Desert, *Dw* Western Desert, *Di* Isthmic Desert, *S* Sinai Peninsula, *R* Red Sea, *O* Oases, and *GE* Gebel Elba

The inland part of the Eastern Desert of Egypt lies between the Red Sea coastal mountains in the east and the Nile Valley in the west, an area of about 223,000 km^2 (Fig. 2.2). It is a rocky plateau dissected by a number of wadis. Each wadi has a channel with numerous tributaries, and the whole desert is divided piecemeal into the catchment areas of these drainage systems. Most of the wadis drain westwards into the Nile.

The coastal mountain ranges of the Red Sea represent a conspicuous habitat type of special interest for their complex patterns of natural communities interrelating the floras and faunas of Egypt, Sudan, and Ethiopia. One of these ranges is the Gebel Elba Mountains of south-eastern Egypt. This mountain range is considered as a continuation of the granitic formation of the Red Sea highland complex between Egypt and Sudan, situated between 36° and 37° of the eastern longitudes and about 22° of the northern latitude. The flora and fauna of this area comprise hundreds of species of plants and animals; these include a number of endemics and a number of species that represent the northern outpost of the biota of the Ethiopian highlands. The floristic richness of Gebel Elba area is noticeable, compared to the rest of

Egypt, that this is considered as one of the main phytogeographical territories of the country (El Hadidi 2000) as it borders the Saharo–Arabian and Sudanian floristic regions. The flora and vegetation of Gebel Elba group is much richer than that of the other coastal mountain groups (Drar 1936; Hassib 1951), where the Palaearctic and Afrotropical regions meet. It comprises elements of the Sahelian regional transition zone (sensu White and Léonard 1991) and represents the northern limit of this geo-element in Africa. Within its massive, the vegetation on the north and northeast flanks is much richer than that on the south and southwest (Kassas and Zahran 1971). Its ecological features, together with its particular geographic position, seem to have promoted plant diversity, singularity, and endemism in this area and favoured the persistence of extensive woodland landscape dominated with thickets of *A. tortilis* (Forssk.) Hayne subsp. *tortilis*, which is not known elsewhere in the Eastern Desert of Egypt (Zahran and Willis 2009).

In spite of the biogeographical and botanical interests of Gebel Elba mountain range, it has been overlooked in most global biodiversity assessments (Heywood and Watson 1995). Of the 142 woody perennial threatened plant species that are included in the Plant Red Data Book of Egypt (El Hadidi et al. 1992), 56 or 39.4% were known from Gebel Elba district. Therefore, this area was protected in 1986 as Gebel Elba National Park (Prime Ministerial Decrees 450/1986, 1185/1986, and 642/1995), covering 35,600 km^2, aimed to promote the sustainable management of natural resources and maintain its biodiversity. Biodiversity conservation in Egypt is supported by a number of important protected areas network (21 representing 8% of the country's land surface, and further 19 area are recently proposed for protection), based on natural region classification of the land, and having for mandate to preserve a representative sample of ecosystem characteristic of each region.

2.2.3 The Sinai Peninsula

The Sinai Desert covers approximately 6% of the total land area of Egypt and is a desert of the "Saharan type" (McGinnies et al. 1968) linking Asia with Africa. The Sinai Peninsula constitutes a transition between the Egyptian deserts and those of the Middle East. It is an interesting phytogeographic region as it borders the Mediterranean, Irano–Turanian, Saharo–Arabian, and Sudanian regions (Zohary 1973). Besides, the great diversity of climate (mean annual precipitation decreases from about 100 mm in the north, near the Mediterranean, to 5–30 mm in the south; Danin 1978), rock and soil types make the existence of some 900 species and 200–300 associations possible (Danin 1986). The northern part of the peninsula is covered with sand; in the central part, limestone hills and gravel plains predominate. The landscape of the southern region is characterized by a variety of landforms which display varied environmental and vegetational spectra. The major landforms include plains, wadis, oases and springs, salt marshes, and sand dunes. Southern Sinai, however, has an intricate complex of high, very rugged igneous and metamorphic mountains that represent the highest peaks in Egypt, among others, Gebel

Katherina (2,641 m), Gebel Musa (2,285 m), and Gebel Serbal (2,070 m). The western coastal plain, known as El-Qaa, borders the Gulf of Suez. These mountains are highly rich in their flora and fauna (Moustafa et al. 1998) and support mainly Irano–Turanian steppe vegetation dominated by *Seriphidium herba-album* accompanied by *Gymnocarpos decanter*. The vegetation is characterized by sparseness of plant cover of semishrubs, restricted to wadis or growing on slopes of rocky hills and in sand fields, and paucity of trees (Danin 1986).

South Sinai Mountains represent a great harbour of endemism (Moustafa 1990) where the area has wetter climate than most of Sinai and characterized by having large outcrops of smooth-faced rocks which support rare species (Danin 1972, 1978, 1983). The mountainous region of southern Sinai probably contains a greater biodiversity than in the rest of Egypt. A large section of the area was declared a Protectorate in 1996, centred upon the town of St. Catherine (1,600 m a.s.l.) with its world-famous sixth-century Monastery built on the traditional site of the "burning bush" of the Bible, at the foot of Mt. Catherine. From the mountain of St. Catherine, at 2,641 m, the highest point in Egypt and marking the watershed of the peninsula, wadi systems drain eastwards towards the Gulf of Aqaba and westwards towards the Gulf of Suez.

Although southern Sinai is classified as "very arid" (Zahran and Willis 2009), there is in fact a great deal of water draining down the wadis, sometimes as violent and destructive flash floods, but under normal circumstances, most of the water is underground, occasionally surfacing to produce short sections of freely flowing permanent water. Sparse vegetation occurs everywhere, but the wet areas are particularly rich with plants and consequently with insects and other animals.

2.2.4 The Nile Land

In Egypt, the River Nile is the primary source of fresh water. It also provides Egypt with a very fertile and productive land along both the Nile Valley and Delta regions (Fig. 2.1). Of the total course of the River Nile, only the terminal 1,530 km lie within the borders of the country. It consists of a complex system of various units of water bodies (lakes, marshes, streams, canals, drains, etc.) and landforms (plains and valleys). Within these units, a great variety of climate, vegetation structure, and land use and also a number of biogeographical regions exist. The Nile land, with its valley and delta, had attained most of its present and prominent features during the Neonile phase (30,000 years BP) of the Pleistocene period. The Nile Valley flows in elongated S-shaped pattern for a distance of about 900 km long from Aswan to Cairo. The Nile Delta, with an area of about 22,000 km^2, comprises about 63% of Egypt's fertile land. It has strong geological similarities with the desert to the west and the Nile Valley to the south. The total length of the canals and drains is approximately 47,000 km (Van der Bleik et al. 1982).

The Nile system had been subjected to a series of large-scale schemes of river control, using a series of barrages and dams that had been built across the river and its tributaries. These dams and barrages had segmented the natural hydrobiological system with undoubted impact on the biota (Kassas 1971). The construction of dams and barrages in the River Nile had caused great environmental changes, including the destruction of many natural habitats and the formation of artificial ones like cultivated fields on river island and aquaculture plots. Khattab and El-Gharably (1984) reported that among the serious problems is the vast spread of aquatic weeds in the Egyptian water bodies, particularly the net of the canals and drains in the Nile Valley region. The degree of infestation is affected by environmental factors, including water transparency, depth of water, physico-chemical water quality, water current, and air temperature. According to Zahran and Willis (2009), the Nile system of Egypt includes a number of habitats formed and/or greatly influenced by the water of the River Nile. These are (1) the aquatic habitat, (2) the swampy habitat, (3) the canal bank habitat, (4) the cultivated lands, (5) the northern lakes, (6) the artificial lakes, and (7) the Nile islands.

In a country like Egypt, where a warm climate prevails most of the year, the hydrophytes of the River Nile and its irrigation and drainage systems are greatly developed. The establishment of the Aswan High Dam in the most extreme south of Egypt controls to great extent the flow of water in the Nile and its Damietta and Rosetta branches. This control has led to numerous ecological changes in the Nile system, the effect of damming on downstream reaches being marked. Changes due to damming include silt-free water running downstream which results in the extensive use of fertilizers to compensate for the lack of the silt. Side effects also include changes in the chemical and physical characteristics of irrigation water, the presence of water in the canals all the year around, and the level of water in the Nile system particularly in Lower Egypt being noticeably lower and the current being of decreased velocity. The absence of silt in the Nile below the High Dam has made it no longer necessary to dredge the canals. Dredging removes large quantities of seeds and perennating organs of water plants; such factors are causing a noticeable and considerable increase in the growth rate and densities of the fresh water hydrophytes of the Nile system. Also the introduction of a new-water weed (*Myriophyllum spicatum*) to the Delta has appeared and started to spread during the last 20 years. The distribution of *M. spicatum* is restricted to the Nile system in Upper Egypt, but it is not yet present northwards in the Nile Delta.

Usually a 3-year crop rotation is applied in the croplands of the Nile land (including Nile Delta, Nile Valley). The crop succession during this period is (1) temporary Egyptian clover (or fallow fields)—cotton; (2) wheat–maize (or rice in the northern Delta); and (3) permanent Egyptian clover (or broad beans)—maize. So, an area is usually divided into three parts in order to have all the crops in the same year (El-Khshin et al. 1980). Planting time for the winter crops is September–November, February–March for cotton, and April–May for maize and rice. The crop longevity is 5–6 months for all crops, except cotton (7–8 months). Hand pulling and manual hoeing are the most frequent methods of all the crops, except rice.

2.2.5 The Western Mediterranean Coast

The Mediterranean coastal land of Egypt extends for about 970 km between Sallum on the Egyptian–Libyan border eastwards and Rafah on the Egyptian–Palestinian border (Fig. 2.1), with an average width ranging from 15 to 20 km in N–S direction. It lies within the Mediterranean/Sahara regional transition zone, where the vegetation comprises floristic elements for both of the Mediterranean and Saharo–Arabian regions (White 1993). Floristically, it remains one of the less known territories of the country. El Hadidi (2000) distinguished between a Mareotis sector which extends between Sallum eastwards to Alexandria, where Cyrenaican elements are prominent, and a Sinaitic sector extending from Port Said eastwards to Rafah, where East Mediterranean taxa prevail. Ecologically, it represents the narrow less arid belt of Egypt that can be divided into three sections: western, middle, and eastern (Zahran et al. 1990). The western section extends from Sallum eastwards to Abu Qir, near Alexandria, for about 550 km.

2.3 Concluding Remarks

1. 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 twenty-one species were 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).
2. Physiographically, the western section of the Mediterranean coastal land can be distinguished into two main provinces: an eastern province between Alexandria and Ras El-Hikma and a western province between Ras El-Hikma and Sallum (Selim 1969). One of the salient features of the latter province is the dissection of its landscape into an extensive system of shallow wadis (gullies; sensu El Hadidi 2000). They drain from the southern limestone plateau which lies parallel to the west Mediterranean coast and reaches a maximum elevation of about 200 m above sea level at Sallum. The phytosociology and vegetation analyses of these wadis were the subject of El Hadidi and Ayyad (1975), El Hadidi et al. (1986), El-Kady and Sadek (1992), Kamal and El-Kady (1993), and El Garf (2003).
3. Since the 1950s, much attention has been paid to the western section of the Mediterranean coastal land. 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. The latter represents the distant part of the western Mediterranean coastal land of Egypt, where the human activities through cultivation, grazing, and urbanization were much less pronounced than in the other parts of the region.

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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

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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.

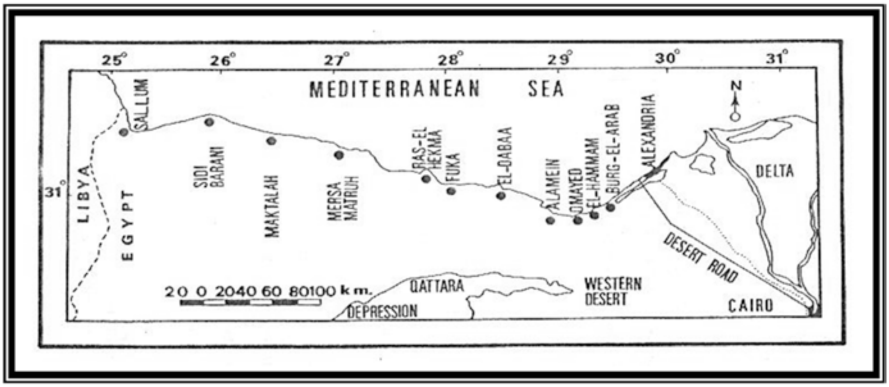


Fig. 3.1 Location map of the western Mediterranean coastal land of Egypt (after Hammouda 1982)

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

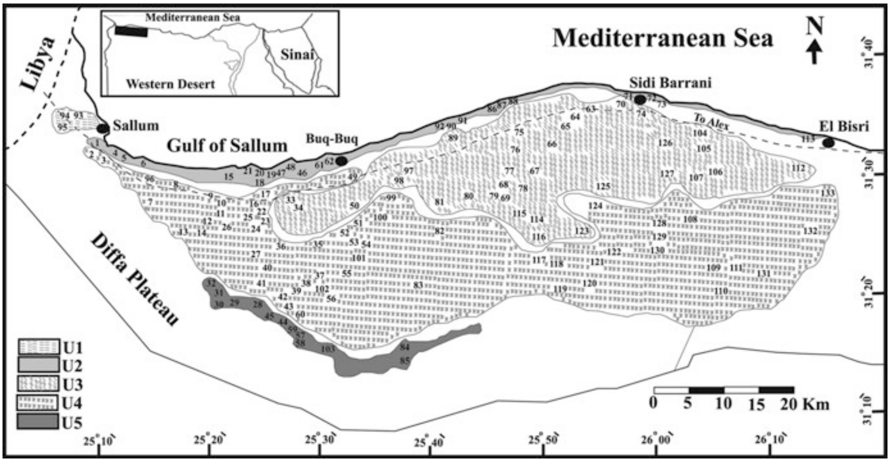


Fig. 3.2 Distribution of the 66 sampled sites in the five landform units of Sallum area. *U1* Sallum plateau, *U2* coastal saline depressions, *U3* inland sandy plains, *U4* inland rocky plains, and *U5* shallow wadis

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

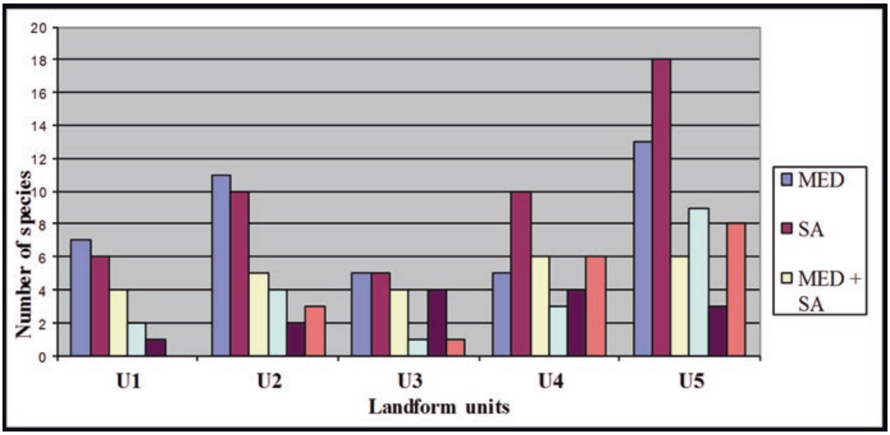


Fig. 3.3 Distribution of the major chorotypes in the five landform units of the Sallum area

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 4	U_2 17	U_3 14	U_4 22	U_5 9	Chorotype	`P (%)
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*.

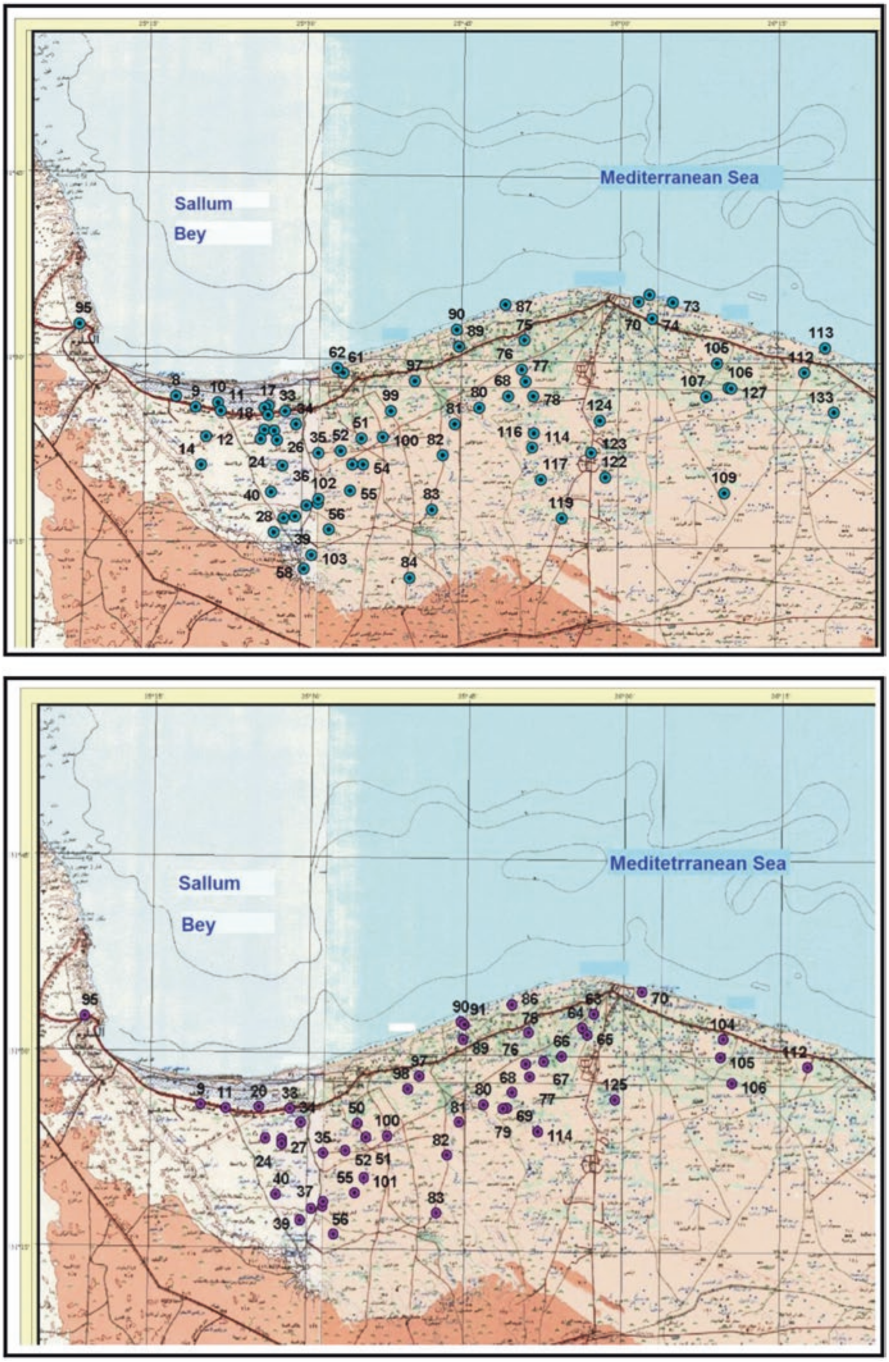
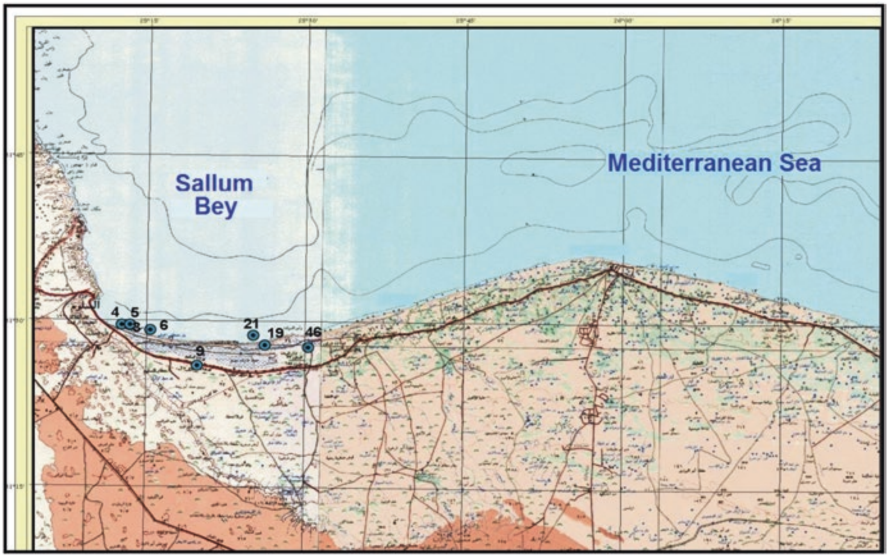


Fig. 3.4 Distribution map of *Thymelaea hirsuta* (*up*) and *Asphodelus ramosus* (*down*)



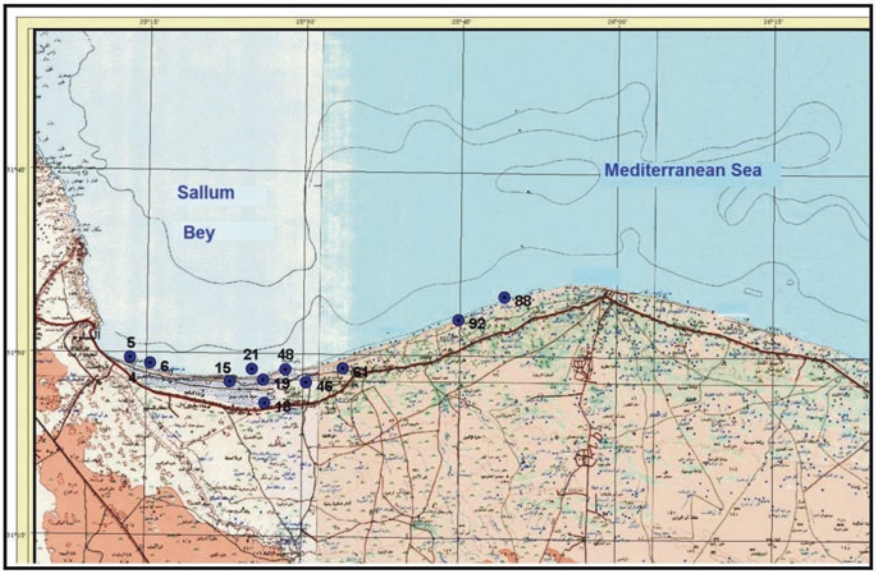


Fig. 3.5 Distribution map of *Halocnemum strobilaceum* (*up*) and *Limoniastrum monopetalum* (*down*)

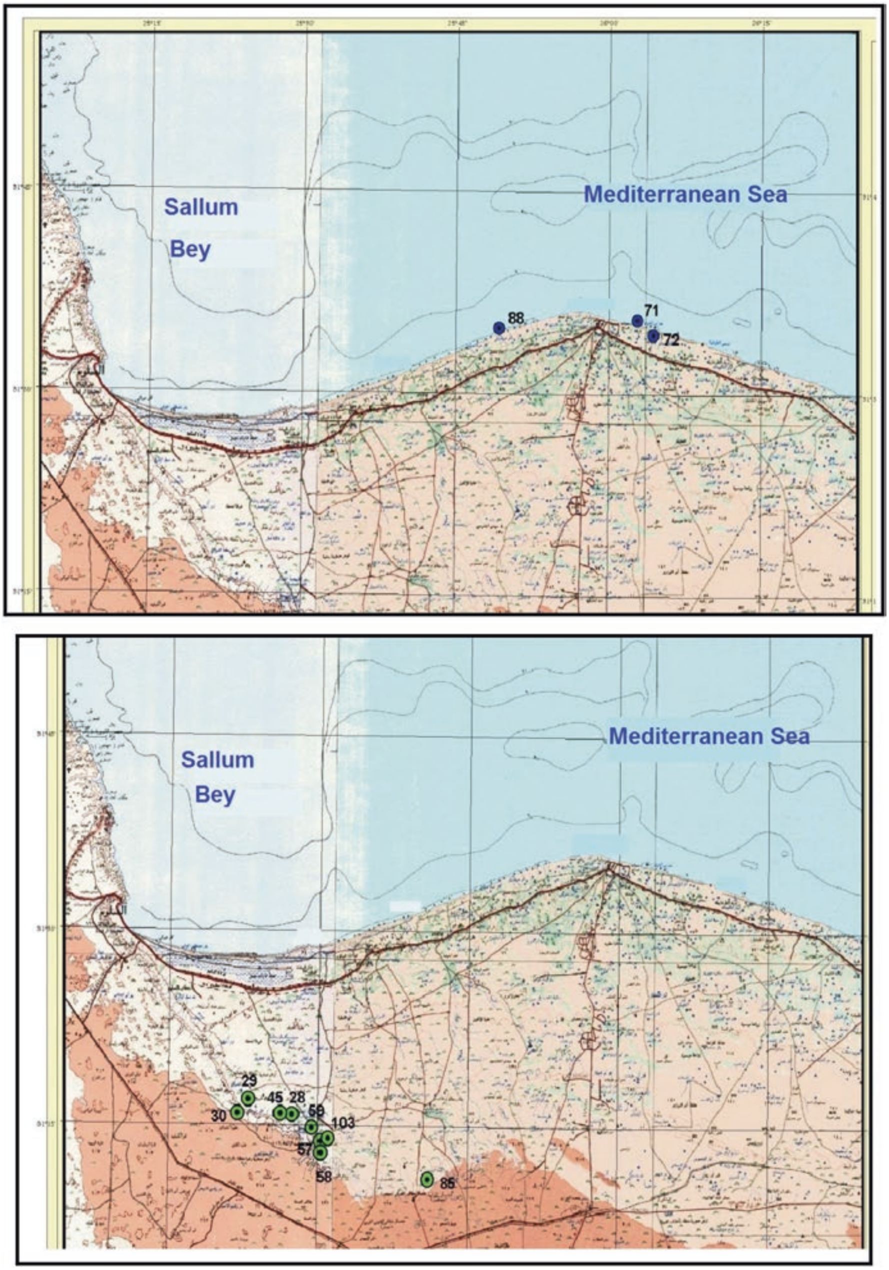


Fig. 3.6 Distribution map of *Pancratium maritimum* (*up*) and *Retama raetam* (*down*)

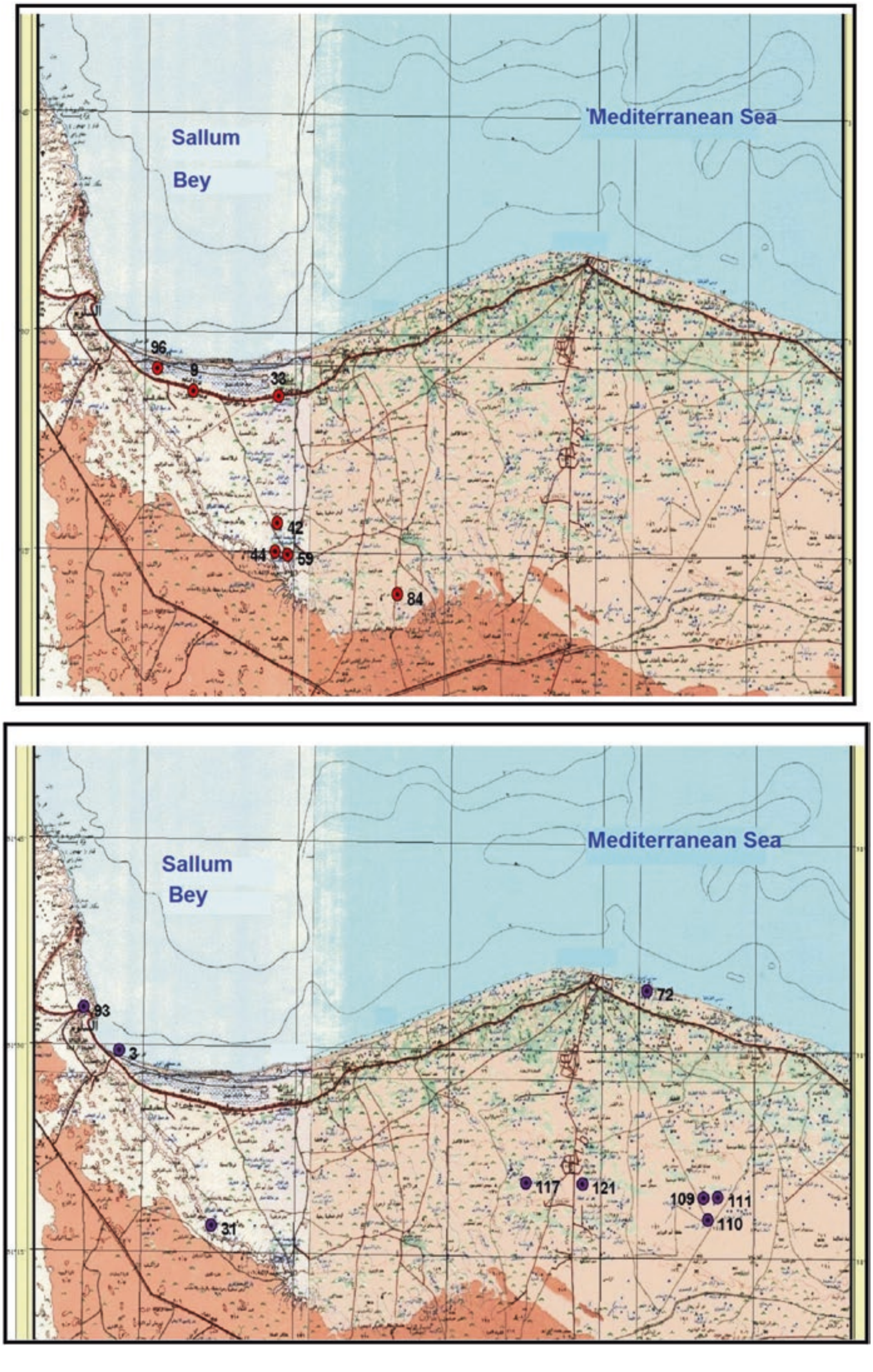


Fig. 3.7 Distribution map of *Periploca angustifolia* (*up*) and *Peganum harmala* (*down*)

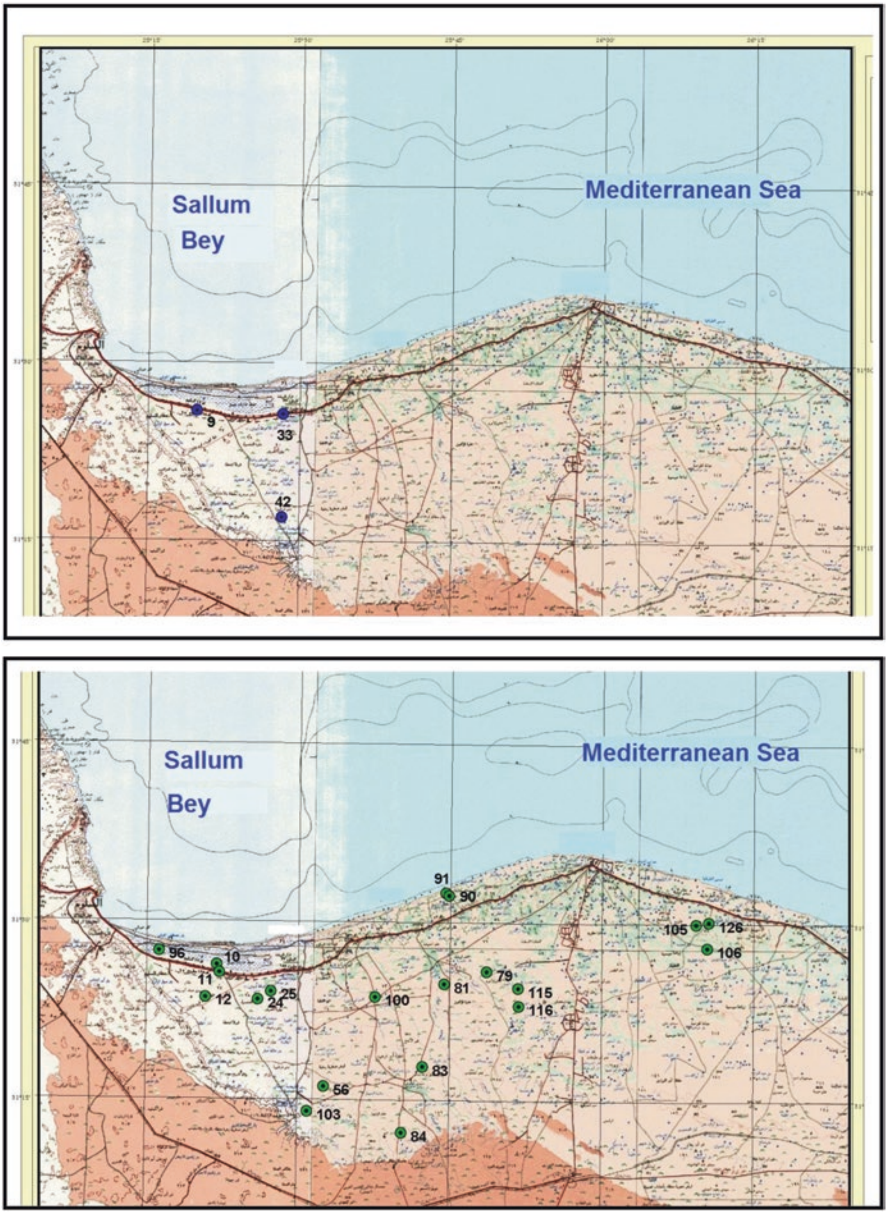


Fig. 3.8 Distribution map of (*up*) and *Globularia arabica* (*up*) and *Gymnocarpos decanter* (*down*)

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.

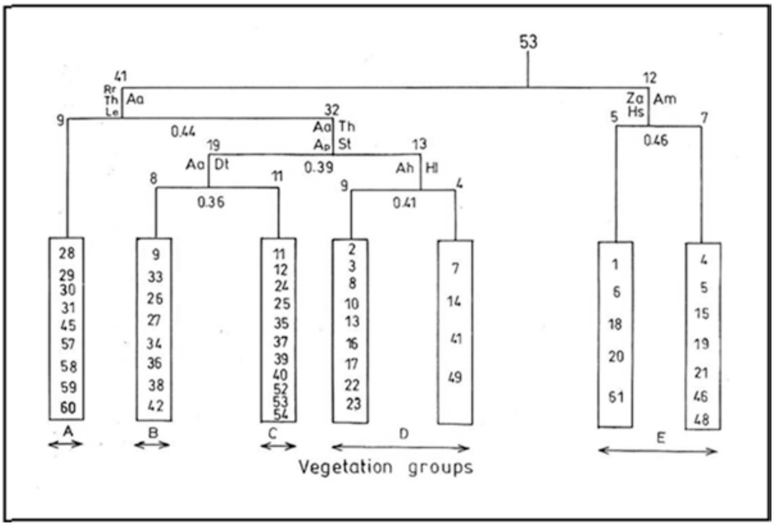


Fig. 3.9 TWINSPAN dendrogram of the 53 studied stands of the Sallum area based on their importance values. A–E are the five vegetation groups

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

Species	TWINSPAN group				
	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.

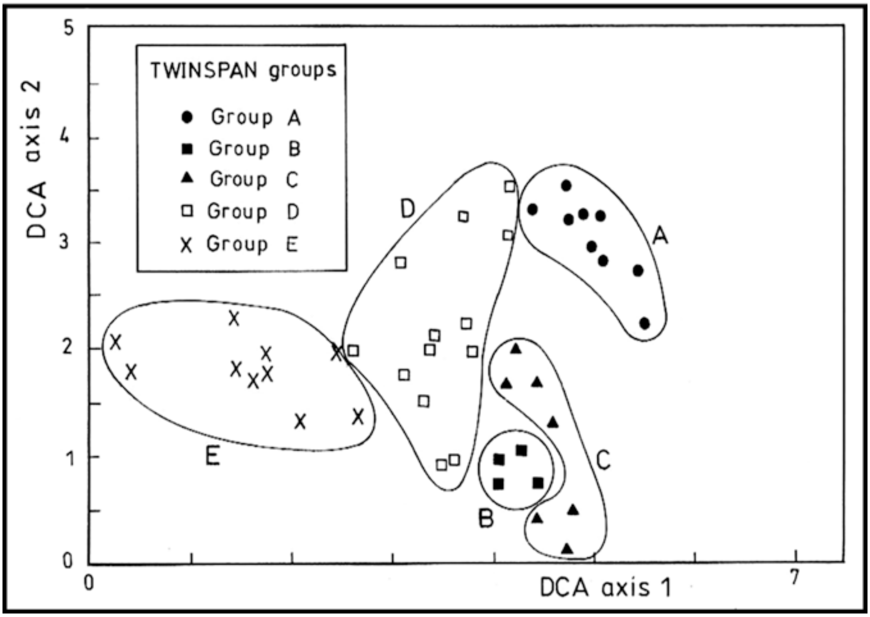


Fig. 3.10 DCA ordination diagram for the 53 stands on the first two axes with the TWINSPAN groups superimposed

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 $p < 0.05$

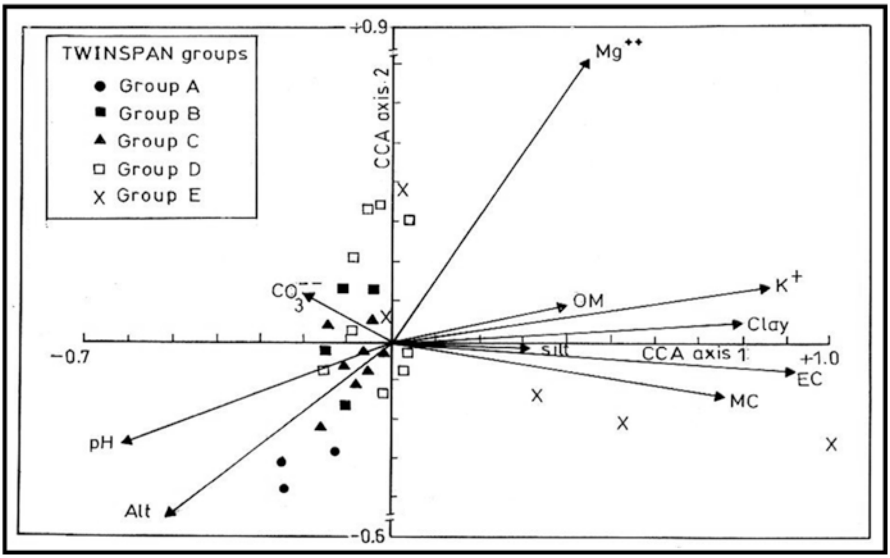


Fig. 3.11 CCA biplot of axes 1 and 2 showing the distribution of the 53 stands with their TWINSPAN groups and soil variables

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%.

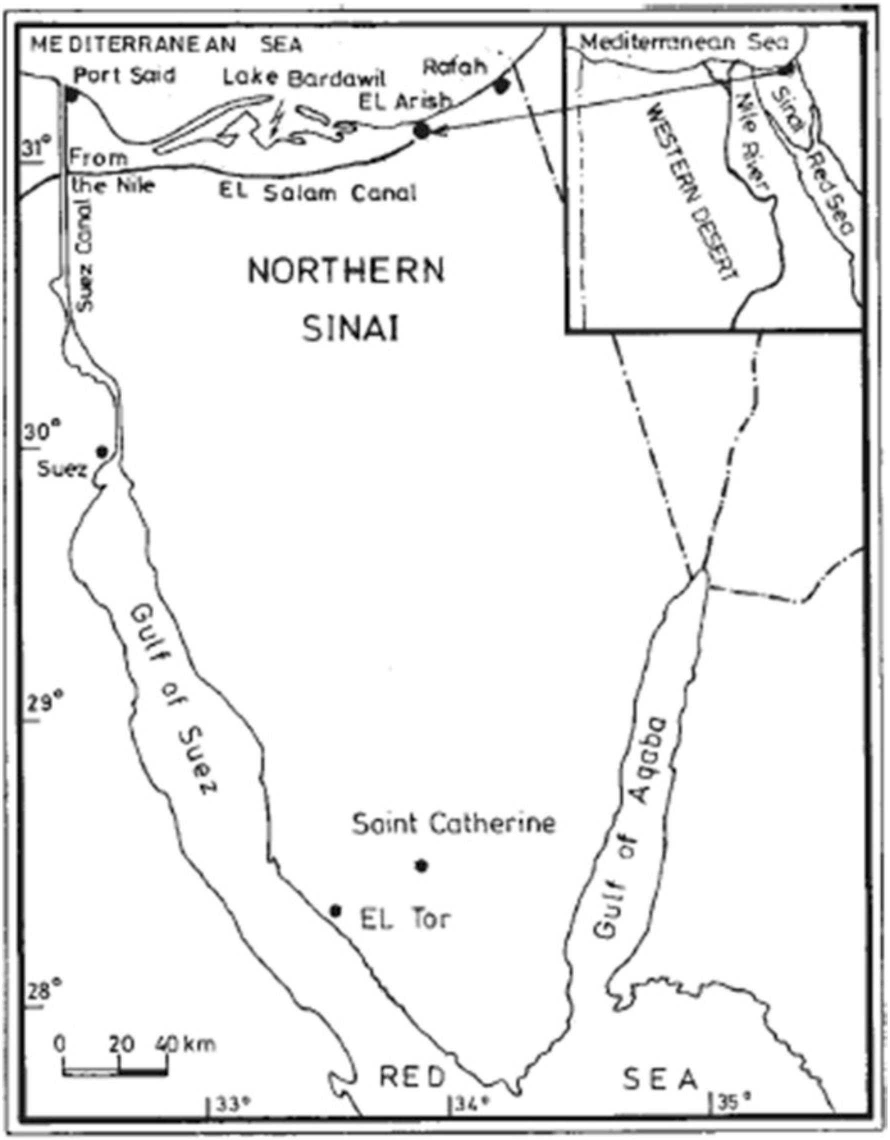


Fig. 3.12 Location map showing El-Arish-Rafah area

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–*

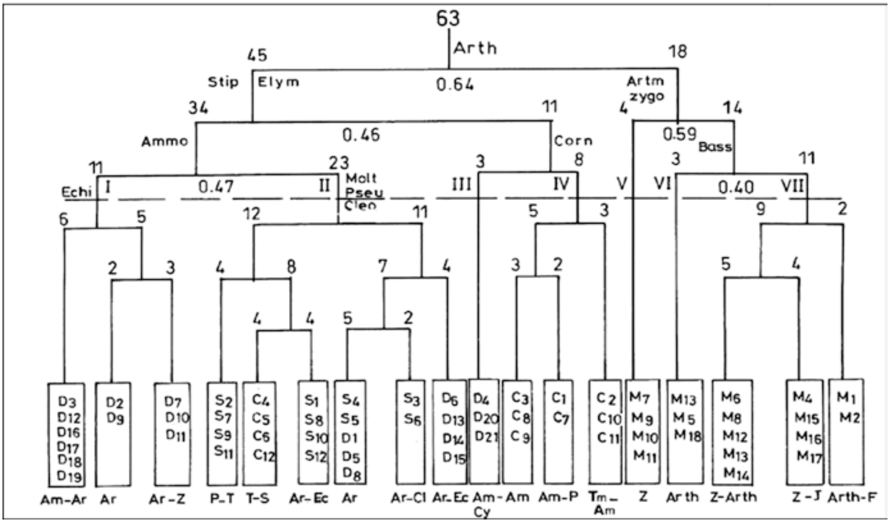


Fig. 3.13 The dendrogram resulting from TWINSPAN analysis of 63 stands of the study area. The *broken line* denotes the level at which the dendrogram yields seven vegetation types (I–VII). Indicator species and vegetation group abbreviations are shown in the Appendix

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-

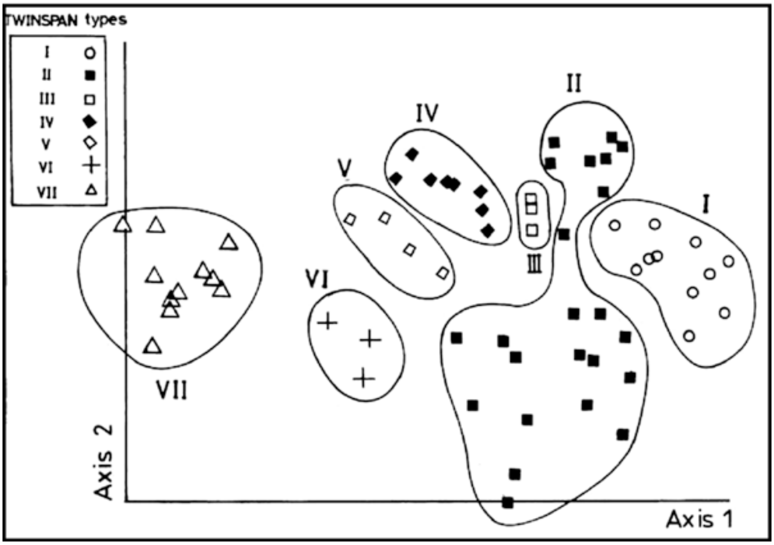


Fig. 3.14 Ordination diagram of Detrended Correspondence Analysis (DCA) of 63 stands, with their TWINSPAN vegetation types

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 $p < 0.05$

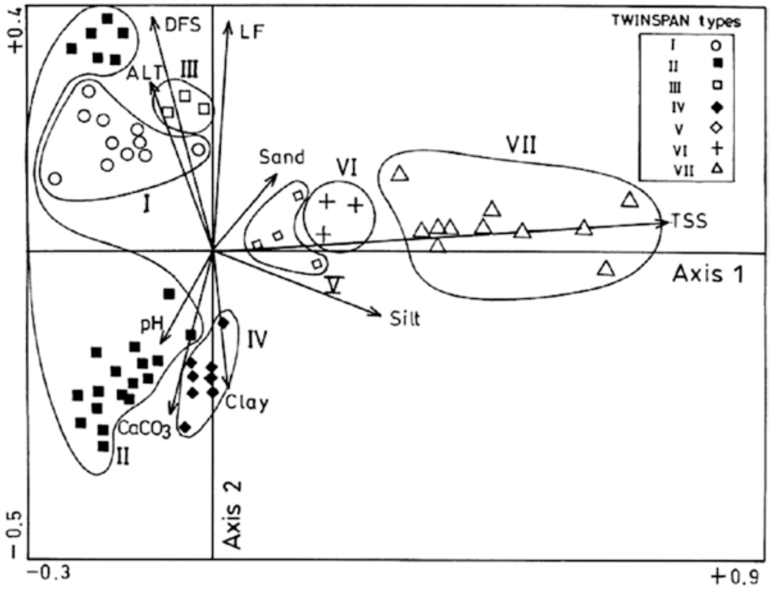


Fig. 3.15 Ordination biplot yielded by canonical correspondence analysis (CCA) of the 63 stands with their TWINSPAN vegetation types and soil variables

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

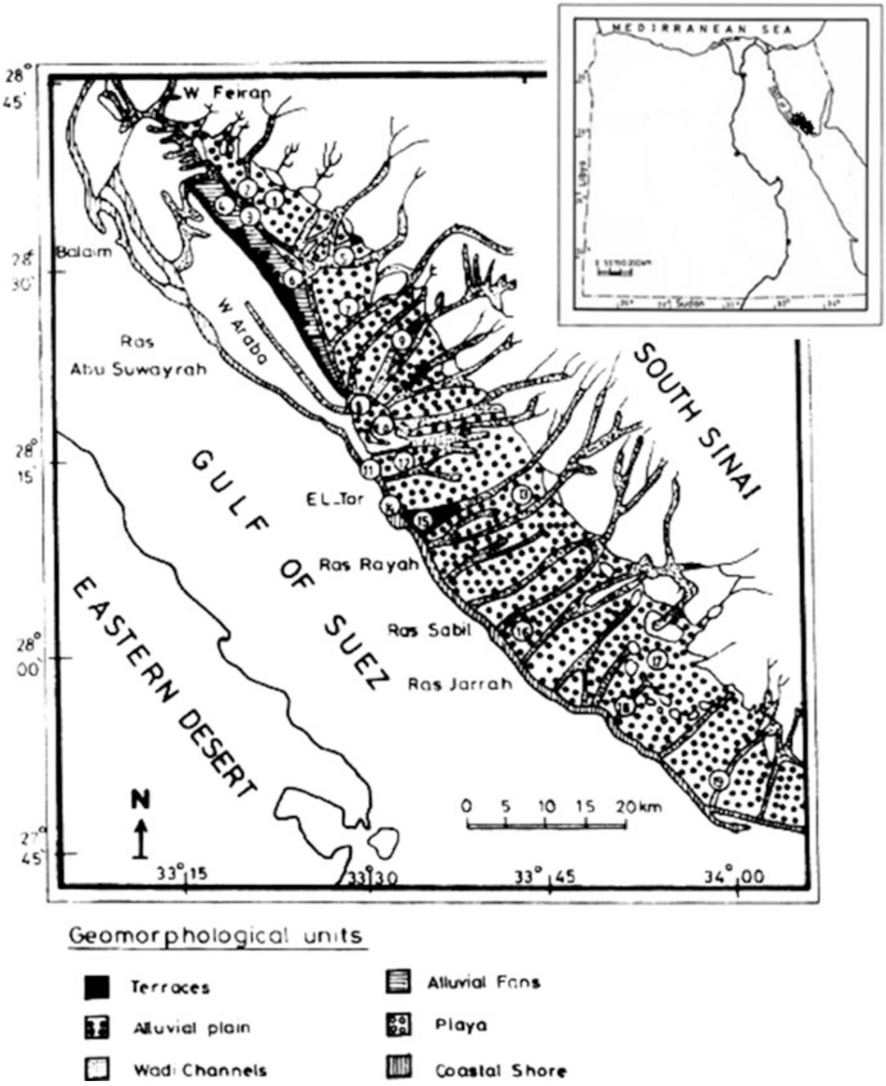


Fig. 3.16 Location map of El-Qaa plain showing the distribution of the studied sites (1–19) within the six geomorphologic units. A, b, and c are three climatic stations at El-Arish, Suez, and El-Tor, respectively

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.

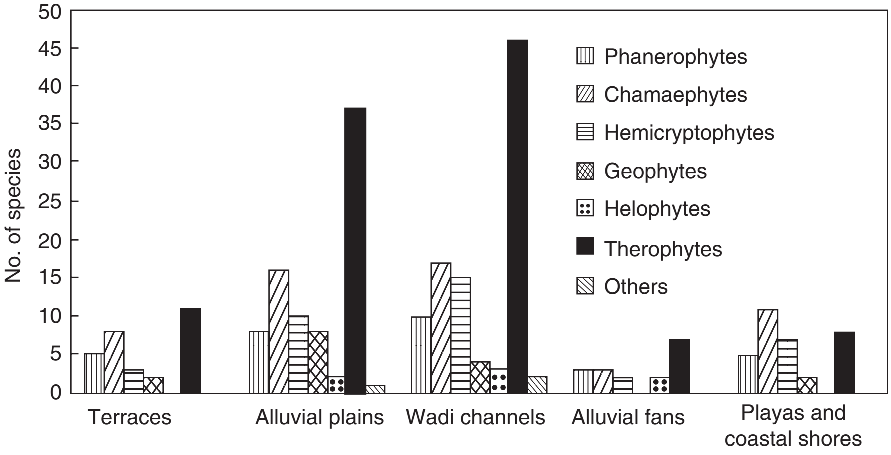


Fig. 3.17 Life-form spectrum within each geomorphologic unit of El-Qaa plain. *Ph* phanerophytes, *CH* chamaephytes, *Hc* hemicryptophytes, *G* geophytes, *He* helophytes, and *Th* therophytes

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
*, $P < 0.01$; **, $p < 0.001$

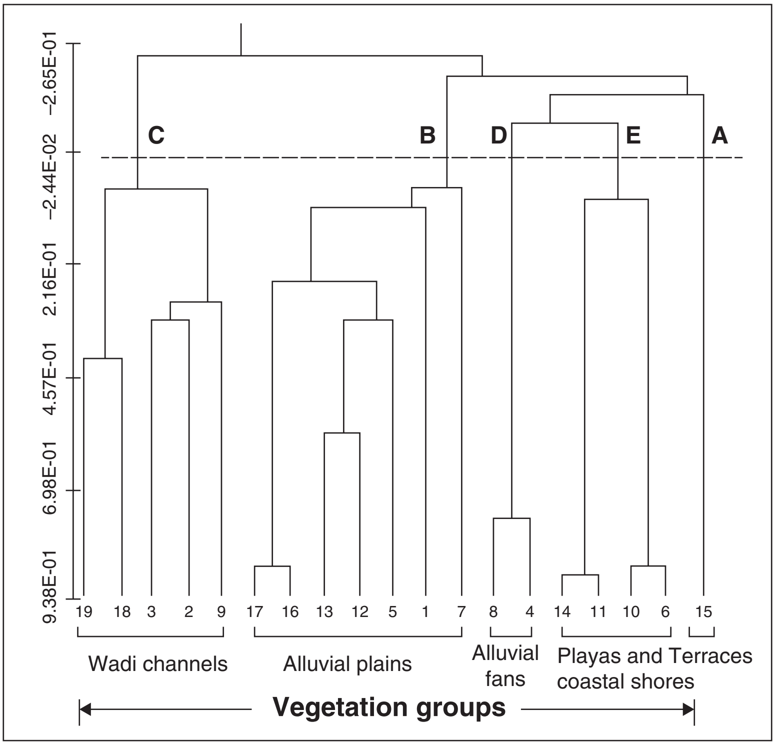


Fig. 3.18 TWINSPAN classification of the 19 sites of EL-Qaa plain. A–E are the five separated vegetation groups

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

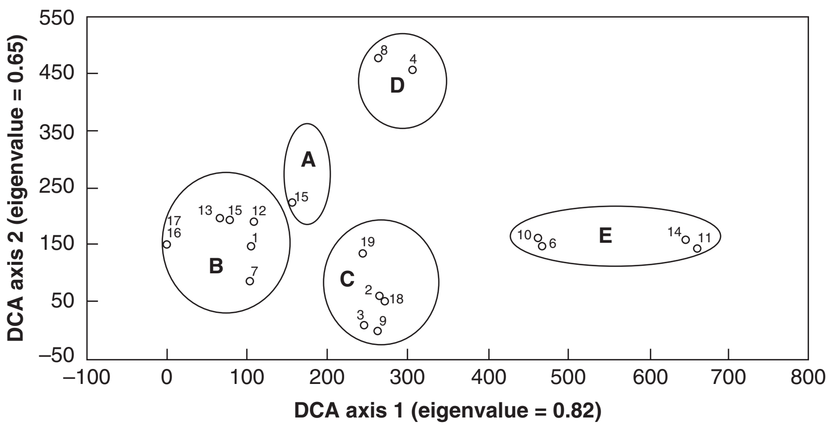


Fig. 3.19 The floristic DCA ordination of the 19 sites with the TWINSPAN groups superimposed

(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

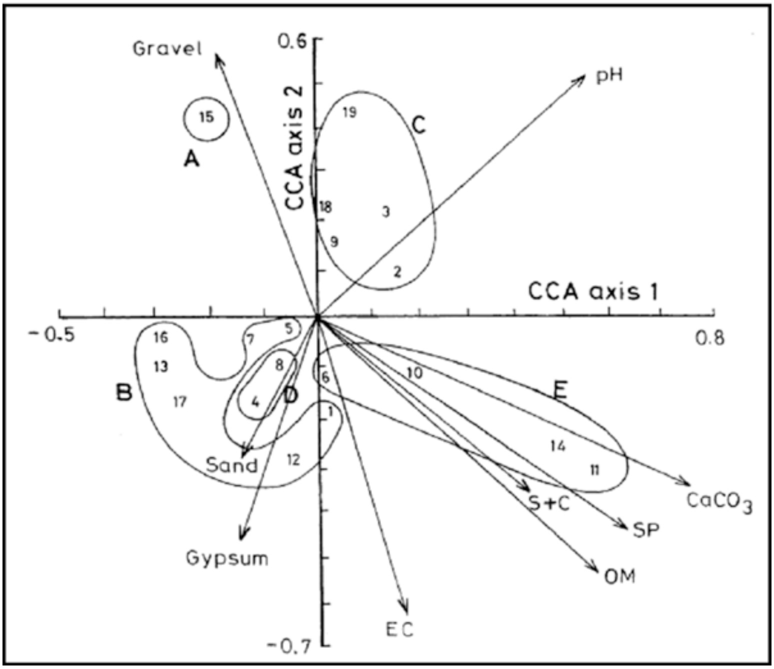


Fig. 3.20 CCA ordination biplot of the first two axes showing the distribution of the 19 sites with their TWINSPAN groups (A–E) and the examined soil variables

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

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Chapter 4
The Inland Eastern Desert of Egypt

Abstract The inland part of the Eastern Desert of Egypt forms an ecosystem with characteristic habitats: (1) rocky surface, (2) erosion pavement, (3) gravel desert, (4) slopes, (5) cliffs, and (6) desert wadi, which represents a drainage system collecting water from extensive catchment area. The geographic position of the mountainous range along the Red Sea coast is very conspicuous. The flora and vegetation of the Gebel Elba mountainous group is much richer than that of the other coastal mountain, where the Palaearctic and Afrotropical regions meet. The species composition of the Gebel Elba National Park was greatly influenced by disturbances such as severe cutting of trees and shrubs either for domestic fuel or charcoal production and browsing. In terms of classification and ordination, the vegetation and environment in northern wadis and southern wadis in four transects representing three different types of desert running from the Nile Valley to the Red Sea coast were investigated. Based on the current status of flora of the Eastern Desert, a biogeographical analysis and phytogeographical divisions of the were re-assessed.

4.1 General

The monumental basic studies on the habitat and plant communities in the Egyptian Eastern Desert were achieved by Kassas M (1952), Kassas (1953a, b), Kassas (1955, 1956, 1960, 1966 and 1971). They proposed a schema for the classification of the different types of habitats and gave an outline of the main ecosystems in the Egyptian Desert. These ecosystems are, (1) Rocky surface, this type of habitat includes chasmophytic plants that can send their roots into rock crevices such as *Stachys aegyptiaca*, *Reaumuria hirtella*, *Helianthemum kahiricum*, and *Iphiona mucronata*. (2) Erosion pavement, the main channels and affluent of this type of habitat include annual and perennial plant species including *Diplotaxis acris*, *Pteranthus dichotomus*, *Zilla spinosa*, and *Zygophyllum coccineum*. (3) Gravel desert, which harbours a group of plants that are peculiar to this type of habitat among others, *Mesembryanthemum forsskalei*, *Aizoon canariense*, *Fagonia glutinosa*, and *Centaurea aegyptiaca*. (4)

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Slopes that are well represented on the plateau edges, wadi sides, and mountain and hill sides. Characteristic species of this type include *Diplotaxis harra*, *Gymnocarpus decandrus*, and *Reaumuria hirtella*. (5) Cliffs, as it is well represented in waterfalls in wadi beds and outer curves of meanders. *Capparis spinosa*, *Iphiona mucronata*, *Cocculus pendulus*, *Ficus palmata*, *Fagonia mollis*, and *Zygophyllum coccineum* are common species of this type of habitat. (6) Desert wadi, which represents a drainage system collecting water from extensive catchment area. It is richer in vegetation than other types of desert habitats. Shallow soil of wadi bed inhabited by *Zygophyllum coccineum*, *Anabasis setifera* communities, and *Zilla spinosa* is the most dominated community at the intermediate stage; *Pennisetum dichotomus* and *Panicum turgidum* communities are in sandy soil; and *Nitraria retusa*, *Atriplex halimus*, *Tamarix nilotica*, and *T. tetragyna* are among the climax vegetation. (7) Sand drifts and dunes, which include plants capable to act as obstacles and have the ability to accumulate wind born materials building mound and dunes around them such as *Zygophyllum album*, *Deverra tortuosa*, *Calligonum polygonoides*, and *Convolvulus lanatus.*

4.2 Surveyed Areas

4.2.1 The Coastal Mountains: Gebel Elba

The coastal mountain ranges of the Red Sea represent a conspicuous habitat type of special interest for their complex patterns of natural communities interrelating the floras and faunas of Egypt, Sudan, and Ethiopia. One of these ranges is the Gebel Elba mountains of south-eastern Egypt. This mountain range is considered a continuation of the granitic formation of the Red Sea highland complex between Egypt and Sudan, situated between 36° and 37° of the eastern longitudes and about 22° of the northern latitude. The flora and fauna of this area comprise hundreds of species of plants and animals; these include a number of endemics and a number of species that represent the northern outpost of the biota of the Ethiopian highlands.

The geographic position of this group of mountains combines the following: (a) the bend of the coastal line, (b) the proximity to a large water body (Red Sea), (c) altitudinal and seaward direction of slope, and (d) a coastal plain with few topographic features. The combination of these features allows for orographic condensation of cloud moisture, particularly on the seaward slopes, which forms an essential source of water for plants in this area. This provides for rich plant growth and creates “mountain oases” or “mist oases” (Troll 1935; Kassas 1955). The floristic richness of the Gebel Elba area is noticeable, compared to the rest of Egypt, and this is considered one of the main phytogeographical territories of the country (El Hadidi 2000a) as it borders the Saharo–Arabian and Sudanian floristic regions. The flora and vegetation of the Gebel Elba group is much richer than that of the other coastal mountain groups (Drar 1936; Hassib 1951), where the Palaearctic and Afrotropical regions meet. It comprises elements of the Sahelian regional transition zone (White and Léonard 1991) and represents the northern limit of this geoelement in Africa. Within its massive, the vegetation on the north and northeast flanks is much richer than that on the south and southwest (Kassas and Zahran 1971). Its ecological features, together with its particular geographic position, seem to have promoted plant diversity, singularity, and endemism in this area and favoured the persistence of an extensive woodland landscape dominated by thickets of *A. tortilis* (Forssk.) Hayne subsp. *tortilis*. It is not known elsewhere in the Eastern Desert of Egypt (Zahran and Willis 1992).

Geographical areas containing high species richness and a high level of endemism and/or harbouring a high number of rare or threatened species have been defined as biodiversity hotspots and have been considered to set priorities for conservation planning (Reid 1998). In spite of the interesting biogeographical and botanical features of the Gebel Elba mountain range, it has been overlooked in most global biodiversity assessments (Heywood and Watson 1995). Of the 142 woody perennial threatened plant species that are included in the Plant Red Data Book of Egypt (El Hadidi et al. 1992), 56 or 39.4% were known from the Gebel Elba district. Therefore, this area was protected in 1986 as the Gebel Elba National Park (Prime Ministerial Decrees 450/1986, 1185/1986, and 642/1995), covering 35,600 km^2, aiming to promote the sustainable management of natural resources and maintain its biodiversity. To fulfil this mandate, it is essential that each national park has adequate knowledge of its biodiversity (Hawksworth and Kalin-Arroyo 1995). Inventorying is, therefore, the fundamental starting point for any strategy of conservation, sustainable use, or management (Strok and Samways 1995). Biodiversity conservation in Egypt is supported by a network of important protected areas (21 representing 8% of the country's land surface, and a further 19 areas are proposed for protection), based on natural region classification of the land, having a mandate to preserve a representative sample of the ecosystem characteristic of each region.

The rugged topography and inaccessibility of the mountainous escarpment of the Gebel Elba district have resulted in a paucity of studies on its vegetation and no complete survey of the flora. Previous studies on the flora and vegetation of the Gebel Elba mountain range are fragmentary and rely on a qualitative description of the vegetation (Drar 1936; Fahmy 1936; Kassas and Zahran 1971). It is worth noting that a complete modern flora (or at least checklist giving a precise account of its extant plant taxa) is still lacking. A complete list of the plant taxa of this area is therefore essential.

The Gebel Elba mountainous group is one of the three coastal mountains in the south-east corner of Egypt that faces the Red Sea, extending between latitude 24° 50′ N and 22° N on the Sudano–Egyptian border (Fig. 4.1). This group is mainly of igneous basement nature, forming a complex of high summits such as Asotriba (2217 m), Shendib (1912 m), Shendodin (1526 m), Elba (1465 m), and Shellal (1409 m). A wide coastal desert plain separates the Gebel Elba mountain range from the Red Sea coast. Although not the highest of its group, Gebel Elba is nearest to the sea (20–25 km).

The igneous mountains extend southwards from latitude 28° N to beyond latitude 22° N (the Sudano–Egyptian frontier). Fahmy (1936) reported that Gebel Elba is a compact mass of light-coloured granite, covered with jagged peaks and numerous precipitous gorges. It is separated from the chain extending further south by the broad deeply wadis of Osir Hadal and Sarimtai. The peak of Gebel Elba (22° 10′ 33″ N and 36° 21′ 52″ E) represents the centre from which drainage systems (wadis) radiate in all directions. The principal of these wadis is Wadi Yahameib, which with

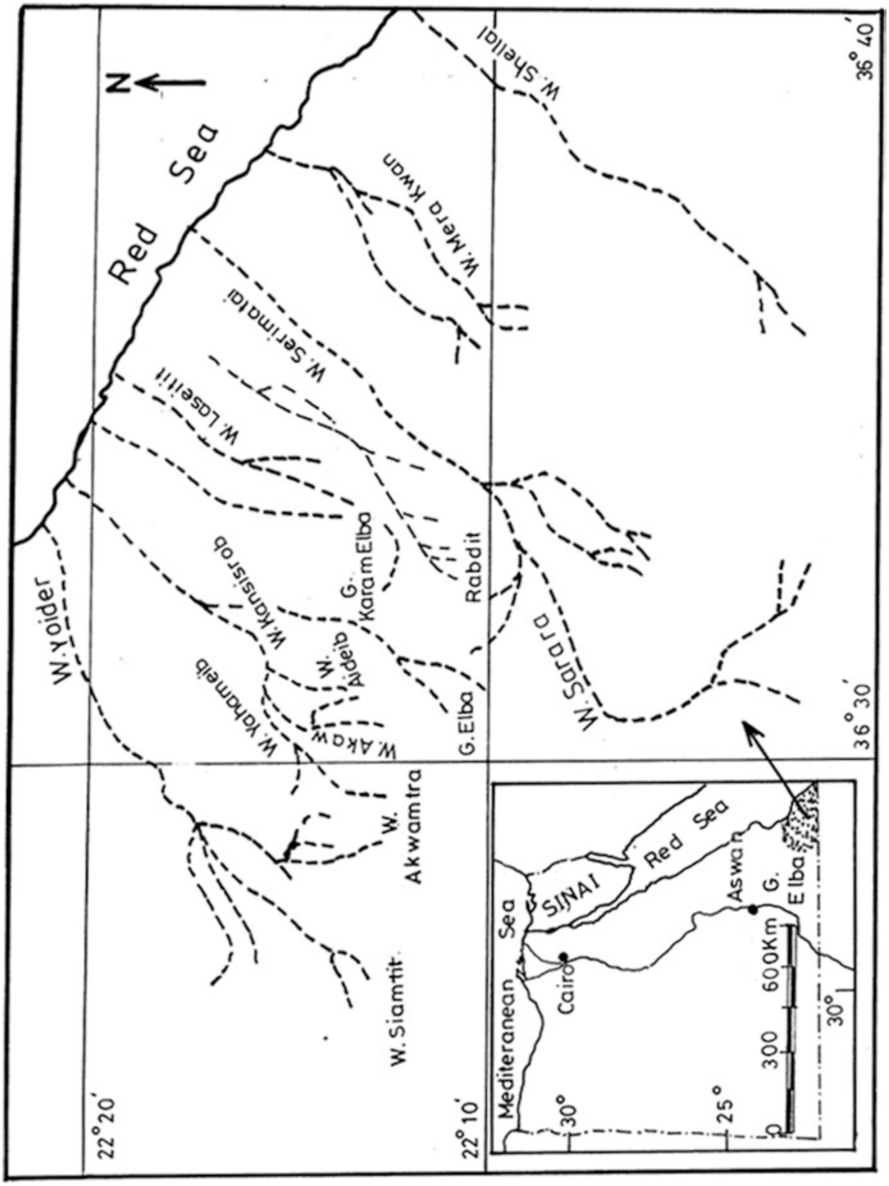

Fig. 4.1 Location map of Gebel Elba region, showing the dissecting wadis

its tributaries Wadi Akaw and Wadi Kansisrob drains the north faces of the mountains (Fig. 4.1). Except for the alluvial wadi fan at the foot of the mountain, which consists of gravel and sandy soil, the surface is of bare exposed rocks. Slopes are steep with sharp rocks. Most of the vegetation grows in soil pockets in the drainage cracks and runnels. Large boulders, small stones, and gravel are found in the steep runnels. Said (1962) described the rock formations in the study area as mainly igneous and metamorphic deposits of very ancient origin. The igneous rocks cover one-third of south-eastern Egypt, forming irregularly distributed tracts alternating with others occupied by metamorphic rocks. In general, gneisses, schists, breccias, and many other minerals comprise the metamorphic rocks in this district. On the other hand, the sedimentary deposits can be classified recently as gypsum and gypseous limestone and Nubian sandstone (Cretaceous).

Within the complex biological and physical framework that constitutes the biodiversity resources of the Gebel Elba National Park, rich ethnic inheritance has lived in, used, and modified the natural habitats in different ways through time. The Bishari tribe, the principal of three tribes, inhabits the immediate vicinity of Gebel Elba. They are sedentary to seminomadic, are related to the tribes in Sudan and Ethiopia, and speak their own language. The Ababda tribe, ranked second, is sedentary to seminomadic people found in the northern areas of the park and is considered Arab in origin. The Rashayda tribe is a nonindigenous tribe inhabiting the coastal plain. The human activities from ancient up to the present time must be considered factors which have contributed to the disturbance of the natural ecosystems, the banality of the flora, and the more or less uniformity of the vegetation in our area. The main socio-economic activities of the local community are livestock herding and charcoal production (especially from *Acacia* trees). The local community relies heavily on the natural flora for their way of life, particularly wood for fuel, building materials, fodder, tools, handicrafts, and other goods, some of which are sold or traded. Plants and animals are also used for medicinal purposes. Other activities include small-scale cultivation along the coastal plain and fisheries in the offshore waters. In the coastal communities, there are commercial enterprises, including trade between the Sudan and Egypt. These activities have produced environmental alterations and in some instances positively influenced the genetic maintenance of some ecosystems.

The climate of the study area seems to occupy an intermediate position between those of the regions of the tropical rains and those of the dry Egyptian rocky deserts with their occasional precipitation in winter months (Fahmy 1936). According to Ayyad and Ghabbour (1986), the study area lies in the arid climatic province characterized by spring rainfall ranges between 50 and 10 mm year^{-1}, mild winters (18–22 °C), and hot summers (28–33 °C). As for its geographical position and peculiar set of environmental conditions, Gebel Elba receives greater water revenue from orographic precipitation than the other northern blocks (Kassas and Zahran 1971). Unfortunately, recent climatic records for the Gebel Elba area are not available.

4.2.1.1 Floristic Richness and Taxonomic Diversity

As a result of the fieldwork, the vascular flora of the Gebel Elba Park contains a total of 179 taxa from 51 families and 124 genera (Table 4.1) . More than 50% of the recorded taxa belong to only ten species-rich families (Fig. 4.2). The largest families in terms of the number of genera were Compositae (14), Gramineae (10),

Table 4.1 Floristic richness of the Gebel Elba Park

Plant group	Families	Genera	Species	Infraspecific taxa
Ferns and allied groups	3	3	3	–
Gymnosperms	1	1	1	–
Angiosperms	47	120	175	23
Monocotyledons	7	16	22	3
Dicotyledons	40	104	153	20
Total of vascular flora	51	124	179	23

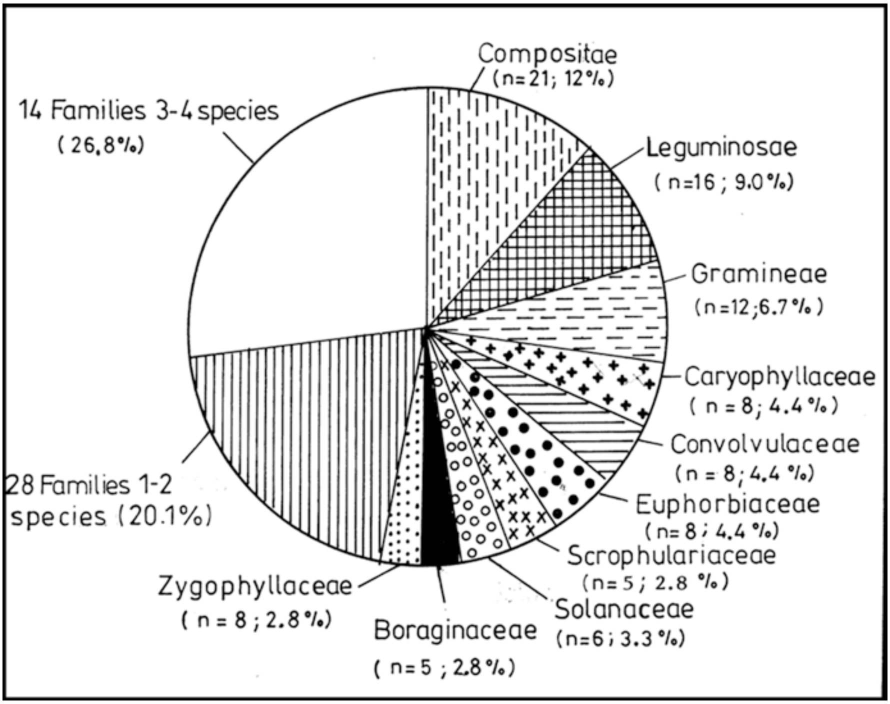

Fig. 4.2 Diagram of floristic composition with the ten families richest in species separately notated (*n* number of species)

Leguminosae (9), Caryophyllaceae (6), and Asclepiadaceae, Cruciferae, Scrophulariaceae, and Zygophyllaceae (4 for each). These families represent the most common in the Mediterranean North African flora (Quézel 1978). On the other hand, Gramineae, Leguminosae, Compositae, and Cruciferae constitute the main bulk of the alien plant species in Egypt and also in the agroecosystems of other adjacent countries such as Saudi Arabia and Kuwait (Abd El-Ghani and El-Sawaf 2004). A comparison of families in terms of the largest number of species recorded in this investigation and in similar studies in neighbouring countries (Table 4.2) revealed an agreement with such studies, e.g. Wickens (1976) in Jebel Marra of

Table 4.2 Comparison of the eight families containing the most species in studies conducted in Egypt and neighbouring countries, with their numbers and percentages (in parentheses)

Families	Estimated number of species in Egypt[a]	Egypt		Jebel Marra (Sudan)[c]	Asir Mountains (Saudi Arabia)[d]
		Present study	Eastern Desert (Egypt)[b]		
Compositae	230 (11.0)	21 (12)	57 (13.2)	76 (8.1)	21 (9.6)
Leguminosae	233 (11.1)	16 (9)	33 (7.6)	108 (11.6)	26 (11.9)
Gramineae	250 (11.9)	12 (6.7)	38 (8.8)	105 (11.3)	40 (18.3)
Caryophyllaceae	85 (4.0)	8 (4.4)	24 (5.5)	10 (1.1)	5 (2.3)
Convolvulaceae	48 (2.3)	8 (4.4)	7 (1.6)	18 (1.9)	3 (1.4)
Euphorbiaceae	55 (2.6)	8 (4.4)	5 (1.1)	21 (2.2	10 (4.6)
Solanaceae	33 (1.6)	6 (3.3)	7 (1.6)	10 (1.1)	8 (3.7)
Scrophulariaceae	62 (2.9)	5 (2.8)	11 (2.5)	23 (2.5)	7 (3.2)

Sources: [a]Boulos (1995, 1999–2002); [b]Hassan (1987); [c]Wickens (1976); [d]Boulos (1985) and Hosni and Hegazy (1996)

Sudan, Hassan (pers. comm.; 1987, Ecological and Floristic Studies on the Eastern Desert, Egypt), and Boulos (1985) and Hosni and Hegazi (1996) in the Asir Mountains of Saudi Arabia. Compositae (the largest family in our list) is not only the largest family in the flora of Egypt (Täckholm 1974; Boulos 2002) but also the largest and most widespread family of flowering plants in the world (Good 1974). This can be attributed to their wide ecological range of tolerance and to their high seed dispersal capability. The largest genera were *Euphorbia* L. (six), *Launaea* Cav. and *Solanum* L. (five for each), and *Acacia* and *Convolvulus* L. (four for each). The species composition of the Park was greatly influenced by disturbances such as severe cutting of trees and shrubs either for domestic fuel or charcoal production and browsing.

These factors affect particularly *Acacia tortilis* (Forssk.) Hayne subsp. *tortilis*, *Balanites aegyptiaca* (L.) Del., and *Maerua crassifolia* Forssk. regrowth while favouring an increase in density of species not browsed, such as *Calotropis procera* (Ait.) Ait., *Leptadenia pyrotechnica* (Forssk.) Decne, and *Senna italica* Mill. The latter were the most frequent species of the Park. On the tropical scale, Vetaas (1992) detected some similar taxa on an arid misty mountain plateau in Sudan and concluded that the species composition, at all spatial scales, was directly or indirectly related to variation in temperature and moisture. Frederiksen and Lwesson (1992), while dealing with the vegetation types and patterns in Senegal, described communities dominated by *Calotropis procera*, *Acacia tortilis*, and *Ziziphus* Mill. spp. in the Sahelian grassland.

The floristic richness of the Gebel Elba Park might be better understood by comparing it to other known taxonomic groups and/or regions located in Egypt. The Park contains approximately 9% of the 2094 vascular plant species found in Egypt (Boulos 1995). The floristic richness of the Park can be compared also to that of other floristically known regions in Egypt, which show different physiographic and geomorphologic features and vegetation communities (Fig. 4.3) . The ratios species/

genera and genera/families for the Gebel Elba Park and other floristically known regions in Egypt (Table 4.3) indicated higher taxonomic diversity (lower ratios) in the Park than in other regions. Pielou (1975) and Magurran (1988) pointed out that, in intuitive terms, hierarchical (taxonomic) diversity will be higher in an area in which the species are divided among many genera as opposed to one in which most species belong to the same genus and still higher as these genera are divided among

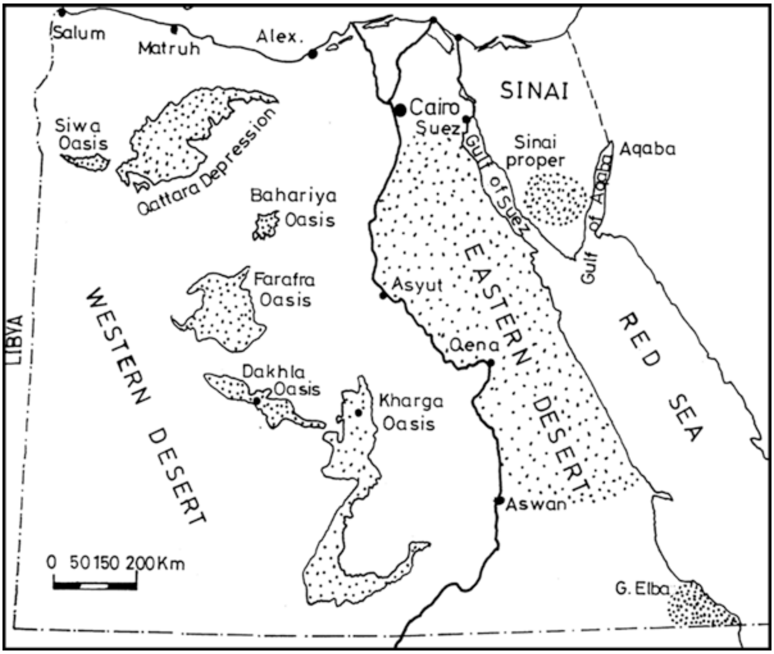

Fig. 4.3 Geographical distribution of the floristic richness of the Gebel Elba Park with other well-studied regions (*dotted areas*) in Egypt

Table 4.3 Comparative floristic richness and taxonomic diversity in some Egyptian regions and in the Gebel Elba Park

	Gebel Elba Park	Eastern Desert (the whole area)[a]	Sinai Peninsula (the whole area)[b]	Sinai proper (S El-Tih Desert)[b]	Western Desert[c]
Total number of species (S)	179	433	1217	716	328
Total number of genera (G)	124	266	566	422	212
Total number of families (F)	51	64	125	105	59
S/G	1.4	1.6	2.1	1.7	1.5
G/F	2.2	4.1	4.5	4.0	3.6

Sources: [a]Hassan (1987); [b]Ayyad et al. (2000); [c]Abd El-Ghani and El-Sawaf (2004)

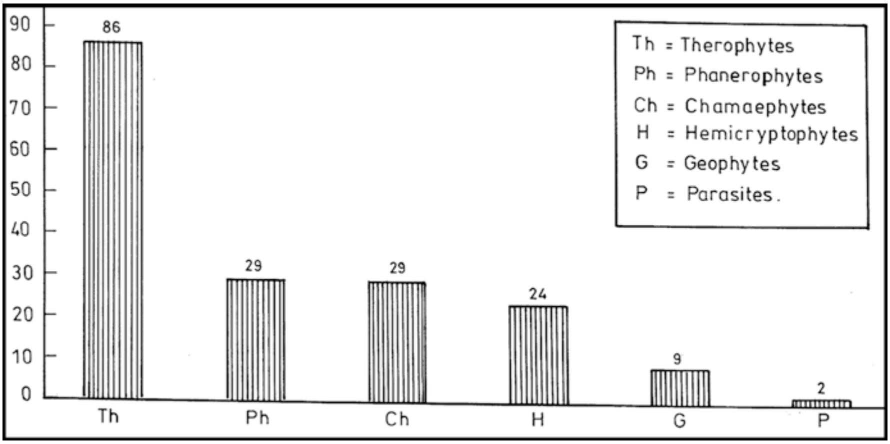

Fig. 4.4 Life-form spectrum of the vascular flora of Gebel Elba Park (figures are the number of species)

many families as opposed to few. The present study revealed that the Gebel Elba Park is more diverse than other well-studied regions in Egypt.

Life Forms

The life-form spectrum in the present study is characteristic of an arid desert region with the dominance of therophytes (48% of the recorded species; Fig. 4.4) , followed by phanerophytes and chamaephytes (16.2% for each) and hemicryptophytes (13.5%). The majority of annuals were winter species or cool-season species; some were hot-weather species (e.g. *Amaranthus graecizans* L. subsp. *graecizans*, *Portulaca oleracea* L., *Eragrostis ciliaris* (L.) R.Br., *Corchorus depressus* (L.) Stocks, and *Setaria viridis* (L.) Beauv.), and a few were nonseasonal species responding to rainfall at any time of the year (e.g. *Tribulus terrestris* L., *Chenopodium murale* L. and *Launaea capitata* (Spreng.) Dandy). The occurrence of the two parasitic plants *Cuscuta chinensis* Lam. and *C. pedicellata* Ledeb. (leafless or functionally so) denotes the importance of water conservation. As in most arid regions, the desert vine species were few, i.e. *Plicosepalus acaciae* (Zucc.) Wiens & Polhill, *P. curviflorus* (Benth. ex Oliv.) Tiegh., *Citrullus colocynthis* (L.) Schrad., *Coccinia grandis* (L.) Voigt, *Cocculus pendulus* (J.R. & G.Forst.) Diels, and *Cucumis prophetarum* Juss. subsp. *prophetarum*.

The dominance of shrubby plant species over the grasses was evident. The relative advantage of shrubs over grasses when water is limited, as in this area, can be explained by their extensive root systems, which are capable of utilizing water stored at different soil depths, whereas grasses utilize the transient water stored in the upper soil synchronic with precipitation pulses. Besides the spatial variations in the species composition of plant communities, the composition of life forms reflects the response of vegetation to variations in certain environmental factors. In this study, the dominance of therophytes, phanerophytes, and chamaephytes over other life forms seems to be a response to the hot dry climate, topographic variations, and human and animal interference.

Therophytes (annuals) are drought evaders in the sense that the whole plant is shed during the unfavourable conditions. Moreover, the high proportion of therophytes in this study is also attributed to human activities according to Barbero et al. (1990). It is also necessary to point out that the increase in both Leguminosae and therophytes in a local flora can be considered a relative index of disturbance for Mediterranean ecosystems. Regardless of the altitude or type of ecosystem, it was noted that the increase in grazing pressure throughout the southern Mediterranean ecosystems leads to the occupation of the understories by invasive therophytes and indicates hyperdegradation (forest therophytization) .

The remarkably high percentages of phanerophytes and chamaephytes (16.2% for both) must also be emphasized. The dominant perennials were the non-succulent trees and shrubs (or subshrubs) and the perennial herbs. Some of these perennials are drought-enduring plants in which the photosynthetically and transpiring organs were maintained at nearly constant proportion (Abdel-Razik et al. 1984). A comparison of the life-form spectra of the northern part of the Eastern Desert of Egypt (Abd El-Ghani 1998) and those in the Tihama coastal plains of Jazan region in southwestern Saudi Arabia (El-Demerdash et al. 1994) showed the same results.

Spatial Distribution Patterns of Species

None of the 93 perennial species occurred at all the 16 studied sites, whereas the annuals, i.e. *Amaranthus graecizans* subsp. *graecizans*, *Achyranthes aspera* L. var. *sicula* L., and *Sisymbrium erysimoides* Desf., showed the highest species occurrences (56% for the first, 50% for the other two species) in the flora. Ninety-two species or 51.4% of the total recorded species (179) demonstrated a certain degree of consistency, where they were exclusively recorded in or confined to a certain site or groups of sites. These species were distributed as follows: 12 in W. Aideib (e.g. *Plicosepalus acaciae*, *Indigofera spinosa*, *Coccinia grandis*, *Commicarpus boissieri*, and *Delonix elata*), 58 in W. Yahameib (e.g. *Acacia oerfota* var. *oerfota*, *A. asak*, *Balanites aegyptiaca*, *Cocculus pendulus*, *Ochradenus baccatus*, *Dracaena ombet*, *Dodonaea viscosa*, *Rhus tripartita*, *Euclea racemosa* subsp. *schimperi*, *Ophioglossum polyphyllum*, and *Aneilema tacazzeanum*), 9 in W. Darawina (e.g. *Ruellia patula*, *Peristrophe paniculata*, *Euphorbia granulata* var. *glabrata*, and *Blainvillea acmella*), 6 in W. Shellal (e.g. *Ficus palmata*, *Acacia mellifera*, *Ziziphus spina-christi*, and *Boerhavia elegans*), 2 in W. Topeet (*Launaea procumbens* and *Senecio flavus*), and 5 in W. Sarara (e.g. *Melanoloma pullatum* and *Leptothrium senegalense*) .

Sørensen's coefficients of floristic similarities between the six studied wadis were generally low, indicating smooth species composition changes among the wadis (Table 4.4). Significant positive similarity and the highest beta diversity were

Table 4.4 Sørensen's coefficients of floristic similarity (lower half) and the beta diversity (upper half) between the studied wadis in the Gebel Elba Park

Wadis	A	Y	D	Sh	T	S
A		0.60	0.3	0.1	0.2	0.05
Y	0.3*		0.3	0.2	0.2	0.07
D	0.1	0.07		0.2	0.07	0.03
Sh	−0.07	−0.07	0.04		0.1	0.1
T	0.1	0.15	−0.05	0.15		0.1
S	−0.06	−0.15**	−0.09	0.08	0.04	

A Wadi Aideib, *Y* W. Yahameib, *D* W. Darawina, *Sh* W. Shellal, *T* W. Topeet, and *S* W. Sarara
*P significant at 0.01 level; **P significant at 0.05 level

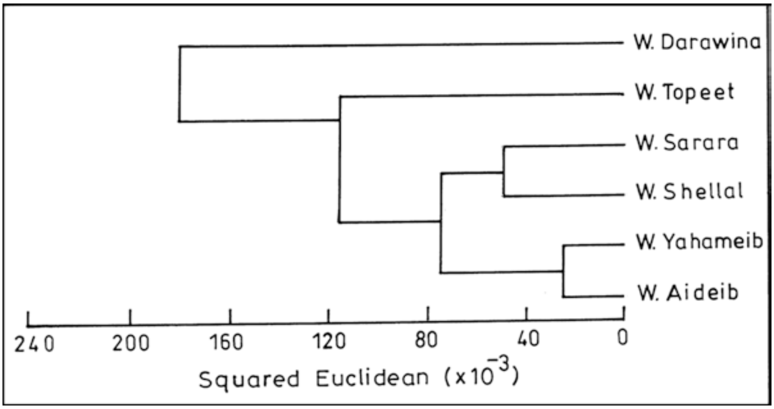

Fig. 4.5 Dendrogram of similarity among the wadis analysed

between W. Yahameib and W. Aideib, but a negative significant correlation was estimated between W. Sarara and W. Yahameib. Floristic composition in the six studied sites showed differences in species richness. The highest species richness value was recorded in W. Yahameib (123 species), whereas the lowest was recorded in W. Sarara (12 species). W. Yahameib, therefore, was the most diversified among the other studied wadis.

From the dendrogram in (Fig. 4.5), four main groups (I–IV) can be recognized. Wadi Darawina (group IV) was markedly dissimilar from the others. Two other large groups were closely associated; the first includes W. Yahameib and W. Aideib (group I) and the other includes W. Sarara and W. Shellal (group II). DCA supported this classification, which indicates a reasonable segregation among these groups along the ordination plane of axes 1 and 2 (Fig. 4.6). In the present study, DCA estimated the compositional gradient in the vegetation data along DCA axis 1 to be larger than 4.8 SD units for all subset analyses, indicating that a complete turnover in species composition took place (Hill 1979) .

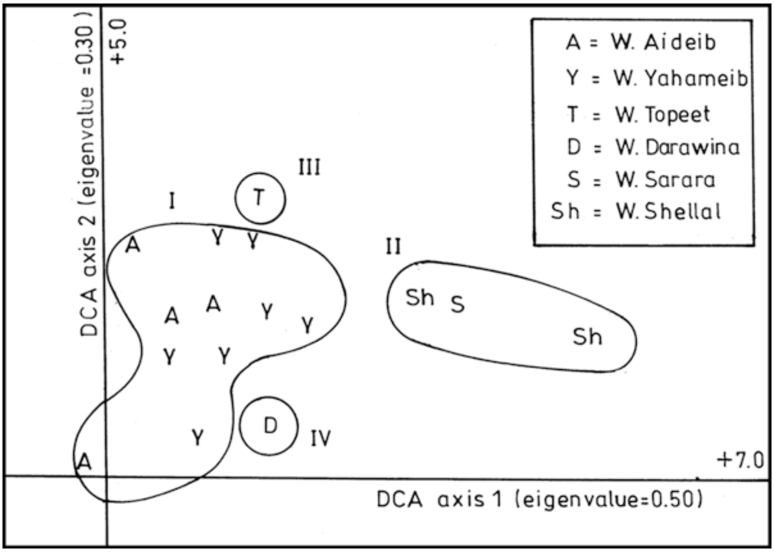

Fig. 4.6 Detrended Correspondence Analysis (DCA) ordination diagram of 16 sample plots and sites represents the four cluster groups (I–IV) resulted in Fig. 4.5

The four DCA axes explain 30.1% of the total variation in the species data. This low percentage of variance explained by the axes was attributed to the many zero values in the data set. DCA axis 1 may represent a geographical trend in the floristic data set, where W. Shellal and W. Sarara are located in the southern part of the region, while the other wadis are located in the northern part.

Species Richness Versus Altitudinal Gradient: A Case Study

This study showed variations in floristic composition and species richness along an altitudinal gradient in Wadi Yahameib (Fig. 4.7). These variations may be attributed to the climatic differences, substrate discontinuities, and mountainous escarpment along the altitudinal gradient. It may be noted that species richness on W. Yahameib was highest (ranged from 47 ± 7.3 to 53 ± 11.0 species) in the middle altitudes from 300 to 450 m. This zone on the mountain was probably more climatically equable for plant growth and diversity than either lower (90–250 m) or higher (460–680 m) altitudes. At lower altitudes (species richness ranged between 15 ± 6.4 and 28 ± 8.6), the temperature is higher and the climate more arid, and although higher altitudes (species richness ranged between 13 ± 5.5 and 24 ± 9.4) are less arid, the temperatures are much lower. Records of some ferns such as *Actiniopteris semiflabellata*, *Onychium divaricatum*, and *Ophioglossum polyphyllum* of less arid habitats were further evidence of this. It can also be noted that trees frequently occurred and constitute the main bulk of the plant cover and in certain instances may form forest-like growth at the middle and higher altitudes of the wadi. Trees and shrubs of *Olea europaea L.* subsp. *africana*, *Ficus salicifolia*, *Acacia tortilis* subsp. *tortilis*,

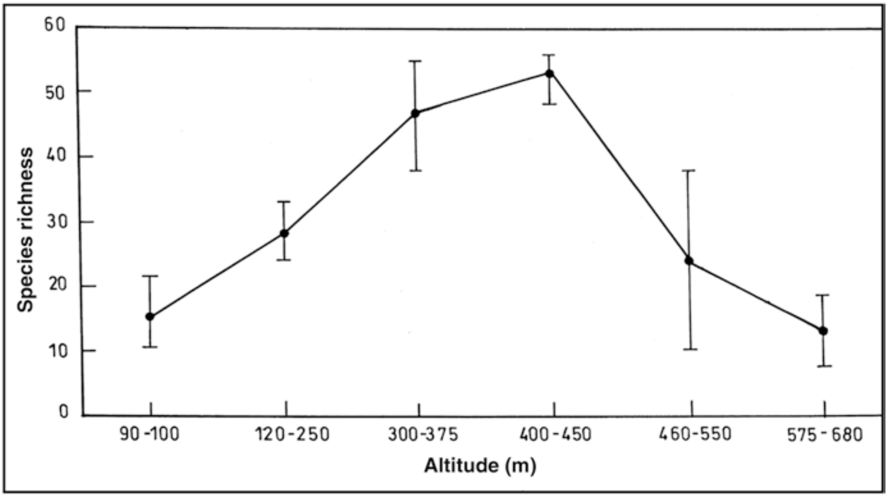

Fig. 4.7 Species richness along the altitudinal gradient of W. Yahameib

Dracaena ombet, *Euclea* spp., *Dodonaea viscosa*, *Delonix elata*, and *Rhus* spp. were recorded. *Dracaena ombet* was recorded in the middle and higher zones of the north and east slopes of Gebel Elba. In several localities there were limited groves of this tree; otherwise there were isolated individuals. Reference may be made to the studies on the growth of *D. ombet* within the Sudanese coastal mountains including the mist oasis of Erkwit (Kassas 1956, 1960). The occurrence of *Dracaena* in the Gebel Elba area represents its most northern limit within the Red Sea coastal mountains (Kassas and Zahran 1971). This pattern of altitudinal variation in species diversity can be contrasted with that of wet tropical mountains, where species richness decreases linearly with increasing altitude (Oshawa et al. 1985).

The altitudinal pattern of plant diversity in W. Yahameib, where the highest diversity occurs at middle altitudes on the mountain, may be more typical of arid mountains in desert regions. These results were consistent with other studies on diversity–altitude relationships from the arid region as in Asir Mountains of southwestern Saudi Arabia (Abulfatih 1984; Hegazy et al. 1998), in Jebel Tageru of the southern Libyan Desert (Neumann 1987), in Jabal Shams of Oman (Ghazanfar 1991), in the central Hijaz mountains of Saudi Arabia (Abd El-Ghani 1997), on the eastern and western sides of the Red Sea (Hegazy and Amer 2001), in Al-Jabal Al-Akhadar of Libya (Al-Sodany et al. 2003), and in the arid parts of Chile (Hoffmann and Hoffmann 1982) .

4.2.1.2 Phytogeographical Affinities

The phytogeographical analysis of the studied area must be regarded as provisional, due to the still poorly known overall distribution features of many taxa. With regard to the relation between biogeographic elements (geoelements) and life forms

Table 4.5 Distribution of the geoelements among life forms (%)

Life form	COSM		PAL		PAN		ME		IT		SA		SZ		Afr. mont. Afr. alp.	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*M*	%
Ph (29)	–	–	1	3.4	–	–	1	3.4	–	–	18	62.1	9	31.1	–	–
Ch (29)	1	3.4	1	3.4	1	3.4	1	3.4	–	–	20	69.1	5	17.3	–	–
H (24)	–	–	3	12.5	–	–	3	12.5	–	–	14	58.3	4	16.7	–	–
G (9)	1	11.1	1	11.1	1	11.1	–	–	–	–	4	44.4	2	22.3	–	–
Th (86)	4	4.7	11	12.8	5	5.8	20	23.2	1	1.2	28	32.6	15	17.4	2	2.3
P (2)	–	–	–	–	–	–	–	–	–	–	2	100.0	–	–	–	–
Total (179)	6	3.3	17	9.5	7	3.9	25	14.0	1	0.6	86	48.0	35	19.6	2	1.1

N number of species, *Ph* phanerophytes, *Ch* chamaephytes, *H* hemicryptophytes, *G* geophytes, *Th* therophytes, *P* parasites, *COSM* Cosmopolitan, *PAL* Palaeotropical, *PAN* Pantropical, *ME* Mediterranean, *IT* Irano–Turanian, *SA* Saharo–Arabian, *SZ* Sudano–Zambezian, *Afr. mont.* Afromontane, *Afr. alp.* Afroalpine

(Table 4.5), therophytes, the most abundant life form, were important in all categories. Trees and shrubs were also more or less fairly represented in almost all categories. Annuals contributed largely to the Saharo–Arabian element. In turn, the Saharo–Arabian element was well represented in the flora of the Gebel Elba Park and constituted 48% of the recorded taxa. In fact, chamaephytes, phanerophytes, and hemicryptophytes make a substantial contribution to the Saharo–Arabian and Sudano–Zambezian geoelements.

Phytogeographically, as the study area lies within the Saharo–Arabian belt of the Holarctic floristic realm, the analysis of the floristic data showed the prevalence of the Saharo–Arabian geoelement (Fig. 4.8) . The Sudano–Zambezian geoelement ranked second. According to Wickens (1976), the Sudano–Zambezian region is bounded to the north by the desert and semi-desert of the Saharo–Arabian region, while in the south it extends to the desert and semi-desert of the Karoo–Namib region. The extent of this geoelement in south-eastern Egypt and along the western coast of the Red Sea has not yet been satisfactorily determined.

It is worth mentioning that the monoregional (pure) Sudano–Zambezian geoelement was not represented further north in the Arabian Desert (Abd El-Ghani 1998), whereas it constituted 14% of the flora of the studied area. These geoelements are more typical of the southern Egyptian Desert (Bornkamm and Kehl 1990; Springuel et al. 1997; Abd El-Ghani et al. 2003). Thus, the tree and shrub layer is composed mainly of Saharo–Arabian geoelement with a Sudano–Zambezian focus of distribution. The Mediterranean geoelement was modestly represented in the tree and shrub layer. This may be attributed to the fact that plants of the Saharo–Arabian and Sudano–Zambezian geoelements are good indicators for harsh desert environmental

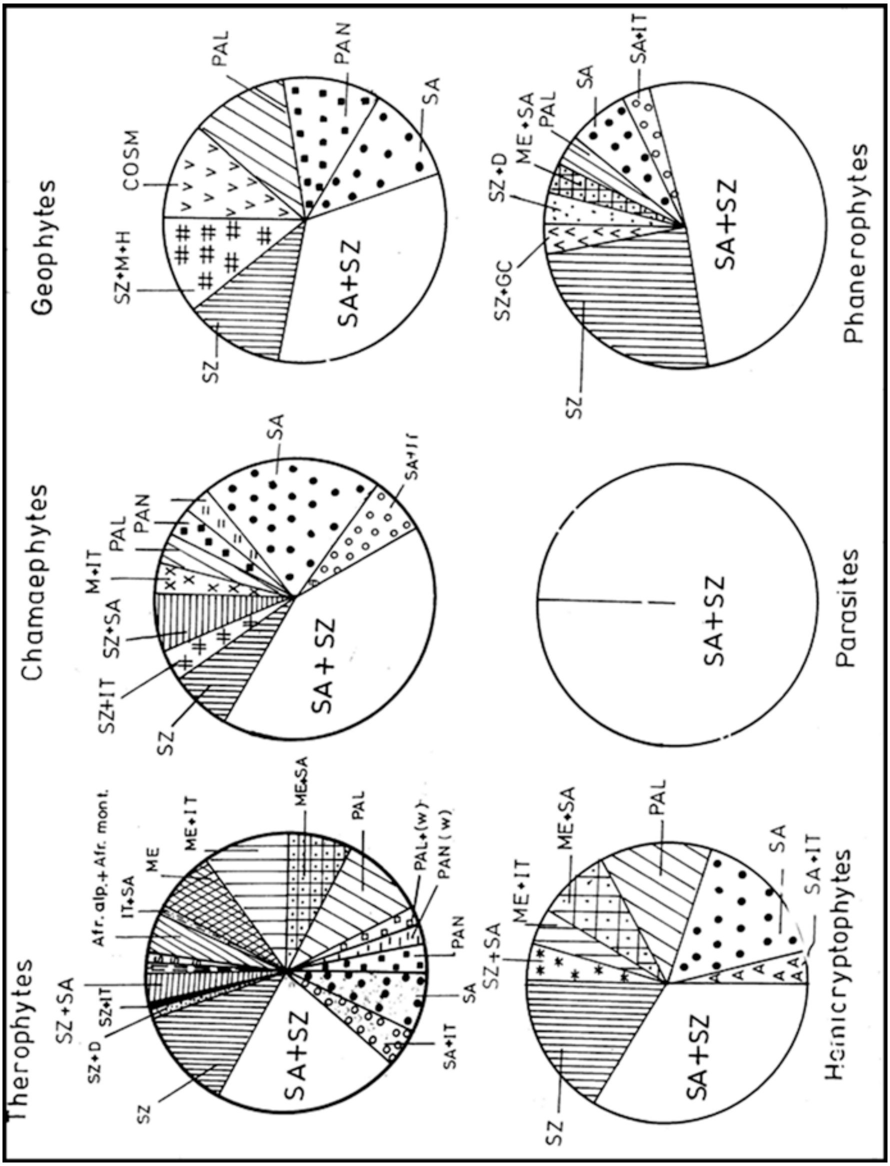

Fig. 4.8 Distribution of the chorotypes in the life-form categories. *D* Deccan, *H* Himalayan, *M* Madagascan, *GC* Guineo–Congo. For other chorotype abbreviations, see Table 4.5

conditions, while Mediterranean species stand for more mesic conditions. It can be, therefore, concluded that the flora of the Gebel Elba Park represents a continuation of the Sudanian tropical region with very similar climatic and topographic conditions. Further studies should attempt to define the environmental constraints on the species distribution recorded here.

4.2.2 The Northern Wadis

4.2.2.1 Wadis of Matuli and Qarn

The inland desert wadis, particularly those intersecting the Eastern Desert, differ greatly in their water resources. The wadis studied in the work hitherto presented lack of water resources and therefore belong to extremely dry habitats among similar wadis that drain this desert into the Nile Valley on rare occasions when rainfall occurs. Such rains usually happen in sudden torrents that overflow in wadi courses usually originating in mountainous areas in the middle of this desert and flowing eastwards or westwards to the Red Sea and Nile Valley, respectively. Torrential rains (in January 2010) that had suddenly swept the general area of Qena–Luxor where these wadis extend (Fig. 4.9) resulted in enriching the vegetation of some extremely dry wadis at this location. This leads to the prevalence of annuals and the flourishing of the scarce perennial vegetation (El-Sharkawi et al. 1982a, b).

Wadi EI-Matuli (25°55′–26°00′ N and 32°50′–33°00′ E) is a tributary of Wadi EI-Qarn, and the latter comprises the deltaic part (Fig. 4.9). Both wadis proliferate in an area extending about 45 km east of the Nile Valley in the vicinity of the town of "Qift" in Upper Egypt. In their extension, the two wadis are rather wide (2 km width in some parts), with a flat floor which is mostly exposed to solar radiation at daytime, and are without microhabitat shelters for shade plants. Meteorological data averages showed that the warmest summer month has maximum temperature of 40.9 °C and minimum temperature of 25.1 °C and the coldest winter month has maximum temperature of 23.3 °C and minimum temperature of 8 °C. Relative

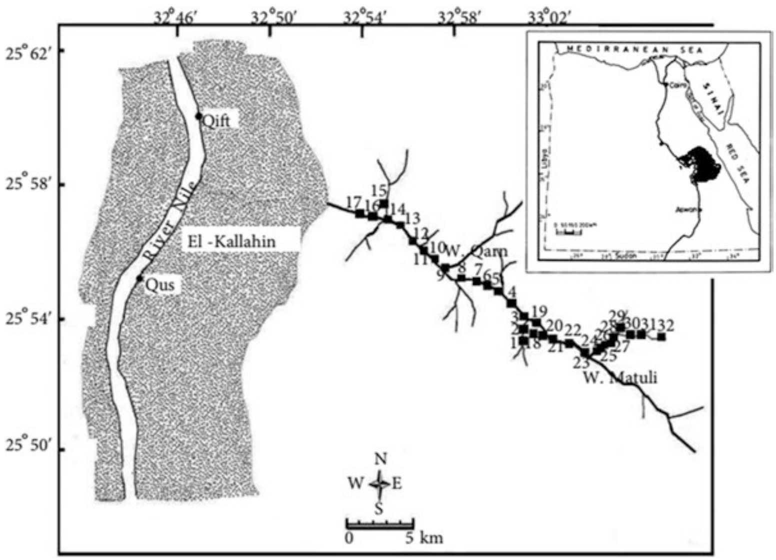

Fig. 4.9 Location map of the study area (*shaded area*)

humidity ranges from 45.9% in winter to 17.1% in summer. Rains occur only in May with 0.5 mm.

Floristic Composition

A total of 32 species (11 annuals and 21 perennials) belonging to 27 genera and 15 families were recorded (Table 4.6). The largest families were Zygophyllaceae (seven), Asteraceae and Boraginaceae (four for each), Papilionaceae (three), and Asclepiadaceae, Chenopodiaceae, and Tamaricaceae (two for each). They constituted about 75% of the recorded flora and represent most of the floristic structure in the Eastern Desert. Seven families were represented by only one species. The largest genus was *Fagonia* (four species) .

Table 4.6 Floristic composition, presence value, life forms, and chorology of the recorded species in the studied area of wadi El-Matuli and wadi El-Qarn in the Eastern Desert of Egypt

Species	Duration	Chorology	L.F	P%
Amaranthaceae				
Amaranthus graecizans L.	Per.	ME+IT	Ch	3.13
Asclepiadaceae				
Calotropis procera (Aiton) W.T.Aiton	Per.	SA+SZ	Ph	6.25
Leptadenia pyrotechnica (Forssk.) Decne.	Per.	SA+SZ	Ph	9.38
Asteraceae				
Cotula cinerea Delile	Ann.	SA	Th	40.63
Launaea cassiniana (Boiss.) Kuntze	Ann.	SA	Th	68.75
Pergularia tomentosa L.	Per.	SA+SZ	Ch	3.13
Pulicaria undulata (L.) C.A.Mey	Per.	SA	H	9.38
Boraginaceae				
Trichodesma africanum (L.) R.Br.	Ann.	SA+SZ	Ch	18.75
Morettia philaeana (Delile) DC.	Ann.	SA	H	12.5
Schouwia purpurea (Forssk.) Schweinf.	Ann.	SA	Th	93.75
Zilla spinosa (L.) Prantl.	Per.	SA	Ch	84.38
Brassicaceae				
Diplotaxis acris (Forssk.) Boiss	Ann.	SA	Th	9.38
Chenopodiaceae				
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	Per.	SA+IT	Ch	21.88
Salsola imbricata Forssk. subsp. *imbricata*	Per.	SA	Ch	96.88
Cucurbitaceae				
Citrullus colocynthis (L.) Schrad.	Per.	ME+SA+IT	H	12.5
Malvaceae				
Malva parviflora L.	Ann.	ME+ES+IT	Th	15.63
Mimosaceae				
Acacia tortilis (Forssk.) Hayne subsp. raddiana (Savi) Brenan	Per.	SA	Ph	6.25

(continued)

Table 4.6 (continued)

Species	Duration	Chorology	L.F	P%
Papilionaceae				
Astragalus hamosus L.	Per.	ME+IT	Th	9.38
Crotalaria aegyptiaca Benth.	Per.	SZ	H	3.13
Lotus hebranicus Brand.	Ann.	SA	H	6.25
Poaceae				
Phragmites australis (Cav.) Trin. ex Steud.	Per.	PAL	G	6.25
Polygonaceae				
Rumex vesicarius L.	Ann.	ME+SA+IT	Th.	21.88
Rhamnaceae				
Ziziphus spina-christi (L.) Desf.	Per.	ME+SA+IT+SZ	Ph	12.5
Tamaricaceae				
Tamarix aphylla (L.) H.Karst.	Per.	SA+SZ+IT	Ph	15.63
T. nilotica (Ehreub.) Bunge	Per.	ME+SA+IT	Ph	53.13
Zygophyllaceae				
Fagonia Arabica L.	Per.	SA	Ch	34.38
F. bruguieri DC	Per.	SA+IT	H	3.13
F. indica Burm.	Per.	SA	Ch	3.13
F. thebaica Bioss	Per.	SA	Ch	3.13
Tribulus pentandrus Forssk	Ann.	SA+SZ	Th	12.5
Zygophyllum coccineum L.	Per.	SA	Ch	93.75
Z. simplex L.	Ann.	SA+SZ	Th	68.75

Four of the recorded species are ubiquitous (have a wide ecological range of distribution), viz. *Salsola imbricata* subsp. *imbricata*, *Schouwia purpurea*, *Zygophyllum coccineum*, and *Zilla spinosa* with highest presence values (96.88%, 93.75%, 93.75%, and 84.38%, respectively). On the other hand, *Launaea cassiniana*, *Zygophyllum simplex*, *Tamarix nilotica*, and *Cotula cinerea* showed the highest presence estimate among annuals (68.75%, 68.75%, 53.13% and 40.63%, respectively). Twenty-one species or about 65.63% of the total recorded species are perennials and demonstrated a certain degree of constancy. The presence of *Tamarix aphylla*, *T. nilotica*, and *Salsola imbricata* subsp. *imbricata* refers to salinization.

Biological Spectrum

According to the Raunkiaer system (1937), six life forms were recognized (Fig. 4.10), of which chamaephytes (31.25%) constitute the largest number of species (ten species) and therophytes (nine species) ranked second with 28.13%. Phanerophytes and hemicryptophytes (six species for each) represent about 37.5% of the total flora. Geophytes (3.13%) are represented by one species.

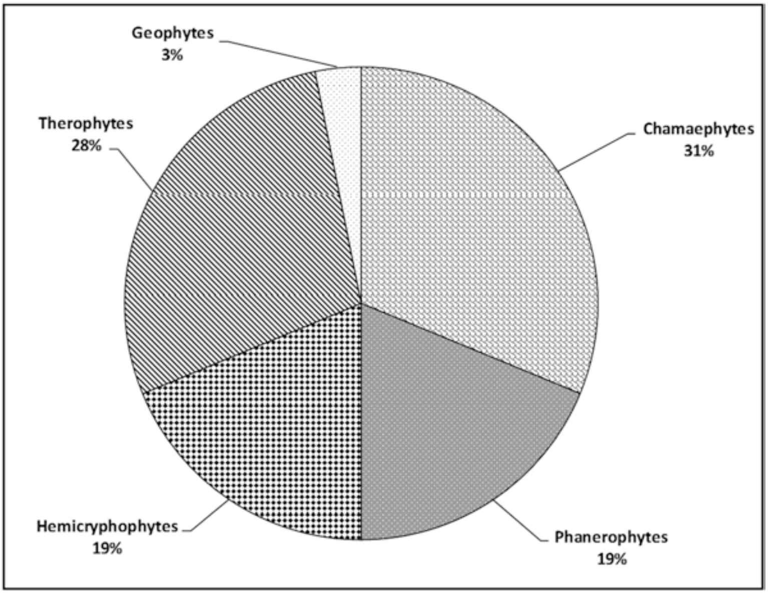

Fig. 4.10 Life-form spectrum of the recorded species in the study area

Chorological Analysis

Results of the total chorological analysis (Fig. 4.11) of the surveyed flora presented revealed that 16 species (50% of the total flora) are monoregional, of which 15 species (46.9%) are native to the Saharo–Arabian chorotype. Sudano–Zambezian ranked second with 3.1%. About 46.9% of the recorded species are biregional and pluriregional extending their distribution all over the Saharo–Arabian, Sudano–Zambezian, Irano–Turanian, and Mediterranean regions. Being part of Saharo–Arabian region, the Saharo–Arabian chorotype (bi- and pluriregional) constitutes 28.1% and 16.7%, respectively, of the recorded species. Thus, it forms the major component of the floristic composition of this study.

Multivariate Analysis

Classification of the presence–absence data set of 32 species recorded in 32 stands using the cluster analysis yielded four vegetation groups at level 3 of the hierarchy (Fig. 4.12; Table 4.7). These groups are named after the first and second dominant species as follows: (A) *Schouwia purpurea–Tamarix nilotica*, (B) *Zilla spinosa–Zygophyllum coccineum*, (C) *Rumex vesicarius–Salsola imbricata* subsp. *imbricata*, and (D) *Fagonia arabica–Launaea cassiniana*. Group C was the largest (7 stands) among other groups including 21 species, followed by group D (9 stands, 20 species). Some species showed certain degree of fidelity; e.g. *Amaranthus*

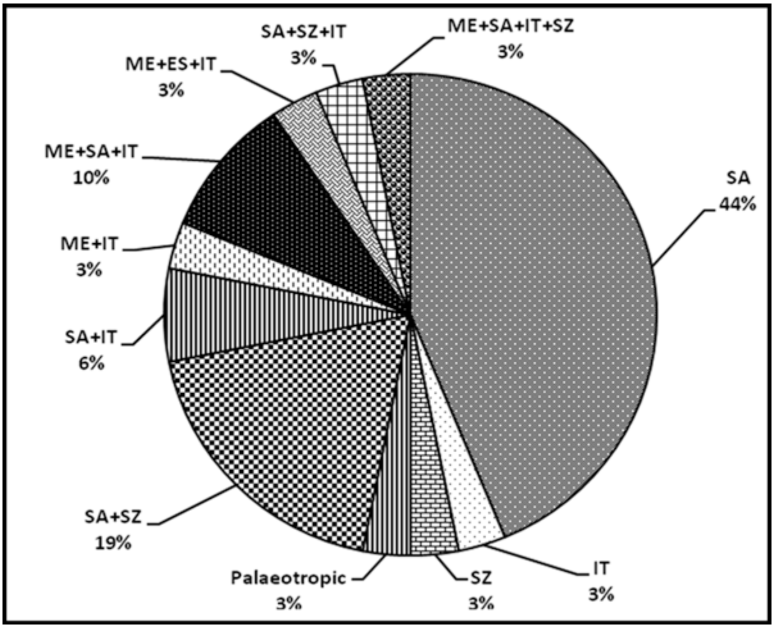

Fig. 4.11 Chorological analysis of the recorded species in the study area. For abbreviations, see (Table 4.6)

graecizans was confined to group A; *Fagonia thebaica*, *F. bruguieri*, and *Crotalaria aegyptiaca* to group B; *Rumex vesicarius* and *Malva parviflora* to group C; and *Astragalus hamosus*, *Lotus hebranicus*, *Pergularia tomentosa*, and *Fagonia indica* to group D . Eight species were recorded in all groups, among others *Cotula cinerea*, *Schouwia purpurea*, and *Zygophyllum simplex* as annuals and *Haloxylon salicornicum*, *Salsola imbricata* subsp. *imbricata*, and *Tamarix nilotica* as woody perennials. Detrended Correspondence Analysis (DCA) represented the distribution of the four vegetation groups along the first two axes (Fig. 4.13).

Soil–Vegetation Relationships

Soil characteristics of each of the four vegetation groups of the study are identified by cluster analysis and summarized in Table 4.8. Soil reaction (pH), total soluble salts (TSS), potassium, calcium, magnesium, and chlorides showed significant differences between the identified vegetation groups. The ordination diagram produced by CCA is shown in Fig. 4.14. The length and the direction of an arrow representing a given environmental variable provide an indication of the importance and direction of the gradient of environmental change for that variable, within the set of samples measured. The cumulative percentage variance of species–environment relations for the four axes amounts to 67.6% that suggests a strong association between vegetation and the measured parameters presented in the biplot (Jongman et al. 1987).

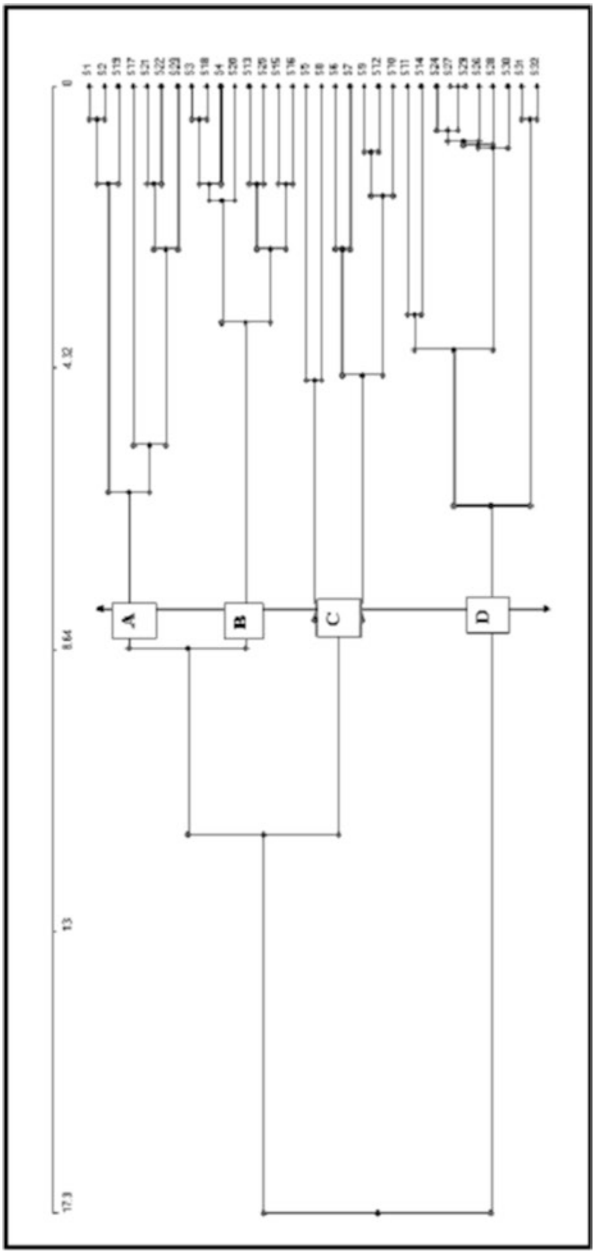

Fig. 4.12 Classification of the studied 32 stands using cluster analysis. A–D are the vegetation groups

Table 4.7 Synoptic table of the vegetation groups yielded from the classification

Species	A	B	C	D
Tamarix nilotica	100	50		
Schouwia purpurea	100	100	71.4	
Zygophyllum coccineum	85.7	100	85.7	100
Salsola imbricata subsp. *imbricata*	85.7	100	100	100
Launaea cassiniana	85.7		85.7	100
Haloxylon salicornicum	57.1			
Zilla spinosa		100	85.7	100
Zygophyllum simplex		75	57.1	88.8
Rumex vesicarius			100	
Malva parviflora			71.4	
Fagonia arabica				100
Cotula cinerea				88.8

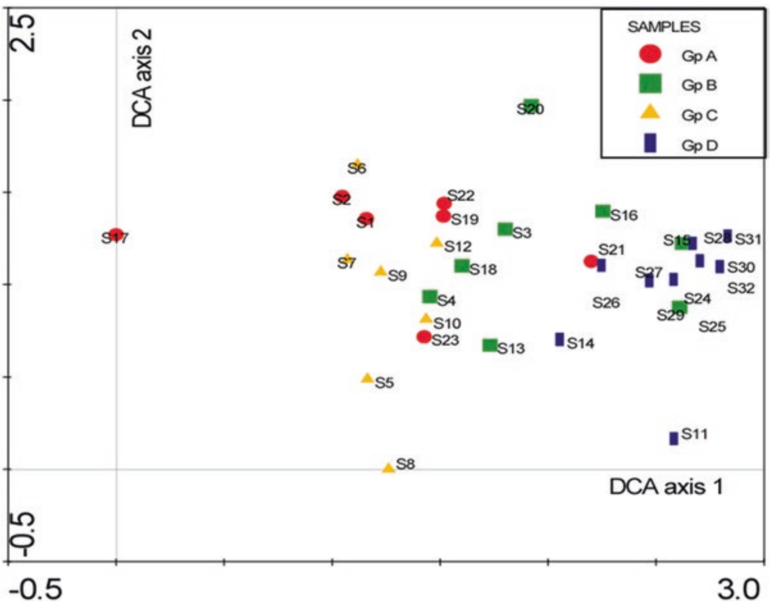

Fig. 4.13 DCA ordination diagram of the 32 stands on axes 1 and 2 as classified by cluster analysis; A–D are the four vegetation groups

Stands of group A and C were highly associated with chlorides. Whereas stands of group A were highly associated with water content, stands of group C and D showed the lowest levels. Gravel, clay, PO_4^{-3}, pH, and organic matter were highly associated with groups B and D. From the inter-set correlations (Table 4.9) resulted from the Canonical Correspondence Analysis (CCA), it demonstrated that CCA axis 1 was highly positively correlated with gravel and pH and negatively correlated

Table 4.8 Mean values, standard errors (±SE), ANOVA F-values of the soil variables in the 32 stands representing the four vegetation groups (A–D) obtained by cluster analysis

Soil variables		Vegetation groups A	B	C	D	F-ratio
pH		8.6 ± 0.3	8.2 ± 0.3	8.4 ± 0.3	8.8 ± 0.3	7.69*
TSS (mg /l)		2.7 ± 3.8	6.4 ± 4.6	78.2 ± 3.9	1.08 ± 7.2	6.2*
Gravel	(%)	2.3 ± 1.6	3.6 ± 5.4	0.39 ± 0.44	6.6 ± 6.4	2.75
Silt	(%)	18.4 ± 11.4	23.2 ± 9.5	21.2 ± 14.6	17.2 ± 12.7	0.43
Clay	(%)	7.5 ± 5.0	7.2 ± 2.9	6.0 ± 2.7	8.8 ± 7.5	0.41
OM	(%)	2.4 ± 1.2	3.2 ± 1.0	2.3 ± 1.5	2.8 ± 1.2	0.82
WC	(%)	0.4 ± 0.6	0.3 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	1.4
K^+	(mg/g soil)	0.1 ± 0.09	0.23 ± 0.07	0.05 ± 0.04	0.06 ± 0.05	13.3*
Ca^{+2}	(mg/g soil)	0.4 ± 0.3	0.7 ± 0.4	0.3 ± 0.09	0.3 ± 0.14	4.8*
Mg^{+2}	(mg/g soil)	0.2 ± 0.1	0.3 ± 0.1	0.1 ± 0.05	0.1 ± 0.05	7.9*
Cl^-	(mg/g soil)	1.0 ± 0.4	1.4 ± 0.4	1.2 ± 0.2	0.9 ± 0.3	3.6**
SO_4^{-2}	(mg/g soil)	4.2 ± 0.5	3.9 ± 1.5	3.5 ± 0.3	2.9 ± 1.2	2.17
PO_4^{-3}	(mg/g soil)	0.17 ± 0.06	0.20 ± 0.04	0.2 ± 0.08	0.2 ± 0.05	2.3

TSS total soluble salts, *OM* organic matter, *WC* water content
**P* < 0.01; ***P* < 0.05

with SO_4^{-2} and chlorides. This axis can be identified as gravel–SO_4^{-2} gradient. The CCA axis 2 was highly positively correlated with K^+, Mg^{+2}, and total soluble salts and negatively with pH. This axis can be identified as K–pH gradient.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 ($P < 0.05$) indicating that the observed patterns did not arise by chance.

4.2.3 *The Southern Wadis (Between 26°45′ and 24°01′ N and 32°45′ and 35°00′ E)*

The surveyed area covered nearly the southern quarter of the Eastern Desert (about 54,500 km^2) between 26° 45′ and 24° 1′ N latitudes and 32° 45′ and 35° 00′ E longitudes (Fig. 4.15). It covered the area between Qena Governorate and Aswan

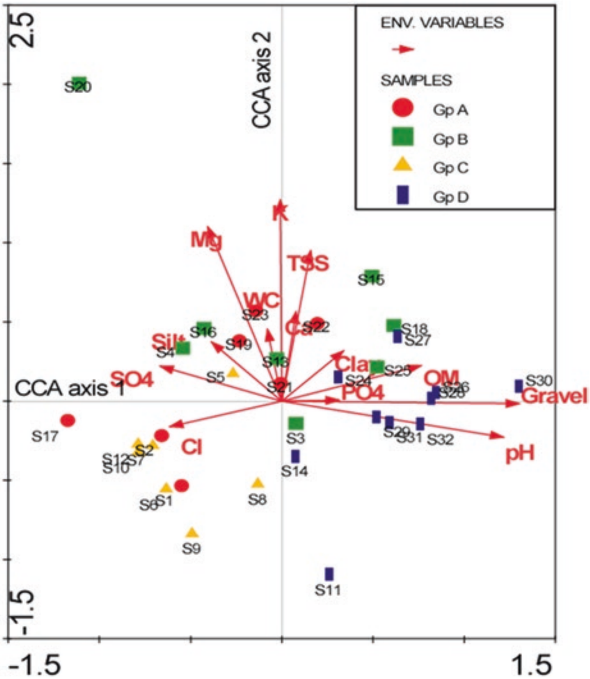

Fig. 4.14 CCA ordination biplot of the studies of 32 stands and soil variables, together with their vegetation groups

Table 4.9 Results of ordination for the first three axes of CCA. Inter-set correlations of the soil variables, together with eigenvalues and species–environment correlation coefficients

	CCA axis		
	1	2	3
Eigenvalues	0.273	0.225	0.153
Species–environment correlation coefficients	0.917	0.926	0.787
pH	0.45	−0.09	0.15
TSS	−0.05	0.38	−0.02
Gravel	0.48	−0.01	0.13
Silt	−0.014	0.15	−0.38
Clay	0.13	0.13	−0.15
Organic matter	0.28	0.09	−0.18
Water content	−0.03	0.18	−0.06
K^+	−0.003	0.51	−0.14
Ca^{+2}	0.03	0.23	−0.11
Mg^{+2}	−0.15	0.44	0.17
Cl^-	−0.23	−0.06	−0.26
SO_4^{-2}	−0.25	0.09	0.17
PO_4^{-3}	0.11	0.002	−0.43

For units and abbreviations, see Table 4.8

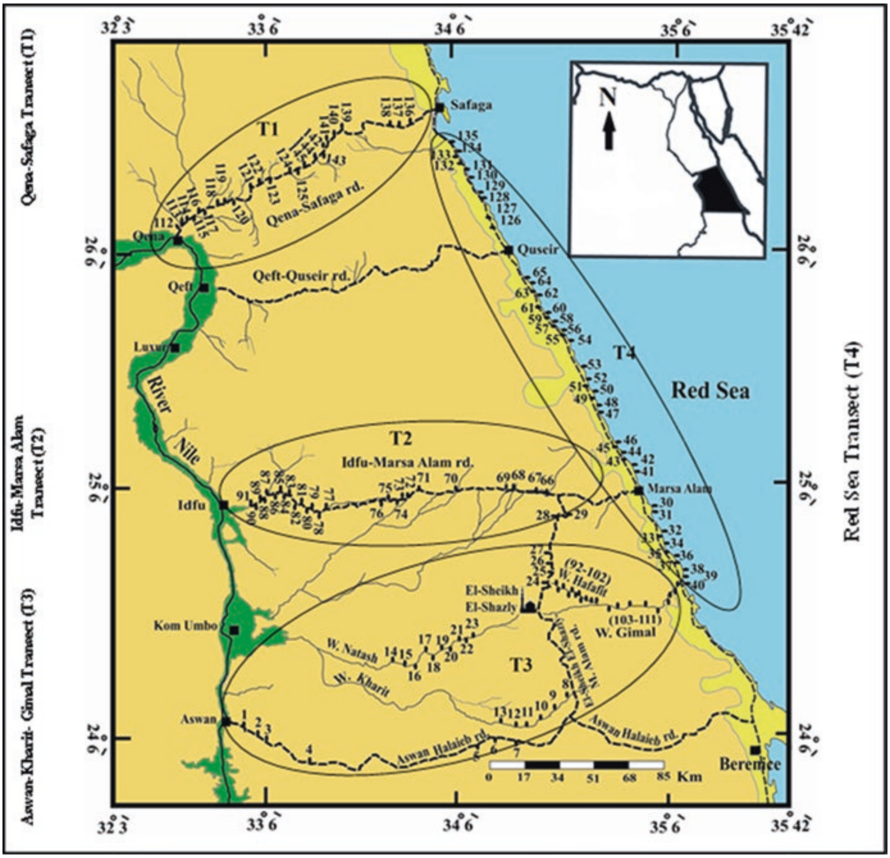

Fig. 4.15 Location map of the study area, showing the distribution of the studied stands along the four transects

Governorate on the Nile Valley and from Safaga to Berenice on the Red Sea coast. According to Zahran and Willis (2009), this area covered three desert types: (1) the limestone desert (Assiut–Qena Desert), (2) the sandstone desert (Edfu–Kom Ombo Desert), and (3) the Red Sea coastal plain. Detailed studies on the geology, geomorphology, topography, and lithology have been documented by Said (1962), Abu Al-Izz (1971), and Zahran and Willis (2009).

Vegetation sampling was performed in the surveyed area using four transects representing the three desert types. The sandstone desert included T1 which comprised of Aswan–Berenice road (300 km, 24° 05′–24° 00′ N, and 32° 55′–35° 24′ E), Wadi Kharit (250 km, 24° 26′ – 24° 12′ N, and 33° 11′–34° 40′ E), W. Natash (100 km, 24° 21′–24° 40′ N, and 33° 24′–34° 30′ E), and W. Gimal (65 km, 24° 34′–24° 40′ N, and 34°35′–35° 05′ E) and T2 which comprised of Edfu–Marsa Alam road (100 km, 25° 55′ N, 32° 55′–34° 55′ E). In the limestone desert, T3 included Qena–Safaga road (155 km, 26° 12′–26° 46′ N, and 32° 44′–33° 56′ E), and along the Red

Sea coastal plain, T4 extends for about 240 km between 24° 39′–26° 36′ N and 32° 05′–34° 00′ E. The degree of occurrence of each species was determined using the *Q*-value (Danin et al. 1985) as follows: *Q* = number of entries of a species × total number of species/13,348 (total number of entries). The *Q*-values and occurrences were categorized as follows: D = dominant, Q-value ≥0.2; VC = very common, Q-value 0.1–0.199; C = common, Q-value 0.05–0.099; O = occasional or rare species, Q-value 0.01–0.049; and S = sporad``ic or very rare, Q-value ≤0.01.

4.2.3.1 Floristic Composition

In total, 94 species (62 perennials and 32 annuals) constituted the floristic composition, representing 76 genera and 33 families (Table 4.10). About more than 50% of these species belonged to six families arranged in the following sequence, Asteraceae > Zygophyllaceae > Fabaceae > Poaceae > Chenopodiaceae > Brassicaceae. The largest family was Asteraceae (7 genera and 10 species), while 18 families were monospecific. The total number of recorded species was 46, 35, 52, and 46 for T1, T2, T3, and T4, respectively.

Table 4.10 Species composition of the four transects classified according to the different functional groups, together with their presence values (P%), chorology, Q-values, and occurrences

Species	P% for each transect				Chorotype	Q-value	Occ
	T1	T2	T3	T4			
Species present in all transects							
Shrubs							
Zilla spinosa (L.) Prantl.	81.8	96.4	73.9	15.2	SA	0.61	D
Zygophyllum coccineum L.	59.1	3.6	8.7	30.4	SA	0.23	D
Caroxylon imbricatum (Forssk.) Akhani & E. H. Roalson	45.5	67.9	2.2	2.2	SA	0.22	D
Lotus hebranicus Hochst. ex Brand	13.6	14.3	17.4	13	M	0.15	VC
Aerva javanica (Burm. F.) Juss ex Schult.	18.2	25	8.7	4.3	SA	0.12	VC
Leptadenia pyrotechnica (Forssk.) Decne.	18.2	7.1	6.5	2.2	SA+SZ	0.07	C
Annual herbs							
Astragalus vogelii (Webb.) Bornm.	9.1	21.4	13	6.5	SA	0.12	VC
Tetraena simplex (L.) Beier & Thulin	9.1	28.6	8.7	2.2	SA+SZ	0.11	VC
Polycarpaea repens (Forssk.) Asch. & Schweinf.	4.5	3.6	4.3	6.5	SA	0.05	C
Species present in three transects							
Trees							
Acacia tortilis (Forssk.) Hayne subsp. *raddiana* (Savi) Brenan	0	46.4	65.2	17.4	SA	0.36	D

(continued)

Table 4.10 (continued)

Species	P% for each transect				Chorotype	Q-value	Occ
	T1	T2	T3	T4			
Tamarix aphylla (L.) H. Karst.	0	10.7	26.1	17.4	SA+IT	0.16	VC
T. nilotica (Ehreub.) Bunge	18.2	0	4.3	30.4	SA+IT	0.14	VC
Calotropis procera (Aiton) W. T. Aiton	4.5	7.1	6.5	0	SA+SZ	0.04	O
Shrubs							
Fagonia thebaica Boiss.	18.2	46.4	0	2.2	SA	0.13	VC
Pulicaria undulata (L.) C. A. Mey	0	39.3	10.9	2.2	SA	0.12	VC
Panicum turgidum Forssk.	0	3.6	15.2	8.7	M+SA	0.08	C
Ochradenus baccatus Delile	18.2	0	2.2	6.5	SA	0.06	C
Pergularia tomentosa L.	13.6	10.7	2.2	0	SA	0.05	C
Suaeda monoica Forssk. ex J. F. Gmel.	0	7.1	2.2	6.5	SA+SZ	0.04	O
Cleome droserifolia (Forssk.) Delile	4.5	0	4.3	6.5	SA+IT	0.04	O
Perennial herbs							
Citrullus colocynthis (L.) Schrad.	22.7	35.7	32.6	0	M+SA+IT	0.21	D
Phragmites australis (Cav.) Trin. ex Steud.	18.2	3.6	0	13	PAN	0.08	C
Monsonia heliotropioides (Cav.) Boiss.	0	3.6	10.9	2.2	SA	0.05	C
Annual herbs							
Morettia philaeana (Delile) DC.	31.8	60.7	39.1	0	SA	0.3	D
Schouwia purpurea (Forssk.) Schweinf.	9.1	35.7	8.7	0	SA	0.11	VC
Trichodesma africanum (L.) R. Br.	22.7	25	4.3	0	SA+SZ	0.1	VC
Cotula cinerea Delile	9.1	3.6	19.6	0	IT	0.09	C
Forsskaolea tenacissima L.	18.2	3.6	6.5	0	SA+SZ	0.06	C
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.	4.5	10.7	2.2	0	SA	0.04	O
Species present in two transects							
Trees							
Phoenix dactylifera L.	22.7	0	0	2.2	SA+SZ	0.04	O
Shrubs							
Farsetia stylosa R. Br.	0	10.7	17.4	0	SA+SZ	0.08	C
Pulicaria incisa (Lam.) DC.	27.3	0	4.3	0	SA	0.06	C
Senna italica Mill	0	3.6	17.4	0	SA+SZ	0.06	C
Convolvulus hystrix Vahl	0	0	2.2	8.7	SA	0.04	O
Fagonia indica Burm. F.	0	0	6.5	2.2	SA	0.03	O
Heliotropium bacciferum Forssk.	0	7.1	0	2.2	SA	0.02	O
Perennial herbs							
Cynodon dactylon (L.) Pers.	13.6	0	0	4.3	COSM	0.04	O
Annual herbs							

(continued)

Table 4.10 (continued)

Species	P% for each transect				Chorotype	Q-value	Occ
	T1	T2	T3	T4			
Launaea nudicaulis (L.) Hook. F.	0	0	13	8.7	SA+IT	0.07	C
Asphodelus tenuifolius Cav.	0	7.1	15.2	0	M+SA+IT	0.06	C
Tribulus pentandrus Forssk.	0	14.3	10.9	0	SA+SZ	0.06	C
Malva parviflora L.	0	0	2.2	10.9	M+ES+IT	0.04	O
Cleome amblyocarpa Barratte &Murb.	0	3.6	10.9	0	SA+SZ	0.04	O
Arnebia hispidissima (Lehm.) DC.	4.5	0	0	4.3	SA	0.02	O
Euphorbia granulata Forssk.	0	3.6	4.3	0	M+SA+IT	0.02	O
Reseda pruinosa Delile	0	0	2.2	2.2	SA	0.01	O
Cistanche phelypaea (L.) Cout.	4.5	3.6	0	0	M+SA+IT	0.01	O
Tribulus megistopterus Kralik	4.5	0	2.2	0	SA+SZ	0.01	O
Species present in one transect							
Trees							
Balanites aegyptiaca (L.) Delile	0	0	28.3	0	SA+SZ	0.09	C
Ziziphus spina-christi (L.) Desf.	18.2	0	0	0	SA	0.03	O
Avicennia marina (Forssk.) Vierh.	0	0	0	8.7	SA	0.03	O
Ricinus communis L.	9.1	0	0	0	PAN	0.01	O
Acacia nilotica (L.) Delile	4.5	0	0	0	SU	0.007	S
Capparis decidua (Forssk.) Edgew.	0	0	2.2	0	SA+SZ	0.007	S
Hyphaene thebaica (L.) Mart.	0	0	0	2.2	SA+SZ	0.007	S
Moringa peregrina (Forssk.) Fiori	4.5	0	0	0	SZ+GC	0.007	S
Shrubs							
Zygophyllum album L.	0	0	0	26.1	M+SA+IT	0.08	C
Nitraria retusa (Forssk.) Asch.	0	0	0	26.1	SA	0.08	C
Limonium axillare (Forssk.) Kuntze	0	0	0	21.7	SA+SZ	0.06	C
Crotalaria aegyptiaca Benth.	0	0	0	10.9	SZ	0.04	O
Arthrocnemum macrostachyum (Moric.) K. Koch	0	0	0	13	M+SA+IT	0.04	O
Salvadora persica L.	0	0	8.7	0	SA+SZ	0.03	O
Cornulaca monacantha Delile	0	0	0	6.5	SA	0.02	O
Artemisia judaica L.	9.1	0	0	0	SA	0.01	O
Senna holosericea (Freseu) Greuter	0	0	4.3	0	SA	0.01	O
Fagonia mollis Delile	9.1	0	0	0	SA	0.01	O
Iphiona mucronata (Forssk.) Asch. & Schweinf	0	7.1	0	0	SA	0.01	O
Atriplex leucoclada Boiss.	4.5	0	0	0	SA+IT	0.007	S
Fagonia bruguieri DC.	4.5	0	0	0	SA+IT	0.007	S
Capparis spinosa L.	0	0	0	2.2	M+SA+SZ	0.007	S
Chrozophora oblongifolia (Delile) Spreng.	4.5	0	0	0	M+SA	0.007	S

(continued)

Table 4.10 (continued)

Species	P% for each transect				Chorotype	Q-value	Occ
	T1	T2	T3	T4			
Oxystelma esculentum (L.F.) R. Br.	0	0	2.2	0	SZ+GC	0.007	S
Caroxylon villosum (Schult.) Akhani & E. H. Roalson	4.5	0	0	0	M+SA+IT	0.007	S
Taverniera aegyptiaca Boiss.	0	0	0	2.2	SA	0.007	S
Perennial herbs							
Aeluropus littoralis (Gouan) Parl.	0	0	0	6.5	M+IT	0.02	O
Imperata cylindrica (L.) Raeusch	9.1	0	0	0	PAN	0.01	O
Juncus rigidus Desf.	0	0	0	2.2	M+SA+IT	0.007	S
Leptochloa fusca (L.) Kunth	0	0	0	2.2	PAL	0.007	S
Stipagrostis plumosa (L.) Munro ex T. Anderson	4.5	0	0	0	M+SA+IT	0.007	S
Dichanthium annulatum (Forssk.) Stapf	4.5	0	0	0	PAL	0.007	S
Cyperus rotundus L.	0	0	0	2.2	PAN	0.007	S
Typha domingensis (Pers.) Poir. ex Steud.	4.5	0	0	0	PAN	0.007	S
Annual herbs							
Astragalus eremophilus Boiss.	0	0	30.4	0	SA	0.1	C
Hippocrepis constricta Knuze	0	0	6.5	0	M+SA+IT	0.02	O
Lupinus digitatus Forssk.	0	0	6.5	0	M	0.02	O
Polycarpaea robbairea (Kuntze) Greuter & Burdet	0	0	6.5	0	SA	0.02	O
Launaea amal-aminae N. Kilian	0	0	4.3	0	SA	0.01	O
Echium horridum Batt.	4.5	0	0	0	SA	0.007	S
Chenopodium album L.	4.5	0	0	0	COSM	0.007	S
Ch. murale L.	0	0	0	2.2	COSM	0.007	S
Launaea capitata (Spreng.) Dandy	0	0	2.2	0	SA	0.007	S
Filago desertorum Pomel	4.5	0	0	0	SA+IT	0.007	S
Glinus lotoides L.	0	0	2.2	0	PAL	0.007	S
Oligomeris linifolia (Vahl.) ex Hornem J. F. Macbr.	0	0	0	2.2	SA+SZ	0.007	S
Sonchus oleraceus L.	0	0	0	2.2	COSM	0.007	S

T1 Qena–Safaga transect, *T2* Edfu–Marsa Alam transect, *T3* Aswan–Kharit–Gimal transect, *T4* Red Sea transect. *SA* Saharo–Arabian, *SZ* Sudano–Zambezian, *M* Mediterranean, *IT* Irano–Turanian, *ES* Euro–Siberian, *SU* Sudanian, *GC* Gueno–Cungo, *COSM* Cosmopolitan, *PAN* Pantropical, *PAL* Palaeotropical, *Occ* occurrence (*D* dominant, *VC* very common, *C* common, *O* occasional, *S* sporadic)

In terms of functional groups (Fig. 4.16), shrubs predominated (37 species, 39.4%) followed by annual herbs (32 species, 34%), trees (13 species, 13.8%), and perennial herbs (12 species, 12.8%). It can be noted that trees and perennial herbs were the least (2–7 species) represented among the four studied transect, while annual herbs and shrubs were the most (14–24 species). The distribution of func-

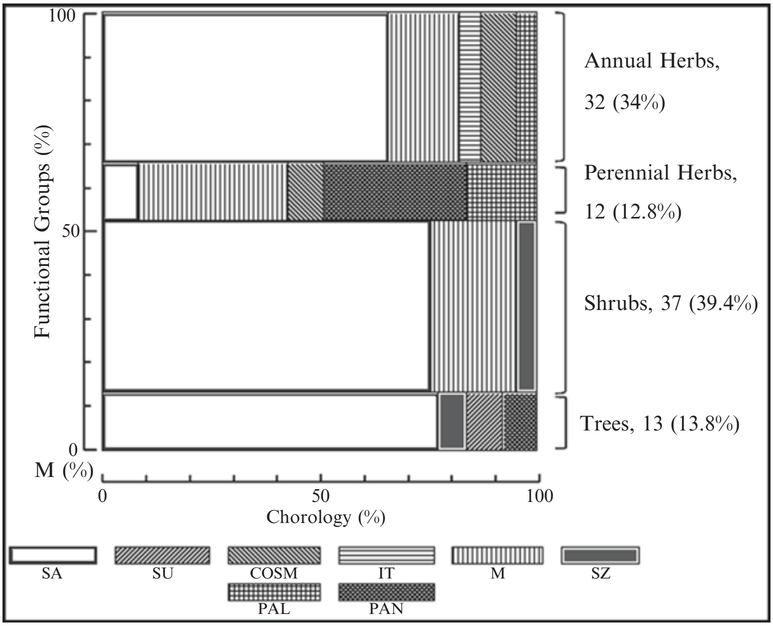

Fig. 4.16 Chorotype spectrum and functional group diagram of the study area. *M* species magnitude and average group abundance

tional groups within the studied transects showed significant difference (F-value = 3.11, *P* = 0.032) for the Red Sea transect (T4) among the others (F-value = 0.92, *P* = 0.44; F-value = 0.51, *P* = 0.68; and F-value = 0.65, *P* = 0.58 for T1, T2, and T3, respectively). Few grasses (Poaceae) were recorded within transects (5, 2, 1, and 5 species in T1, T2, T3, and T4, respectively), whereas shrubs dominated (17, 14, 20, and 23 species in T1, T2, T3, and T4, respectively).

Table 4.10 also showed the distribution of the different functional groups within the study area. The recorded 13 tress were, among others, *Acacia tortilis* subsp. *raddiana*, *Tamarix aphylla*, *Balanites aegyptiaca*, *Ziziphus spina-christi*, *Avicennia marina*, *Hyphaene thebaica*, and *Moringa peregrina*.

Shrubs were the largest (37 species) represented functional group. The widely distributed species included *Zygophyllum coccineum*, *Zilla spinosa*, *Caroxylon imbricatum*, *Aerva javanica*, and *Leptadenia pyrotechnica* that occurred in all transects. Whereas *Caroxylon villosum*, *Artemisia judaica*, *Atriplex leucoclada*, *Chrozophora oblongifolia*, *Fagonia mollis*, and *F. bruguieri* were represented only in the northern transect (T1), *Zygophyllum album*, *Nitraria retusa*, *Limonium axillare*, *Arthrocnemum macrostachyum*, *Cornulaca monacantha*, *Taverniera aegyptiaca*, and *Capparis spinosa* were confined to the Red Sea transect (T4), and another three shrubs showed consistency to the southern sector (Aswan–Kharit–Gimal transect; T3) .

Four perennial herbs (*Aeluropus littoralis*, *Juncus rigidus*, *Leptochloa fusca*, and *Cyperus rotundus*) showed consistency to the Red Sea transect (T4). For the northern transect (T1), *Imperata cylindrica*, *Stipagrostis plumosa*, *Dichanthium annulatum*, and *Typha domingensis* exhibited certain degree of consistency to this transect.

Three annual herbs (*Astragalus vogelii*, *Polycarpaea repens*, and *Tetraena simplex*) had wide range of distribution (occurred in all transects). The Aswan–Kharit–Gimal transect (T3) was characterized by *Astragalus eremophilus*, *Hippocrepis constricta*, *Lupinus digitatus*, *Launaea amal-aminae*, *L. capitata*, *Polycarpaea robbairea*, and *Glinus lotoides* which were not recorded elsewhere.

4.2.3.2 Species Abundance

The recorded species were categorized according to their Q-values as follows: (i) dominant species, of which *Zilla spinosa* had presence value of 61% and *Acacia tortilis* subsp. *raddiana* with $P = 36\%$. *Caroxylon imbricatum* and *Zygophyllum coccineum* (shrubs), *Morettia philaeana* (annual herb), and *Citrullus colocynthis* (perennial herb) had lower presence values; (ii) very common species, ten species (e.g. *Tamarix aphylla*, *Fagonia thebaica*, *Aerva javanica*, *Pulicaria undulata*, *Schouwia purpurea*); (iii) common species, 20 species included some salt-tolerant species such as *Nitraria retusa*, *Zygophyllum album*, and *Phragmites australis*; (iv) occasional species, constituted the main bulk of the flora (33 species, 35.1% of total species), with their Q-values ranged between 0.01 and 0.049; and (v) sporadic species, comprised of 25 species with Q-values = 0.007 which included four trees, seven shrubs, six perennial herbs, and eight annual herbs.

4.2.3.3 Chorological Affinities

The chorological spectrum of the recorded species was illustrated in Fig. 4.15. The Cosmopolitan, Palaeotropical, and Pantropical species constituted 12 species (12.8% of the total flora). Monoregional Saharo–Arabian chorotype was well represented (35 species) in the study area, while species of Sudano–Zambezian (*Crotalaria aegyptiaca*), Sudanian (*Acacia nilotica*), Mediterranean (*Lotus hebranicus* and *Lupinus digitatus*), and Irano–Turanian (*Cotula cinerea*) were very modestly represented.

A total of 30 species were biregional chorotypes representing 31.9% of the recorded species, distributed as follows: (1) 18 species belonging to Saharo–Arabian+Sudano–Zambezian (e.g. *Trichodesma africanum*, *Balanites aegyptiaca*, *Leptadenia pyrotechnica*, *Calotropis procera*, *Cleome amblyocarpa*, *Salvadora persica*, *Limonium axillare*, and *Hyphaene thebaica*), (2) 7 species belonging to the Saharo–Arabian+Irano–Turanian (e.g. *Tamarix aphylla*, *Launaea nudicaulis*, *Cleome droserifolia*, and *Fagonia bruguieri*), (3) 2 species belonging to Sudano–Zambezian+Guineo–Congo (*Moringa peregrina* and *Oxystelma esculentum*), (4) 1 species belonging to Mediterranean+Irano–Turanian (*Aeluropus littoralis*), and (5) 2 species belonginig to Mediterranean+Saharo–Arabian (*Panicum turgidum* and *Chrozophora oblongifolia*). In general, 18 species belonged to Saharo–Arabian+Sudano–Zambezian, while the Saharo–Arabian+Irano–Turanian species were represented by 7 species.

About 12.8% of the recorded species (12 species) were pluriregional with wide geographical range of distribution (e.g. *Citrullus colocynthis*, *Zygophyllum album*, *Arthrocnemum macrostachyum*, *Juncus rigidus*, and *Capparis spinosa*) .

4.2.3.4 Classification of the Vegetation

Application of classification using cluster analysis to the floristic presence–absence data matrix of the study area yielded seven vegetation groups (Fig. 4.17, Table 4.11). Each of the identified vegetation group will be named after the dominant species

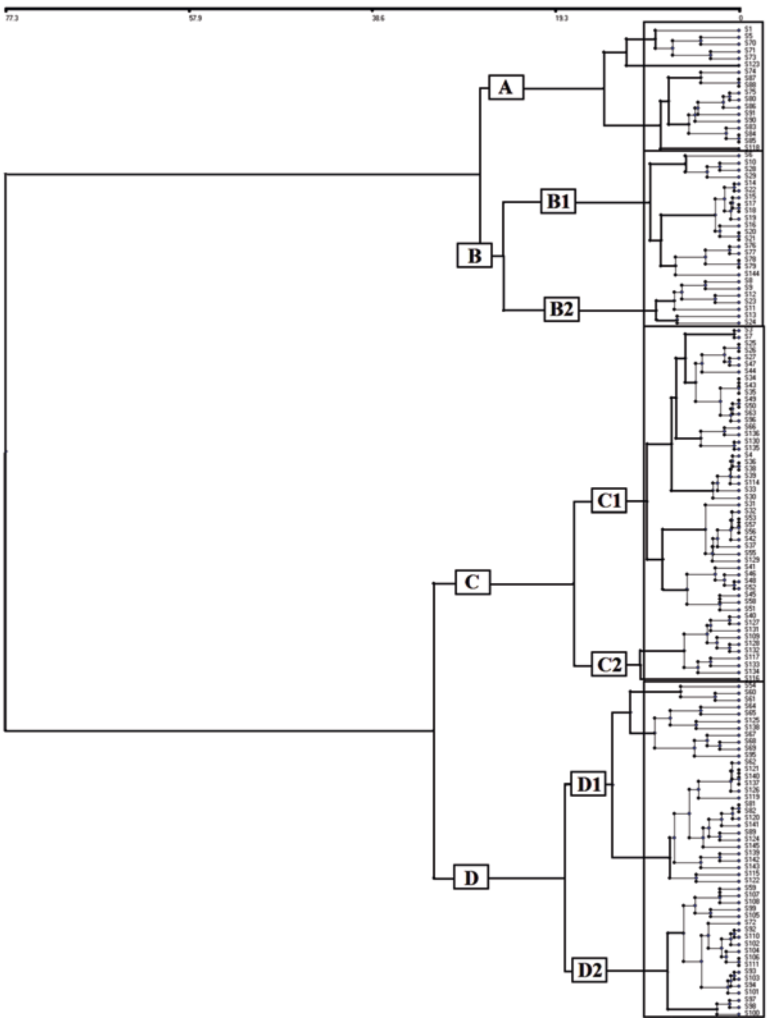

Fig. 4.17 Dendrogram showing cluster analysis of the studied 142 stands, with the 7 vegetation groups (*A*–*D2*) separated

Table 4.11 Species composition of the obtained seven vegetation groups, together with their presence values (P%)

Vegetation groups	A	B1	B2	C1	C2	D1	D2
Total number of stands	18	18	7	41	8	31	19
Total number of species	41	26	30	32	19	53	20
Species present in six groups							
Zilla spinosa	100	94.4	100		12.5	90.3	78.9
Acacia tortilis subsp. *raddiana*	38.9	77.8	71.4	19.5		16.1	63.2
Species present in five groups							
Tamarix aphylla	16.7			14.6	12.5	3.2	63.2
Zygophyllum coccineum	5.6			7.3	100	51.6	21.1
Aerva javanica	27.8		14.3	12.2		16.1	5.3
Pulicaria undulata	27.8	22.2		4.9		9.7	15.8
Lotus hebranicus	27.8	5.6	57.1	7.3		25.8	
Species present in six groups							
Citrullus colocynthis	44.4	83.3	57.1			9.7	
Morettia philaeana	94.4	83.3	85.7			12.9	
Pergularia tomentosa	5.6	5.6	14.3			12.9	
Tetraena simplex	50	11.1	14.3			9.7	
Tribulus pentandrus	27.8	11.1	14.3				5.3
Caroxylon imbricatum	83.3	22.2		2.4		35.5	
Astragalus vogelii	38.9		85.7			9.7	5.3
Forsskaolea tenacissima	11.1		28.6			9.7	5.3
Phragmites australis	11.1			7.3	37.5	9.7	
Tamarix nilotica	5.6			22	100	6.5	
Malva parviflora	5.6			2.4		9.7	5.3
Leptadenia pyrotechnica		5.6		4.9		12.9	15.8
Panicum turgidum			14.3	12.2		12.9	10.5
Species present in three groups							
Asphodelus tenuifolius	5.6	22.2	57.1				
Astragalus eremophilus	11.1	33.3	85.7				
Cotula cinerea	16.7	16.7	85.7				
Monsonia heliotropioides	11.1		57.1			3.2	
Pulicaria incisa	11.1		28.6			12.9	
Schouwia purpurea	61.1		42.9			6.5	
Trichodesma africanum	44.4		14.3			16.1	
Eremobium aegyptiacum	16.7		14.3				5.3
Farsetia stylosa	16.7		85.7				10.5
Arnebia hispidissima	5.6			2.4		3.2	
Fagonia indica	5.6			4.9		3.2	
Cynodon dactylon	5.6				25	6.5	
Fagonia thebaica	72.2				12.5	12.9	
Polycarpaea robbairea		5.6	14.3	2.4			
Convolvulus hystrix		5.6		2.4		9.7	

(continued)

Table 4.11 (continued)

Vegetation groups	A	B1	B2	C1	C2	D1	D2
Calotropis procera		11.1				3.2	15.8
Launaea nudicaulis			85.7	2.4		9.7	
Polycarpaea repens			28.6	2.4		12.9	
Nitraria retusa				17.1	50		5.3
Ochradenus baccatus					12.5	19.4	5.3
Species present in two groups							
Euphorbia granulata	11.1	5.6					
Suaeda monoica	16.7			7.3			
Cistanche phelypaea	5.6					3.2	
Ricinus communis	5.6					3.2	
Cleome amblyocarpa		11.1	57.1				
Hippocrepis constricta		5.6	28.6				
Lupinus digitatus		5.6	28.6				
Senna italica		44.4	14.3				
Artemisia judaica		5.6				3.2	
Fagonia mollis		5.6				3.2	
Limonium axillare				19.5	25		
Zygophyllum album				24.4	25		
Crotalaria aegyptiaca				7.3		6.5	
Heliotropium bacciferum				2.4		6.5	
Reseda pruinosa				2.4		3.2	
Balanites aegyptiaca				2.4			63.2
Cleome droserifolia					25	12.9	
Phoenix dactylifera					12.5	16.1	
Species present in one group							
Echium horridum	5.6						
Glinus lotoides	5.6						
Oxystelma esculentum	5.6						
Caroxylon villosum	5.6						
Stipagrostis plumosa	5.6						
Tribulus megistopterus	11.1						
Chenopodium album		5.6					
Filago desertorum		5.6					
Launaea capitata			14.3				
L. amal-aminae			28.6				
Aeluropus littoralis				7.3			
Arthrocnemum macrostachyum				14.6			
Avicennia marina				9.8			
Capparis spinosa				2.4			
Cornulaca monacantha				7.3			
Senna holosericea				4.9			
Chenopodium murale					12.5		

(continued)

Table 4.11 (continued)

Vegetation groups	A	B1	B2	C1	C2	D1	D2
Cyperus rotundus					12.5		
Hyphaene thebaica					12.5		
Juncus rigidus					12.5		
Leptochloa fusca					12.5		
Sonchus oleraceus					12.5		
Acacia nilotica						3.2	
Atriplex leucoclada						3.2	
Chrozophora oblongifolia						3.2	
Dichanthium annulatum						3.2	
Fagonia bruguieri						3.2	
Imperata cylindrica						6.5	
Iphiona mucronata						6.5	
Moringa peregrina						3.2	
Oligomeris linifolia						3.2	
Taverniera aegyptiaca						3.2	
Typha domingensis						3.2	
Ziziphus spina-christi						12.9	
Capparis decidua							5.3
Salvadora persica							21.1

(i.e. highest presence percentages). Notably, none of the recorded species occurred in all the identified groups. Apart from coarse sand, clay, and bicarbonates, the other 13 (out of total of 16) measured soil variables showed significant differences ($p < 0.05, 0.01$) between the vegetation groups (Table 4.12).

Group (A): *Zilla spinosa–Morettia philaeana* Group

The 18 stands of this group (41 species) were mostly located along Edfu–Marsa Alam transect (T2), with soil rich in its organic matter (OM) content and highest pH but had the lowest contents of fine sand, water content, Mg^{+2}, and Cl^{-}. Co-dominant species included *Caroxylon imbricatum*, *Fagonia thebaica*, *Schouwia purpurea*, and *Tetraena simplex*. Consistent species to this group were *Echium horridum*, *Glinus lotoides*, *Oxystelma esculentum*, *Caroxylon villosum*, *Stipagrostis plumosa*, and *Tribulus megistopterus*.

Group (B1): *Zilla spinosa–Citrullus colocynthis–Morettia philaeana* Group

The 18 stands of this group (26 species) were located along Wadi Natash, W. Kharit, and El-Sheikh El-Shazly-Marsa Alam road (T3). Soil contents of gravels, fine sand, OM, and pH were higher than the total means. The lowest contents were recorded in Na^{+2} and HCO_3^{-}.

Besides the dominants, *Acacia tortilis* subsp. and *Senna italica* were the co-dominants. Some species were confined to this group such as *Chenopodium album* and *Filago desertorum.*

Group (B2): *Zilla spinosa* Group

Table 4.12 Mean values, standard deviations (±SD), and ANOVA values of the soil variables in the vegetation groups (A–D2) of the study area

Soil factors	Total means	Vegetation groups A	B1	B2	C1	C2	D1	D2	F-value
Gravel	11.27 ± 10.62	13.03 ± 10.4	12.03 ± 8.3	6.91 ± 3.6	9.56 ± 10.1	7.44 ± 14.1	16.22 ± 11.7	7.76 ± 9.9	2.223*
CS	20.97 ± 16.5	15.37 ± 10.6	21.67 ± 12	20.49 ± 9.3	25.44 ± 21.9	8.53 ± 7.6	24.06 ± 15	16.36 ± 14.6	2.145
FS	9.31 ± 6.19	5.59 ± 2.9	11.40 ± 7.9	12.83 ± 4.9	9.70 ± 6.4	7.58 ± 6.3	8.39 ± 5.4	10.99 ± 6.3	2.421**
Silk	35.52 ± 16.51	39.59 ± 13.7	34.16 ± 13	44.85 ± 9.0	33.44 ± 17.6	48.35 ± 14.8	26.38 ± 13	43.52 ± 19.2	4.36**
Clay	22.91 ± 18.13	26.43 ± 13.7	20.74 ± 20	14.93 ± 6.1	21.86 ± 19.3	28.10 ± 14.6	24.95 ± 23.7	21.37 ± 9.7	0.592
TSS	0.39 ± 1.07	0.10 ± 0.04	0.07 ± 0.02	0.07 ± 0.02	0.52 ± 0.7	2.81 ± 3.4	0.19 ± 0.3	0.12 ± 0.2	11.296**
WC	2.61 ± 4.40	1.20 ± 1.1	1.51 ± 1.2	1.27 ± 0.8	5.16 ± 6.1	5.33 ± 8.7	1.58 ± 2.1	0.53 ± 1.1	5.186**
OM	1.09 ± 0.1	1.13 ± 0.1	1.12 ± 0.04	1.01 ± 0.1	1.08 ± 0.1	1.12 ± 0.03	1.11 ± 0.1	1.03 ± 0.1	3.639**
pH	7.80 ± 0.5	8.02 ± 0.3	7.97 ± 0.7	7.67 ± 0.8	7.7 ± 0.4	7.20 ± 0.5	7.77 ± 0.4	7.86 ± 0.2	3.599**
EC	1.22 ± 3.3	0.32 ± 0.1	0.22 ± 0.05	0.21 ± 0.05	1.62 ± 2.3	8.78 ± 10.8	0.60 ± 1.00	0.39 ± 0.5	11.296**
Na^+	0.83 ± 2.3	0.11 ± 0.1	0.05 ± 0.02	0.05 ± 0.02	1.29 ± 1.7	5.68 ± 7.3	0.31 ± 0.7	0.25 ± 0.5	10.916**
K^+	0.08 ± 0.1	0.04 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	0.11 ± 0.1	0.21 ± 0.3	0.05 ± 0.03	0.11 ± 0.2	3.606**
Ca^{+2}	0.63 ± 1.5	0.31 ± 0.3	0.16 ± 0.04	0.15 ± 0.05	0.83 ± 0.9	3.80 ± 5.0	0.38 ± 0.7	0.17 ± 0.1	9.575**
Mg^{+2}	0.26 ± 0.5	0.08 ± 0.03	0.10 ± 0.04	0.14 ± 0.05	0.43 ± 0.7	1.04 ± 1.4	0.16 ± 0.2	0.05 ± 0.03	5.53**
Cl^-	1.41 ± 6.0	0.09 ± 0.1	0.10 ± 0.03	0.10 ± 0.03	1.51 ± 4.1	15.0 ± 20	0.33 ± 0.8	0.15 ± 0.2	10.51**
HCO_3^-	0.18 ± 0.1	0.18 ± 0.05	0.16 ± 0.05	0.16 ± 0.1	0.18 ± 0.1	0.20 ± 0.1	0.17 ± 0.05	0.18 ± 0.04	0.64
SO_4^{-2}	5.47 ± 7.4	1.36 ± 1.2	1.44 ± 1.7	0.67 ± 1.0	10.27 ± 8.3	15.11 ± 10.1	4.29 ± 6.6	2.46 ± 2.7	12.009**

EC electrical conductivity ($mS.cm^{-1}$), soil fractions (%), *CS* coarse sand, *FS* fine sand, *OM* organic matter, Na+, K+, Ca^{+2}, Mg^{+2}, Cl^-, and HCO_3^- ($mg.g^{-1}$ d.wt. soil), SO_4^{-2} ($\mu g.g^{-1}$ d.wt. soil), OM (%)
*$p < 0.05$; **$p < 0.01$

This group (7 stands, 30 species) was characterized by the dominance of *Zilla spinosa* ($P = 100\%$), distributed along Aswan–Kharit–Gimal transect (T3). Most of the examined soil variables (gravels, clay, EC, OM, Na^{+}, K^{+}, Ca^{+2}, HCO_3^{-}, and SO_4^{-2}) attained their lowest levels in the stands of this group. However, fine sand content was the highest among the others. Among the important co-dominant species, *Astragalus vogelii*, *Cotula cinerea*, and *Launaea nudicaulis* were included. Consistent species to this group were *Launaea capitata* and *L. cassiniana*.

Group (C1): *Zygophyllum album–Tamarix nilotica* Group

Most stands of this group (41 stands, 32 species) were located along the Red Sea coast transect (T4) between Marsa Alam and Quseir and occurred on saline soil with soluble anion and cation contents higher than the groups (A, B1, B2, D1, and D2). The dominant species of this group, together with the co-dominants *Nitraria retusa* and *Limonium axillare*, exhibited the saline nature of this group. Certain species showed consistency to this group such as *Aeluropus littoralis*, *Arthrocnemum macrostachyum*, and *Avicennia marina*.

Group (C2): *Zygophyllum coccineum–Tamarix nilotica* Group

This group (8 stands) was the least diversified (19 species) among others. The stands of this group were mainly located in T4 (Quseir–Safaga transect) along the Red Sea coast which occurred on saline soil with the highest silt, clay, electric conductivity, water content, and all the examined ions. However, it recorded the lowest pH and coarse sand content. The co-dominant species included *Phragmites australis*, *Nitraria retusa*, *Limonium axillare*, and *Zygophyllum album*. Four weed species (*Chenopodium murale*, *Cyperus rotundus*, *Leptochloa fusca*, and *Sonchus oleraceus*) were recorded among the six confined species to this group.

Group (D1): *Zilla spinosa–Zygophyllum coccineum* Group

This group of stands (31) was the most diversified (53 species) among other groups and collected from three different transects (T1, T2, and T4) found on soil rich in gravels and poor in silt content. The other soil factors had intermediate position among the other groups. The co-dominant species included *Caroxylon imbricatum*, *Lotus hebranicus*, and *Ochradenus baccatus*. Twelve species showed consistency to this group such as *Acacia nilotica*, *Moringa peregrina*, *Ziziphus spina-christi* (trees), *Atriplex leucoclada*, *Fagonia bruguieri* (shrubs), and *Dichanthium annulatum* and *Imperata cylindrica* (herbs) .

Group (D2): *Zilla spinosa–Acacia tortilis* subsp.–*Tamarix aphylla–Balanitesaegyptiaca* Group

This group (19 stands, 20 species) was characterized by the combination of the dominant species, mostly located in Wadi Gimal and its tributaries (T3) on a soil rich in fine sand, silt, pH, and K^{+} and poor in Mg^{+2} and water contents. The co-dominants of this group had low presence values such as *Zygophyllum coccineum*, *Pulicaria undulata*, and *Calotropis procera*. Two species were confined to this group: *Capparis decidua* and *Salvadora persica*.

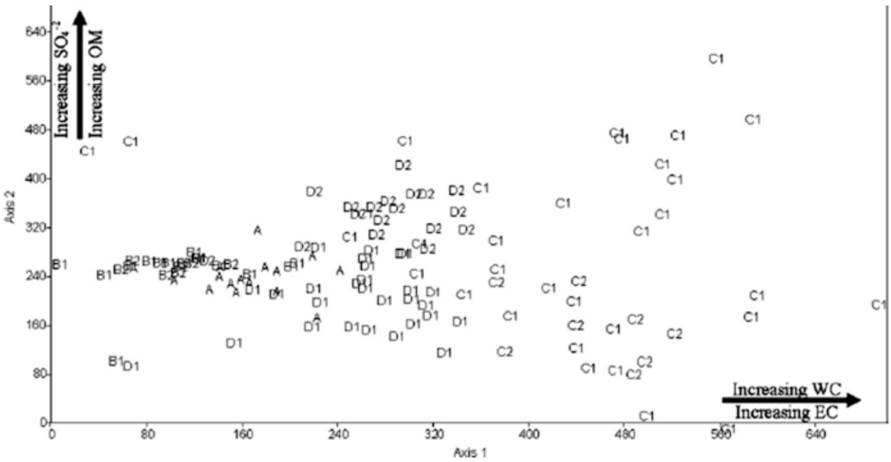

Fig. 4.18 The first two axes of the DCA ordination of 142 stands with the 7 vegetation groups (*A*–*D2*) separated by cluster analysis superimposed

4.2.3.5 Ordination of the Vegetation

Analysis of 142 stands along axes 1 and 2 (eigenvalues 0.707 and 0. 497, respectively) by DCA confirms the classification results, where the seven vegetation groups were also segregated (Fig. 4.18). Linear response models were dropped because gradients along the first two axes were longer than 4 SD units (Jongman et al. 1987). The length of gradient represented by axis 1 was >9 SD, indicating a complete turnover in species composition along this gradient. Therefore, DCA was the appropriate ordination method or indirect gradient analysis to be used.

The four DCA axes explained 5.3%, 3.7%, 2.8%, and 2.6% of the total variation in the species data, respectively. This low percentage of variance explained by the axes was attributed to the many zero values in the vegetation data set. It can be observed that the eigenvalue for the first DCA axis was high, indicating that it captured the greater proportion of the variation in species composition among stands. It is clear that group C1 occupied the positive end of the first DCA axis, while groups B1 and B2 occupied the negative end. This arrangement may explain a gradient of increasing soil salinity and moisture content, where stands of group C1 were located along the Red Sea coast transect, while B1 and B2 in the inland desert of Wadi Gimal–Aswan–Wadi Kharit transect. The first DCA axis (Table 4.13) was positively correlated with electrical conductivity ($r = 0.297$), sodium ($r = 0.342$), potassium ($r = 0.307$), calcium ($r = 0.296$), magnesium ($r = 0.318$), chlorides ($r = 0.217$), moisture contents ($r = 0.418$), and sulphates ($r = 0.612$) and negatively with pH ($r = -0.167$) and gravels ($r = -0.249$). The second axis was positively correlated with sulphates ($r = 0.172$) and organic matter ($r = 0.218$) .

Table 4.13 Simple linear correlation coefficient (r) between the soil variables and DCA axes

Soil variables	DCA axis 1	DCA axis 2
pH	−0.167*	−0.15
EC	0.297**	0.116
Na^+	0.342**	0.146
K^+	0.307**	0.026
Ca^{+2}	0.296**	0.119
Mg^{+2}	0.318**	−0.015
Cl^-	0.217**	0.098
HCO_3^-	0.119	0.072
SO_4^{-2}	0.612**	0.172*
MC	0.418**	−0.058
OM	−0.024	0.218**
Gravels	−0.249**	0.022
CS	0.034	−0.111
FS	−0.013	0.081
Silt	0.073	0.009
Clay	0.053	0.052

For soil factor abbreviations and units, see Table 4.12
*$p < 0.05$; **$p < 0.01$

4.2.3.6 Comparison Between Northern and Southern Parts of the Eastern Desert

Table (4.14) displayed the floristic composition between two geographically distant (253 km) parts (northern and southern) of the Eastern Desert. Whereas the southern part was represented by the four transects included in this study, the northern part (c. 28,800 km^2; 30° 05′ – 28° 21′ N and 31° 20′ – 33° 50′ E) included three transects, Cairo–Suez (T1N; 112 species), Korimat–Zafarana (T2N; 111 species), and Sheikh Fadl–Ras Gharib (T3 N; 54 species) mainly in the limestone part of this desert (Abdel-Aleem 2013). Altogether, 60 species were in common, 103 species confined to the northern part, and 34 to the southern part (Table 4.14).

Four trees, *Acacia tortilis* subsp. *raddiana*, *Tamarix aphylla*, *T. nilotica*, and *Calotropis procera*, exhibited a wide range of distribution where they were recorded in both parts. While nine tree species were confined to the southern part and do not penetrate northwards (e.g. *Avicennia marina*, *Hyphaene thebaica*, *Balanites aegyptiaca*, *Moringa peregrina*), the northern part was devoid of any characteristic tree species. Twenty-eight shrubby species were recorded in both areas and included among others *Zilla spinosa*, *Zygophyllum coccineum*, *Caroxylon imbricatum*, *Suaeda monoica*, *Zygophyllum album*, and *Pulicaria incisa*. Whereas 33 species were confined to the northern part, 9 species characterized the southern part. Perennial herbs were represented by 19 species, of which 6 were in common (e.g. *Phragmites australis*, *Citrullus colocynthis*, *Stipagrostis plumosa*), 7 species showed consistency to the northern part (e.g. *Lavandula stricta*, *Lasiurus scindicus*, *Aeluropus lagopoides*), and 6 species to the southern part (e.g. *Juncus rigidus*,

Table 4.14 Floristic diversity between the northern and southern parts of the Eastern Desert

Species	North[a]			South			
	T1N	T2N	T3N	T1S	T2S	T3S	T4S
Trees							
Species present in both parts							
Acacia raddiana (Savi) Brenan	35	18.2	16.7	0	46.4	65.2	17.4
Tamarix aphylla (L.) H Karst.	0	0	16.7	0	10.7	26.1	17.4
Tamarix nilotica (Ehrenb.) Bunge	40	59.1	30	18.2	0	4.3	30.4
Calotropis procera (Aiton) W. T. Aiton	30	0	0	4.5	7.1	6.5	0
Species present in the southern part							
Phoenix dactylifera L.	0	0	0	22.7	0	0	2.2
Avicennia marina (Forssk.) Vierh.	0	0	0	0	0	0	8.7
Hyphaene thebaica (L.) Mart.	0	0	0	0	0	0	2.2
Balanites aegyptiaca (L.) Delile	0	0	0	0	0	28.3	0
Capparis decidua (Forssk.) Edgew.	0	0	0	0	0	2.2	0
Ziziphus spina-christi (L.) Willd.	0	0	0	18.2	0	0	0
Acacia nilotica (L.) Delile	0	0	0	4.5	0	0	0
Ricinus communis L.	0	0	0	9.1	0	0	0
Moringa peregrina (Forssk.) Fiori	0	0	0	4.5	0	0	0
Shrubs							
Species present in both parts							
Zilla spinosa (L.) Prantl.	95	81.8	83.3	81.8	96.4	73.9	15.2
Zygophyllum coccineum L.	85	63.6	83.3	59.1	3.6	8.7	30.4
Salsola imbricata Forssk.	0	22.7	40	45.5	67.9	2.2	2.2
Aerva javanica (Burm. F.) Juss. ex Schult.	10	0	10	18.2	25	8.7	4.3
Lotus hebranicus Brand	0	0	6.7	13.6	14.3	17.4	13
Leptadenia pyrotechnica (Forssk.) Decne.	0	0	10	18.2	7.1	6.5	2.2
Pulicaria undulata (L.) C. A. Mey	50	77.3	40	0	39.3	10.9	2.2
Panicum turgidum Forssk.	55	22.7	0	0	3.6	15.2	8.7
Suaeda monoica Forssk. ex J. F. Gmel.	0	13.6	0	0	7.1	2.2	6.5
Ochradenus baccatus Delile	55	59.1	56.7	18.2	0	2.2	6.5
Cleome droserifolia (Forssk.) Delile	0	0	3.3	4.5	0	4.3	6.5
Fagonia indica Burm.	20	22.7	10	0	0	6.5	2.2
Heliotropium bacciferum Forssk.	30	4.5	6.7	0	7.1	0	2.2
Zygophyllum album L.	0	9.1	0	0	0	0	26.1
Nitraria retusa (Forssk.) Asch.	0	4.5	0	0	0	0	26.1
Capparis spinosa L.	0	4.5	0	0	0	0	2.2
Taverniera aegyptiaca Boiss.	0	9.1	0	0	0	0	2.2
Crotalaria aegyptiaca Benth.	20	0	0	0	0	0	10.9
Cornulaca monacantha Delile	5	0	0	0	0	0	6.5
Pergularia tomentosa L.	25	40.9	6.7	13.6	10.7	2.2	0
Senna italica Mill.	15	0	0	0	3.6	17.4	0
Pulicaria incisa (Lam.) DC.	10	18.2	0	27.3	0	4.3	0
Fagonia arabica L.	10	4.5	0	0	0	2.2	0

(continued)

Table 4.14 (continued)

Species	North[a]			South			
	T1N	T2N	T3N	T1S	T2S	T3S	T4S
Iphiona mucronata (Forssk.) Asch. & Schweinf.	20	31.8	0	0	7.1	0	0
Artemisia judaica L.	5	9.1	10	9.1	0	0	0
Fagonia mollis Delile	25	50	13.3	9.1	0	0	0
Fagonia bruguieri DC.	30	36.4	43.3	4.5	0	0	0
Atriplex leucoclada Boiss.	0	0	6.7	4.5	0	0	0
Chrozophora oblongifolia (Delile) Spreng.	10	0	0	4.5	0	0	0
Species present in the northern part							
Atriplex halimus L.	15	40.9	36.7	0	0	0	0
Anabasis setifera Moq.	40	31.8	33.3	0	0	0	0
Farsetia aegyptia Turra	60	50	13.3	0	0	0	0
Haloxylon salicornicum (Moq.) Bung ex Boiss.	65	59.1	56.7	0	0	0	0
Launaea spinosa (Forssk.) Sch. Bip.	10	18.2	3.3	0	0	0	0
Retama raetam (Forssk.) Webb & Berthel.	45	27.3	13.3	0	0	0	0
Hyoscyamus muticus L.	50	22.7	3.3	0	0	0	0
Astragalus trigonus DC.	0	9.1	3.3	0	0	0	0
Calligonum polygonoides L.	0	9.1	26.7	0	0	0	0
Deverra tortuosa (Desf.) DC.	35	0	3.3	0	0	0	0
Hyoscyamus boveanus(Dunal) Asch. & Schweinf.	0	0	3.3	0	0	0	0
Achillea fragrantissima (Forssk.) Sch. Bip.	5	13.6	0	0	0	0	0
Anabasis articulata (Forssk.) Moq.	40	9.1	0	0	0	0	0
Cynanchum acutum L.	15	9.1	0	0	0	0	0
Ephedra alata Decne.	10	9.1	0	0	0	0	0
Fagonia tristis Sickenb.	20	4.5	0	0	0	0	0
Gymnocarpos decanter Forssk.	5	9.1	0	0	0	0	0
Haplophyllum tuberculatum (Forssk.) A. Juss.	10	9.1	0	0	0	0	0
Lycium shawii Roem. et Sch.	10	18.2	0	0	0	0	0
Nauplius graveolens (Forssk.) Wiklund	10	31.8	0	0	0	0	0
Agathophora alopecuroides (Delile) Fenzl ex Bunge	0	13.6	0	0	0	0	0
Astragalus sieberi DC.	0	9.1	0	0	0	0	0
Cullen plicatum (Delile) C. H Stirt.	0	4.5	0	0	0	0	0
Helianthemum kahiricum Delile	0	4.5	0	0	0	0	0
Reaumuria hirtella Jaub. et Sp.	0	31.8	0	0	0	0	0
Ephedra aphylla Forssk.	10	0	0	0	0	0	0
Artemisia monosperma Del.	20	0	0	0	0	0	0
Convolvulus lanatus Vahl	5	0	0	0	0	0	0
Helianthemum lipii (L.) Dum.-Cours.	5	0	0	0	0	0	0
Kickxia aegyptiaca (Dum.) Nabelek	45	0	0	0	0	0	0

(continued)

Table 4.14 (continued)

Species	North[a]			South			
	T1N	T2N	T3N	T1S	T2S	T3S	T4S
Phagnalon barbeyanum Asch. & Schweinf.	5	0	0	0	0	0	0
Pluchea dioscoridis (L.) DC.	15	0	0	0	0	0	0
Zygophyllum decumbens Del.	10	0	0	0	0	0	0
Species present in the southern part							
Convolvulus hystrix Vahl	0	0	0	0	0	2.2	8.7
Fagonia thebaica Boiss.	0	0	0	18.2	46.4	0	2.2
Limonium axillare (Forssk.) Kuntze	0	0	0	0	0	0	21.7
Arthrocnemum macrostachyum (Moric.) K. Koch	0	0	0	0	0	0	13
Farsetia stylosa R. Br.	0	0	0	0	10.7	17.4	0
Oxystelma esculentum (L.F.) R. Br.	0	0	0	0	0	2.2	0
Salvadora persica L.	0	0	0	0	0	8.7	0
Senna holosericea (Freseu) Greuter	0	0	0	0	0	4.3	0
Salsola villosa Schult.	0	0	0	4.5	0	0	0
Perennial herbs							
Species present in both parts							
Phragmites australis (Cav.) Trin. ex Steud.	10	13.6	3.3	18.2	3.6	0	13
Cynodon dactylon (L.) Pers.	10	0	0	13.6	0	0	4.3
Leptochloa fusca (L.) Kunth	0	9.1	0	0	0	0	2.2
Citrullus colocynthis (L.) Schrad.	5	27.3	16.7	22.7	35.7	32.6	0
Stipagrostis plumosa (L.) Munro ex T. Anderson	0	4.5	3.3	4.5	0	0	0
Imperata cylindrica (L.) Raeusch	0	13.6	0	9.1	0	0	0
Species present in the northern part							
Lavandula stricta Del.	5	4.5	0	0	0	0	0
Erodium glaucophyllum (L.) L'Hér.	20	4.5	0	0	0	0	0
Erodium oxyrrhynchum M. Bieb.	10	18.2	0	0	0	0	0
Lasiurus scindicus Henrad	5	18.2	0	0	0	0	0
Launaea mucronata (Forssk.) Muschl.	40	31.8	0	0	0	0	0
Aeluropus lagopoides (L.) Trin. ex Thwaites	0	4.5	0	0	0	0	0
Pennisetum divisum (Forssk. ex J. F. Gmel.) Henrard	10	0	0	0	0	0	0
Species present in the southern part							
Monsonia heliotropioides (Cav.) Boiss.	0	0	0	0	3.6	10.9	2.2
Aeluropus littoralis (Gouan) Parl.	0	0	0	0	0	0	6.5
Juncus rigidus C. A. Mey.	0	0	0	0	0	0	2.2
Cyperus rotundus L.	0	0	0	0	0	0	2.2
Polygonum equisetiforme Sm.	0	0	0	4.5	0	0	0
Dichanthium annulatum (Forssk.) Stapf	0	0	0	4.5	0	0	0
Typha domingensis (Pers.) Poir. ex Steud.	0	0	0	4.5	0	0	0

(continued)

Table 4.14 (continued)

Species	North[a]			South			
	T1N	T2N	T3N	T1S	T2S	T3S	T4S
Annual herbs							
Species present in both parts							
Zygophyllum simplex L.	60	18.2	30	9.1	28.6	8.7	2.2
Astragalus vogelii (Webb) Bornm.	0	9.1	10	9.1	21.4	13	6.5
Launaea nudicaulis (L.) Hook.	25	59.1	6.7	0	0	13	8.7
Reseda pruinosa Del.	5	4.5	10	0	0	2.2	2.2
Malva parviflora L.	15	0	0	0	0	2.2	10.9
Sonchus oleraceus L.	15	45.5	0	0	0	0	2.2
Chenopodium murale L.	10	0	0	0	0	0	2.2
Cotula cinerea Delile	10	31.8	13.3	9.1	3.6	19.6	0
Forsskaolea tenacissima L.	10	4.5	10	18.2	3.6	6.5	0
Trichodesma africanum (L.) R. Br.	25	40.9	20	22.7	25	4.3	0
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.	0	4.5	0	4.5	10.7	2.2	0
Cleome amblyocarpa Barratte & Murb.	25	22.7	6.7	0	3.6	10.9	0
Euphorbia granulata Forssk.	0	9.1	0	0	3.6	4.3	0
Asphodelus tenuifolius Cav.	20	0	0	0	7.1	15.2	0
Senecio glaucus L.	25	36.4	3.3	4.5	0	2.2	0
Polypogon monspeliensis (L.) Desf.	0	13.6	0	4.5	0	2.2	0
Tribulus megistopterus Kralik	0	4.5	0	4.5	0	2.2	0
Glinus lotoides L.	0	40.9	6.7	0	0	2.2	0
Polycarpaea robbairea (Kuntze) Greuter & Burdet	0	0	6.7	0	0	6.5	0
Hippocrepis constricta Knuze	0	4.5	0	0	0	6.5	0
Launaea capitata (Spreng.) Dandy	0	36.4	0	0	0	2.2	0
Cistanche phelypaea (L.) Cout.	15	31.8	6.7	4.5	3.6	0	0
Diplotaxis acris (Forssk.) Boiss.	10	4.5	0	8.3	0	0	0
Rumex vesicarius L.	30	22.7	0	4.5	0	0	0
Reichardia tingitana (L.) Roth	25	18.2	0	4.5	0	0	0
Filago desertorum Pomel	0	9.1	0	4.5	0	0	0
Chenopodium album L.	5	0	0	4.5	0	0	0
Species present in the northern part							
Anastatica hierochuntica L.	10	40.9	16.7	0	0	0	0
Bassia muricata (L.) Murr. var. brevispina Bornm.	30	18.2	3.3	0	0	0	0
Trigonella stellata Forssk.	35	54.5	3.3	0	0	0	0
Centaurea aegyptiaca L.	5	13.6	10	0	0	0	0
Euphorbia retusa Forssk.	35	22.7	13.3	0	0	0	0
Bassia indica (Wight) A.J. Scott	15	0	13.3	0	0	0	0
Lotus glinoides Delile	15	0	3.3	0	0	0	0
Lotononis platycarpa (Viv.) Pic. Serm.	0	0	3.3	0	0	0	0

(continued)

Table 4.14 (continued)

Species	North[a]			South			
	T1N	T2N	T3N	T1S	T2S	T3S	T4S
Suaeda altissima (L.) Pall.	0	0	3.3	0	0	0	0
Althaea ludwigii L.	5	27.3	0	0	0	0	0
Anchusa hispida Forssk.	20	18.2	0	0	0	0	0
Diplotaxis harra (Forssk.) Boiss.	45	36.4	0	0	0	0	0
Centaurea calcitrapa L.	40	31.8	0	0	0	0	0
Astragalus bombycinus Boiss.	10	4.5	0	0	0	0	0
Conyza bonariensis (L.) Cronquist	5	4.5	0	0	0	0	0
Echinops spinosissimus Turra	70	22.7	0	0	0	0	0
Emex spinosus (L.) Campd.	5	4.5	0	0	0	0	0
Erodium malacoides (L.) L'Hér.	5	9.1	0	0	0	0	0
Matthiola livida (Del.) DC.	35	4.5	0	0	0	0	0
Paronychia arabica (L.) DC.	10	18.2	0	0	0	0	0
Plantago ovata Forssk.	5	27.3	0	0	0	0	0
Pteranthus dichotomus Forssk.	10	18.2	0	0	0	0	0
Convolvulus pilosellifolius Desr.	0	4.5	0	0	0	0	0
Astragalus hamosus L.	0	4.5	0	0	0	0	0
Astragalus schimperi Boiss.	0	4.5	0	0	0	0	0
Atractylis mernephtae Asch.	0	9.1	0	0	0	0	0
Avena sterilis L.	0	4.5	0	0	0	0	0
Cannabis sativa L.	0	4.5	0	0	0	0	0
Caylusea hexagyna (Forssk.) M.L. Green	0	4.5	0	0	0	0	0
Crypsis aculeata (L.) Aiton	0	4.5	0	0	0	0	0
Glossostemon bruguieri Desf.	0	4.5	0	0	0	0	0
Herniaria hemistemon J. Gay	0	4.5	0	0	0	0	0
Ifloga spicata (Forssk.) Sch.-Bip.	0	22.7	0	0	0	0	0
Lappula spinocarpos (Forssk.) Asch. ex Kuntze	0	13.6	0	0	0	0	0
Medicago laciniata (L.) Mill.	0	27.3	0	0	0	0	0
Phalaris paradoxa L.	0	4.5	0	0	0	0	0
Plantago amplexicaulis Cav.	0	9.1	0	0	0	0	0
Plantago ciliata Desf.	0	22.7	0	0	0	0	0
Spergularia marina (L.) Griseb.	0	13.6	0	0	0	0	0
Volutaria lippii (L.) Cass. ex Maire	0	18.2	0	0	0	0	0
Gypsophila capillaris (Forssk.) C.Chr.	10	0	0	0	0	0	0
Lolium perenne L.	5	0	0	0	0	0	0
Atractylis carduus (Forssk.) Christens	10	0	0	0	0	0	0
Fagonia glutinosa Delile	10	0	0	0	0	0	0
Aizoon canariense L.	30	0	0	0	0	0	0
Amaranthus viridis L.	5	0	0	0	0	0	0
Anthemis melampodina Delile	20	0	0	0	0	0	0
Astragalus annularis Forssk.	15	0	0	0	0	0	0

(continued)

Table 4.14 (continued)

Species	North[a]			South			
	T1N	T2N	T3N	T1S	T2S	T3S	T4S
Avena fatua L.	5	0	0	0	0	0	0
Bromus madritensis L.	5	0	0	0	0	0	0
Cichorium pumilum Jacq.	5	0	0	0	0	0	0
Eruca sativa Miller	10	0	0	0	0	0	0
Lotus halophilus Boiss. & Spruner	10	0	0	0	0	0	0
Mesembryanthemum forsskalei Hochst.	15	0	0	0	0	0	0
Neurada procumbens L.	20	0	0	0	0	0	0
Plantago cylindrica Forssk.	15	0	0	0	0	0	0
Reseda arabica Boiss.	25	0	0	0	0	0	0
Reseda decursiva Forssk.	5	0	0	0	0	0	0
Savignya parviflora (Del.) webb	5	0	0	0	0	0	0
Tribulus terrestris L.	5	0	0	0	0	0	0
Species present in the southern part							
Polycarpaea repens (Forssk.) Asch. & Schweinf.	0	0	0	4.5	3.6	4.3	6.5
Arnebia hispidissima (Lehm.) DC.	0	0	0	4.5	0	0	4.3
Oligomeris linifolia (Hornem) J. F. Macbr.	0	0	0	0	0	0	2.2
Morettia philaeana (Delile) DC.	0	0	0	31.8	60.7	39.1	0
Schouwia purpurea (Forssk.) Schweinf.	0	0	0	9.1	35.7	8.7	0
Tribulus pentandrus Forssk.	0	0	0	0	14.3	10.9	0
Lactuca serriola L.	0	0	0	4.5	0	2.2	0
Solanum nigrum L.	0	0	0	4.5	0	2.2	0
Astragalus eremophilus Boiss.	0	0	0	0	0	30.4	0
Amaranthus graecizans L.	0	0	0	0	0	2.2	0
Lupinus digitatus Forssk.	0	0	0	0	0	6.5	0
Launaea cassiniana (Boiss.) Kuntze	0	0	0	0	0	4.3	0
Euphorbia prostrata Aiton.	0	0	0	4.5	0	0	0
Sisymbrium irio L.	0	0	0	4.5	0	0	0
Trigonella hamosa L.	0	0	0	4.5	0	0	0
Echium horridum Batt.	0	0	0	4.5	0	0	0

T1N Cairo–Suez transect, *T2N* Korimat–Zafarana transect, *T3N* Sheikh Fadl–Ras Gharib transect, *T1S* Qena–Safaga transect, *T2S* Edfu–Marsa Alam transect, *T3S* Aswan–Kharit–Gimal transect, *T4S* Red Sea transect

[a]Data from Abdel-Aleem (2013)

Aeluropus littoralis) which inhabited wet and saline habitats. The annual herbs (96 species) constituted the major component of the floristic diversity and structure; 22 were in common, 64 species confined to the northern part, and 10 species confined to the southern part. The northern part included *Conyza bonariensis*, *Emex spinosa*, *Phalaris paradoxa*, *Lolium perenne*, *Cichorium endivia*, *Amaranthus viridis*, *Spergularia marina*, and *Avena fatua* which are among the common weeds of the Egyptian arable lands.

4.2.3.7 Soil–Vegetation Relationships Among the Four Transects

The inter-set correlations of CCA analysis for the soil variables, together with eigenvalues and species–environment correlation in the studied four transects, are demonstrated in Table (4.15). For T1, CCA axis 1 was highly positively correlated with silt and highly negatively correlated with pH. So, this axis can be interpreted as silt–pH gradient. CCA axis 2 was highly positively correlated with EC and highly negatively with OM. Thus, this axis can be interpreted as EC–OM gradient. CCA axis 1 for T2 was highly positively correlated with Na^+ and highly negatively correlated with silt, and this axis can be inferred as Na^+–silt gradient. CCA axis 2 for the same transect was correlated highly positively with Mg and highly negatively

Table 4.15 Inter-set correlation of CCA analysis for the soil variables, together with eigenvalues and species–environment correlation in the studied transects

Transect		T1		T2		T3		T4	
Axes		1	2	1	2	1	2	1	2
Eigenvalues		0.563	0.457	0.55	0.4	0.593	0.565	0.674	0.508
Species–environment correlations		0.986	0.988	0.948	0.98	0.963	0.942	0.957	0.927
Gravels	(%)	NI	NI	-0.233	0.239	0.727	0.246	−0.403	0.179
Coarse sand	(%)	−0.41	−0.37	0.32	0.02	0.26	−0.02	0.30	0.43
Fine sand	(%)	NI	NI	0.307	−0.08	−0.19	−0.07	0.28	−0.17
Silt	(%)	0.39	0.28	−0.35	−0.47	−0.49	−0.19	0.15	−0.24
Clay	(%)	−0.23	0.26	0.11	0.24	−0.3	0.04	−0.28	−0.25
WC	(%)	0.31	0.3	0.26	0.16	−0.01	−0.63	0.5	−0.01
OM	(%)	−0.37	−0.51	0.13	0.42	0.002	−0.1	−0.16	−0.35
pH		−0.76	0.04	0.09	0.03	0.16	0.003	−0.59	0.64
EC (mS cm^{-1})		0.14	0.51	0.17	0.02	−0.12	0.22	0.35	−0.53
Na	(mg g^{-1} dry soil)	NI	NI	0.72	−0.27	−0.05	0.34	0.38	−0.51
K	(mg g^{-1} dry soil)	−0.06	0.441	0.49	0.04	−0.14	0.23	NI	NI
Ca	(mg g^{-1} dry soil)	NI	NI	−0.1	−0.05	−0.14	−0.07	NI	NI
Mg	(mg g^{-1} dry soil)	−0.53	−0.06	0.06	0.45	−0.19	−0.79	0.44	−0.32
Cl	(mg g^{-1} dry soil)	NI	NI	0.38	0.43	−0.12	0.17	0.31	−0.54
HCO_3	(mg g^{-1} dry soil)	−0.21	0.19	−0.23	−0.08	−0.04	0.02	−0.03	−0.14
SO_4 (μg g^{-1} dry soil)		0.51	0.35	0.09	0.41	−0.34	0.37	0.56	−0.24
Species richness (SR)		−0.34	0.31	−0.25	−0.38	0.71	−0.49	−0.63	−0.16
Shannon index (H′)		−0.45	0.23	−0.21	−0.31	0.57	−0.56	−0.55	−0.17

NI not included due to high inflation factor

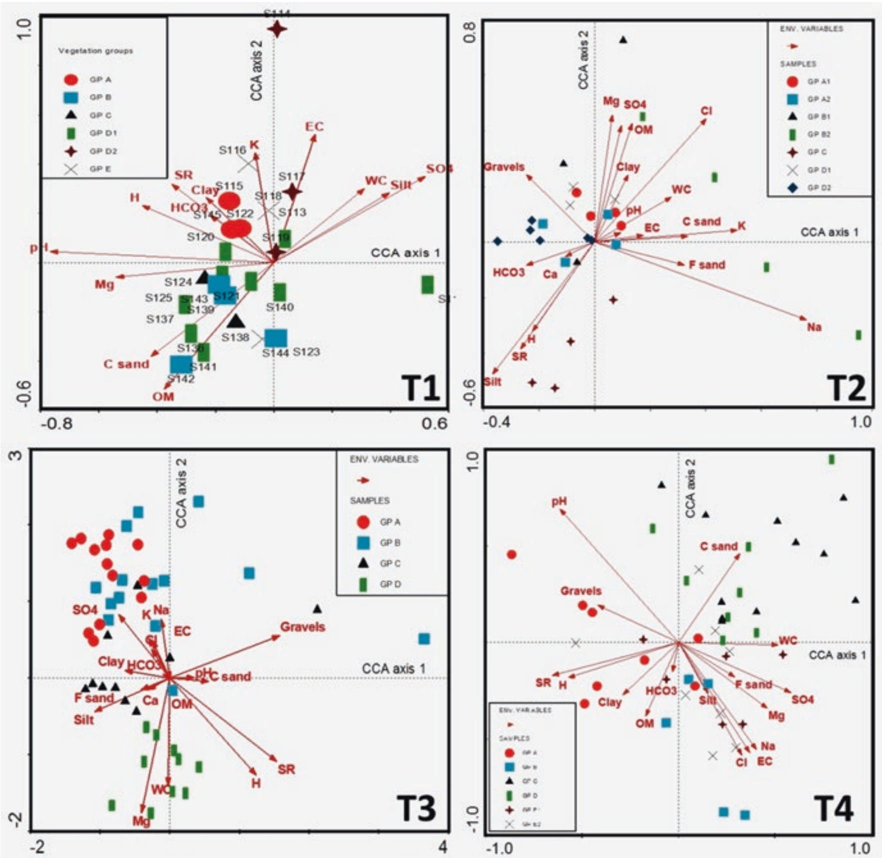

Fig. 4.19 CCA biplot of axes 1 and 2 showing the distribution of the studied stands of each transect, together with their vegetation groups and soil variables

with silt (Mg–silt gradient). CCA axis 1 for T3 can be interpreted as gravel–silt gradient, and CCA axis 2 can be interpreted as SO_4–Mg gradient. For Red Sea coast transect (T4), the inter-set correlations between the first two axes of CCA biplot revealed that SO_4^{-2}, pH, and Cl^- were the main operating factors for the vegetation of this transect.

The species–environment correlations were high for the first two axes, explaining 51.5%, 49.9%, 51.5%, and 46.7% of the cumulative variance for T1, T2, T3, and T4, respectively. These results suggested an association between the vegetation and the measured soil parameters presented in the biplot (Fig. 4.19). The species–environment correlations were high for the first two axes for all the studied transects (T1, 0.986 and 0.988; T2, 0.948 and 0.98; T3, 0.963 and 0.942; and T4, 0.957 and 0.927for axis 1 and 2, respectively) indicating that the species data were related to the measured environmental variables. A test for significance with an unrestricted Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be significant (P = 0.026, 0.038, 0.004, and 0.002 for T1, T2, T3, and T4, respectively), indicating that the observed patterns did not arise by chance.

4.3 Concluding Remarks

1. The classification and ordination analyses proposed that the vegetation of the surveyed area can be divided into seven major vegetation groups (plant communities): (A) *Zilla spinosa–Morettia philaeana*, (B1) *Zilla spinosa–Citrullus colocynthis–Morettia philaeana*, (B2) *Zilla spinosa*, (C1) *Zygophyllum album–Tamarix nilotica*, (C2) *Zygophyllum coccineum–Tamarix nilotica*, (D1) *Zilla spinosa–Zygophyllum coccineum*, and (D2) *Zilla spinosa–Acacia tortilis* subsp. *raddiana–Tamarix aphylla–Balanites aegyptiaca*. The members of each pair of groups are, in some cases, linked together by having one of the dominant species in common. It can be noted that certain vegetation groups characterized one or more of the studied transects: group (A) in Edfu–Marsa Alam transect (T2); groups (B1), (B2), and (D2) in Aswan–Kharit–Gimal transect (T3); groups (C1) and (C2) in Quseir–Safaga transect along Red Sea coast (T4); and group (D1) widely distributed in the study area including T1, T2, and T4. It can be noted that the salt-tolerant plant *Tamarix nilotica* characterized vegetation group (C1) and (C2) forming hillocks of considerable sizes characterizing the Red Sea coast transect (T4) and vigorously growing southwards (Springuel et al. 1991) representing the natural climax community type of the desert wadis with deep deposits and an underground water reserve (Kassas and Zahran 1962). *Tamarix* has been identified as a major cause of salt accumulation on the soil surface (Springuel and Ali 1990) and concentrating a high amount of sodium chloride in specialized glands within its leaves (Bosabalidis 1992). In addition, there is a relationship between the amount of *Tamarix* litter and the electric conductivity of soil (Briggs et al. 1993). Meanwhile, the lower number of recorded species in vegetation group (C1) inhabiting the coastal plains of the Red Sea may be related to its high soil salinity. Such salinity stress on floristic diversity in the study area and related areas was reported by Moustafa and Klopatek (1995) and Shaltout et al. (1997). Most of the identified vegetation groups have very much in common with that recorded in some wadis of the Eastern Desert (Salama et al. 2012, 2013), the Western Desert (Bornkamm and Kehl 1990; Abd El-Ghani 2000), in south Sinai region (Moustafa and Zaghloul 1996), and in northwestern Negev, Israel (Tielbörger 1997).
2. In extreme deserts, as in the study area, the plant growth is triggered mainly by rain and thus is as scarce and unpredictable as the precipitation itself. Vegetation develops in "contracted mode" (Monod 1954), only in habitats receiving runoff water including wadis, depressions, and channels (contracted desert; Shmida 1985). This highly dynamic vegetation is neither permanent nor seasonal but is accidental (Kassas 1966; Bullard 1997; Bornkamm 2001). The vegetation structure in the study area is relatively simple, in which the species have to withstand

the harsh environmental conditions. This is can be reflected by the presence of several highly adapted, drought-resistant species. The floristic diversity of the study area included 94 species of the vascular plants (67 perennials and 27 annuals) indicating the predominance of perennials. Asteraceae, Fabaceae, Poaceae, Zygophyllaceae, and Chenopodiaceae were the species-rich families which formed the major component of the flora. The first three families represent the most common in the Mediterranean North African flora (Quézel 1978; White 1993). These findings were in line with those of Salama et al. (2012, 2013) in the Eastern Desert and Abd El-Ghani and Fahmy (1998) in south Sinai and Salama et al. (2005) along the western Mediterranean coast.

3. Chorological analysis revealed that the Saharo–Arabian element (37.2% monoregional, 28.7% biregional, and 11.7% as pluriregional floras) forms the major component of the floristic structure along the four transects. That is because the study area lies within the Saharo–Arabian region of the Holarctic Kingdom (White 1993). The results were in agreement with those of El-Demerdash et al. (1990), Fossati et al. (1998), and Salama et al. (2012) who concluded that plants of Saharo–Arabian region constituting the shrub layer are good indicators for desert environmental conditions, while Mediterranean taxa (as mono-, bi-, or pluriregional) flourish in more mesic conditions.
4. Comparing the results of floristic diversity in the study area (south of the Eastern Desert) with that in the northern part (Abdel-Aleem 2013) indicated that 60 species were in common, 103 confined to the northern part, while 34 species were consistent to the southern part. So, the floristic diversity in the northern part is three times higher than that of the southern part of the Eastern Desert, which may be attributed to the mild climatic conditions prevailing in the north. Also, increasing the aridity southwards plays a paramount role in reducing floral diversity. On the other hand, 60% of the northern vegetation (not present in the south) was represented as annual herbs. Decreased numbers of annuals in the southern part of the Eastern Desert can be attributed to the environmental aridity and thermal continentality which increases from north to south (Abd El-Ghani 1998).
5. Vast areas in the Egyptian deserts (Western, Eastern, and Sinai) were subjected to land reclamation due to increased population growth (Biswas 1993). In the study area, agricultural processes were practised in the deltaic parts of several wadis such as Wadi Kherit, W. Natash, and W. El-Sheikh. As the land reclamation processes entail an almost complete change of the environmental factors, several common weeds of the agroecosystem were recorded (e.g. *Cynodon dactylon*, *Malva parviflora*, *Dicanthium annulatum*, *Cyperus rotundus*, *Sonchus oleraceus*, and *Chenopodium murale*). Thus, weeds find the new conditions favourable for their growth. Close to the boundaries of the desert in this study, xerophytic species naturally grow among the weeds of the cultivation. This indicated that these species are native to the natural desert vegetation and can remain after the reclamation process. Therefore, the reclaimed lands found at the desert outskirts can be considered as transitional areas of the succession process between the old cultivated lands and that of the desert (Shaheen 2002; Abd El-Ghani et al. 2013b).

6. As for species abundance, *Zilla spinosa*, *Acacia tortilis* subsp. *raddiana*, *Morettia philaeana*, *Zygophyllum coccineum*, *Caroxylon imbricatum*, and *Citrullus colocynthis* (especially in Wadi Natash) had the highest Q-values ($P = 0.61\%$, 0.36%, 0.3%, 0.23%, 0.22%, and 0.21%, respectively). This result was in line with that obtained by Abd El-Ghani et al. (2013a) and Salama et al. (2012) in the northern and central parts of the Eastern Desert and Springuel et al. (2006) in the south-eastern part of this desert. *Acacia tortilis* subsp. *raddiana*, *Morettia philaeana*, and *Citrullus colocynthis* were completely absent in the Red Sea transect, while the presence of the salt-tolerant species such as *Tamarix nilotica*, *Limonium axillare*, *Arthrocnemum macrostachyum*, *Juncus rigidus*, and *Nitraria retusa* with high presence values in the Red Sea transect indicated its salinized habitat. The record of *Avicennia marina* dominating the mangal vegetation along the Red Sea coast (T4) is notable and was documentd by Zahran and Willis (2009).

4.3.1 Biogeographical Analysis of the Eastern Desert

Five hundred sites (full-detailed data can be requested from the first author) were located with GPS representing 34 sectors covering as much as possible the different landforms in the study area that were studied between 2009 and 2012. The occurrence of species was organized into five constancy (% occurrence of a certain species in its sites/total number of sites) classes: dominant (81–100%), very common (61–80%), common (41–60%), occasional (21–40%), and sporadic (1–20%).

4.3.1.1 Floristic Analysis

This study confirmed the record of 14 species, mostly weeds, which can be considered as new additions to the flora of the study area. Altogether, 328 species were recorded from various landforms through 34 sectors representing 206 genera in 55 families (Fig. 4.20; Table 4.16) . More than 50% (188 species) of the recorded species belong to 8 families (Table 4.17); these are the species-rich families: Asteraceae (41 species), Poaceae (27 species), Fabaceae (34 species), Chenopodiaceae (24 species), Brassicaceae and Zygophyllaceae (18 species for each), and Boraginaceae and Caryophyllaceae (13 species for each). These families represent the most common in the Mediterranean North African flora (Quézel 1978; Funk et al. 2009). Asteraceae (the largest family in our list) is not only the largest family in the flora of Egypt (Täckholm 1974; Shaltout et al. 1999; Boulos 2002) but also the largest and most widespread of the flowering plants in the world (Good 1974; Funk et al. 2009). It can also be noted that *Astragalus* (ten species), *Plantago* (nine species), *Fagonia* (eight species), *Erodium* (seven species), and *Atriplex*, *Cleome*, *Heliotropium*, and *Zygophyllum* (five species for each) were the largest genera. The highest numbers of species (72, 71, and 68) were recorded in sectors 1, 8, and 3, respectively, while the lowest numbers (10, 8) were in sectors 25 and 34, respectively.

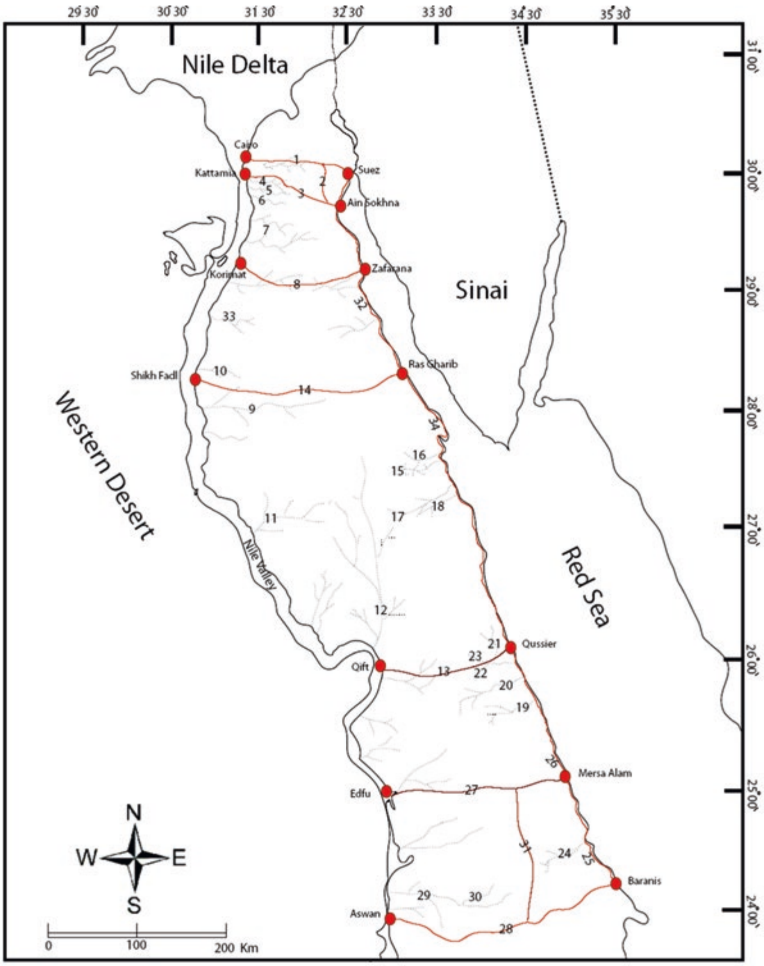

Fig. 4.20 Map of the Eastern Desert showing the location of the 34 studied sectors

Taking into account the Q-values of the recorded species, ten species showed dominancy with their Q-values ranged between 0.802 and 0.2 (Table 4.17). The highest among others were *Zilla spinosa* and *Zygophyllum coccineum* which recorded in more than 65% of the studied sites and spread their dominancy all over the Eastern Desert of Egypt. Their dominance over the communities of the Eastern Desert was documented by many scholars, among others Montasir (1938), Hassib (1951), Kassas and Imam (1954), Kassas and El Abyad (1962), Kassas and Girgis (1964), Salama and El-Naggar (1991), Abd El-Ghani (1998), and Galal and Fahmy (2012). In his account on the northern wadies of the Eastern Desert of Egypt, Fossati (1998) recorded *Zilla spinosa* and *Zygophyllum coccineum* on more than half of his reléves and indicated their wide range of distribution, often on fine calcareous neu-

Table 4.16 Characteristics of the 34 sectors, together with their names and the total number of studied sites

Symbol	Sector	Total number of sites
T1	Cairo–Suez road	20
T2	Wadi Hagul	10
T3	Kattamia–Ain Sokhna road	15
T4	Wadi Degla	20
T5	Wadi Hof	20
T6	Wadi Garawi	10
T7	El-Saff Desert	20
T8	Korimat–Zafarana road	22
T9	Wadi Tarfa	11
T10	Wadi El-Tahnawi	10
T11	Wadi Assiuty	12
T12	Wadi Qena	21
T13	Qift–Quseir road	32
T14	Ras Gharib–Sheikh Fadl road	30
T15	Wadi Abu Had	16
T16	Wadi Deb	9
T17	Wadi El-Qattar	16
T18	Wadi Beli	9
T19	Wadi Um Ghig	13
T20	Wadi Assal	12
T21	Wadi El-Nakhil	7
T22	Wadi Karim	6
T23	Wadi El-Hammaria	11
T24	Wadi El-Gemal	20
T25	Marsa Alam–Hammata road	11
T26	Marsa Alam–Quseir road	25
T27	Edfu-Marsa Alam road	26
T28	Aswan–Baranis road	7
T29	Wadi Kherit	6
T30	Wadi Natash	10
T31	El-Sheikh Salem road	6
T32	Suez–Ras Gharib road	15
T33	Wadi El-Sheikh	12
T34	Gharib–Quseir road	10

tral or alkaline substratum. The remaining eight dominant species (*Pulicaria undulata*, *Ochradenus baccatus*, *Zygophyllum simplex*, *Acacia tortilis*, *Trichodesma africanum*, *Morettia philaeana*, *Farsetia aegyptia*, and *Tamarix nilotica*) showed a regional dominancy over certain sectors. Fifty-six very common and common species with Q-values that ranged from 0.198 to 0.05 were identified and included *Haloxylon salicornicum*, *Launaea nudicaulis*, *Echinops spinosus*, *Fagonia mollis*, *Atriplex halimus*, *Euphorbia retusa*, and *Calotropis procera*. Occasional (rare) spe-

Table 4.17 Species composition of the study area arranged according to their Q-values, together with their floristic groups, status, life forms, and chorotypes

Chenopodiaceae	*Halocnemum strobilaceum* (Pall.) M.Bieb.	A1	0.002	Spo.	Ch.	Med., Sa–Si, Ir–Tu
Chenopodiaceae	*Halopeplis perfoliata* (Forssk.) Bunge ex Asch.	A1	0.002	Spo.	Ch.	Sa–Si
Cistaceae	*Helianthemum schweinfurthii* Grosser	A2	0.002	Spo.	Ch.	End.
Cleomaceae	*Cleome arabica* L.	A2	0.002	Spo.	H.	Sa–Si
Cleomaceae	*Cleome brachycarpa* DC.	D2	0.002	Spo.	Th.	Sa–Si
Convolvulaceae	*Convolvulus arvensis* L.	A2	0.002	Spo.	Geo.	Pal.
Cucurbitaceae	*Cucumis prophetarum* L.	D2	0.002	Spo.	H.	Sa–Si
Cyperaceae	*Cyperus alopecuroides* Rottb.	A2	0.002	Spo.	Hel.	Un
Cyperaceae	*Cyperus articulata* L.	A2	0.002	Spo.	H.	Pal.
Cyperaceae	*Cyperus conglomeratus* Rottb.	D2	0.002	Spo.	H.	Med., Sa–Si, Su–Za
Ephedraceae	*Ephedra ciliata* Fisch, ex C.A.Mey.	A2	0.002	Spo.	Ph.	Su–Za
Euphorbiaceae	*Chrozophora plicata* (Vahl) Spreng.	A2	0.002	Spo.	Ch.	Med., Sa–Si
Euphorbiaceae	*Euphorbia peplus* L.	A1	0.002	Spo.	Th.	Med., Ir–Tu, Eu–Si
Euphorbiaceae	*Ricinus communis* L.	A1	0.002	Spo.	Ph.	Pal.
Fabaceae	*Acacia saligna* (Labill.) Wendl.f.	B	0.002	Spo.	Ph.	Aus.
Fabaceae	*Cullen plicata* (Delile) C. H. Stirt.	A1	0.002	Spo.	H.	Sa–Si
Fabaceae	*Lotus creticus* L.	A2	0.002	Spo.	Ch.	Med.
Fabaceae	*Sesbania sesban* (L.) Merr.	A2	0.002	Spo.	Ph.	Su–Za
Fabaceae	*Tephrosia purpurea* (L.) Pers.	D2	0.002	Spo.	Ch.	Sa–Si
Frankeniaceae	*Frankenia hirsuta* L.	A1	0.002	Spo.	Ch.	Med., Eu–Si
Frankeniaceae	*Frankenia pulverulenta* L.	A1	0.002	Spo.	Th.	Med., Sa–Si, Ir–Tu
Geraniaceae	*Erodium cicutarium* (L.) L'Her.	A1	0.002	Spo.	Th.	Ir–Tu, Med.
Juncaceae	*Juncus acutus* L.	A2	0.002	Spo.	H.	Ir–Tu, Med.
Molluginaceae	*Glinus lotoides* L.	C1	0.002	Spo.	Th.	Ir–Tu, Med.
Moraceae	*Ficus palmata* Forsk.	A2	0.002	Spo.	Ph.	Sa–Si

(continued)

Table 4.17 (continued)

Orobanchaceae	*Orobanche ramosa* L.	B	0.002	Spo.	Pa.	Un
Oxalidaceae	*Oxalis corniculata* L.	A1	0.002	Spo.	Th.	Un
Plantaginaceae	*Plantago afra* L.	A1	0.002	Spo.	Th.	Med., Sa–Si, Ir–Tu
Plantaginaceae	*Plantago crypsoids* Boiss.	A2	0.002	Spo.	Th.	Near End.
Plantaginaceae	*Plantago exigua* Murray	D2	0.002	Spo.	Th.	Un
Plantaginaceae	*Plantago major* L.	A2	0.002	Spo.	Th.	Med., Ir–Tu, Eu–Si
Poaceae	*Cenchrus ciliaris* L.	A1	0.002	Spo.	H.	Su–Za, Ka–Na, Cape, Sa–Si
Poaceae	*Crypsis schoenoides* (L.) Lam.	A1	0.002	Spo.	Th.	Med., Ir–Tu, Eu–Si
Poaceae	*Dactyloctenium aegyptium* (L.) Willd.	A2	0.002	Spo.	Th.	Pal.
Poaceae	*Desmostachya bipinnata* (L.) Stapf.	A2	0.002	Spo.	Geo.	Sa–Si
Poaceae	*Dichanthium annulatus* (Forssk.) Stapf	A2	0.002	Spo.	H.	Pal.
Poaceae	*Echinochloa colona* (L.) Link.	C1	0.002	Spo.	Th.	Sa–Si, Ir–Tu
Poaceae	*Hordeum murinum* L.	A1	0.002	Spo.	Th.	Sa–Si, Ir–Tu
Chenopodiaceae	*Halocnemum strobilaceum* (Pall.) M.Bieb.	A1	0.002	Spo.	Ch.	Med., Sa–Si, Ir–Tu
Chenopodiaceae	*Halopeplis perfoliata* (Forssk.) Bunge ex Asch.	A1	0.002	Spo.	Ch.	Sa–Si
Cistaceae	*Helianthemum schweinfurthii* Grosser	A2	0.002	Spo.	Ch.	End.
Cleomaceae	*Cleome arabica* L.	A2	0.002	Spo.	H.	Sa–Si
Cleomaceae	*Cleome brachycarpa* DC.	D2	0.002	Spo.	Th.	Sa–Si
Convolvulaceae	*Convolvulus arvensis* L.	A2	0.002	Spo.	Geo.	Pal.
Cucurbitaceae	*Cucumis prophetarum* L.	D2	0.002	Spo.	H.	Sa–Si
Cyperaceae	*Cyperus alopecuroides* Rottb.	A2	0.002	Spo.	Hel.	Un
Cyperaceae	*Cyperus articulata* L.	A2	0.002	Spo.	H.	Pal.
Cyperaceae	*Cyperus conglomeratus* Rottb.	D2	0.002	Spo.	H.	Med., Sa–Si, Su–Za
Ephedraceae	*Ephedra ciliata* Fisch. ex C.A.Mey.	A2	0.002	Spo.	Ph.	Su–Za
Euphorbiaceae	*Chrozophora plicata* (Vahl) Spreng.	A2	0.002	Spo.	Ch.	Med., Sa–Si
Euphorbiaceae	*Euphorbia peplus* L.	A1	0.002	Spo.	Th.	Med., Ir–Tu, Eu–Si

Euphorbiaceae	*Ricinus communis* L.	A1	0.002	Spo.	Ph.	Pal.
Fabaceae	*Acacia saligna* (Labill.) Wendl.f.	B	0.002	Spo.	Ph.	Aus.
Fabaceae	*Cullen plicata* (Delile) C. H. Stirt.	A1	0.002	Spo.	H.	Sa–Si
Fabaceae	*Lotus creticus* L.	A2	0.002	Spo.	Ch.	Med.
Fabaceae	*Sesbania sesban* (L.) Merr.	A2	0.002	Spo.	Ph.	Su–Za
Fabaceae	*Tephrosia purpurea* (L.) Pers.	D2	0.002	Spo.	Ch.	Sa–Si
Frankeniaceae	*Frankenia hirsuta* L.	A1	0.002	Spo.	Ch.	Med., Eu–Si
Frankeniaceae	*Frankenia pulverulenta* L.	A1	0.002	Spo.	Th.	Med., Sa–Si, Ir–Tu
Geraniaceae	*Erodium cicutarium* (L.) L'Her.	A1	0.002	Spo.	Th.	Ir–Tu, Med.
Juncaceae	*Juncus acutus* L.	A2	0.002	Spo.	H.	Ir–Tu, Med.
Molluginaceae	*Glinus lotoides* L.	C1	0.002	Spo.	Th.	Ir–Tu, Med.
Moraceae	*Ficus palmata* Forsk.	A2	0.002	Spo.	Ph.	Sa–Si
Orobanchaceae	*Orobanche ramosa* L.	B	0.002	Spo.	Pa.	Un
Oxalidaceae	*Oxalis corniculata* L.	A1	0.002	Spo.	Th.	Un
Plantaginaceae	*Plantago afra* L.	A1	0.002	Spo.	Th.	Med., Sa–Si, Ir–Tu
Plantaginaceae	*Plantago crypsoids* Boiss.	A2	0.002	Spo.	Th.	Near End.
Plantaginaceae	*Plantago exigua* Murray	D2	0.002	Spo.	Th.	Un
Plantaginaceae	*Plantago major* L.	A2	0.002	Spo.	Th.	Med., Tr–Tu, Eu–Si
Poaceae	*Cenchrus ciliaris* L.	A1	0.002	Spo.	H.	Su–Za, Ka–Na, Cape, Sa–Si
Poaceae	*Crypsis schoenoides* (L.) Lam.	A1	0.002	Spo.	Th.	Med., Ir–Tu, Eu–Si
Poaceae	*Dactyloctenium aegyptium* (L.) Willd.	A2	0.002	Spo.	Th.	Pal.
Poaceae	*Desmostachya bipinnata* (L.) Stapf.	A2	0.002	Spo.	Geo.	Sa–Si
Poaceae	*Dichanthium annulatus* (Forssk.) Stapf	A2	0.002	Spo.	H.	Pal.
Poaceae	*Echinochloa colona* (L.) Link	C1	0.002	Spo.	Th.	Sa–Si, Ir–Tu
Poaceae	*Hordeum murinum* L.	A1	0.002	Spo.	Th.	Sa–Si, Ir–Tu
Poaceae	*Lolium rigidum* Gaudin	A1	0.002	Spo.	Th.	Ir–Tu, Med.

(continued)

Table 4.17 (continued)

Poaceae	*Pennisetum setaceum* (Forssk.) Chiov.	A1	0.002	Spo.	H.	Un
Poaceae	*Schismus barbatus* (L.) Thell.	A1	0.002	Spo.	Th.	Med., Ir–Tu, Eu–Si
Poaceae	*Stipa capensis* Thunb.	B	0.002	Spo.	Th.	Sa–Si, Ir–Tu
Polygonaceae	*Rumex cyprius* Murb.	A1	0.002	Spo.	Th.	Sa–Si
Polygonaceae	*Rumex dentatus* L.	A2	0.002	Spo.	Th.	Sa–Si
Polygonaceae	*Rumex simpliciflorus* Murb.	A1	0.002	Spo.	Th.	Sa–Si
Portulacaceae	*Portulaca oleracea* L.	C1	0.002	Spo.	Th.	Cosm.
Primulaceae	*Anagallis arvensis* L.	C1	0.002	Spo.	Th.	Cosm.
Resedaceae	*Reseda decursiva* Forssk.	A1	0.002	Spo.	Th.	Sa–Si
Scrophulariaceae	*Kickxia* acerbiana (Boiss.) Taeckh. & Boulos	D1	0.002	Spo.	Ch.	Sa–Si
Scrophulariaceae	*Lindenbergia indica* (L.) Vatke	C1	0.002	Spo.	Ch.	Sa–Si
Solanaceae	*Datura stramonium* L.	B	0.002	Spo.	Th.	Un
Solanaceae	*Hyoscyamus baveanus* L.	D2	0.002	Spo.	H.	End.
Solanaceae	*Hyoscyamus desertorum* (Aschers. ex Boiss.) Täckholm	A1	0.002	Spo.	H.	Med.
Solanaceae	*Withania somnifera* (L.) Dunal	B	0.002	Spo.	Ch.	Ir–Tu, Med.
Sterculiaceae	*Glossostemon bruguieri* Desf.	A1	0.002	Spo.	Th.	Ir–Tu
Thymelaeaceae	*Thymelaea hirsuta* (L.) Endl.	A1	0.002	Spo.	Th.	Sa–Si
Urticaceae	*Urtica urens* L.	B	0.002	Spo.	Th.	Med., Eu–Si
Zygophyllaceae	*Zygophyllum propinquum* Decne.	A2	0.002	Spo.	Ch.	Sa–Si
Amaranthaceae	*Amaranthus viridis* L.	A1,C1	0.004	Spo.	Th.	Cosm.
Asteraceae	*Asteriscus pygmaeus* (DC.) Coss. & Durieu	A2	0.004	Spo.	Th.	Sa–Si
Asteraceae	*Atractylis mernephthae* Asch.	A1	0.004	Spo.	Th.	Sa–Si
Asteraceae	*Filago desertorum* Pomel	A1	0.004	Spo.	Th.	Sa–Si, Ir–Tu
Asteraceae	*Iphiona scabra* DC.	D2	0.004	Spo.	Ch.	Sa–Si
Asteraceae	*Senecio flavus* (Decne.) Sch. Bip.	D2	0.004	Spo.	Th.	Sa–Si
Asteraceae	*Seriphidium herba-album* (Asso) Soják	A2	0.004	Spo.	Ch.	Sa–Si, Ir–Tu

Avicenniaceae	*Avicennia marina* (Forssk.) Vierh.	C2	0.004	Spo.	Hy.-Hel.	Sa-Si
Boraginaceae	*Arnebia hispidissima* (Lehm.) A. DC.	B	0.004	Spo.	Th.	Sa–Si
Boraginaceae	*Heliotropium ramosissimum* (Lehm.) Sieb. ex. A. DC.	A1	0.004	Spo.	Ch.	Sa–Si, Ir–Tu
Caryophyllaceae	*Sclerocephalus arabicus* Boiss.	D1	0.004	Spo.	Th.	Sa–Si
Chenopodiaceae	*Atriplex lindleyi* Moq.	A1	0.004	Spo.	Ch.	Med., Sa–Si
Chenopodiaceae	*Salsola villosa* Delile ex Schult.	C2	0.004	Spo.	Ch.	Sa–Si, Ir–Tu
Chenopodiaceae	*Suaeda monoica* Forssk. ex J. Gmelin	A1	0.004	Spo.	Ph.	Sa–Si, Su–Za
Convolvulaceae	*Convolvulus lanatus* Vahl	A1,A2	0.004	Spo.	Ch.	Sa–Si
Convolvulaceae	*Cressa cretica* L.	A1	0.004	Spo.	H.	Cosm.
Convolvulaceae	*Cuscuta pedicellata* Ledeb	A2	0.004	Spo.	Pa.	Sa–Si
Fabaceae	*Astragalus spinosus* (Forssk.) Muschl.	A2	0.004	Spo.	Ch.	Ir–Tu
Fabaceae	*Senna holosericea* (Freseu.) Greuter	C1	0.004	Spo.	H.	Af-Mo
Juncaceae	*Juncus rigidus* Desf.	A1,C1	0.004	Spo.	Hel.	Med., Sa–Si, Ir–Tu
Lamiaceae	*Lavandula pubescens* Decne.	A2	0.004	Spo.	H.	Med., Sa–Si
Plantaginaceae	*Plantago ciliata* Desf.	A1	0.004	Spo.	Th.	Sa–Si, Ir–Tu
Poaceae	*Aeluropus lagopoides* (L.) Trin. ex Thwaites	A1	0.004	Spo.	H.	Med., Ir–Tu, Eu–Si, Sa–Si
Poaceae	*Bromus madritensis* L.	A1,A2	0.004	Spo.	Th.	Med., Sa–Si, IrTu
Poaceae	*Leptochloa fusca* (L.) Kunth	A1,C1	0.004	Spo.	H.	Pal.
Poaceae	*Lolium perenne* L.	A1,B	0.004	Spo.	H.	Med., IrTu, EuSi
Polygonaceae	*Polygonum equisetiforme* Sm.	A1	0.004	Spo.	Ch.	Med., SaSi, IrTu
Solanaceae	*Solanum nigrum* L.	A2,C2	0.004	Spo.	Th.	Cosm.
Zygophyllaceae	*Peganum harmala* L.	A1	0.004	Spo.	H.	Med., IrTu, EuSi,SaSi
Zygophyllaceae	*Tribulus bimucronatus* Viv.	A2,D1	0.004	Spo.	Th.	SuZa
Zygophyllaceae	*Tribulus megistopterus* Kralik	A1,C1	0.004	Spo.	Th.	SaSi

(continued)

Table 4.17 (continued)

Arecaceae	*Phoenix dactylifera* L.	A2,C2,D1	0.006	Spo.	Ph.	SaSi
Asteraceae	*Atractylis carduus* (Forssk.) Christens.	A1,A2	0.006	Spo.	H.	SaSi
Boraginaceae	*Lappula spinocarpos* (Forssk.) Asch. ex Kuntze	A1	0.006	Spo.	Th.	SaSi, IrTu
Caryophyllaceae	*Herniaria hemistemon* J. Gay	A1,A2	0.006	Spo.	Th.	SaSi, IrTu
Chenopodiaceae	*Chenopodium album* L.	A1,A2	0.006	Spo.	Th.	Cosm.
Convolvulaceae	*Convolvulus pilosellifolius* Desr.	A1,B	0.006	Spo.	H.	SaSi, IrTu
Fabaceae	*Astragalus annularis* Forssk.	A1	0.006	Spo.	Th.	SaSi, Ir–Tu
Fabaceae	*Astragalus schimperi* Boiss.	A1,D2	0.006	Spo.	Th.	SaSi
Fabaceae	*Lotus glinoides* Delile	A1	0.006	Spo.	Th.	SaSi
Fabaceae	*Lotus halophilus* Boiss. & Spruner	A1,A2	0.006	Spo.	Th.	Med., SaSi, IrTu
Fabaceae	*Lupinus digitatus* Forssk.	C1	0.006	Spo.	Th.	Med.
Fabaceae	*Melilotus indica* (L.) All.	B	0.006	Spo.	Th.	Cosm.
Lamiaceae	*Salvia aegyptiaca* L.	A2,B	0.006	Spo.	Ch.	SaSi, IrTu
Menispermaceae	*Cocculus pendulus* (J.R. & G. Forst.) Diels	A2	0.006	Spo.	Ph.	SaSi
Orobanchaceae	*Cistanche tubulosa* (Schenk) Hook.f.	A1	0.006	Spo.	Pa.	SaSi, Ir–Tu
Poaceae	*Aeluropus littoralis* (Gouan) Parl.	C2	0.006	Spo.	H.	Sa–Si
Poaceae	*Avena sterilis* L.	A1,B	0.006	Spo.	Th.	Ir–Tu, Med.
Poaceae	*Phalaris paradoxa* L.	A1,B	0.006	Spo.	Th.	Ir–Tu, Med.
Polygonaceae	*Emex spinosa* (L.) Campd.	A1,A2	0.006	Spo.	Th.	Ir–Tu, Med.
Resedaceae	*Caylusea hexagyna* (Forssk.) M.L. Green	A1,A2	0.006	Spo.	Th.	Sa–Si
Rhamnaceae	*Ziziphus spina-christi* (L.) Desf.	A2	0.006	Spo.	Ph.	Sa–Si
Solanaceae	*Hyoscyamus albus* L.	A1,D1	0.006	Spo.	H.	Med.
Typhaceae	*Typha domingensis* (Pers.) Poir. ex Steud.	A1,A2,B	0.006	Spo.	Hy.-Hel.	Pan.
Asteraceae	*Anthemis melampodina* Delile	A1	0.008	Spo.	Th.	Sa–Si, Ir–Tu
Asteraceae	*Centaurea scoparia* Sieber ex Spreng.	A1,C1	0.008	Spo.	Ch.	Sa–Si
Asteraceae	*Conyza bonariensis* (L.) Cronquist	A1	0.008	Spo.	Th.	Un

Asteraceae	*Echinops galalensis* Schweinf	A2	0.008	Spo.	H.	Near End.
Asteraceae	*Phagnalon barbeyanum* Asch. & Schweinf.	A1,A2	0.008	Spo.	Ch.	Sa–Si
Caryophyllaceae	*Cometes abyssinica* R. Br.	D2	0.008	Spo.	Ch.	Af-Mo
Caryophyllaceae	*Spergularia diandra* (Guss.) Boiss.	A1,A2	0.008	Spo.	Th.	Med., Sa–Si, Ir–Tu
Chenopodiaceae	*Chenopodium ficifolium* Sm.	A1,A2,B	0.008	Spo.	Th.	Un
Cistaceae	*Helianthemum kahiricum* Delile	A2	0.008	Spo.	Ch.	Sa–Si
Cistaceae	*Helianthemum lipii* (L.) Dum. Cours.	A1,A2,B	0.008	Spo.	Ch.	Sa–Si
Cleomaceae	*Cleome chrysantha* Decne.	C1,D1,D2	0.008	Spo.	H.	Sa–Si
Ephedraceae	*Ephedra aphylla* Forssk.	A1	0.008	Spo.	Ph.	Sa–Si
Fabaceae	*Astragalus sieberi* DC.	A1,D1	0.008	Spo.	Ch.	Sa–Si
Fabaceae	*Astragalus tribuloides* Delile	A1,A2	0.008	Spo.	Th.	Sa–Si, Ir–Tu
Fabaceae	*Astragalus trigonus* DC.	A1	0.008	Spo.	Ch.	Sa–Si
Fabaceae	*Hippocrepis constricta* Knuze	A1,C1	0.008	Spo.	Th.	Med.
Fabaceae	*Lotononis platycarpos* (Viv.) Pichi-Serm.	A1,C1,D1	0.008	Spo.	Th.	Su–Za
Geraniaceae	*Erodium malacoides* (L.) L'Hér.	A1	0.008	Spo.	Th.	Ir–Tu, Med.
Geraniaceae	*Erodium touchyanum* Delile	A1,B	0.008	Spo.	Th.	Sa–Si
Orobanchaceae	*Orobanche cernua* Loefl.	A2	0.008	Spo.	Pa.	Med., Sa–Si, Ir–Tu
Poaceae	*Avena fatua* L.	A1,B,C2	0.008	Spo.	Th.	Cosm.
Zygophyllaceae	*Fagonia scabra* Forssk.	A1,A2,B	0.008	Spo.	Chas.	Sa–Si
Zygophyllaceae	*Tribulus terrestris* L.	A1,B,C1	0.008	Spo.	Th.	Pan.
Asteraceae	*Artemisia monosperma* Delile	A1	0.01	Occ.	Ch.	Sa–Si
Brassicaceae	*Eruca sativa* Miller	A1,B,C1	0.01	Occ.	Th.	Sa–Si, Ir–Tu
Capparidaceae	*Capparis cartilaginea* Decne.	D1,D2	0.001	Occ.	Ph.	Sa–Si
Capparidaceae	*Capparis decidua* (Forssk.) Edgew.	D2	0.001	Occ.	Ph.	Su–Za
Euphorbiaceae	*Euphorbia granulata* Forssk.	A1,C1	0.01	Occ.	Th.	Sa–Si
Fabaceae	*Astragalus bombycinus* Boiss.	A1	0.01	Spo.	Th.	Sa–Si, Ir–Tu

(continued)

Table 4.17 (continued)

Geraniaceae	*Erodium arborescens* (Desf.) Willd.	A2	0.01	Occ.	H.	Sa–Si
Aizoaceae	*Aizoon canariense* L.	A1	0.012	Occ.	Th.	Su–Za
Asteraceae	*Pluchea dioscoridis* (L.) DC.	A1,A2	0.012	Occ.	Ph.	Sa–Si, Su–Za, Ka–Na
Fabaceae	*Acacia ehrenbergiana* Hayne	C1	0.012	Occ.	Ph.	Sa–Si
Fabaceae	*Medicago laciniata* (L.) Mill.	A1	0.012	Occ.	Th.	Sa–Si
Geraniaceae	*Monosonia nivea* (Decne.) Webb	B,C1,D1	0.012	Occ.	H.	Sa–Si
Orobanchaceae	*Orobanche crenata* Forssk.	A1,A2,B	0.012	Occ.	Pa.	Med., Sa–Si, Ir–Tu
Plantaginaceae	*Plantago amplexicaulis* Cav.	A1,D2	0.012	Occ.	Th.	Med., Sa–Si, Ir–Tu
Plantaginaceae	*Plantago cylindrica* Frossk.	A1,A2,C1,D1	0.012	Occ.	Th.	Sa–Si
Poaceae	*Imperata cylindrica* (L.) Raeusch.	A1,B,C1	0.012	Occ.	H.	Med., Sa–Si, Ir–Tu
Poaceae	*Stipagrostis ciliata* (Desf.) De Winter	A1,B,C1	0.012	Occ.	H.	Sa–Si, Ka–Na, Cape
Aizoaceae	*Mesembryanthemum forsskalei* Hochst.	A1	0.014	Occ.	Th.	Sa–Si
Brassicaceae	*Pseuderucaria clavata* (Boiss. & Reut.) O.E. Schulz	A1,A2	0.014	Occ.	Th.	Sa–Si
Caryophyllaceae	*Spergularia marina* (L.) Griseb.	A1,A2	0.014	Occ.	Th.	Med., Ir–Tu, Eu–Si
Chenopodiaceae	*Chenopodium murale* L.	A1,A2,B,C1	0.014	Occ.	Th.	Cosm.
Convolvulaceae	*Convolvulus hystrix* Vahl	A1,C1,C2,D1,D2	0.014	Occ.	Ch.	Sa–Si
Fabaceae	*Taverniera aegyptiaca* Boiss.	A1,D1,D2	0.014	Occ.	Ch.	Near End.
Lamiaceae	*Stachys aegyptiaca* Pers.	A2	0.014	Occ.	H.	Sa–Si
Resedaceae	*Reseda arabica* Boiss.	A1,A2	0.014	Occ.	Th.	Sa–Si
Rutaceae	*Haplophyllum tuberculatum* (Forssk.) Juss.	A1,A2,D2	0.014	Occ.	Ch.	Sa–Si
Scrophulariaceae	*Scrophularia deserti* Delile	A1,A2	0.014	Occ.	H.	Sa–Si
Caryophyllaceae	*Polycarpaea repens* (Forssk.) Asch & Schweinf.	A2,C1,C2	0.016	Occ.	Th.	Sa–Si
Caryophyllaceae	*Pteranthus dichotomus* Forssk.	A1,A2	0.016	Occ.	Th.	Sa–Si
Chenopodiaceae	*Atriplex dimorphostegia* Kar. & Kir.	A1,A2,C1	0.016	Occ.	Th.	Ir–Tu
Euphorbiaceae	*Chrozophora oblongifolia* (Delile) Spreng.	A1,D1	0.016	Occ.	Ch.	Med., Sa–Si
Malvaceae	*Althaea ludwigii* L.	A1	0.016	Occ.	Th.	Sa–Si
Plantaginaceae	*Plantago ovata* Forssk.	A1,A2	0.016	Occ.	Th.	Med., Sa–Si, Ir–Tu

Plumbaginaceae	*Limonium axillare* (Forssk.) Kuntze	C1,C2	0.016	Occ.	H.	Sa–Si
Chenopodiaceae	*Suaeda vermiculata* Forssk. ex J.F.Gmel.	A2	0.018	Occ.	Ch.	Sa–Si
Fabaceae	*Trifolium alexandrinum* L.	A1,A2,B	0.018	Occ.	Th.	Sa–Si
Geraniaceae	*Monsonia heliotropoides* (Cav.) Boiss.	C1,D2	0.018	Occ.	H.	Sa–Si
Poaceae	*Polypogon monspeliensis* (L.) Desf.	A1,C1,C2	0.018	Occ.	Th.	Cosm.
Acanthaceae	*Blepharis edulis* (Forssk.) Pers.	D1	0.02	Occ.	H.	Sa–Si
Chenopodiaceae	*Traganum nudatum* Delile	A1,A2	0.02	Occ.	Ch.	Sa–Si
Geraniaceae	*Erodium oxyrhynchum* M.Bieb.	A1,A2	0.02	Occ.	H.	Sa–Si
Moringaceae	*Moringa peregrina* (Forssk.) Fiori	D2	0.02	Occ.	Ph.	Su–Za, Gu–Co
Plantaginaceae	*Plantago coronopus* L.	A1,B	0.02	Occ.	Th.	Med., Sa–Si, Ir–Tu
Brassicaceae	*Farsetia stylosa* R. Br.	C1,D2	0.022	Occ.	Ch.	Su–Za
Salvadoraceae	*Salvadora persica* L.	D1,D2	0.022	Occ.	Ph.	Sa–Si
Zygophyllaceae	*Fagonia tristis* Sickenb.	A1	0.022	Occ.	Ch.	Sa–Si
Asteraceae	*Launaea capitata* (Spreng.) Dandy	A1,B,C1	0.024	Occ.	Th.	Sa–Si
Boraginaceae	*Anchusa hispida* Forssk.	A1,A2	0.024	Occ.	Th.	Sa–Si, Ir–Tu
Chenopodiaceae	*Arthrocnemum macrostachyum* (Moric.) K. Koch	A1,C2	0.024	Occ.	Ch.	Med., Sa–Si
Liliaceae	*Asphodelus tenuifolius* Cav.	A1,C1,D2	0.024	Occ.	Th.	Med., Sa–Si, Ir–Tu
Caryophyllaceae	*Paronychia arabica* (L.) DC.	A1,A2,B	0.026	Occ.	Th.	Sa–Si, Ir–Tu
Chenopodiaceae	*Suaeda altissima* (L.) Pall.	A1,A2,C1,C2	0.026	Occ.	Th.	Med., Ir–Tu, Eu–Si
Fabaceae	*Astragalus hamosus* L.	A1,B,C1	0.026	Occ.	Th.	Med.
Zygophyllaceae	*Fagonia thebaica* Boiss.	C1	0.026	Occ.	Ch.	Sa–Si
Asteraceae	*Ifloga spicata* (Forssk.) Sch.-Bip.	A1,A2,C1	0.028	Occ.	Th.	Med., Sa–Si, Ir–Tu
Fabaceae	*Senna italica* Mill.	A1,C1,D2	0.028	Occ.	H.	Su–Za
Neuradaceae	*Neurada procumbens* L.	A1,B	0.028	Occ.	Th.	Sa–Si
Plumbaginaceae	*Limonium pruinosum* (L.) Kuntze Charz.	A2	0.028	Occ.	H.	Sa–Si
Asteraceae	*Volutaria lippii* (L.) Cass. ex Maire	A1,A2,B	0.03	Occ.	Th.	Med., Sa–Si
Chenopodiaceae	*Atriplex leucoclada* Boiss.	A1,A2,C1	0.03	Occ.	Ch.	Sa–Si, Ir–Tu

(continued)

Table 4.17 (continued)

Ephedraceae	*Ephedra alata* Decne.	A1,A2,D1	0.03	Occ.	Ph.	Med., Sa–Si
Asteraceae	*Pulicaria incisa* (Lam.) DC.	A1,C1,D2	0.032	Occ.	H.	Sa–Si, Gu–Co
Boraginaceae	*Heliotropium arbainense* Fresen.	A2,B,C2	0.032	Occ.	Ch.	Ir–Tu
Lamiaceae	*Lavandula coronopifolia* Poir.	A1,A2,D2	0.032	Occ.	Ch.	Sa–Si
Apiaceae	*Deverra triradiata* Hochst. ex Boiss.	A2,B	0.034	Occ.	Ch.	Sa–Si
Asteraceae	*Nauplius graveolens* (Forssk.) Wilklund	A1,A2	0.034	Occ.	H.	Sa–Si
Chenopodiaceae	*Agathophora alopecuroides* (Delile) Fenzl ex Bunge	A1,A2	0.034	Occ.	Ch.	Sa–Si
Chenopodiaceae	*Bassia indica* (Wight) A.J.Scott	A1,B,C2	0.034	Occ.	Th.	Sa–Si, Ir–Tu
Geraniaceae	*Erodium crassifolium* L'Her.	A1,A2,B,D2	0.034	Occ.	Geo.	Sa–Si
Malvaceae	*Malva parviflora* L.	A1,B,C1,C2	0.034	Occ.	Th.	Med., Ir–Tu, Eu–Si
Poaceae	*Cynodon dactylon* (L.) Pers.	A1,A2,B,C1	0.034	Occ.	Geo.	Cosm.
Zygophyllaceae	*Fagonia arabica* L.	A1,A2,B,C1	0.034	Occ.	Ch.	Sa–Si
Zygophyllaceae	*Fagonia glutinosa* Delile	A1,A2	0.034	Occ.	H.	Sa–Si
Apocynaceae	*Cynanchum acutum* L.	A1,A2	0.036	Occ.	Ch.	Sa–Si
Caryophyllaceae	*Gypsophila capillaris* (Forssk.) C. Chr.	A1,A2	0.036	Occ.	H.	Med., Sa–Si
Fabaceae	*Crotalaria aegyptiaca* Benth.	A1,A2,C1,C2	0.036	Occ.	H.	Sa–Si
Tamaricaceae	*Tamarix tetragyna* Ehrenb.	A1,A2,C1,C2,D1,D2	0.036	Occ.	Ph.	Med., Sa–Si, Ir–Tu
Zygophyllaceae	*Balanites aegyptiaca* (L.) DC.	D1,D2	0.036	Occ.	Ph.	Sa–Si, Su–Za
Asteraceae	*Launaea spinosa* (Forssk.) Sch. Bip.	A1,A2,D2	0.038	Occ.	Ch.	SaSo
Caryophyllaceae	*Polycarpaea robbairea* (Kuntze) Greuter & Burdet	A1,C1,D1,D2	0.038	Occ.	Th.	SaSi
Fabaceae	*Astragalus eremophilus* Boiss.	A1,C1	0.038	Occ.	Th.	SaSi
Geraniaceae	*Erodium glaucophyllum* (L.) L'Hér.	A1,A2,B	0.038	Occ.	H.	SaSi
Scrophulariaceae	*Kickxia aegyptiaca* (Dum.) Nabelek	A1,A2,B	0.038	Occ.	Ch.	SaSi
Asteraceae	*Centaurea aegyptiaca* L.	A1,A2,B	0.04	Occ.	H.	SaSi
Fabaceae	*Alhagi graecorum* (DC.) Alef.	A1,A2,C1,C2	0.04	Occ.	H.	SaSi, IrTu
Asteraceae	*Reichardia tingitana* (L.) Roth	A1,A2,B	0.042	Occ.	Th.	Med., SaSi, IrTu
Boraginaceae	*Heliotropium bacciferum* Forssk.	A1,A2,D1,D2	0.042	Occ.	Ch.	SaSi

Capparidaceae	*Capparis spinosa* L.	A1,A2,C2	0.042	Occ.	Ch.	Med., SaSi, IrTu
Poaceae	*Lasiurus scindicus* Henrard	A1,A2,B,C2	0.044	Occ.	H.	SaSi
Zygophyllaceae	*Zygophyllum decumbens* Delile	A1,A2	0.046	Occ.	Ch.	SaSi
Poaceae	*Phragmites australis* (Cav.) Trin. ex Steud.	A1,A2,B,C1,C2,D1	0.048	Occ.	Hy.-	Pan.
Resedaceae	*Oligomeris linifolia* (Vahl) Macbr.	A1,A2,B,C1,C2	0.05	Com.	Th.	SaSi
Asteraceae	*Centaurea calcitrapa* L.	A1,A2,C2	0.052	Com.	H.	Med., SaSi, IrTu
Chenopodiaceae	*Bassia muricata* (L.) Murr.	A1,A2,B	0.052	Com.	Th.	SaSi, IrTu
Poaceae	*Pennisetum divisum* (Forssk. ex J. F. Gmel.) Henrard	A1,A2,C2	0.052	Com.	H.	SaSi
Solanaceae	*Hyoscyamus muticus* L.	A1,A2,B,D1,D2	0.052	Com.	H.	SaSi, IrTu
Boraginaceae	*Heliotropium digynum* (Forssk.) Asch.	A1,A2,B,C1,C2	0.054	Com.	Ch.	SaSi
Nitrariaceae	*Nitraria retusa* (Forssk.) Asch.	A1,A2,C2	0.054	Com.	Ph.	SaSi
Asteraceae	*Sonchus oleraceus* L.	A1,A2,B,C1	0.056	Com.	Th.	Cosm.
Brassicaceae	*Anastatica hierochuntica* L.	A1,A2,B	0.056	Com.	Th.	SaSi
Chenopodiaceae	*Cornulaca monacantha* Delile	A1,A2,B,C2,D1	0.06	Com.	Ch.	SaSi
Fabaceae	*Acacia seyal* Delile	A1,C1,C2	0.06	Com.	Ph.	Un
Apocynaceae	*Calotropis procera* (Ait.) Ait. f.	A1,A2,B,C1,C2,D2	0.062	Com.	Ph.	SaSi
Brassicaceae	*Eremobium aegyptiacum* (Spreng) Asch. & Schweinf. ex Boiss	A1,A2,B,C1	0.064	Com.	Th.	SaSi
Zygophyllaceae	*Zygophyllum album* L.f.	A1,A2,C2	0.066	Com.	Ch.	SaSi, IrTu
Euphorbiaceae	*Euphorbia retusa* Forssk.	A1,A2,B	0.068	Com.	H.	SaSi
Brassicaceae	*Schouwia purpurea* (Forssk.) Schweinf.	B,C1	0.07	Com.	Th.	SaSi
Fabaceae	*Astragalus vogelii* (Webb) Bomm.	A1,C1,C2,D1,D2	0.07	Com.	Th.	SaSi
Orobanchaceae	*Cistanche phelypaea* (L.) Count.	A1,A2,C1,D1	0.07	Com.	Pa.	Med., SaSi, IrTu
Polygonaceae	*Calligonum polygonoides* L.	A1,B,C1	0.07	Com.	Ch.	Med., SaSi
Asteraceae	*Achillea fragrantissima* (Forssk.) Sch. Bip.	A1,A2	0.072	Com.	Ch.	SaSi, IrTu
Tamaricaceae	*Tamarix aphylla* (L.) H. Karst.	A1,A2,C1,C2,D1,D2	0.072	Com.	Ph.	SaSi
Zygophyllaceae	*Fagonia indica* Burm.f.	A1,C1,D1,D2	0.072	Com.	Ch.	SaSi

(continued)

Table 4.17 (continued)

Chenopodiaceae	*Anabasis articulata* (Forssk.) Moq.	A1,A2,C1	0.074	Com.	Ch.	SaSi, IrTu
Cleomaceae	*Cleome droserifolia* (Forssk.) Delile	A1,A2,C1,C2,D1,D2	0.074	Com.	H.	SaSi
Amaranthaceae	*Aerva javanica* (Burm. f.) Spreng.	A1,C1,D1,D2	0.076	Com.	Ch.	SaSi
Asteraceae	*Artemisia judaica* L.	A1,A2,B,C1,C2,D2	0.076	Com.	Th.	SaSi
Solanaceae	*Lycium shawii* Roem. & Sch.	A1,A2,C2	0.078	Com.	Ph.	SaSi
Asteraceae	*Launaea mucronata* (Forssk.) Muschl.	A1,A2,B,C1,D1,D2	0.082	Com.	H.	SaSi
Cleomaceae	*Cleome amblyocarpa* Barratte & Murb.	A1,A2,B,C1	0.082	Com.	Th.	SaSi, SuZa
Brassicaceae	*Matthiola livida* (Delile) DC.	A1,A2,B,C1	0.09	Com.	Th.	SaSi
Fabaceae	*Retama raetam* (Forssk.) Webb & Berthel.	A1,A2,C1,C2	0.09	Com.	Ph.	SaSi
Asteraceae	*Senecio glaucus* L.	A1,A2,B	0.092	Com.	Th.	Med., SaSi, IrTu
Fabaceae	*Trigonella stellata* Forssk.	A1,A2,B	0.092	Com.	Th.	SaSi, IrTu
Apocynaceae	*Leptadenia pyrotechnica* (Forssk.) Decne.	A1,A2,B,C1,C2,D2	0.094	Com.	Ph.	SaSi
Tamaricaceae	*Reaumuria hirtella* Jaub. & Spach	A1,A2,B,D1	0.094	Com.	Ch.	SaSi
Caryophyllaceae	*Gymnocarpos decandrum* Forssk.	A1,A2,B	0.098	Com.	Ch.	SaSi
Poaceae	*Panicum turgidum* Forssk.	A1,A2,B,C1, C2,D2	0.104	V. Com.	Geo.	Med., SaSi, IrTu
Polygonaceae	*Rumex vesicarius* L.	A1,A2,B,C1	0.108	V. Com.	Th.	SaSi, IrTu
Urticaceae	*Forsskaolea tenacissima* L.	A1,A2,C1,D1,D2	0.108	V. Com.	H.	SaSi, Su–Za
Fabaceae	*Lotus hebranicus* Brand	A1,C1,C2,D1,D2	0.11	V. Com.	H.	Near End.
Asteraceae	*Iphiona mucronata* (Forssk.) Asch. & Schweinf.	A1,A2,C1	0.112	V. Com.	Ch.	SaSi
Asteraceae	*Cotula cinerea* Delile	A1,A2,B,C1	0.114	V. Com.	Th.	SaSi
Brassicaceae	*Diplotaxis acris* (Forssk.) Boiss.	A1,A2,B,C1	0.114	V. Com.	Th.	SaSi
Brassicaceae	*Diplotaxis harra* (Forssk.) Boiss.	A1,A2	0.114	V. Com.	H.	SaSi
Resedaceae	*Reseda pruinosa* Delile	A1,A2,C1,D1,D2	0.116	V. Com.	Th.	SaSi
Apocynaceae	*Pergularia tomentosa* L.	A1,A2,B,C1,C2,D1,D2	0.118	V. Com.	Ch.	SaSi
Apiaceae	*Deverra tortuosa* (Desf.) DC.	A1,A2,C2	0.132	V. Com.	Ch.	SaSi
Chenopodiaceae	*Anabasis setifera* Moq.	A1,A2,C1	0.134	V. Com.	Ch.	SaSi, IrTu
Chenopodiaceae	*Atriplex halimus* L.	A1,A2,B,C2	0.142	V. Com.	Ph.	Med., Sa–Si, Ir–Tu

Zygophyllaceae	*Fagonia mollis* Delile	A1,A2,B,D1,D2	0.146	V. Com.	Ch.	Near End.
Asteraceae	*Echinops spinosus* L.	A1,A2,B,C2	0.156	V. Com.	Ch.	Sa–Si, Ir–Tu
Asteraceae	*Launaea nudicaulis* (L.) Hook. f.	A1,A2,B,C1,C2,D1	0.16	V. Com.	H.	Sa–Si, Ir–Tu
Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.	A1,A2,C1,C2,D1,D2	0.17	V. Com.	H.	Med., Sa–Si, Ir–Tu
Chenopodiaceae	*Haloxylon salicornicum* (Moq.) Bunge ex Boiss.	A1,A2,B,C2,D1	0.188	V. Com.	Ch.	Sa–Si, Ir–Tu
Chenopodiaceae	*Salsola imbricata* Forssk.	A1,A2,B,C1,C2,D1,D2	0.198	V. Com.	Ch.	Sa–Si
Zygophyllaceae	*Fagonia bruguieri* DC.	A1,A2,C1,D1,D2	0.198	V. Com.	H.	Sa–Si, Ir–Tu
Tamaricaceae	*Tamarix nilotica* (Ehrenb.) Bge	A1,A2,B,C1,C2,D1,D2	0.2	Dom.	Ph.	Sa–Si, Ir–Tu
Brassicaceae	*Farsetia aegyptia* Turra	A1,A2,B	0.202	Dom.	Ch.	Sa–Si
Brassicaceae	*Morettia philaeana* (Delile) DC.	C1,D1,D2,C1	0.21	Dom.	H.	Sa–Si
Boraginaceae	*Trichodesma africanum* (L.) R. Br.	A1,A2,B,C1,C2,D1,D2	0.214	Dom.	Ch.	Sa–Si, Su–Za, Gu–Co
Fabaceae	*Acacia tortilis* (Forssk.) Hayne	A1,A2, B,C1,C2,D1,D2	0.244	Dom.	Ph.	Sa–Si, Su–Za
Zygophyllaceae	*Zygophyllum simplex* L.	A1,A2,B,C1,C2,D1,D2	0.308	Dom.	Th.	Sa–Si, Ka–Na
Resedaceae	*Ochradenus baccatus* Delile	A1,A2,B,C1,C2,D1,D2	0.336	Dom.	Ph.	Sa–Si
Asteraceae	*Pulicaria undulata* (L.) Kostel	A1,A2,B,C1,C2,D1,D2	0.348	Dom.	Ch.	Sa–Si
Zygophyllaceae	*Zygophyllum coccineum* L.	A1,A2,B,C1,C2,D1,D2	0.696	Dom.	Ch.	Sa–Si
Brassicaceae	*Zilla spinosa* (L.) Prantl	A1,A2,B,C1,C2,D1,D2	0.802	Dom.	Ch.	Sa–Si

For status and life form abbreviations, see text. *Med.* Mediterranean, *EuSi* Euro–Siberian, *Sa–Si* Saharo–Sindian, *IrTu* Irano–Turanian, *Su–Za* Sudano–Zambezian, *Pal.* Palaeotropical, *Pan.* Pantropical, *Cosm.* Cosmopolitan, *Af-Mo* Afromontane, *Aus.* Australian, *End.* endemic, *Near End.* near endemic, *Ka–Na* Karoo–Namib, *GuCo* Guineo-Congo, *Un* undetermined cies were represented by 90 species such as *Zygophyllum decumbens*, *Heliotropium bacciferum*, *Capparis spinosa*, *Centaurea aegyptiaca*, *Launaea spinosa*, and *Kickxia aegyptia*ca. Sporadic (very rare) that have Q-values less than 0.01 constituted the main bulk of the recorded flora (172 species, ca. 49.5% of the total species) and included among others *Cometes abyssinica*, *Helianthemum kahiricum*, *Cleome arabica*, *Halopeplis perfoliata*, *Calendula arvensis*, and *Xanthium strumarium*.

Ninety-two historical records (61 perennials, 31 annuals) were documented, and there was no other indication about their presence till to date. These included Schweinfurth's records of *Krascheninnikovia ceratoides* from Wadi El-Abiad and *Galium spurium* from South Galala in 1887; Keller's record of *Echium longifolium* from Wadi Hof in 1904; Simpson's records of *Colchicum cornigerum*, *Heteroderus pusilla*, *Origanum syriacum*, and *Volutaria crupinoides* in 1924; and Simpson's record of *Schimpera arabica* from Wadi Araba in 1928. Of the remarkable records, the stem parasite *Cusuta brevistyle* and the water-loving species *Ruppia maritima*, *Veronica anagallis-aquatica*, and *V. beccabunga* can be mentioned (full information about these records are ready upon direct request from the authors). The endemic *Fagonia täeckhomiana* was the only species that was reported as extinct by El Hadidi (1979) and El Hadidi (2000). The establishment of new settlements and resorts along the Red Sea coast, building new cities beside the old one along the Nile Valley and its expansion to the desert fringes, and the construction of highways that connect the Nile Valley with most of the cities along the Red Sea coast may explain the disappearance of many species and the remarkable changed flora and vegetation that occurred in the study area (El Hadidi (2000b).

The comparison between the results of this study with that of Hassan (1987) revealed that 270 species were in common out of the total of 496 species recorded. The index of similarity (Cs) is therefore 80.9%. This high value can be attributed to the stability of the flora in this area, with limited changes that occurred. Seventy-four species characterized the study of Hassan (1987) on the flora of the Eastern Desert, which have not been recorded in this investigation. Forty-eight species in the seven largest families: Asteraceae (ten species), Caryophyllaceae (eight species), Chenopodiaceae and Poaceae (seven species for each), Aizoaceae (six species), and Brassicaceae and Lamiaceae (five species for each), formed the major part of the characteristic species. On the other hand, 14 species, mostly weeds, characterized the present study that neither recorded in previous studies nor in the literature. These may be considered as new additions to the flora of the Eastern Desert of Egypt. Recorded weeds included *Ammi majus*, *Convolvulus arvensis*, *Plantago major*, *Lolium rigidum*, and *Rumex dentatus* which are among the most common weeds of Egyptian arable lands (El Hadidi and Kosinova 1971; Abd El-Ghani and Amer 1990; Abd El-Ghani and El-Sawaf 2004; Abd El-Ghani et al. 2011).

Reclamation of the desert appears natural due to population growth and increased congestion in the so-called old lands in the Nile Valley and the Delta. Since the early 1960s, vast areas in the Egyptian deserts (Western, Eastern, and Sinai) were subjected to land reclamation. Not surprisingly, 61% of the priority reclaimable land through the Nile waters is located on the fringes of the Valley and Delta regions where soil, in parts of these areas, is loamy in nature; cultivation can be relatively successful (Biswas 1993). In the study area, agricultural processes were practised in the deltaic parts of several wadis such as Wadi El-Assiuty, W. Qena, W. Kherit, W. Natash, and W. El-Sheikh. The land reclamation processes entail an almost complete change of the environmental factors. Thus, weeds find the new conditions favourable for their growth. Close to the boundaries of the desert in this study, xerophytic species naturally grow among the weeds of the cultivation. This indicated that these species are native to the natural desert vegetation and can remain after the reclamation process. Therefore, the reclaimed areas of this study can be considered as transitional areas of the succession process between the old cultivated lands and that of the desert (Bennoba 2011).

The floristic similarities between the two adjacent deserts (the Eastern and Sinai) resulted in 141 species in common out of the total of 1378, with an index of similarity of about 20.5%. This low similarity may be attributed to the geographical position of both deserts where Sinai Desert is part of the Irano–Turanian region, while the Eastern Desert is a part of the Saharo–Sindian region. Notably, 335 species were consistent to the Sinai Desert, while the Eastern Desert is characterized by 64 species. The similarities in the flora of the Eastern Desert and Sinai accounted for 56.5% at the family level and 64.6% at the generic level.

4.3.1.2 Spatial Distribution Patterns of Species

The application of cluster analysis (Fig. 4.21) and Detrended Correspondence Analysis (DCA; Fig. 4.22) produced four major floristic groups (A–D) at the second level of classification and yielded seven subgroups at the third level. The total number of species varied from one subgroup to another. Floristic group (A) was

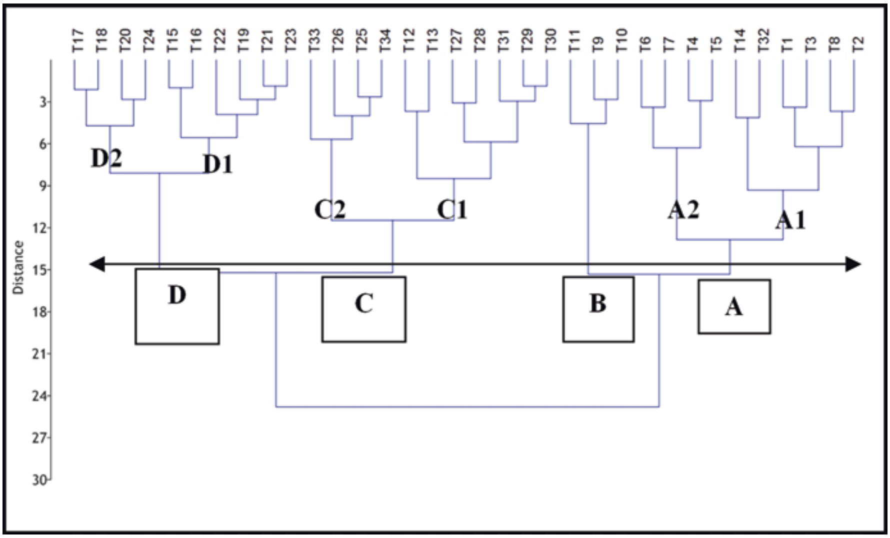

Fig. 4.21 A dendrogram shows the four major floristic groups (*A*–*D*) at the second level of classification and their subgroups (third level of classification) resulting from the cluster analysis of the 34 sampled sectors

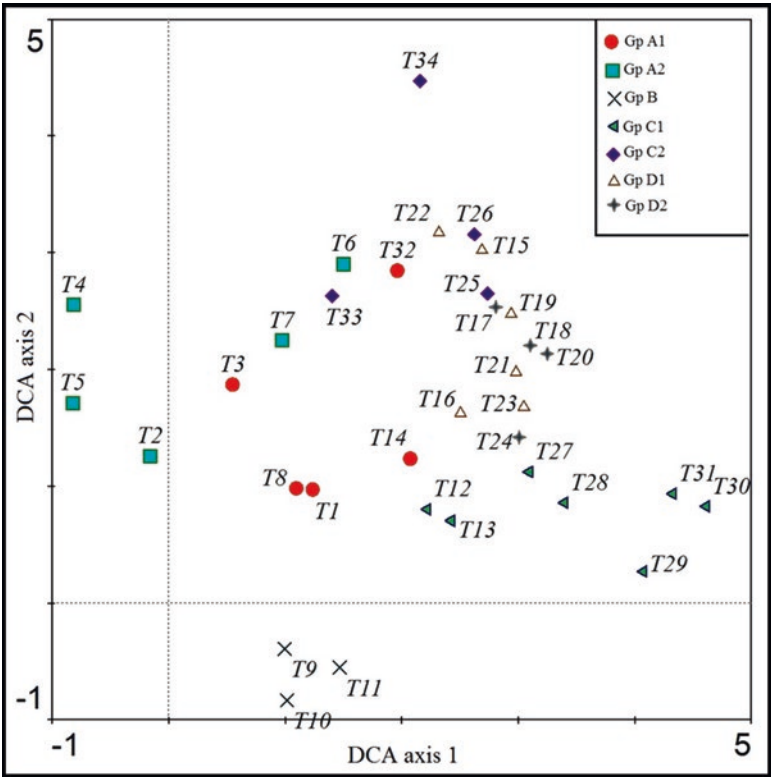

Fig. 4.22 DCA ordination diagram of the 34 sectors on the first two axes as classified by cluster analysis, with the floristic subgroups indicated

dominated by *Zilla spinosa* and *Zygophyllum coccineum* and comprised of ten sectors representing the northern part (Lat. 30° 05′–28°18′ N) of the study area. *Zygophyllum coccineum–Zilla spinosa* communities are among widespread communities within the limestone habitat with different floristic composition. It is plentiful in the affluent of the drainage systems and in the parts of the main channels where the deposits are shallow and coarse. It is less common in the basement complex and is absent from the sandstone habitat (Zahran and Willis 1992).This first group can be divided into two subgroups; the first (A_1) comprised of five desert roads in the northern part of the Eastern Desert (Cairo–Suez road, Kattamia–Ain Sokhna road, Korimat–Zafarana road, Sheikh Fadl–Ras Gharib road, Suez–Ras Gharib road) and Wadi Hagul. It is the most diversified subgroup (92 species), dominated by 23 species (P = 100%) including *Atriplex halimus*, *Farsetia aegyptia*, *Ochradenus baccatus*, *Pergularia tomentosa*, and *Trichodesma africanum*. Other associates of remarkable presence included *Anabasis articulata*, *Citrullus colocynthis*, *Echinops spinosus*, and *Iphiona mucronata*. The second subgroup (A_2) included the flora of the northern wadis of the Eastern Desert (Wadi Degla, W. Hof, W. Garawi, and El-Saff desert). It comprised of 80 species, with 16 species dominated with

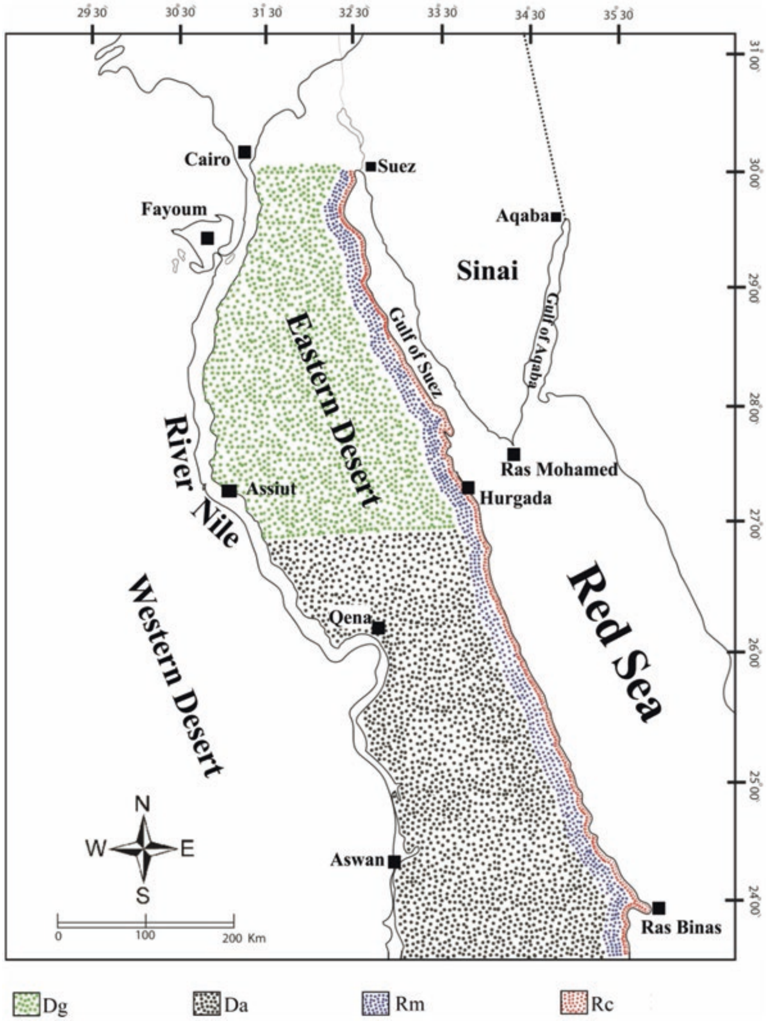

Fig. 4.23 Map of the study area showing the proposed phytogeographical sub-territories of the study area, *Dg* Galala Desert, *Da* Arabian Desert, *Rm* Red Sea Mountain, *Rc* Red Sea coastal plain

100% presence value such as *Anabasis setifera*, *Deverra tortuosa*, *Echinops spinosus*, and *Retama raetam*. Nineteen species were recorded in only one sector of this subgroup with 20% presence value which included *Centaurea calcitrapa*, *Cleome droserifolia*, *Ifloga spicata*, *Leptadenia pyrotechnica*, and *Suaeda altissima*.

Floristic group (B) consisted of 53 species that is dominated *by Calligonum polygonoides* and *Diplotaxis acris* representing the desert vegetation in three sectors in the riverine zone (close to the Nile) of Minya–Assiut area of the Eastern Desert. Twenty species shared the dominance, among others *Cornulaca monacantha*, *Rumex vesicarius*, *Zygophyllum coccineum*, and *Zygophyllum simplex*. Other associates included *Centaurea aegyptiaca*, *Fagonia indica*, *Pergularia tomentosa*, *Salsola imbricata* subsp. *imbricata*, and *Schouwia purpurea*.

Citrullus colocynthis and *Zygophyllum coccineum* dominated floristic group (C) that included 11 sectors representing the southern zone and Red Sea coastal land (Lat. 27° 24′–24° 00′ N). Two subgroups can be identified; the first (C_1; 59 species) included six sectors and dominated by *Citrullus colocynthis* associated with *Astragalus vogelii*, *Cotula cinerea*, *Lotus hebranicus*, *Morettia philaeana*, *Zilla spinosa*, and *Zygophyllum simplex* ($P = 85\%$). Among sporadic species, *Artemisia judaica*, *Heliotropium digynum*, *Ifloga spicata*, *Oligomeris linifolia*, and *Reseda pruinosa* can be noted. The second subgroup (C_2; 42 species) included four sectors that are dominated by *Zygophyllum coccineum* and *Zygophyllum album*. Notably, *Nitraria retusa* and *Salsola imbricata* subsp. *imbricata* were the most represented associates ($P = 75\%$). Other associates included *Atriplex halimus*, *Haloxylon salicornicum*, *Panicum turgidum*, *Suaeda altissima*, *Tamarix nilotica*, and *Tamarix aphylla*.

Floristic group (D) was dominated by *Aerva javanica* and *Zilla spinosa* and can be identified as the Red Sea highland zone of the study area. Two subgroups can be recognized; the first (D_1) is dominated by nine species such as *Acacia tortilis*, *Fagonia mollis*, *Pulicaria undulata*, *Zilla spinosa*, and *Zygophyllum coccineum*. Occasional species included *Heliotropium bacciferum*, *Hyoscyamus muticus*, *Launaea mucronata*, and *Tamarix aphylla*. Ten species shared the dominancy of the second subdivision (D_2), including *Aerva javanica*, *Cleome droserifolia*, *Leptadenia pyrotechnica*, and *Ochradenus baccatus*. It can be noted that *Forsskaolea tenacissima*, *Lotus hebranicus*, and *Trichodesma africanum* were of remarkable presence ($P = 75\%$). Both subgroups comprised of approximately the same number of species (37 for D_1 and 38 for D_2). The correlation coefficients (r) between the different subgroups revealed high significant correlations ($P = 0.01$) between floristic group (B) and subgroup (C_2) and between subgroups (D_1) and (D_2). Significant correlations ($P = 0.05$) occurred between subgroup (D_1) and both of (A_1) and (C_2).

4.4 Phytogeographical Reassessment

4.4.1 The Saharo–Sindian Chorotype

Phytogeographically, the Saharo–Sindian region is the great desert belt. It extends from the Atlantic coasts of Morocco and Mauritania eastwards across the Sahara, Sinai, and extratropical Arabia, Southern Iraq, Iran, and Balochistan to the deserts of Sind, Thar, the Punjab, and South of Afghanistan (Zohary 1973). It has extreme dryness of the air, high temperature, and low rainfall.

The Saharo–Sindian (mono-, bi-, and pluriregional) chorotype constituted the largest group of species (226 species or about 68.9% of the total flora), with variations in their growth habits and life span. The pure (monoregional) Saharo–Sindian chorotype was represented by 137 species (60.6% of the total chorotype). These species showed different geographical distribution patterns in the proposed local subtypes.

4.4.1.1 Local Subtype 1: Widely Distributed Species

This group included ten species with wide distribution patterns and environmental tolerances throughout the study area. *Zilla spinosa* and *Zygophyllum coccineum* were the most dominant species that showed a wide range of conjunct distribution pattern all over the study area. Other species that showed a considerable wide range of distribution included *Pulicaria undulata*, *Trichodesma africanum*, *Acacia tortilis*, *Ochradenus baccatus*, *Tamarix nilotica*, and *Zygophyllum simplex*. (Fig. 4.24)

4.4.1.2 Local Subtype 2: Northerly Distributed Species

This group of species included 119 species (3 very common, 12 common, 45 occasional, 59 occasional), mostly restricted and characteristic to the inland wadis of the study area and not recorded eastwards along the Red Sea coast. *Agathophora alopecuroides*, *Deverra triradiata*, *Limonium pruinosum*, *Stachys aegyptiaca*, and *Traganum nudatum* are confined to Helwan and El-Saff desert, while *Pseuderucaria clavata* showed a higher presence along Kattamia–Ain Sokhna road and its surrounding wadis.

Some species showed certain degree of consistency to certain localities in the northern part of the study area. These species were not recorded since several years and hence

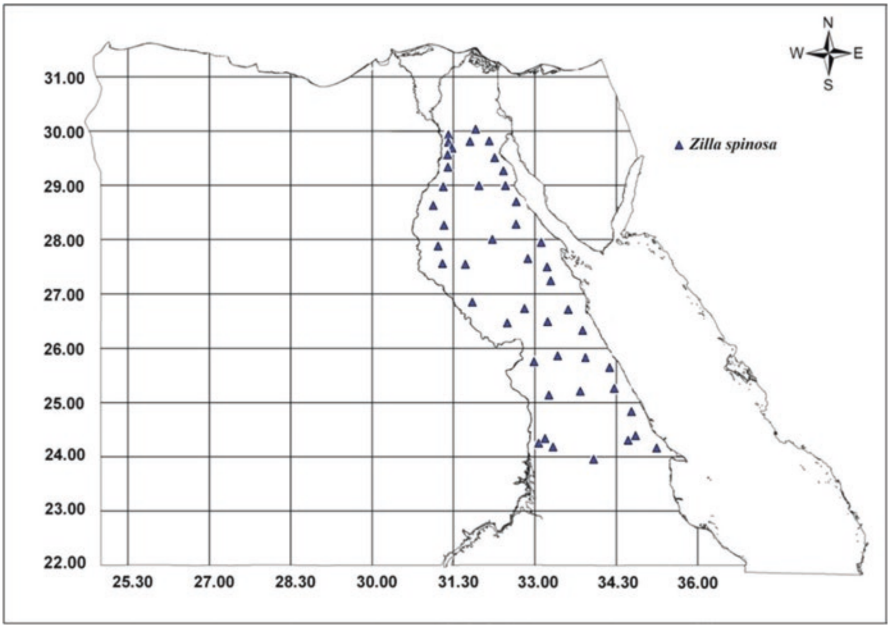

Fig. 4.24 Distribution map of *Zilla spinosa* (widely distributed Saharo–Sindian species)

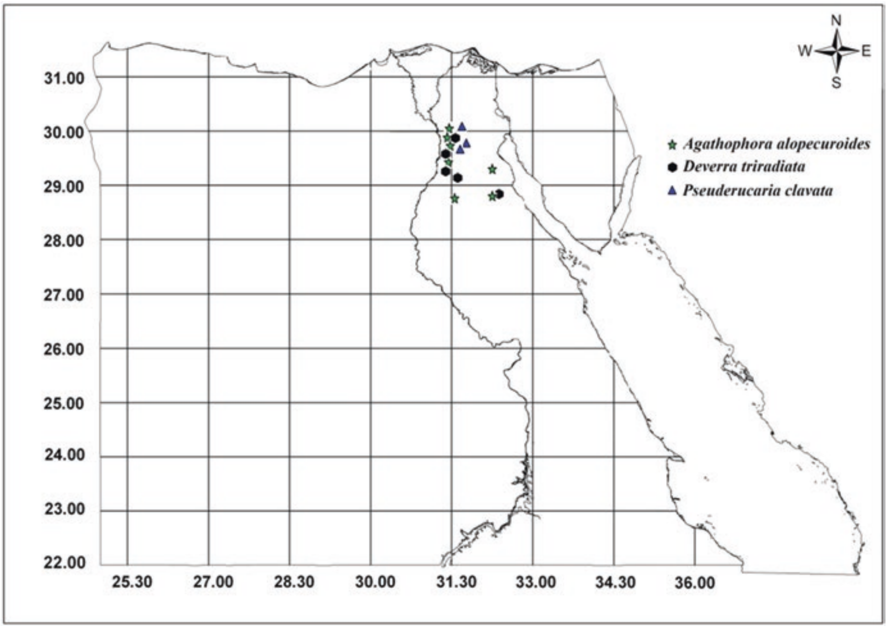

Fig. 4.25 Distribution map of *Agathophora alopecuroides*, *Deverra triradiata*, and *Pseuderucaria clavata* (northerly distributed Saharo–Sindian species)

can be considered as historical records, among others *Abutilon pannosum*, *Echium longifolium*, *Fagonia latifolia*, *Haloxylon persicum*, *Helianthemum sancti-antonii*, *Kickxia acerbiana*, *Onobrychis ptolemaica*, and *Scabiosa eremophila* (Fig. 4.25).

4.4.1.3 Local Subtype 3: Southerly Distributed Species

Eight species of the Saharo–Sindian chorotype showed certain degree of consistency to the southern part of the study area; in the meantime, they were characteristic to the southern inland wadis. For example, *Morettia philaeana*, *Salsola villosa*, and *Schouwia purpurea* showed high presence in this area, while *Acacia ehrenbergiana*, *Fagonia thebaica*, and *Iphiona scabra* were of low presence (Fig. 4.26).

4.4.1.4 Local Subtype 4: Easterly Distributed Species

This group of species were distributed along the eastern part of the study area and not penetrated westwards. These species can be considered as the Red Sea characteristic species such as *Atriplex farinosa*, *Avicennia marina*, and *Halopeplis perfoliata* that were distributed along the southern part of the Red Sea coastal plain. *Blepharis edulis*, *Capparis cartilaginea*, *Cleome chrysantha*, *C. droserifolia*, *Convolvulus hystrix*, and *Periploca aphylla* are recorded from the Red Sea wadis and mountains (Fig. 4.27).

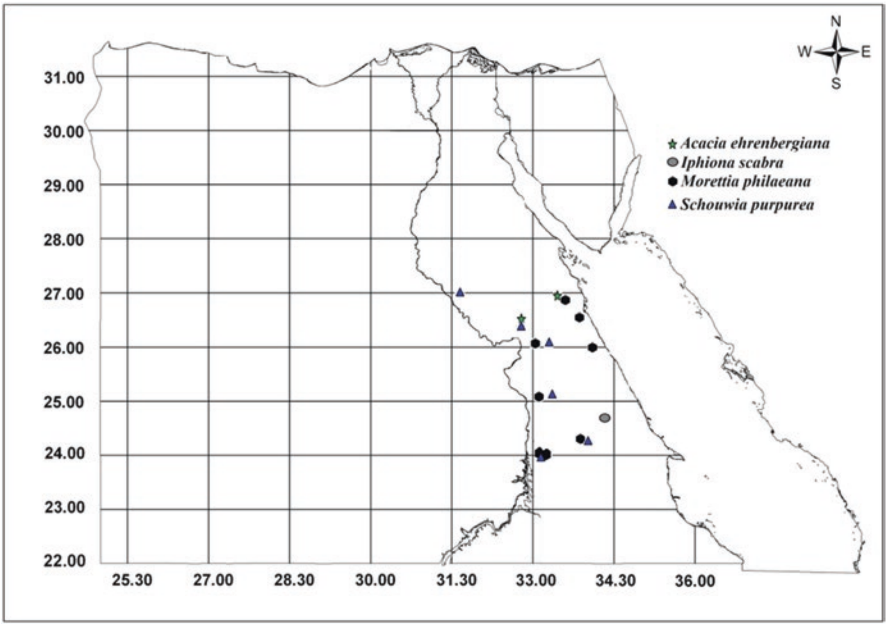

Fig. 4.26 Distribution map of *Acacia ehrenbergiana, Iphiona scabra*, *Morettia philaeana*, and *Schouwia purpurea* (southerly distributed Saharo–Sindian species)

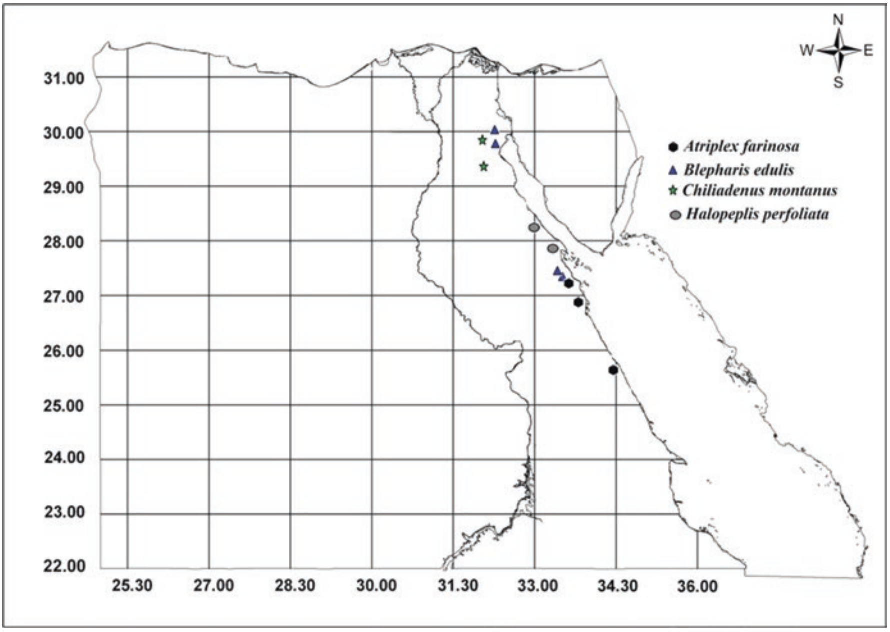

Fig. 4.27 Distribution map of *Atriplex farinosa*, *Blepharis edulis*, *Chiliadenus montanus*, and *Halopeplis perfoliata* (easterly distributed Saharo–Sindian species)

4.4.1.5 Local Subtype 5: Westerly Distributed Species

This group was represented by 57 species, mainly distributed in the desert wadis close to the River Nile Valley. The very common, common, and the sporadic species were represented by relatively equal numbers of species (15, 18, and 17, respectively). The highest occurrences were for *Fagonia bruguieri* and *Caroxylon imbricatum*, followed by *Haloxylon salicornicum* and *Citrullus colocynthis*. Conspicuous stratification (layering) of different life-form categories in this subtype was noted: phanerophytes (*Phoenix dactylifera*), chamaephytes (*Centaurea scoparia* and *Heliotropium ramosissimum*), hemicryptophytes (*Cucumis prophetarum*), and therophytes (*Arnebia hispidissima, Lotus halophilus*, and *Tribulus megistopterus*) .

4.4.2 The Mediterranean Chorotype

As defined by Zohary (1973), the Mediterranean region includes the most northern part of the African continent and the southern part of Europe surrounding the Mediterranean Sea. It bounded from south by the desert and semi-desert of Saharo–Sindian region and from the east by Irano–Turanian region. It is characterized by mild winter rich in rainfall and dry summer. In this investigation, a total of 32 species were of Mediterranean origin, of which 7 were monoregional (pure) Mediterranean chorotype. Therophytes (24 species) were the dominant life form. The following shows the patterns of their distribution in the different local subtypes. Generally, the species comprising the subtypes were either occasional or sporadic.

4.4.2.1 Local Subtype 1: Widely Distributed Species

Not represented.

4.4.2.2 Local Subtype 2: Northerly Distributed Species

The majority (21 species) of the Mediterranean chorotype was restricted in their distribution to the northern part of the study area and not extended or recorded southwards. Notably, 16 species were therophytes and known among the common weeds of Egyptian arable lands (El Hadidi and Kosinová 1971) among others *Cichorium pumilum*, *Emex spinosa*, *Euphorbia peplus*, and *Plantago major*. Meanwhile some desert annuals were recorded such as *Astragalus hamosus*, *Schismus barbatus*, and *Mesembryanthemum crystallinum*. (Fig. 4.28)

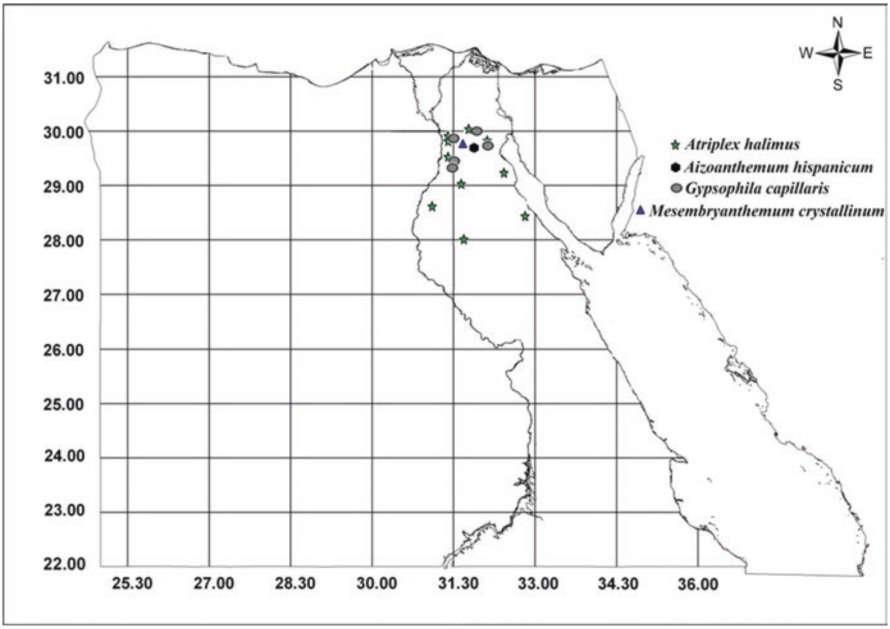

Fig. 4.28 Distribution map of *Atriplex halimus*, *Aizoanthemum hispanicum*, *Gypsophila capillaris*, and *Mesembryanthemum crystallinum* (northerly distributed Mediterranean species)

4.4.2.3 Local Subtype 3: Southerly Distributed Species

Mediterranean chorotype showed fewer (three) species in the southern part of the study area. Only three weedy species, *Hippocrepis constricta*, *Lactuca serriola*, and *Lupinus digitatus*, were recorded in this part. (Fig. 4.30)

4.4.2.4 Local Subtype 4: Easterly Distributed Species

These species were confined to the eastern part of the study area and characteristic to the Red Sea region. Most of these species were rare and very rare (Täckholm 1974) and collected from certain localities along the Red Sea coastal lands such as *Koelpinia linearis*, *Malabaila suaveolens*, and *Umbilicus intermedia* (El Hadidy and Fayed 1994/1995). In this subtype, some salt-tolerant species *Frankenia hirsuta*, *Sarcocornia fruticosa*, and *Suaeda altissima* were recorded (Fig. 4.29).

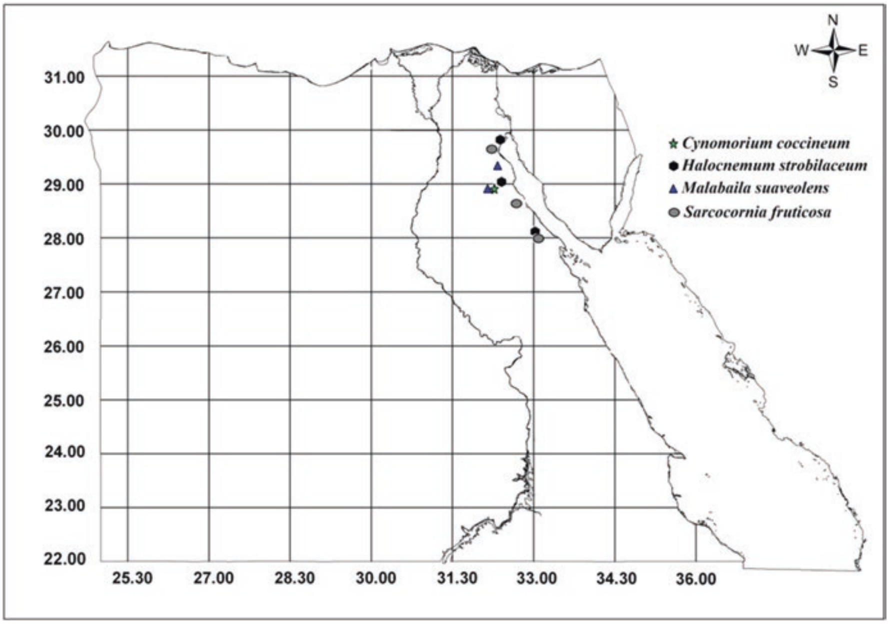

Fig. 4.29 Distribution map of *Cynomorium coccineum*, *Halocnemum strobilaceum*, *Malabaila suaveolens*, and *Sarcocornia fruticosa* (easterly distributed Mediterranean species)

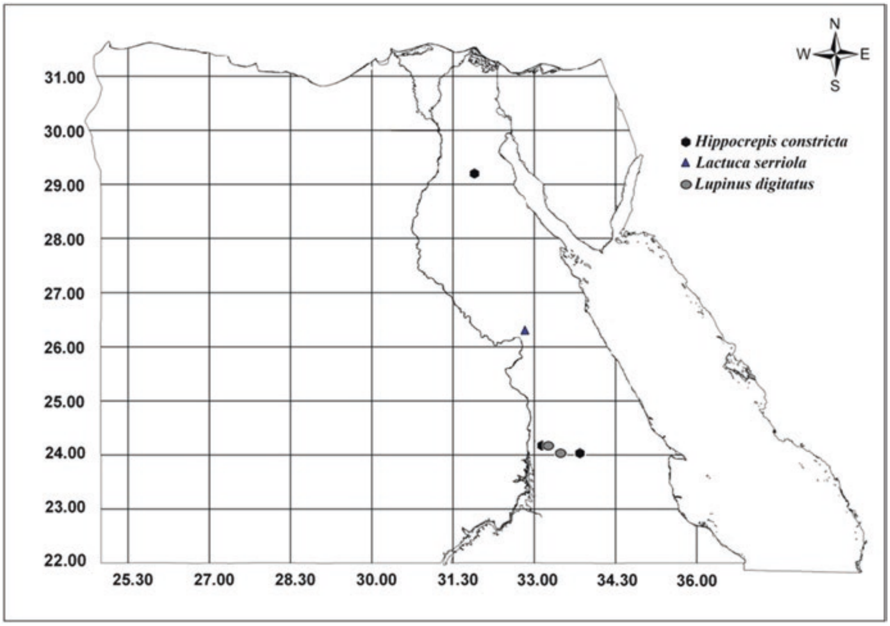

Fig. 4.30 Distribution map of *Hippocrepis constricta*, *Lactuca serriola*, and *Lupinus digitatus* (southerly distributed Mediterranean species)

4.4.2.5 Local Subtype 5: Westerly Distributed Species

Three species were recorded in this subtype; all are among the common weeds of arable lands that were reclaimed in the western part close to the Nile River Valley.

4.4.3 The Irano–Turanian Chorotype

According to Zohary (1973), the Irano–Turanian region covered a large area stretching from east towards China–Japan, west to Mediterranean, north to northern extra-tropical, and south to north African–Indian desert region. In this study, it was represented by six species, all confined to the northern part of the study area.

4.4.3.1 Local Subtype 1: Widely Distributed Species

Not represented.

4.4.3.2 Local Subtype 2: Northerly Distributed Species

All the six recorded species were confined to the northern part, among others *Atriplex dimorphostegia*, *Glossostemon bruguieri*, *Heliotropium arbainense*, and *Paronychia sinaica* were found (Fig. 4.31).

4.4.3.3 Local Subtype 3: Southerly Distributed Species

Not represented.

4.4.3.4 Local Subtype 4: Easterly Distributed Species

A total of 23 species belonged to this group. Most of these species were considered as historical records such as; A*traphaxis spinosa, Ballota saxatilis, Galium spurium, Heliotropium rotundifolium, Heteroderus pusilla, Krascheninnikovia ceratoides, Matricaria aurea* and *Teucrium polium* (Fig. 4.32).

4.4.3.5 Local Subtype 5: Westerly Distributed Species

Not represented.

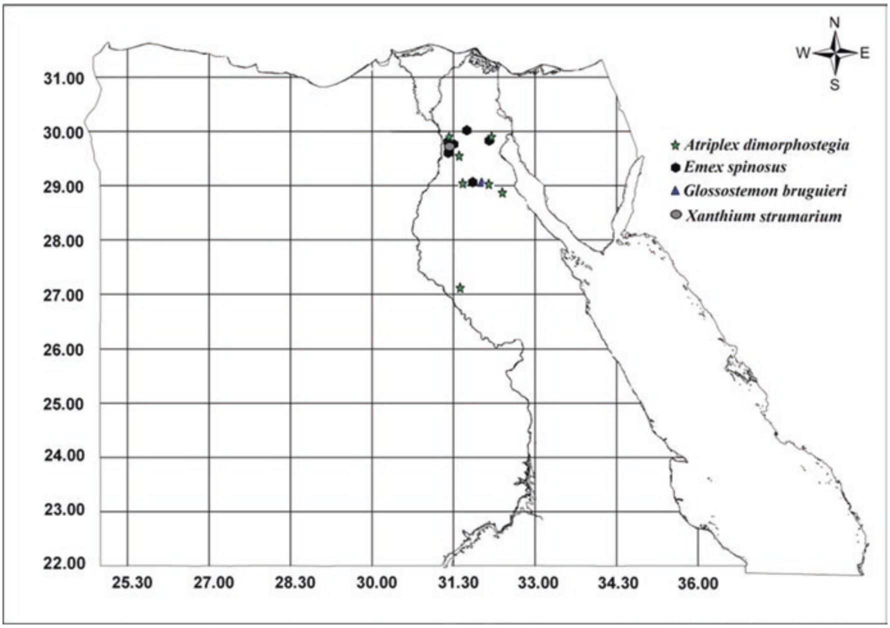

Fig. 4.31 Distribution map of *Atriplex dimorphostegia*, *Emex spinosa*, *Glossostemon bruguieri*, and *Xanthium strumarium* (northerly distributed Irano–Turanian species)

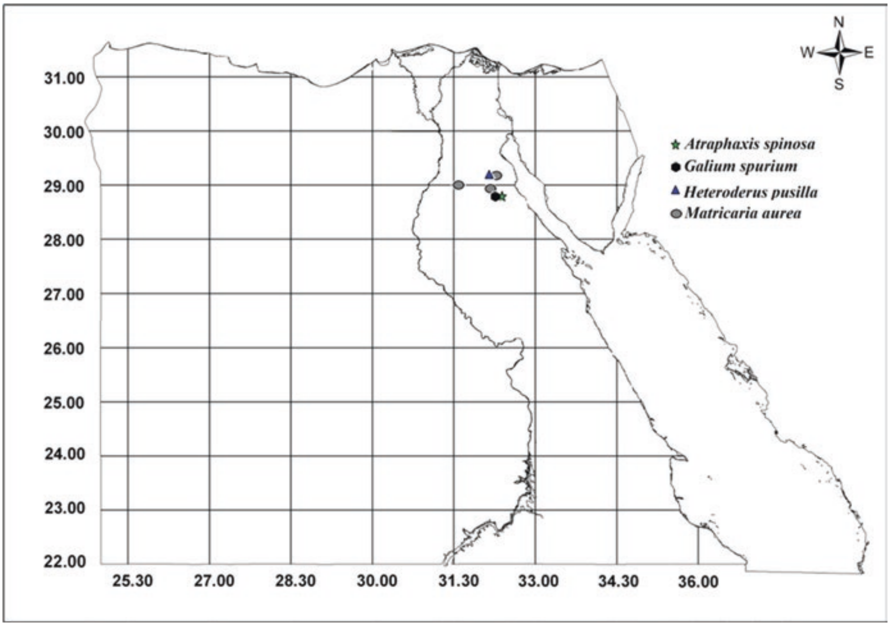

Fig. 4.32 Distribution map of *Atraphaxis spinosa*, *Galium spurium*, *Heteroderus pusilla*, and *Matricaria aurea* (easterly distributed Irano–Turanian species)

4.4.4 The Sudano–Zambezian Chorotype

The Sudano–Zambezian region corresponds to largest ecological formation in Africa, the tropical savanna to the north. It is bounded by the desert and semi-desert of the Saharo–Sindian region (Zohary 1973).

4.4.4.1 Local Subtype 1: Widely Distributed Species

Among these species *Senna italica* had a relatively wide range of distribution (Fig. 4.33 for all subtypes).

4.4.4.2 Local Subtype 2: Northerly Distributed Species

Four Sudano–Zambezian species showed consistency to the eastern part of the study area, e.g. *Ephedra ciliata* (gymnosperm) and the shrubs of *Farsetia longisiliqua* and *Abutilon fruticosum*.

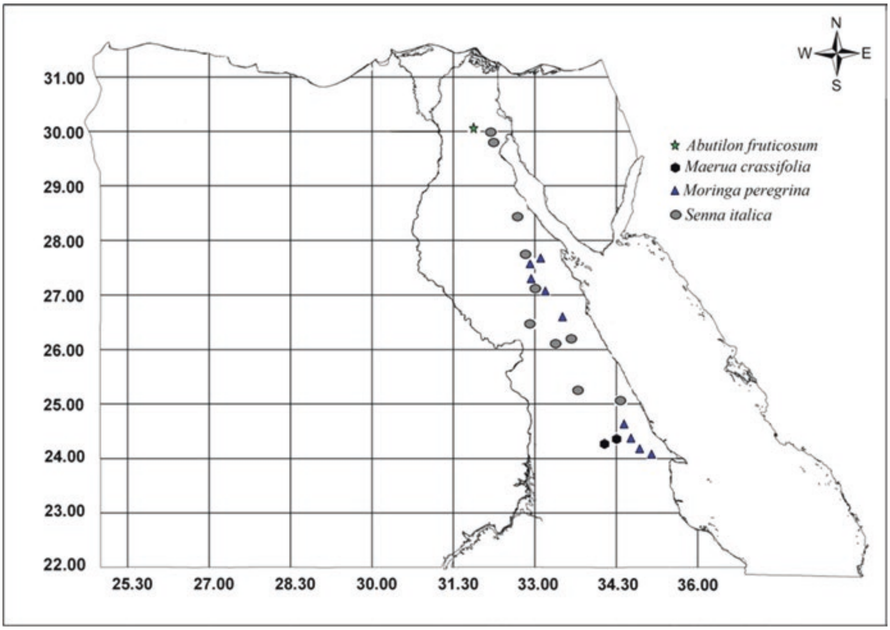

Fig. 4.33 Distribution map of Sudano–Zambezian species: *Senna italica* (widely distributed), *Maerua crassifolia* (southerly distributed), *Abutilon fruticosum* (northerly distributed), and *Moringa peregrina* (easterly distributed)

4.4.4.3 Local Subtype 3: Southerly Distributed Species

The common recorded was *Acacia seyal* (tree). Another two occasional trees were also recorded in the southern stretches of the surveyed area: *Hyphaene thebaica* and *Maerua crassifolia*.

4.4.4.4 Local Subtype 4: Easterly Distributed Species

Altogether, two occasionals (*Capparis deciduas* and *Farsetia stylosa*) and one sporadic (*Tribulus bimucronatus*) occurred in the eastern part.

4.4.4.5 Local Subtype 5: Westerly Distributed Species

Senna italica was the only occasional species that was recorded from the western part.

4.4.5 The Cosmopolitan, Palaeotropical, and Pantropical Species

Altogether, 27 species were recorded, of which 16 (ca. 59%) were Cosmopolitans. This group included some of the most common weeds of the arable lands in Egypt such as *Sonchus oleraceus* (common), *Chenopodium murale*, *Cynodon dactylon*, and *Polypogon monspeliensis* (occasional), and the remaining were sporadic (Fig. 4.34).

4.4.5.1 Local Subtype 1: Widely Distributed Species

Not represented.

4.4.5.2 Local Subtype 2: Northerly Distributed Species

Seventeen species (10 Cosmopolitan, 4 Palaeotropical, and 3 Pantropical) were included. Therophytes (12 species) dominated the other life forms and were found in northern inland wadis of the study area. The salt-tolerant species *Cressa cretica* which characterizes the salinized soils was recorded.

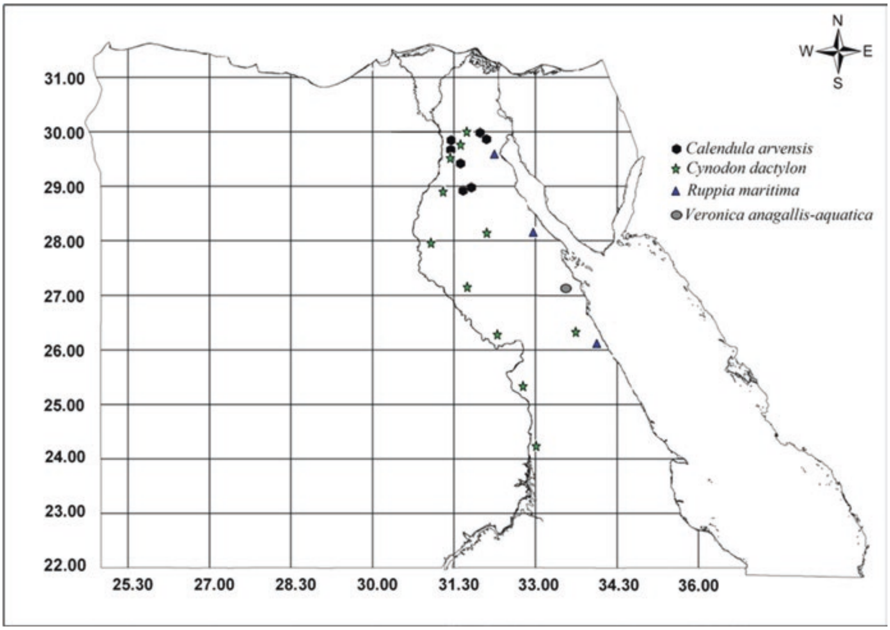

Fig. 4.34 Distribution map of Cosmopolitan species: *Cynodon dactylon* (widely distributed), *Calendula arvensis* (northerly distributed), *Ruppia maritima*, and *Veronica anagallis-aquatica* (easterly distributed)

4.4.5.3 Local Subtype 3: Southerly Distributed Species

Not represented.

4.4.5.4 Local Subtype 4: Easterly Distributed Species

Leptochloa fusca was the only Palaeotropical species included. It was found in water catchment areas where water is collected. On the other hand, *Brassica nigra*, *Pseudognaphalium luteoalbum*, *Ruppia maritima*, *Veronica anagallis-aquatica*, and *V. beccabunga* were recorded once from the eastern part of the study area (Cairo University Herbarium records, in the year 1938) and not recorded in this work. These can be considered as historical records.

4.4.5.5 Local Subtype 5: Westerly Distributed Species

Nine species were recorded, with *Sonchus oleraceus* (common); *Cynodon dactylon*, *Phragmites australis*, and *Polypogon monspeliensis* (occasional); and *Amaranthus viridis*, *Avena fatua*, *Ricinus communis*, *Solanum nigrum*, and *Typha domingensis* (sporadic).

Based on the presented distribution patterns of the recorded species, the geographical distribution maps, the biogeographical relationships, and the vegetation analysis (Abd El-Ghani et al. 2013a), it is suggested to divide the study area into two major phytogeographical divisions: the Eastern Desert and the Red Sea (Fig. 4.23), each of which can be further split into other subdivisions as follows.

4.4.5.6 Division 1: The Eastern Desert

This division comprised the inland desert of the study area from River Nile Valley eastwards to the limits of the Red Sea Mountains. Taking into account variations in the floristic composition and species distribution, it is suggested to divide this division into two subdivisions: Galala (northern) and Arabian (southern).

Subdivision 1: The Northern Galala Desert (Dg)

This sub-territory comprised the northern part of the study area. It extends from the northern limits of the study area at latitude 30°N southwards to Minya–Assiut desert at latitude 27°N. This sub-territory is most rich with plant species and characterized by restriction of numerous families including Aizoaceae, Alliaceae, Amaryllidaceae, Anacardiaceae, Cannabaceae, Cistaceae, Dipsacaceae, Ephedraceae, Neuradaceae, Orobanchaceae, Oxalidaceae, Portulacaceae, Primulaceae, Rutaceae, Sterculiaceae, and Thymelaeaceae.

Subdivision 2: The Southern Arabian Desert (Da)

It occupied the southern part of the study area, south of latitude 27°N. This sub-territory was characterized by low diversity of species (25 species) and absence of restricted families.

4.4.5.7 Division 2: The Red Sea Coast (R)

This territory included the area between Red Sea coasts westwards to Red Sea Mountains. This territory can be subdivided into two main sub-territories: Red Sea coastal plain and Red Sea Mountains.

Subdivision 1: The Red Sea Coastal Plain (Rc)

This sub-territory occupied the coastal plain of the Red Sea. It varies from 8 to 35 km from the coast (Zahran and Willis 1992). Here, very few characteristic species were represented: *Avicennia marina*, *Halocnemum strobilaceum*, *Atriplex* *farinosa*, *Arthrocnemum glaucum*, *Halopeplis perfoliata*, *Limonium axillare*, *Aeluropus lagopoides*, *Sporobolus spicatus*, and *Suaeda monoica*.

Subdivison 2: The Red Sea Mountains (Rm)

It occupied the area from the limit of Red Sea coastal plain westwards to the west limit of the Red Sea Mountain. This area is characterized by large number of coastal wadis and high diversity of plant.

4.5 Concluding Remarks

1. From a phytogeographical point of view, and according to Takhtajan (1969) and Wickens (1976), the study area lies within the Saharo–Sindian region of boreo-subtropical zone of the Tropical Kingdom. This area is influenced by its inclusion in the Mediterranean, Sudano–Zambezian, and Irano–Turanian regions (White 1993). These facts were obvious from the detailed chorological analysis of the recorded species, where the Saharo–Sindian constituted the majority of mono-, bi-, and pluriregional chorotypes. Species of the Saharo–Sindian region are known as good indicators of the harsh environments of the arid desert (Hegazy et al. 1998; Abd El-Ghani and Amer 2003). The dominance of Saharo–Sindian chorotype in the study area is coinciding with the results of El Hadidi (1993), Fossati (1998), and Hassan (2003).
2. The relationship between the life forms and chorological affinities in floristic studies contributed significantly to the prevailing climatic conditions and human impacts as well. Several studies can be reported, among others, Batalha and Martins (2002) in Brazilian cerrado sites, Klimeš (2003) in NW Himalayas, Becker and Müller (2007) in semiarid regions of West and Southern Africa, Gouvas and Theodoropoulos (2007) in Mount Hymettus (Central Greece), Carvalho da Costa et al. (2007) in deciduous thorn woodland (caatinga) in northeastern Brazil, and Al-Sherif et al. (2013) in the arid region of Saudi Arabia. In the present study, the life-form spectrum is characteristic of an arid desert region with the dominance of therophytes, followed by chamaephytes, hemicryptophytes, and phanerophytes over other life forms that seem to be a response to the hot dry climate, topographic variations, and/or human and animal interference. A comparison of the life-form spectra of the Eastern Desert of Egypt and those in the Tihama coastal plains of Jazan region in southwestern Saudi Arabia (El-Demerdash et al. 1994) showed the same results. Similar conclusions were also reported by Arshad et al. (2008) in various locations of the Cholistan Desert in Pakistan.

3. In hyperarid deserts, as in the study area, plant growth is triggered mainly by rain, as it is scarce, patchy, and restricted to wadis, runnels, and depressions with deep fine sediments where runoff water collects and provides sufficient moisture for plant growth (Shmida 1985; Bornkamm 2001). Consequently, several highly adapted, drought-resistant species such as *Acacia tortilis* subsp. *raddiana*, *Tamarix aphylla*, and *Ziziphus spina-christi* (trees) and *Capparis spinosa*, *Convolvulus hystrix*, *Fagonia bruguieri*, *Zygophyllum coccineum*, and *Zilla spinosa* (shrubs) were among the widely distributed and very common species in this desert.
4. Results on the distribution of different biological spectrum confirmed the dominance of therophytes, mostly of Saharo–Sindian affinities. Frequent occurrence of therophytes may be attributed to their short life cycle, water availability, and the prevailing climatic conditions (Shaltout and El-Fahar 1991). The preponderance of therophytes could be related to their high reproductive capacity and ecological, morphological, and genetic plasticity under high level of disturbance (Grime 1979). This spectrum strongly resembles that reported by Danin and Orshan (1990) for corresponding environments in Israel.
5. The notable decrease of the recorded species from the northern part to the southern part can be attributed to the decrease of the mean annual averages of rainfall along this gradient from 25 mm^{-1} in Suez to almost 0 mm^{-1} in Marsa Alam along the Red Sea coast (Abd El-Ghani 1998). However, the Red Sea coast (eastern border of the Eastern Desert) and its mountains receive more precipitation than the Nile Valley (western border of the Eastern Desert). Most of the studied wadis (valleys) crossing the Eastern Desert in E–W direction debouch their water in the Nile River. This may explain the increase of the recorded species along E–W direction. Plant species growth in the desert wadis, as water catchment areas, other than surrounding areas, was reported by several authors (El Hadidi et al. 1986; El-Bana and Al-Mathnani 2009; Abdel Khalik et al. 2013; Salama et al. 2016).
6. The results showed that some weeds of the arable lands of Egypt were recorded. These weeds belonged to the common weeds of Egypt (El Hadidi and Kosinová 1971; Abd El-Ghani and El-Sawaf 2004). That could be explained by the proximity of the study area to the boundaries of the agroecosystem of the Nile Valley, where many land stretches have been reclaimed and recently considered under cultivation. Thus weeds have found new favourable conditions for their growth, and their invasion has expanded.
7. The phytogeographical divisions of Egypt, and especially for the Eastern Desert, were a matter of controversy. Hassib (1951) divided the study area into three main phytogeographical regions: (1) Northern Arabian Desert from Wadi Tumilat to Qena–Quseir region (Da. Sept.); (2) Southern Arabian Desert from Qena–

Quseir southwards to Sudanian borders (Da. mer); and (3) Red Sea coast comprising the coast of Red Sea from Suez Gulf southwards to Gebel Elba region. On the other hand, El Hadidi (1980) included the Eastern Desert in two phytogeographical units: (1) Eastern Desert region (D) and (2) Red Sea region (R). The former can be further subdivided into Galala Desert (Dg) and Arabian Desert (Da). While the latter can be subdivided into the Arabian sector (Ra) that lies between latitudes 22°N–28°N and the Suez Gulf sector (Rz) that lies between latitudes 28–30°N.

Photo Gallery

Photo 4.1 Mixed plant growth of *Zygophyllum coccineum* (dominant) and *Tamarix aphylla* (background) which forms huge hillocks at Wadi Matuli, Eastern Desert

Photo 4.2 Mixed desert vegetation of *Zilla spinosa* (dry, foreground), *Zygophyllum coccineum*, and *Tamarix nilotica* (background) at Wadi El-Qarn, Eastern Desert

Photo 4.3 A water-collecting area along Qift-Quseir road, showing dense cover of *Juncus rigidus*, *Tamarix nilotica*, and *Phragmites australis* (green colour in the backround)

Photo 4.4 S*alsola imbricata* subsp. *imbricata* dominating the desert vegetation at Wadi El-Qarn, Eastern Desert

Photo 4.5 Dense growth of *Schouwia thebaica* and *Zygophyllum coccineum* at Wadi Habib, Eastern Desert (April 14, 2011)

Photo 4.6 After rainfall at Wadi El-Assiuty (Eastern Desert), mixed growth of *Zilla spinosa*, *Schouwia thebaica*, and *Rumex vesicarius* (red flowers) forms the desert vegetation (April 10, 2011)

Photo 4.7 A scrubland of *Acacia seyal* forms part of the vegetation at Wadi Kharit, Eastern Desert (January 22, 2011)

Photo 4.8 A camel browsing *Acacia seyal* at Wadi Kharit, Eastern Desert (January 22, 2011)

Photo 4.9 A mangrove of *Avicennia marina* (note the long respiratory roots) at Marsa Alam along the Red Sea coast (January 25, 2011)

Photo 4.10 General view of Wadi El-Mallaha (in Arabic = salt marsh) at the northern part of the Eastern Desert.Date palm trees together with *Tamarix nilotica* and *Nitraria retusa* form the vegetation of this salinized land (March 07, 2017)

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Chapter 5
The Inland Western Desert of Egypt

Abstract Outside the oases of the Western Desert, five desert zones along a precipitation gradient were distinguished. In addition to the well-known semi-desert and full desert zones in the very north, three zones of extreme desert show a significant differentiation where the "accidental vegetation" occurs as precipitation is so low and falls so irregularly and no permanent vegetation exists. The accidental vegetation along two transects, the northern along Siwa Oasis–Mersa Matruh road and the southern along the Dakhla Oasis–Farafra Oasis road, was botanically explored, through their vegetation characteristics and soil attributes. The only known five populations of the endangered spinescent shrub, *Randonia africana* along Siwa Oasis–Mersa Matruh road, were examined with respect to their vegetation composition and soil features. *Randonia africana* reaches its easternmost limit of distribution in Egypt along this road. The oases are the most prominent features of the Western Desert of Egypt. A common irrigation pattern and habitat types around these wells were recognized and described. Floristically, this study confirms the separation of the northern oases (Siwa and Bahariya) in the limestone or white desert from those in the southern (Farafra, Dakhla and Kharga) in the sandstone desert. Vegetation and environment in the inland salt marshes of Siwa and Dakhla Oases and the saline lakes of Wadi El-Natrun were also studied.

5.1 General Features

The Western Desert of Egypt extends over more than 1000 km throughout the country, from the Mediterranean coast to the Sudanese border and from the Libyan border to the Nile Valley. It thus covers approximately two-thirds of the Egyptian territory. The precipitation gradient is prominent: decreasing from 150 mm at the coast to practically zero at the south. However, southwest Egypt has been known as the driest part of the globe. The interior plateau is flat; there is nothing but plains or rocks either bare or covered with sand and detrital material. This surface is sudden broken by any conspicuous relief feature. It thus appears as a large rocky plateau of

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moderate altitude (mean elevation c. 500 m above sea level). The Western Desert as a whole, though considered barren, supports certain types of plants which occur in areas with enough water resources (rainfall and/or underground).

Ecologically, Zahran and Willis (1992) divide the area into three main regions: (1) the western Mediterranean coastal belt, (2) the inland oases and depressions, and (3) the Gebel Uweinat. On a phytogeographical basis, El Hadidi (1980a) defined two subterritories: (A) the Libyan Desert, being the northern and major part, formed of limestone plateau which slopes gradually to the northwest towards Siwa Oasis and Qattara Depression, where the ground descends below sea level, and (B) the Nubian Desert in the southern part, mainly of sandstone which is delimited northwards by the Kharga and Dakhla depressions. Well-marked drainage systems (wadis) comparable to those of the Eastern Desert are not found. Despite many floristic, taxonomic, and plant ecological investigations that have been carried out in the northern coastal part of this desert and the oases (for literature see Kehl and Bornkamm 1993), little is known about the vegetation of the large parts of the inland desert outside the inhabited oases.

In the south-eastern part of the Western Desert, Egypt's giant project "Toschka project" is currently running. With the completion of this project (between the years 2002 and 2010), the water of the Nile will be transferred from Toschka depression (southwest to Aswan) to a long water canal crossing the oases of Kharga, Dakhla, and Farafra (Fig. 5.1). Thus, a "real New Valley" will be developed and running parallel to the "Old" one. With no doubt, transferring the Nile water to these areas will change the vegetation outside it as well as their floristic composition. Therefore, a recent quantitative study of the desert vegetation in some parts of the Western Desert before changing the pattern of its plant life is strongly recommended.

The vegetation patterns of arid regions are often patchy, with variation in the abundance and distribution of both species and community types across the landscape. Because arid zones are characterized by minimal precipitation and frequent droughts (Mabbutt 1977; Cole 1986), availability of water may be one of the primary factors controlling the distribution of species (Noy-Meir 1973; Yair and Danin 1980). The most critical gradients in abiotic factors may be those related to water availability, including annual precipitation, soil characteristics, and topography. Constant water availability is found only in oases that constitute a tiny part of the arid region. Outside the oases, resources which are rich and easy to use are episodic. The largest five Egyptian oases (Fig. 5.1) constitute about 48.5% of the total area of Egypt and contain the largest underground water reservoir (Nubian Sandstone aquifer) ever known in the whole desert or may be in the Sahara area.

In Egypt, the desert vegetation is by far the most important and characteristic type of the natural plant life. It covers vast areas and is formed mainly of xerophytic shrubs and subshrubs. Monod (1954) recognized two types of desert vegetation, namely, contracted and diffuse. Both types refer to permanent vegetation which can be accompanied by ephemeral (or annual) plant growth depending on the amount of precipitation in a given year. Kassas (1966, 1971) added a third type as "accidental vegetation" where precipitation is so low and falls so irregularly that no permanent vegetation exists. It occurs mainly as contracted patches in runnels, shallow depressions, hollows, wadis and on old dunes with coarse sand. Accidental

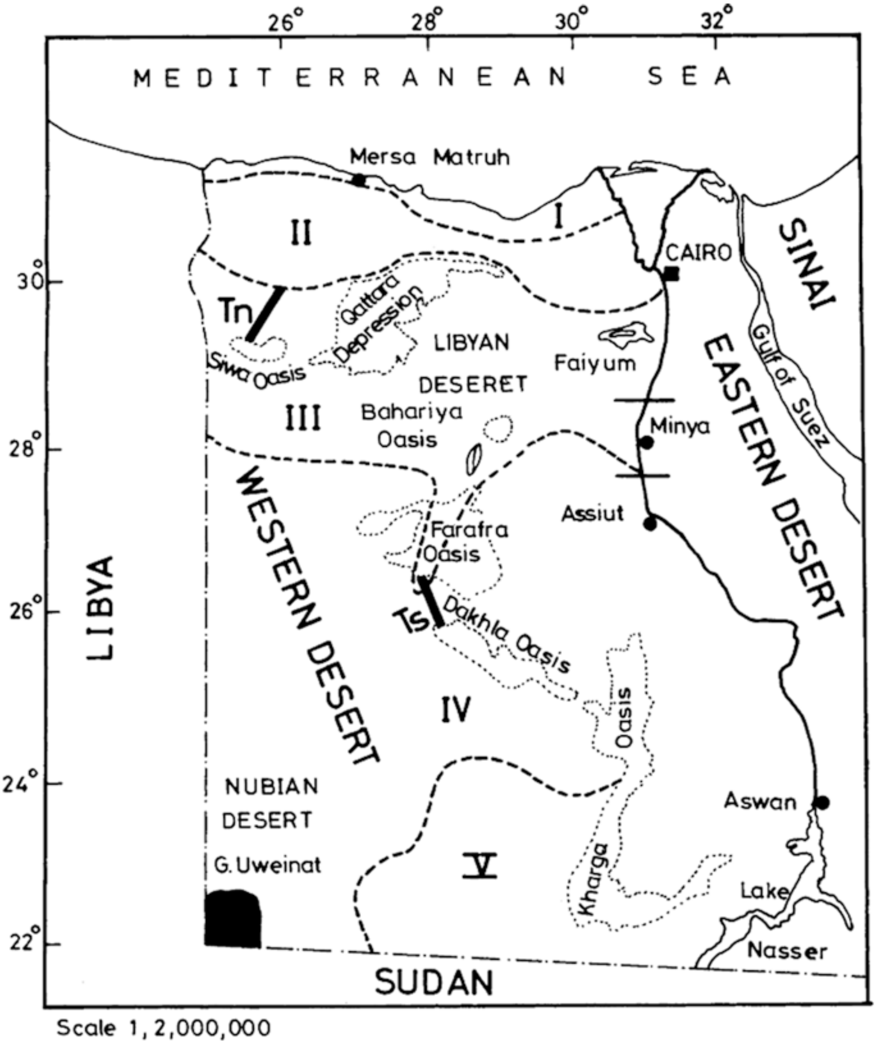

Fig. 5.1 Map showing the five vegetation zones of the Western Desert of Egypt (after Bornkamm and Kehl 1990), indicating the position of the two transects studied: T_n northern transect, T_s southern transect located in the extreme desert zones III and IV

vegetation consists of species which are able to perform an annual life cycle, potential annuals (Haines 1951) or potential perennials (sensu Bornkamm 1987), but can likewise continue growing as long as water persists in the soil. Thomas (1988) identified these plants as those with episodic growth strategies linked to immediate water availability. Recently, Springuel (1997) classifies the accidental vegetation in south-eastern Egypt into three groups: (i) runoff-dependent vegetation in the main wadi channels, (ii) run-on-dependent vegetation of playa formation, and (iii) rain-dependent vegetation on levelled plains of sand sheets.

In a survey of the vegetation units in the Western Desert of Egypt, outside the oases, Bornkamm and Kehl (1990) distinguished five desert zones along a precipitation gradient. Besides the well-known semi-desert and full desert zones in the very north, three zones of extreme desert show a significant differentiation. Both extreme desert zones III and IV support the growth of accidental vegetation, where the precipitation in the former amounts to 5–10(20) mm year^{-1}, whereas in the latter 1–5 mm year^{-1}. On the other hand, extreme desert V in the very south of Egypt is practically void of vegetation where precipitation is proposed to be less than 1 mm year^{-1}. Typical accidental vegetation types in the Western Desert of Egypt are *Zygophyllum coccineum–Salsola imbricata* subsp. *imbricata*, *Stipagrostis acutiflora–Zilla spinosa*, and stands of *Salsola imbricata* subsp. *imbricata–Fagonia arabica*. However, groundwater-dependent vegetation in all the three extreme desert zones exists too: Zahran (1972) and Abd El-Ghani (1981, 1985) in Siwa, in Bahariya and Farafra Oases, and in small uninhabited or inhabited depressions and El Hadidi (1980b), Bornkamm (1986), and Abd El-Ghani (1992) in Bir Safsaf, Bir El-Shab, Bir Tarfawi, and Qara Oasis.

5.2 The Accidental Vegetation Along Two Transects

Although our knowledge of the growth of accidental vegetation in Egypt is considerably increased during the two decades (Alaily et al. 1987; Bornkamm 1987; Springuel et al. 1990) so far much is less about the analysis of this vegetation in quantitative terms. This study has been conducted in two consecutive extreme desert zones (sensu Bornkamm and Kehl 1990), where the accidental type of vegetation exists. Data is from two transects: the northern ($T_{n;}$ c. latitude 29° 30′–30° N) extends for a distance of about 150 km and half-way along Siwa Oasis–Mersa Matruh road representing the extreme desert zone III (Fig. 5.1). This transect is principally located in the inland part of the Middle Miocene plateau that extends south from Siwa Oasis from the north and rises to about 100 m above the depression floor (reaches 20 m below sea level). The southern transect (T_s; c. latitudes 25° 30′–26° N) extends for a distance of about 140 km, along the Dakhla Oasis–Farafra Oasis road representing the extreme desert zone IV, and is located in the middle limestone plateau (500 m above sea level). The northern boundary of these oases is marked by a high escarpment which forms the southern edge of a great plateau of

Table 5.1 Climatic characteristics (average 1931–1978) of three stations, one on the western Mediterranean coast and the others of two oases within the study area (after Zahran 1972; Zahran and Willis 1992)

Station	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Evaporation (mm day^{-1})
	Min	Mx	Min	Mx		
Mersa Matruh	12.4	24.7	51	67	144.0	8.3
Siwa	4.1	38.0	42	61	9.6	11.5
Dakhla	5.8	39.3	19	42	0.7	18.4

Eocene limestone (Said 1962). The northern transect lies in the Libyan Desert, while the southern transect in the Nubian Desert (El Hadidi 1980a). In general, the landscape of the northern transect is a part of the Central Sahara, whereas the southern transect is a part of the Southern Sahara (Schiffers 1971).

According to Walter and Breckle (1984), the study area lies in the zone of subtropical arid deserts. The temperature regime is characterized by mild winters and very hot summers. Whereas average January temperature remains rather constant between 12 and 14 °C, the July mean rises to approximately 31 °C. The absolute maxima of the southern region of the study area may reach 49 °C. Precipitation is erratic, variable, and unpredictable with frequent long dry periods, the mean annual total ranging from 9.6 mm year^{-1} in Siwa Oasis, the nearest station to the northern transect, to nearly 1 mm year^{-1} in Dakhla Oasis, the nearest station to the southern transect (Zahran and Willis 1992). The climatic gradient along the N–S direction in the study area is obvious (Table 5.1). The pluviothermic quotient (Emberger 1955) for Siwa Oasis is about 1.43, while in Dakhla Oasis is nearly zero indicating extreme aridity.

5.2.1 Species and Life-Form Spectrum

Sixty plant species related to 19 families of the angiosperms and one of the gymnosperms were recorded in this study. They constituted 40 perennial and 20 annual species, Cruciferae and Chenopodiaceae (13.3% each), Zygophyllaceae (11.7%), and Caryophyllaceae, Compositae, and Leguminosae (10.0% each), while the other 14 families share 31.7%. Chamaephytes are the most abundant life form and constituted 40.0% of the total flora, followed by therophytes (33.3%), hemicryptophytes (15.0%), and phanerophytes (11.7%). The most common perennials recorded were *Prosopis farcta*, *Tamarix nilotica*, *Fagonia arabica*, *Zygophyllum coccineum*, *Salsola imbricata* subsp. *imbricata*, *Cornulaca monacantha*, *Alhagi graecorum*, *Atriplex leucoclada*, *Randonia africana*, *Deverra tortuosa*, *and Capparis spinosa* var. *aegyptia.* Each of these species attains a maximum importance value (IV) of more than 140 (out of 300 for all species in a stand) and a mean of more than 60 (Table 5.2). Common but less important perennials are *Phoenix dactylifera*, *Pulicaria crispa*, *Anabasis articulata*, *Zilla spinosa* subsp. *spinosa*, *Stipagrostis plumosa*, and *Pulicaria incisa*. Common annuals include *Trigonella stellata*, *Zygophyllum simplex*, *Cotula cinerea*, *Eremobium aegyptiacum*, *Schouwia thebaica*, and *Paronychia arabica* subsp. *arabica.*

5.2.2 Classification of Vegetation

The 144 stands were classified into eight TWINSPAN groups. Each group is defined as a floristic group. A dendrogram with the indicator species is depicted in Fig. 5.2. In the eight TWINSPAN groups 000, 001, 010, 011, 100, 101, 110, and 111, the

Table 5.2 Species composition of the 144 stands in the two transects, arranged in order of occurrence in the eight TWINSPAN groups

TWINSPAN group	000	001	010	011	100	101	110	111
Group sizer	7	16	45	19	5	23	24	5
Prosopis farcta	V. 121	I. 2	I. 1	–	–	–	–	–
Phoenix dactylifera	III. 15	I. 9	I. 5	–	–	–	–	–
Calotropis procera	I. 1	III. 12	I. 1	–	–	–	–	–
Tamarix nilotica	IV. 30	V. 109	II. 19	I. 4	II. 23	II. 6	I. 1	–
Stipagrostis plumosa	–	I. 2	II. 6	II. 3	II. 6	–	I. 1	III. 9
Pulicaria incisa	–	I. 1	I. 1	I. 1	II. 12	I. 4	II. 8	II. 5
Heliotropium digynum	–	I. 5	I. 1	–	I. 7	I. 3	I. 2	II. 4
Alhagi graecorum	–	IV. 77	II. 22	–	–	I. 2	I. 3	I. 2
Citrullus colocynthis	–	I. 1	I. 2	–	I. 2	I. 1	–	–
Fagonia bruguieri	–	I. 1	III. 9	I. 3	–	–	–	–
Zygophyllum album	–	II. 12	–	II. 4	–	–	–	–
Traganum nudatum	–	I. 1	II. 2	–	–	–	–	–
Imperata cylindrica	–	II. 5	I. 1	–	–	–	–	–
Nitraria retusa	–	I. 11	I. 1	–	–	–	–	–
Launaea nudicaulis	–	I. 5	I. 2	–	–	–	–	–
Hyoscyamus muticus	–	I. 1	I. 1	–	–	–	–	–
Zygophyllum coccineum	–	II. 8	V. 69	II. 14	I. 5	I. 4	I. 5	–
Salsola imbricata subsp. *imbricata*	–	II. 18	IV. 62	II. 10	–	–	–	–
Cornulaca monacantha	–	I. 1	III. 15	V. 142	–	I. 5	–	–
Fagonia arabica	–	I. 1	I. 1	IV. 71	I. 5	II. 6	I. 1	–
Pulicaria crispa	–	–	III. 36	I. 4	–	I. 2	I. 5	–
Monsonia nivea	–	–	I. 2	I. 1	I. 3	I. 2	I. 1	–
Fagonia indica	–	–	I. 4	–	–	–	–	–
Sarcocornia fruticosa	–	–	I. 1	–	–	–	–	–
Calligonum polygonoides subsp. *comosum*	–	–	I. 1	I. 3	–	I. 1	–	–
Zilla spinosa subsp. *spinosa*	–	–	II. 10	I. 2	I. 9	II. 4	I. 2	I. 1
Acacia tortilis subsp. *raddiana*	–	–	I. 1	III. 19	–	I. 6	I. 2	–
Astragalus trigonus	–	–	I. 3	I. 2	I. 3	I. 2	II. 2	–
Anabasis articulata	–	–	I. 3	II. 13	–	III. 14	I. 1	IV. 15
Atriplex leucoclada	–	–	–	–	V. 109	II. 4	II. 2	–
Herniaria hemistemon	–	–	–	–	–	I. 1	–	I. 1
Deverra tortuosa	–	–	–	–	II. 14	IV. 39	V. 86	–
Randonia africana	–	–	–	–	–	V. 107	II. 26	II.19

(continued)

Table 5.2 (continued)

TWINSPAN group	000	001	010	011	100	101	110	111
Carduncellus mareoticus	–	–	–	–	–	I. 2	III. 14	–
Farsetia aegyptia	–	–	–	–	–	II. 3	I. 1	–
Capparis spinosa var. *aegyptia*	–	–	–	–	–	I. 12	IV.96	V. 75
Zilla spinosa subsp. *biparmata*	–	–	–	–	–	I. 3	I. 7	IV. 33
Helianthemum lippii	–	–	–	–	–	I. 1	I. 1	III. 6
Salsola villosa	–	–	–	–	–	I. 4	I. 2	–
Ephedra alata	–	–	–	–	–	–	I. 3	–

The five constancy classes (I–V) and the mean importance value rounded to the nearest integer are given in each group. Constancy classes: I = 1–20%, II = 21–40%, III = 41–60%, IV = 61–80% and V = 81–100%

species have been assigned to five constancy classes (I–V). In Table 5.2 the species are arranged into the eight groups with constancy classes and mean importance values. Species constancy classes IV and V are called *constants*, and those with a mean importance value of more than 10 in a group are called *dominants* if the constancy class is II or higher. *Faithful* species are defined as those species that occur in only one group with a constancy class II or higher or those that occur in several groups but have a constancy class at least two levels higher in one group (the one it is faithful to) than in the others. Species in constancy class I and with lowest importance value (1%) are inferred to *occasional.*

The first level of the dendrogram separates all the stands into two main groups. Group 1 represents 57 stands with species recorded only from the northern transect and group 0 with 87 stands sampled from the northern and southern transects but displaying higher importance values of species recorded from the southern stands. Results of the statistical evaluation of the difference at each level represented by *p* values of Mann–Whitney test at the first level and Kruskal–Wallis test at the second and third levels are displayed in Table 5.3. Notably, the first level in TWINSPAN analysis separates the 144 stands into two main groups which are related to electric conductivity (EC), pH, and soil moisture content. At the second level of hierarchy, the two main groups were split into four subgroups based on the soil variables pH, calcium carbonate, soil moisture, and organic matter content. Finally, the third level of classification shows that soil organic matter is the only significant difference among the eight TWINSPAN groups indicating relatively high similarities between each pair of the groups. Table 5.4 summarizes the mean values and the standard deviations of the measured soil variables in the eight floristic groups derived from TWINSPAN. Generally, pH and sand show the least variations among groups. It can be also noted that, whereas levels of lime and fine materials attain their highest values in the groups of the northern transect, the organic matter content reaches its highest levels in the southern transect.

Group 000. *Prosopis farcta–Tamarix nilotica* Group

Table 5.3 Significance values (*p* values) of Mann–Whitney and Kruskal–Wallis tests for the statistical evaluation of the differences in mean soil variables in relation to TWINSPAN groups

	TWINSPAN (level)		
	1st	2nd	3rd
Soil variables	Mann–Whitney		Kruskal–Wallis
Electric conductivity	0.026*	0.34	0.73
pH	0.016*	0.005*	0.243
Calcium carbonate	0.512	0.001*	0.33
Moisture content	0.003*	0.003*	0.17
Organic matter	0.29	0.002*	0.001*
Sand	0.40	0.57	0.62
Silt + clay	0.51	0.49	0.90

*$p > 0.01$

The seven stands in this group are sampled only from the lower part of the southern transect in the vicinity of the lowlands of Dakhla Oasis. Apart from *Launaea capitata*, only recorded annually, the herb layer is not represented.

Group 001. *Tamarix nilotica–Alhagi graecorum* Group

Among the 16 stands in this group, 12 are sampled from the southern transect (Fig. 5.2). The highest values of salinity (2.76 mS cm^{-1}) of this group of stands may favour the growth of some halophytic species, e.g. *Nitraria retusa* and *Zygophyllum album.*

Group 010. *Zygophyllum coccineum–Salsola imbricata* subsp. *imbricata* Group

This is the largest (45 stands) and one of the most common floristic groups of the southern transect. It grows in runnels and depressions where good runoff conditions exist. *Farsetia ramosissima*, *Astragalus vogelii*, and *Trichodesma africanum* are among the recorded annuals.

Group 011. *Cornulaca monacantha–Fagonia arabica* Group

The majority (13) of the 19 stands in this group are sampled from larger catchment areas of the northern transect. It is noteworthy that this group includes some species which do not penetrate into other floristic groups that characterizing the northern transect. Among the important annuals are *Cotula cinerea*, *Reseda pruinosa*, *Opophytum forsskaoli*, *Trigonella stellata*, and *Pteranthus dichotomus.*

Group 100. *Atriplex leucoclada* Group

The five stands in this group are sampled only from the lower part of the northern transect, around the northern boundaries of Siwa Oasis. This group had the largest share (16) of annual species: *Polycarpon tetraphyllum* and *Eremobium aegyptiacum* are the most common.

Group 101. *Randonia africana–Deverra tortuosa* Group

The 23 stands representing this group are mainly confined to the silty runnels and occupying a distance of about 20 km of the middle part of the northern transect.

Group 110. *Deverra tortuosa–Capparis spinosa* var. *aegyptia* Group

The 24 stands in this group occupy a distance of about 30 km in the upper stretches of the middle part of the northern transect. This group represents one of the most common floristic groups in the northern transect.

Table 5.4 Mean values and standard deviation error (±) of the soil variables in the stands representing the floristic groups obtained by TWINSPAN

Soil variables		TWINSPAN groups							
		000	001	010	011	100	101	110	111
EC (mS cm^{-1})		0.54±0.33	2.76±0.75	0.83±0.89	0.86±0.66	220±0.22	0.74±0.69	0.52±0.29	1.08±0.89
pH		7.97±0.64	8.07±0.38	7.95±0.47	7.93±0.36	7.74±0.54	7.72±0.48	7.88±0.45	7.64±0.44
$CaCO_3$	(%)	9.61±2.63	11.26±4.9	14.99±5.80	13.54±5.29	21.04±8.1	14.83±6.02	15.11±5.50	19.08±3.85
MC	(%)	1.67±0.30	1.97±0.61	2.12±0.67	2.27±0.53	2.54±0.25	2.62±0.76	2.86±0.67	3.31±0.67
OM	(%)	1.46±0.24	0.28±0.36	0.21±0.33	0.21±0.27	0.11±0.05	0.12±0.07	0.11±0.08	0.09±0.06
Sand	(%)	93.54±1.38	93.29±1.8	94.54±14.1	92.42±2.01	91.20±0.9	91.57±0.93	88.36±16.87	90.43±0.93
Silt + clay	(%)	6.46±1.38	6.71±1.80	5.46±2.1	7.58±2.03	8.80±0.93	8.43±0.93	11.64±1.13	9.57±0.95

EC electric conductivity, *$CaCO_3$* calcium carbonate, *MC* moisture content, *OM* organic matter

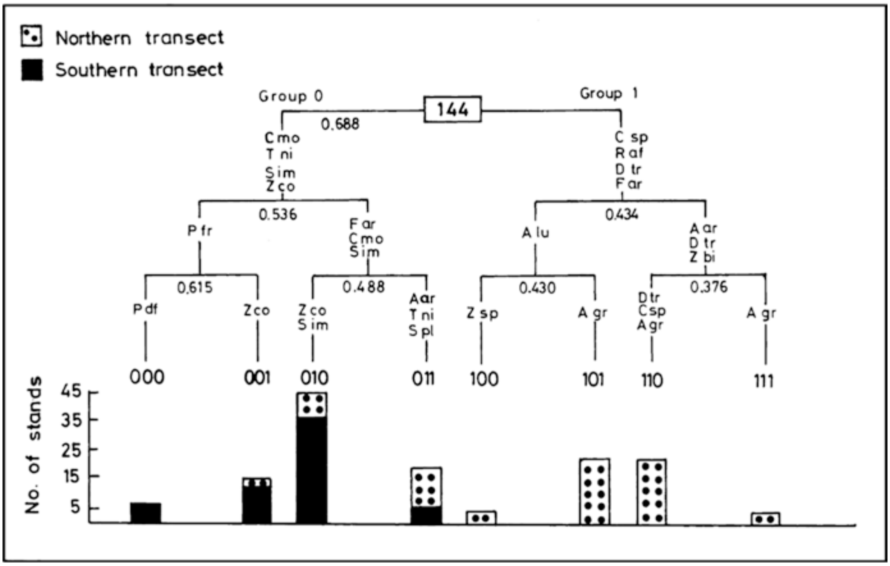

Fig. 5.2 TWINSPAN results for the three levels of division. Indicator species are given together with pseudospecies values. The number of stands and their distribution along the two transects are indicated. Species abbreviations are shown in Appendix

Group 111. *Capparis spinosa* var. *aegyptia–Zilla spinosa* subsp. *biparmata* Group
Most of the five stands in this group are sampled in the low depressions between 185 and 198 km along Siwa Oasis–Mersa Matruh road, the lower part of the northern transect.

5.2.3 Ordination

Linear response models were dropped because gradients along the first two axes are longer that four standard deviation (SD) units (Jongman et al. 1987). The length of gradient represented by axis 1 was >6 SD, indicating a complete turnover in species composition along this gradient. Thus, Detrended Correspondence Analysis (DCA) is the appropriate ordination method or indirect gradient analysis to be used. The four DCA axes explain 11.7%, 7.0%, 5.3%, and 3.4% of the total variation in the species data, respectively. Table 5.5 shows that the eigenvalue for the first DCA axis was high indicating that it captured the greater proportion of the variation in species composition among stands, but the species–environment correlation coefficients were low for DCA axes.

Ordination of the perennial species by using DCA is depicted in Fig. 5.3. Species with high positive scores on DCA axis 1 are found mainly in stands of the southern transect and ordinated close to the right endpoint: *Prosopis farcta*, *Phoenix dactylifera*, *Nitraria retusa*, *Sarcocornia fruticosa*, and *Imperata cylindrica.* The species

Table 5.5 Comparison of the results of ordination by DCA and CCA: eigenvalues and species–environment correlation coefficients for the first four axes are demonstrated

Axis				
	1	2	3	4
Eigenvalues				
DCA	0.830	0.496	0.377	0.238
CCA	0.474	0.376	0.292	0.090
Species–environment correlation coefficients				
DCA	0.724	0.468	0.409	0.331
CCA	0.781	0.871	0.658	0.476

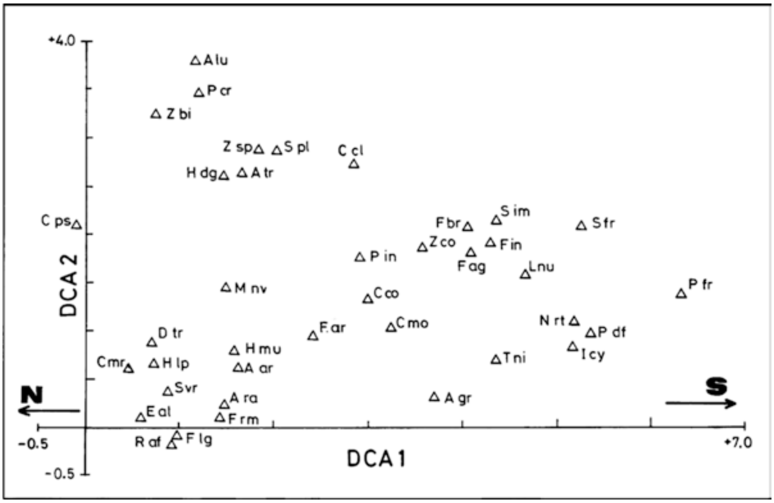

Fig. 5.3 DCA ordination diagram of the 40 species scores on axes 1 and 2. For species abbreviations see Appendix

positioned on the other end of this axis include *Capparis spinosa* var. *aegyptia* (negative end), *Deverra tortuosa*, *Randonia africana*, *Ephedra alata*, and *Helianthemum lippii.* These and many other species are commonly found in the upper and middle parts of the northern transect. In the centre of DCA axis 1, there are many species found throughout the investigated area with no preference to any geographical aspect. Examples are *Zygophyllum coccineum*, *Tamarix nilotica*, *Alhagi graecorum*, *Fagonia arabica*, and *Cornulaca monacantha.* This suggests that DCA axis 1 may represent a geographical trend in the floristic data set. The main reason for this may be a gradient in the local harsh climate within the study area. Along DCA axis 2, species with high positive scores include *Atriplex leucoclada* and *Zilla spinosa* subsp. *biparmata.* These species are recorded from the lower part of the northern transect, whereas species on the other end are of common occurrence in the middle and upper parts. This suggests that DCA axis 2 may represent a distribution trend which separates the lower part of the northern transect from its upper and middle parts.

To compare the classification and ordination results, the TWINSPAN floristic groups are superimposed onto the DCA diagram, and the TWINSPAN group that the individual stand belongs to is given in Fig. 5.4. The eight TWINSPAN groups are separated, but there is some overlap between related groups. It is clear that stands of group 000 are separated along the positive end of DCA axis 1, while groups 100, 101, 110, and 111 are spread out along the other end. It can be also noted that the four floristic TWINSPAN groups that characterize the northern transect are distributed along DCA axis 2. Significance correlations of soil variables with the first four DCA axes revealed greater correlations along axis 1 than the higher order axes. DCA axis 1 shows significant positive correlations with salinity ($r = 0.37$) and organic matter content ($r = 0.57$) and negative correlations with soil moisture ($r = -0.42$) and fine materials ($r = -0.71$). DCA axis 2 is negatively correlated with salinity ($r = -0.44$) and fine sediments ($r = -0.67$) and positively correlated with $CaCO_3$ ($r = 0.52$).

The successive eigenvalues of the first four axes of the Canonical Correspondence Analysis (CCA) carried out on all the 144 stands decrease rapidly, suggesting a well-structured data set. These eigenvalues were somewhat lower than for the DCA axes, indicating that important explanatory site variables were not measured in the analysis or some of the variation was not explained by environmental variables. However, the expected species–environment correlations were higher for the first three canonical axes explaining 84.1% of the cumulative variance. The eight soil variables contributed independently to the overall ordination since none of the inflation variables

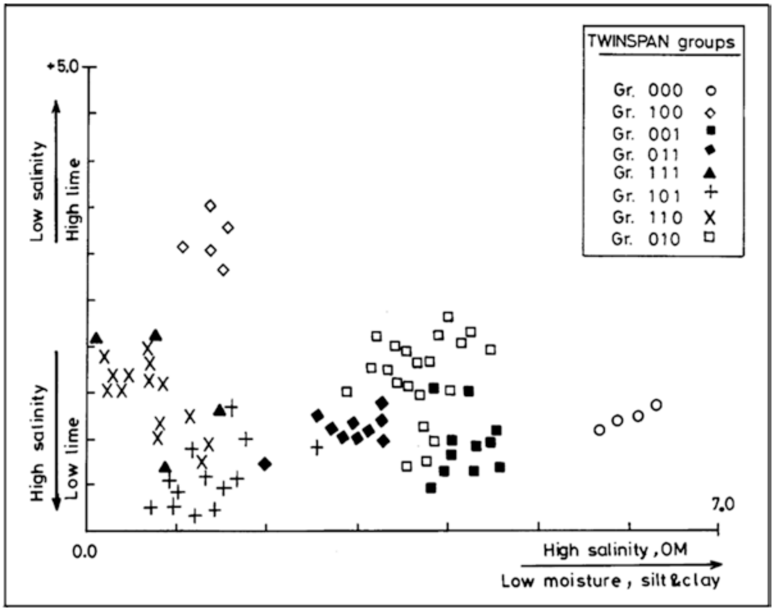

Fig. 5.4 DCA ordination diagram for 144 stands on axes 1 and 2, with TWINSPAN groups superimposed

Table 5.6 Canonical coefficients and the intra-set correlations of soil variables with the first three axes of CCA

Soil variables	Canonical coefficients			Intra-set correlations		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
EC	−0.48[a]	0.88[a]	0.01	−0.50	0.85	0.35
pH	−0.13	−0.16[a]	−0.10	−0.22	0.07	0.06
$CaCO_3$	−0.08	0.02	−0.21	0.06	−0.08	−0.37
MC	0.28[a]	0.09	0.10	0.49	−0.10	0.24
OM	−0.33[a]	−0.19[a]	0.88[a]	−0.41	−0.28	0.85
Sand	0.12	−0.06	0.01	−0.09	−0.07	0.005
Silt + clay	0.53[a]	0.29[a]	0.25	0.67	0.53	0.27

EC electric conductivity, *$CaCO_3$* calcium carbonate, *MC* moisture content, *OM* organic matter
[a]*t*-values > 2.3 (only indicative of strength of coefficient)

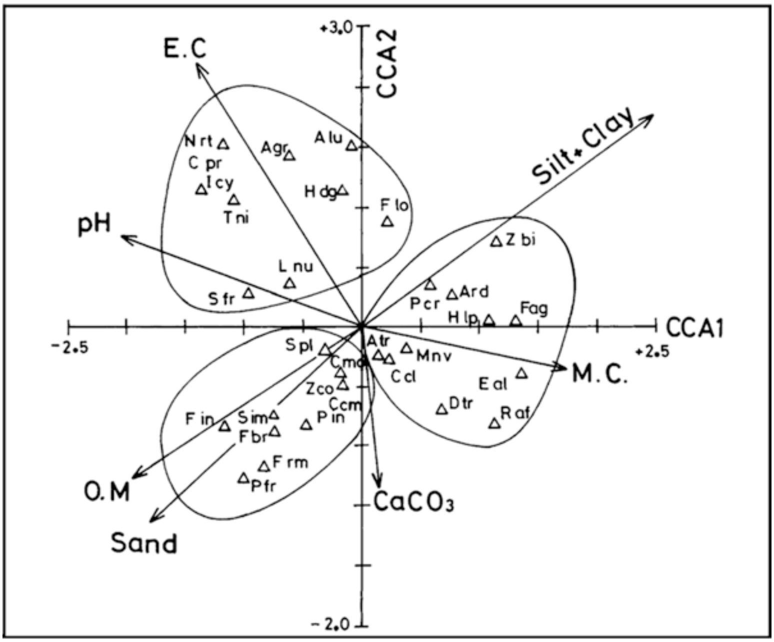

Fig. 5.5 CCA ordination diagram of the first two axes showing the distribution of the 40 species and soil variables (for complete names of the species, see Appendix)

reached higher scores than 1.8. From the intra-set correlations of the soil factors with the first three axes of CCA shown in Table 5.6, it can be inferred that the first axis was shaped by fine sediments, moisture content, and salinity, while the second axis was defined by salinity and organic matter content. This fact is also evident in the ordination diagrams (Figs. 5.5 and 5.6). Contribution of salinity, fine sediments, organic

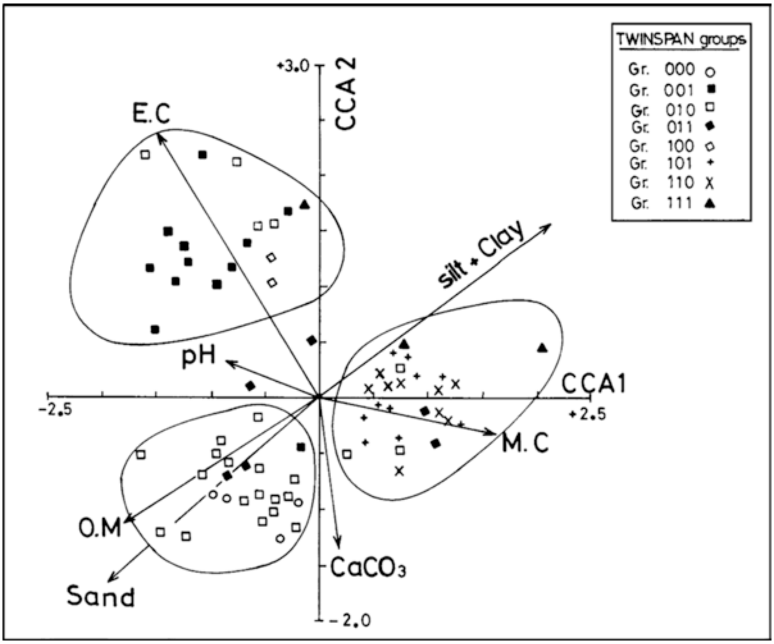

Fig. 5.6 CCA ordination diagram of the first two axes showing the distribution of the 144 stands with their TWINSPAN groups and soil variables

matter, and moisture content, which were selected by the forward selection option in the program CANOCO, to the variation in species data was 29.4%, 29.0%, 22.1%, and 11.3%, respectively. A test for significance with unrestricted Monte Carlo permutation test (99 permutations: ter Braak 1988) found the F-ratio for the eigenvalue of axis 1 and the trace statistic to be significant ($p > 0.01$) indicating that observed patterns did not arise by chance.

Figure 5.5 demonstrated the CCA ordination diagram for the species scores and canonical coefficient scores of the environmental variables. The variables are represented by arrows pointing in the direction of maximum variation, with their length proportional to the rate of change (ter Braak 1986). Each arrow determines an axis on which the species points can be projected. Generally, these projected points estimate the optima of species distribution for each environmental variable. Three species groupings are evident. The first is highly associated with organic matter and sand variables and includes species such as *Prosopis farcta*, *Salsola imbricata* subsp. *imbricata*, *Fagonia bruguieri*, *Zygophyllum coccineum*, and *Cornulaca monacantha.*

The corresponding TWINSPAN floristic groups were 000, 010, and 011 (Fig. 5.6). A second group of species was evident in the upper left quadrant of the biplot associated with salinity and pH that include *Tamarix nilotica*, *Alhagi graeco-*

rum, *Nitraria retusa*, *Atriplex leucoclada*, and *Calotropis procera.* Floristic groups located here are 001 and 100. A third general group of species was evident through the central area of the biplot (Fig. 5.6) closely associated with moisture content, fine materials, and lime with the remaining floristic groups (e.g. 101, 110, and 111).

5.2.4 Concluding Remarks

1. A great deal of the Western Desert of Egypt was submerged up to the Pleistocene, during which its flora and vegetation was established. Climatic changes during this period have had notable ecological effects and have been responsible for the occurrence of elements of different floristic regions. Species with Saharo–Arabian, Irano–Turanian, and Mediterranean chorotypes are well represented. Phytogeographically, the importance of this area may be attributed to its position as a transition between the Mediterranean region to the north and the Saharo–Arabian region to the south. Therefore, its remarkable borderline with the latter region has never been always clear, either in climate or vegetation (Huzayyin 1956). The floristic analysis in the present study revealed that the Saharo–Arabian element constitutes the main bulk (76.7%) of the total species recorded, while Mediterranean element is very modestly represented (3.3%). This shows that the study area is within the Saharo–Arabian region of the Holarctic Kingdom. This is congruent with the work of Bornkamm and Kehl (1985) on the plant communities of the Western Desert of Egypt. Plants of the Saharo–Arabian region are known to be good indicators for arid environmental conditions. Thus, the shrub layer is composed mainly of Saharo–Ar abian with Irano–Turanian and/or Sudano–Zambezian focus of distribution.
2. Along gradients of decreasing precipitation, vegetation varies from grasslands to shrublands (Westoby 1980). The relative advantage of shrubs over grasses when water is limiting, as in the study area, can be explained by their extensive root systems which are capable to utilize water stored in different soil depths, whereas grasses utilize the transient water stored in the upper soil synchronic with precipitation pulses. The upper dry layer of the surface deposits acts as a protective layer, moisture is stored in subsurface layers, and the underlying sandstone provides added water storage capacity. The presence of a subsurface layer that is permanently wet is a well-known phenomenon in the Egyptian Deserts (Kassas and Batanouny 1984). As presented in the results, the dominance of shrubby plant species over the grasses is evident. Chamaephytes constitute 40% of the floristic composition, followed by therophytes. The dominance of both chamaephytes and therophytes over other life forms seem to be a response to the hot dry climate and human and animal interferences. In a comparison of the life-form spectrum of the same 5° of the northern latitude in the corresponding Eastern Desert of Egypt (25–30° N), Abd El-Ghani (1998) showed more therophytes (38.3%) and hemicryptophytes (22.0%) and less chamaephytes (29.0%).

3. The habitat investigated in this study is a relatively simple one, in which the species capable of surviving have to withstand 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). In this respect, the vegetation along the two studied transects has very much in common with that of gorges (karkurs) of Gebel Uweinat and some neighbouring areas of southwestern Egypt (Boulos 1982; Bornkamm 1986). A major difference between the two corresponding habitat types is the high degree of scarceness of precipitation which may fall once every 7–10 years in Uweinat and for longer intervals up to 20 years or more in Gilf Kebir and the neighbouring areas. The vegetation cover of the latter landscape is less than 1% in the extreme desert (Stahr et al. 1985). Thus, often just one species reaches dominance forming monotypic stands as has also been reported by Dasti and Agnew (1994) in the Cholistan and Thal Deserts of Pakistan. However, monodominant stands in this study are not as common as those co-dominated by more than one species.
4. In terms of classification (using TWINSPAN), the accidental vegetation that characterizes the study area can be divided into eight floristic groups: *Prosopis farcta–Tamarix nilotica*, *Tamarix nilotica–Alhagi graecorum*, *Zygophyllum coccineum–Salsola imbricata* subsp. *imbricata*, *Cornulaca monacantha–Fagonia arabica*, *Atriplex leucoclada*, *Randonia africana–Deverra tortuosa*, *Deverra tortuosa–Capparis spinosa* var. *aegyptia*, and *Capparis spinosa* var. *aegyptia–Zilla spinosa* subsp. *biparmata.* This classification differs from previous efforts (e.g. Kassas 1971; Bornkamm and Kehl 1990) because it identified the role of environmental factors. The following facts can be noted: (1) The presence of *Atriplex leucoclada*, *Anabasis articulata*, *Capparis spinosa* var. *aegyptia*, and *Randonia africana* common to the northern Mediterranean coastal belt of the Western Desert (Ayyad and Ammar 1974; Abdel-Razik et al. 1984) is found in the "moist" sites characterizing the northern transect where more silty ground decreases water infiltration. (2) A group of salt-tolerant plants including *Nitraria retusa*, *Tamarix nilotica*, *Sarcocornia fruticosa*, and *Alhagi graecorum* found in the "dry saline" sites forming phytogenic mounds of variable size along the southern transect. *Alhagi graecorum* is a widely distributed species that seems to grow in different habitats (Kassas 1952). It is also considered by Girgis (1972) as a groundwater-indicating plant. 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). *Nitraria retusa*, however, has not been recorded beyond latitude 28°N in Egypt (M. Kassas, pers. comm.). Further studies concerning the distribution of this plant in the country are recommended. (3) The positioning of *Prosopis farcta*, *Imperata cylindrica*, and *Salsola imbricata* subsp. *imbricata* commonly found in the "dry sandy plains" along the southern

transect. The growth of *Imperata cylindrica* in this habitat and disappearance in others are remarkable. Restriction of *Imperata* to the high sandy plains is apparently due to the inability of the species to reach the capillary fringe of the groundwater which is fairly close to the surface (Rikli 1943). The species is considered as facultative halophyte mainly occurring on sandy soil with slight salt content. Thus, this habitat may represent a transitional habitat between the "moist" and the "dry saline" habitat. (4) The xero-psammophytes *Fagonia arabica*, *Cornulaca monacantha*, *Zilla spinosa* subsp. *spinosa*, *Calligonum polygonoides* subsp. *comosum*, *Pulicaria incisa*, *Citrullus colocynthis*, and *Heliotropium digynum* were found in "dry nonsaline" sandy sites along both transects where infiltration is higher and water accumulated in deeper layers and with high fertile soil. This group of species is more widely distributed in Egypt and neighbouring countries (Frankenberg and Klaus 1980; Wojterski 1985) and occurs on different geological substrata.

5. The factorial approach in analysis of plant distribution emphasizes that this distribution is controlled by the interaction between several environmental factors capable of independent variation (Gorham 1954). Ayyad (1976) pointed out that physiographic and edaphic factors play a paramount role in the distribution of plant communities in the Western Desert of Egypt. The vegetation–environment relationships were assessed by both DCA and CCA. CCA analysis shows well the relative positions of species and sites along the most important ecological gradients. Both ordination techniques emphasized that salinity, fine sediments, organic matter, and moisture content are the significant factors controlling the distribution of the vegetation. This has been reported by other researches, among others El-Ghareeb and Hassan (1989), El-Demerdash et al. (1995), and Shaltout et al. (1997). The soil texture gradient that exists from sandy uplands to fine-textured flats in arid desert environments results in gradient of available soil moisture. Therefore, moisture content is probably one of the most effective physical factors leading to vegetation variations from north to south in the study area. The organic matter content plays an important role as a key element in soil fertility. Sharaf El Din and Shaltout (1985) and Abd El-Ghani (1998) provide evidences of soil organic matter in arid desert ecosystems of Egypt.

5.3 Endangered Species: *Randonia africana*

Randonia africana Coss. (Resedaceae) is a spinescent perennial deciduous woody shrublet. It has a fairly continuous range of distribution in the African continent, extending from Senegal and Mauritania eastwards to North Africa, Ethiopia, and Somalia. It is definitely Sahel–Arabian with some trends to Sudanian territories. In Egypt, its distribution shows a restricted geographical range (Fahmy 1990) and represents the easternmost limit in North Africa (Quézel 1978). The plant is currently endangered (El Hadidi et al. 1992). Road construction, overgrazing, ecological disasters, and exploitation of mature plants by desert dwellers and herbalists for use in folk medicine may also significantly contribute to its gradual decline. Only five populations of *Randonia africana* were known in the southern part of Mersa Matruh–Siwa Oasis road (c. 300 km) crossing the Western Desert in the NE–SW direction. The importance of the study area from both floristic and conservation point of views lies in the fact that it represents the limits of distribution range of another two taxa, viz. *Capparis spinosa* L. subsp. *canescens* Coss. (Capparaceae) and *Zilla spinosa* (L.)Prantl subsp. *biparmata* (O.E. Schulz) Maire and Weiller (Cruciferae). These two taxa were recorded in the five population sites. The objective of this study was undertaken to analyse the vegetation associates with *Randonia africana*, in relation to the prevailing soil gradients. It will provide the baseline data on the vegetation structure of *Randonia africana* and the communities in which the species occurs.

5.3.1 Species Composition of Population Sites

Twenty-nine taxa from 14 angiosperm and one gymnosperm family were recorded in this study. They constituted 17 perennials and 12 annuals. *Capparis spinosa* var. *aegyptia*, *Pulicaria undulata*, *Zilla spinosa* subsp. *biparmata*, and *Zygophyllum coccineum* were the most associated perennials. Common annuals included *Trigonella stellata*, *Cotula cinerea*, *Eremobium aegyptiacum*, and *Opophytum forsskaolii*. As can be seen in Table 5.7, there is a core of rather few vascular plant species that frequently associated with *R. africana*, but there is a wide range of other species, which occur more rarely.

5.3.2 Classification of Vegetation Data

TWINSPAN technique helped to distinguish five vegetation groups (A–E) at the third level of hierarchical classification (Fig. 5.7). The five vegetation groups were named after their characteristic species as follows: (A) *Randonia africana–Capparis spinosa* var. *aegyptia*, (B) *R. africana*, (C) *R. africana–Pulicaria undulata*, (D) *R. africana–Zilla spinosa* subsp. *biparmata*, and (E) *R. africana–Zygophyllum coccineum*. The stands of group A have the lowest amount of importance value (91), while those of groups B and E were the highest (IV = 138 and 137, respectively). Some taxa exhibited certain degree of fidelity, e.g. *Deverra tortuosa* in group A and *Schouwia thebaica* in group E. Although not co-dominants and with low IV estimates, certain species have higher constancy levels in their groups, e.g. *Anabasis articulata* (group B), *Fagonia arabica* var. *arabica* and *Tamarix nilotica* (group C), and *Zilla spinosa* subsp. *biparmata* (group E). While *Randonia africana–Zygophyllum coccineum* group (group E) was the most diversified (10.0 ± 5.6 species stands^{-1}) among the other vegetation groups, it had the lowest share of annuals (33.3% of the total).

Table 5.7 Species composition of the five population sites of *R. africana*, arranged in order of occurrence in the five TWINSPAN groups

TWINSPAN group	A	B	C	D	E
Group size	>5		6	4	3
Total number of species	15	19	20	12	15
Mean species richness	6.0±1.4	5.1±2.3	7.2±2.6	5.2±0.5	10.0±5.6
Total number of annuals	5	9	9	5	5
% of annual/total species	35.7	47.4	45.0	41.7	33.3
Randonia africana Cross. (Ra)	91.V	138.V	103.V	101.V	137.V
Capparis spinosa L. var. *aegyptia* (Lam) Boiss. (Cs)	53.IV	3.I	3.I	–	–
Deverra tortuosa (Desf.) DC. (Dt)	30.III	–	–	–	–
Trigonella stellata Forssk. (Ts)	5.III	1.1	–	3.II	10.II
Helianthemum lippii (L.) Dum. Cours. (Hl)	5.III	2.I	–	–	3.II
Cotula cinerea Delile (Cc)	4.II	4.I	3.I	9.III	–
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf.ex Boiss. (Ea)	5.II	3.I	6.II	–	11.II
Atriplex leucoclada Boiss. var. *inamoena* (Aellen) Zohary (Al)	5.II	3.I	1.1	–	–
Monsonia nivea (Decne.) Webb (Mn)	7.II	5.II	–	–	5.I
Fagonia arabica L. var. *arabica* (Fa)	–	6.III	6.IV	–	–
Reseda pruinosa Delile (Rp)	2.I	6.III	1.I	–	–
Erucaria hispanica (L.) Druce (Eh)	–	6.III	5.II	–	2.II
Anabasis articulata (Forssk.) Moq. (Aa)	1.I	15.IV	–	–	8.II
Pulicaria undulata (L.) C.A Moq. subsp *undulata* (Pu)	2.I	–	65.IV	6.II	–
Tamarix nilotica (Ehrenb.) Bunge (Tn)	2.I	–	15.IV	–	13.II
Paronychia arabica (L.) DC. subsp. *arabica* (Pa)	–	1.I	5.III	–	–
Farsetia aegyptia Turra (Fa)	–	–	3.II	–	13.II
Opophytum forsskaolii Boiss. (Of)	–	–	3.II	1.II	–
Heliotropium digynum (Forssk.) C. Chr. (Hd)	1.I	–	6.II	5.II	–
Polycarpon tetraphyllum (L.) L. (Pt)	–	5.II	4.II	–	–
Alhagi graecorum Boiss. (Ag)	–	2.II	2.I	2.II	8.II
Zilla spinosa (L.) Prantl subsp. *biparmata* (O.E. Schulz) Maire & Weiller (Zs)	–	–	–	55.V	11.IV
Carduncellus mareoticus (Delile) Hanelt (Cm)	–	3.II	2.I	5.II	–
Bassia indica (Wight) A.J. Scott (Bi)	–	2.II	2.I	2.II	–
Zygophyllum coccineum L. (Zc)	–	2.II	–	11.III	67.V
Pteranthus dichotomus Forssk. (Pd)	–	–	–	4.III	3.I
Ephedra alata Decne. (El)	1.I	–	1.I	–	–
Schouwia thebaica Webb (St)	–	–	–	–	4.II
Rumex vesicarius L. (Rv)	–	2.I	3.III	–	–

The five constancy classes (I–V) and their mean importance value (IV) rounded to the nearest integer are given in each group. *Bold* entries are indicator and preferential species in each group. Abbreviation of each species is given between parentheses

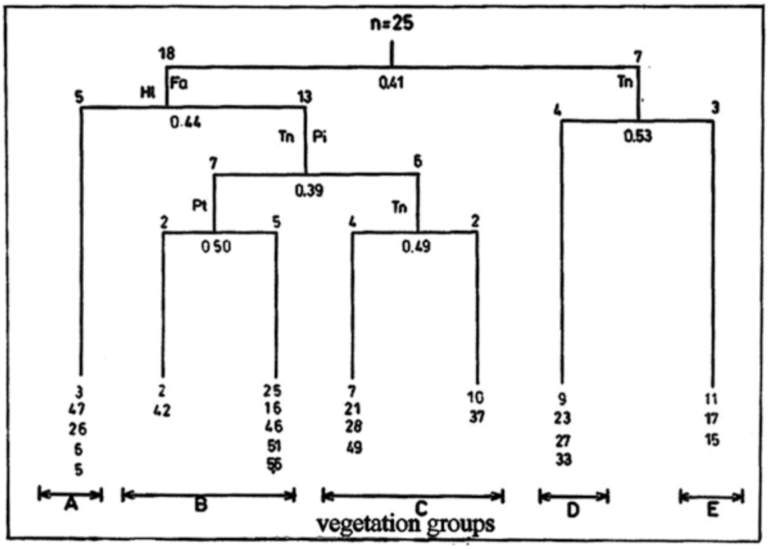

Fig. 5.7 TWINSPAN classification of the 25 stands of *R. Africana*; *A–E* are the five vegetation groups. For indicator species abbreviations, see Table 5.7

5.3.3 Soil Characteristics of the Vegetation Groups

Soil characteristics of each of the five vegetation groups of *R. africana* were summarized in Table 5.8. Of the measured soil factors, calcium carbonate and organic matter contents showed highly significant differences between groups. It can also be noted that $CaCO_3$ attained its highest levels in group A, organic matter in groups C and D, and moisture content in group E. The soil of the stands of group B was characterized by the highest levels of salinity and fine sediments and the lowest levels of sand and moisture content.

5.3.4 Stand Ordination

Figure 5.8 shows the ordination results of the DCA analysis of the floristic data set. The 25 site scores were plotted along axes 1 and 2 and clustered into the five groups that obtained from TWINSPAN. The four DCA axes explained 21.6%, 8.0%, 3.9%, and 2.2% of the total variation in species data, respectively. This low percentage of variance explained by the axes is attributed to the many zero values in the vegetation data set. Table 5.9 demonstrates that the eigenvalue for the first DCA axis was high indicating that it captured the greater proportion of the variation in species composition among stands, but the species–environment correlation coefficients were low for the DCA axes.

Stands of groups A and B were separated towards the positive end of DCA axis 1, groups D and E were separated out along the other end, and those of group C were

Table 5.8 The range and mean ± standard deviation (SD) of the soil variables for the five vegetation groups associated with *Randonia africana* in the study area

Soil variables		Mean ± S.D	Range	TWINSPAN groups					F-ratio
				A	B	C	D	E	
EC (mS cm^{-1})		0.61 ± 0.48	2.31	0.59 ± 0.2	0.93 ± 0.7	0.45 ± 0.5	0.40 ± 0.2	0.5 ± 0.6	1.22
pH		7.8 ± 0.4	1.5	7.8 ± 0.5	7.9 ± 0.5	7.7 ± 0.5	7.7 ± 0.3	8.2 ± 0.5	0.63
$CaCO_3$	(%)	13.9 ± 5.8	21.5	18.8 ± 4.8	15.4 ± 6.2	10.7 ± 4.5	9.0 ± 3.1	16.0 ± 4.9	2.94*
MC	(%)	2.7 ± 0.8	3.00	2.9 ± 0.9	2.5 ± 0.9	2.5 ± 0.6	2.8 ± 0.9	3.5 ± 0.2	0.9
OM	(%)	0.13 ± 0.007	0.27	0.1 ± 0.005	0.09 ± 0.005	0.2 ± 0.009	0.2 ± 0.006	0.05 ± 0.002	3.1*
Sand	(%)	91.6 ± 0.9	4.9	90.9 ± 0.9	91.0 ± 1.3	92.0 ± 0.8	91.08 ± 0.6	91.6 ± 0.2	0.74
Silt	(%)	3.0 ± 0.7	2.90	2.9 ± 0.3	3.2 ± 0.9	3.1 ± 0.9	2.9 ± 0.6	2.5 ± 0.7	0.32
Clay	(%)	5.4 ± 0.6	3.00	5.2 ± 0.7	5.7 ± 0.6	5.0 ± 0.7	5.3 ± 0.3	5.7 ± 0.5	1.2

EC electric conductivity, *$CaCO_3$* calcium carbonate, *MC* moisture content, *OM* organic matter

*$p < 0.01$

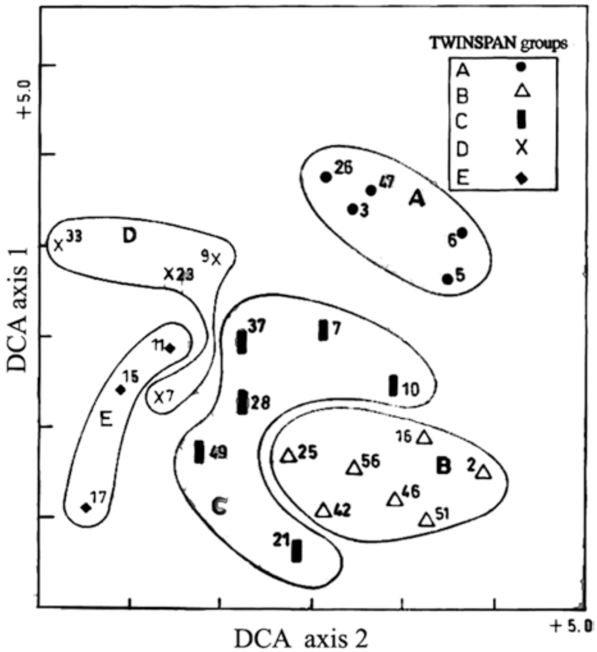

Fig. 5.8 DCA ordination of the 25 stands of *R. africana* on DCA axes 1 and 2 as classified by TWINSPAN

Table 5.9 Comparison of the results of ordination for the first three axes of DCA and DCCA

	DCA axis			DCCA axis		
Soil variables	1	2	3	1	2	3
Eigenvalues	0.72	0.27	0.13	0.40	0.21	0.11
Sp.–env. corr. coeff.	0.47	0.64	0.61	0.91	0.71	0.68
EC	0.15*	−0.35*	−0.034	0.29*	−0.08	0.06
pH	−0.20*	−0.26	0.16	0.24	−0.24	0.45*
$CaCO_3$	0.11	0.29*	0.22	−0.32*	0.03	0.50*
MC	−0.16*	0.16	0.07	−0.17	0.11	0.20
OM	0.002	0.45*	0.05	0.30	0.62*	0.07
Silt	0.08	−0.13	−0.26	0.48*	0.25	−0.21
Clay	0.20*	−0.39*	−0.18	0.25	−0.48*	0.46*

Intra-set correlation of the soil variables, together with eigenvalues and species–environment correlation coefficients. For soil variable abbreviations and units, see (Table 5.8)
*$p < 0.01$

transitional in their composition between the other groups. Detrended Correspondence Analysis axis 2 (eigenvalue = 0.27) and a gradient length of 2.6±SD was less important. It can be noted that DCA axis 1 showed significant positive correlations with salinity, $CaCO_3$, and clay and negative correlations with pH and moisture content. This axis can be interpreted as calcium carbonate–clay gradient. On the other hand, DCA axis 2 was positively correlated with organic matter and negatively with salinity, pH, and clay. This axis can be interpreted as clay–organic matter gradient.

5.3.5 Soil–Vegetation Relationships

The species–environment correlations (Table 5.9) were higher for the first three canonical axes, explaining 68.5% of the cumulative variance. From the intra-set correlations of the soil factors with the first three axes of DCCA, it can be noted that DCCA axis 1 was positively correlated with soil salinity (EC) and silt and negatively with $CaCO_3$. We interpret DCCA axis 1 as electric conductivty–calcium carbonate gradient. This fact becomes more clearly in the ordination biplot (Fig. 5.9). 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. Axis 2 of the DCCA analysis was clearly positively related to organic matter and negatively to clay. We interpret DCCA axis 2 as organic matter–clay gradient.

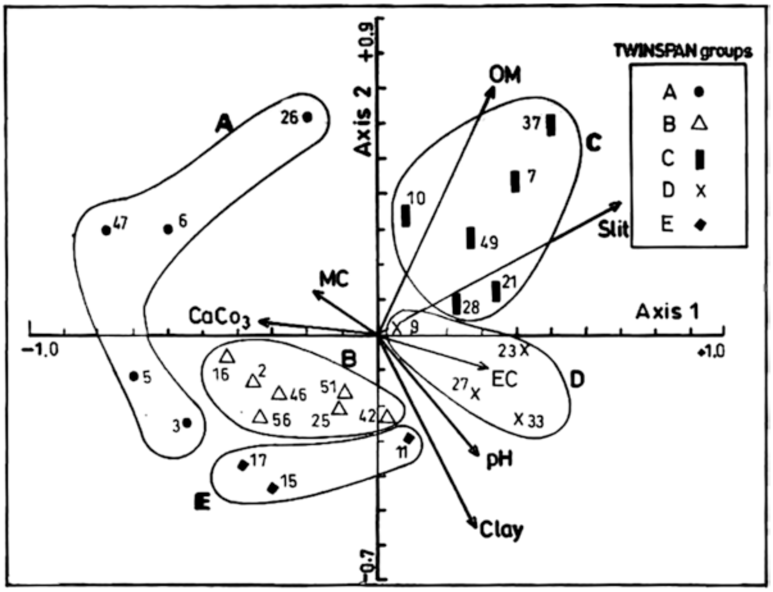

Fig. 5.9 DCCA ordination biplot of the first two axes showing the distribution of *R. africana* stands, with their TWINSPAN groups and soil variables

5.3.6 General Remarks

1. Spatial distribution of plant species and communities over a small geographic area in desert ecosystems is related to heterogeneous topography and landform pattern (Parker 1991). The heterogeneity of local topography, edaphic factors, and microhabitat conditions lead to variation of the distributional behaviour of *R. africana* and its associates. Bornkamm and Kehl (1990) described *Capparis aegyptia–Randonia africana* association to cover the southern part of the Marmarica plateau. Certainly, the identified vegetation groups belong to this association. It is interesting to note that *Anabasis articulata*, *Cotula cinerea*, *Opophytum forsskaolii*, and *Helianthemum lippii* were only included in this study. It may also be concluded that the recent occurrence of such species in the area during the last two decades may be attributed to anthropogenic activities (e.g. tourist resorts, construction of highways, water pipelines, land reclamation projects, medicinal and ornamental plantations).
2. The vegetation cover of the landscape of the study area was less than 5% on the average. As a part of the limestone formations (white desert) of the Western Desert of Egypt, the study area showed the presence of *Zygophyllum coccineum*, *Capparis spinosa* subsp. *aegyptia*, and *Anabasis articulata* (calcicolous species) common to the limestone desert landforms (Kassas and Girgis 1970). Except the latter, those species were also recorded in wadis of the Eastern Desert as well (Springuel et al. 1991; Abd El-Ghani 1998). A group of salt-tolerant plants included *Tamarix nilotica*, *Alhagi graecorum*, and *Bassia indica* were found in the relatively saline stands and form phytogenic mounds of variable size. *Alhagi graecorum* is a widely distributed species that seems to grow in different habitats (Kassas 1952). It is also considered as a groundwater-indicating plant (Girgis 1972). The xero-psammophytes *Fagonia arabica* var. *arabica*, *Farsetia aegyptia*, *Pulicaria undulata*, and *Heliotropium digynum* were found in dry nonsaline stands where infiltration is higher and water accumulated in deeper layers. This group of species is of common occurrence in Egypt (Zahran and Willis 1992), in neighbouring countries of North Africa (Wojterski 1985), and in the Middle East (Yair et al. 1980) as well.
3. The limited number of abiotic environmental factors used with the species data left with *c*. 30% unexplained variation is possibly related to disturbance or competition. This conclusion is in accordance with Jean and Bouchard (1993) who found that only half of the species variation could be related to abiotic variables. In this study there is no evidence of recent disturbance in the stands of *R. africana*, suggesting that the development of plant communities has been mainly influenced by edaphic conditions for a long time. Analysis of the relationship between variations in vegetation composition of the 25 stands supporting *R. africana* and those edaphic factors indicated that species distribution was mainly controlled by soil salinity, percentages of surface sediments of different size classes, calcareous deposits, and organic matter. The percentage of surface sediments of different size classes plays a paramount role in determining the spatial distribu-

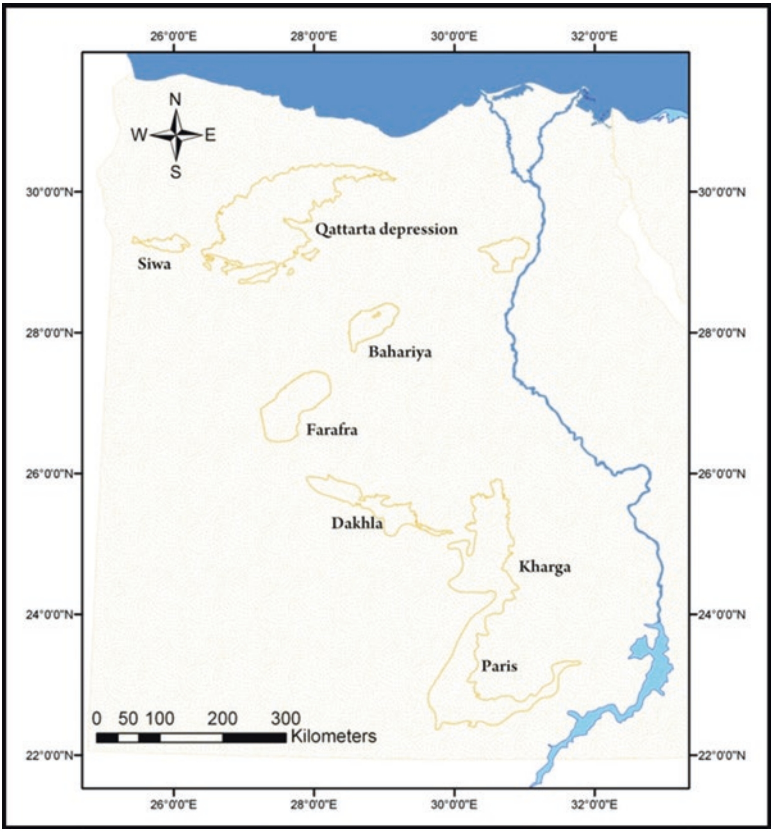

Fig. 5.10 The major desert oases in the Western Desert

tion of soil moisture (El-Ghareeb and Shabana 1990). Many studies provided evidence of the importance of soil organic matter in delimiting vegetation groups not only in the Eastern and the Western Desert of Egypt but also in Sinai Peninsula.

5.4 The Desert Oases

Though considered barren, the Western Desert supports plants in areas with enough water resources (rainfall and/or underground). The oases are the most prominent features of the Western Desert of Egypt. They are green patches amidst the surrounding sterile desert. Siwa, Bahariya, Farafra, Dakhla, and Kharga (Fig. 5.10) are the five inhabited Egyptian oases which contain the largest underground water reservoir (Nubian Sandstone aquifer) known in the whole desert. Other oases have been abandoned as their water supply has depleted.

The main source of irrigation is naturally flowing springs (some hot) or is pumped from wells. This type of irrigation, though simple, is carried out through a peculiar system of side channels specially designed to cope with insufficient supply of water. Accordingly, agriculture and vegetation in these areas are mainly groundwater dependent (Bornkamm and Kehl 1990).

Being lower in level than the surrounding territories, the inland salt marshes are characterized by a shallow underground water table. In certain instances, the underground water is exposed forming lakes of brackish or saline water (Zahran and Girgis 1970). The formation of these salines is due to the uncontrolled spilling of water and flooding of the plains or to the water table which is being close to the ground (Migahid et al. 1960). Under the severe arid conditions of the oases and the lack of a drainage system, flooding of the soil with slightly saline artesian water increases rapidly its salinity. The inland salt marshes of the Western Desert of Egypt are found in the form of sabkhas around the lakes, springs, and wells of the oases, e.g. Siwa, Dakhla, Kurkur, Dungul, etc., and the depressions, e.g. Qattara, Wadi El-Natrun, El-Faiyum, etc. In contrast to the littoral salt marshes, these salines can be considered as secondary. The vegetation has a patchy structure: different patches contain different species (or sometimes one species) and even different growth forms (Abu-Ziada 1980; El Hadidi 1993).

5.4.1 Flora and Vegetation in Ancient Wells

The ancient wells of the Farafra and Qara Oases of the Western Desert and the Feiran Oasis of the Sinai proper provide an example of smaller oases with ancient patterns of agriculture. Abd El-Ghani (1985, 1992, 1998) reported the common irrigation pattern and recognized the habitat types around these wells. The method of irrigation follows a common pattern. The ancient wells of these oases provide an example of the ancient agricultural system. Abd El-Ghani (1985, 1992) reported the common irrigation pattern and recognized special habitats around these wells. This type of irrigation, though simple, is carried out through a peculiar system of side channels specially designed to cope with insufficient supply of water. Figures 5.11 and 5.12 present a diagrammatic sketch of the different habitats of an old well near Siwa Oasis in the former and in Kharga Oasis in the latter. The well opening is usually located in the middle of an elevated mound. Frequently, one or more date palm trees (*Phoenix dactylifera* L.) grow which is clearly marked by the growth of the tall reed *Phragmites australis*. The water flows from the opening through a principal canal of variable length to a storage basin (reservoir or *mahbas* in Arabic). This reservoir is used for collecting water from the main well and then discharging it through several side irrigation canals into the cultivated areas. The excess irrigation water is usually drained to a shallow depression (*sabkha*). Each of the aforementioned habitats has its characteristic vegetation. A similar pattern of irrigation is recorded in the irrigated arable lands of Feiran Oasis of southern Sinai (Abd El-Ghani 1998) and in Al-Hassa Oasis of eastern Saudi Arabia (Shaltout and El-Halawany 1993).

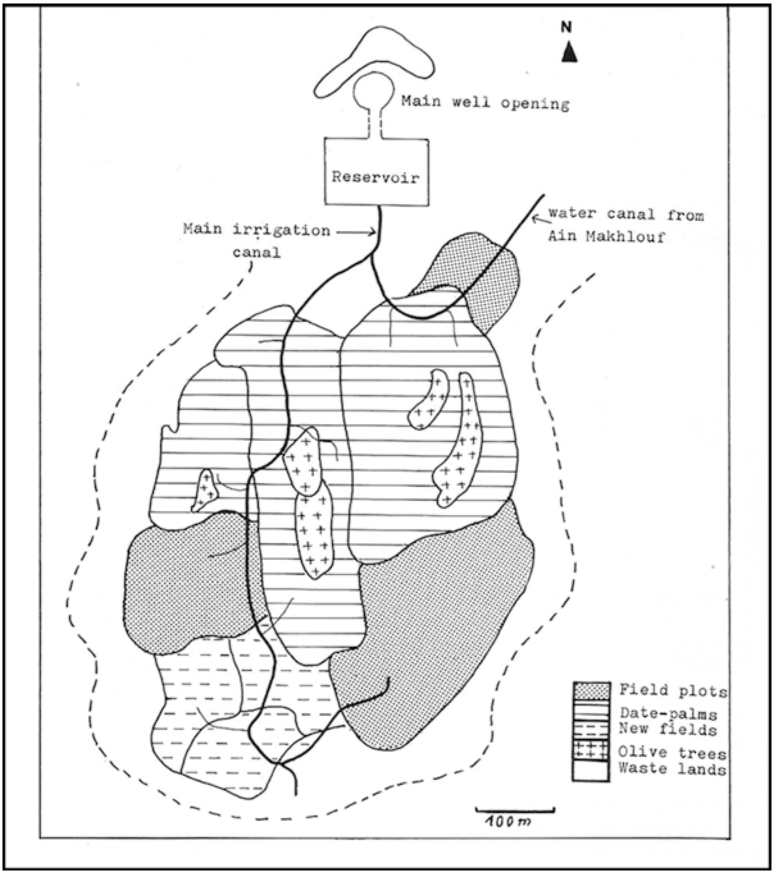

Fig. 5.11 Sketch presentation of Ain Fares, Qara Oasis

Field data on the floristic composition was gathered from 59 sites including 12 in Siwa, 15 in Bahariya, 12 in Farafra, 8 in Dakhla, and 12 in Kharga Oasis. One hundred seventy-two species, 131 genera, and 39 families of the vascular plants were recorded in the five surveyed oases. This represents approximately 51% of the total reported flora of the Egyptian oases (Abd El-Ghani 2000a, b). Though floristic similarities prevail among these oases (Table 5.10), the floristic composition showed perceptible variations within each area.

The irrigated croplands represent a special ecosystem in Egypt. The largest belongs to the Nile region with the Valley and Delta and owes its existence to the alluvial deposits of the Nile River. The water flows through a well-established network of irrigation channels, irrigating about 1.0 million hectares of the most fertile land. The cultivated areas of the oases of the Western Desert (Siwa, Bahariya, Farafra, Dakhla, and Kharga) rank second to the Nile region in area. The main source of irrigation is naturally flowing springs (some hot) or is pumped from wells. With the increased requirement of land for cultivation, reclamation of desert plains has taken

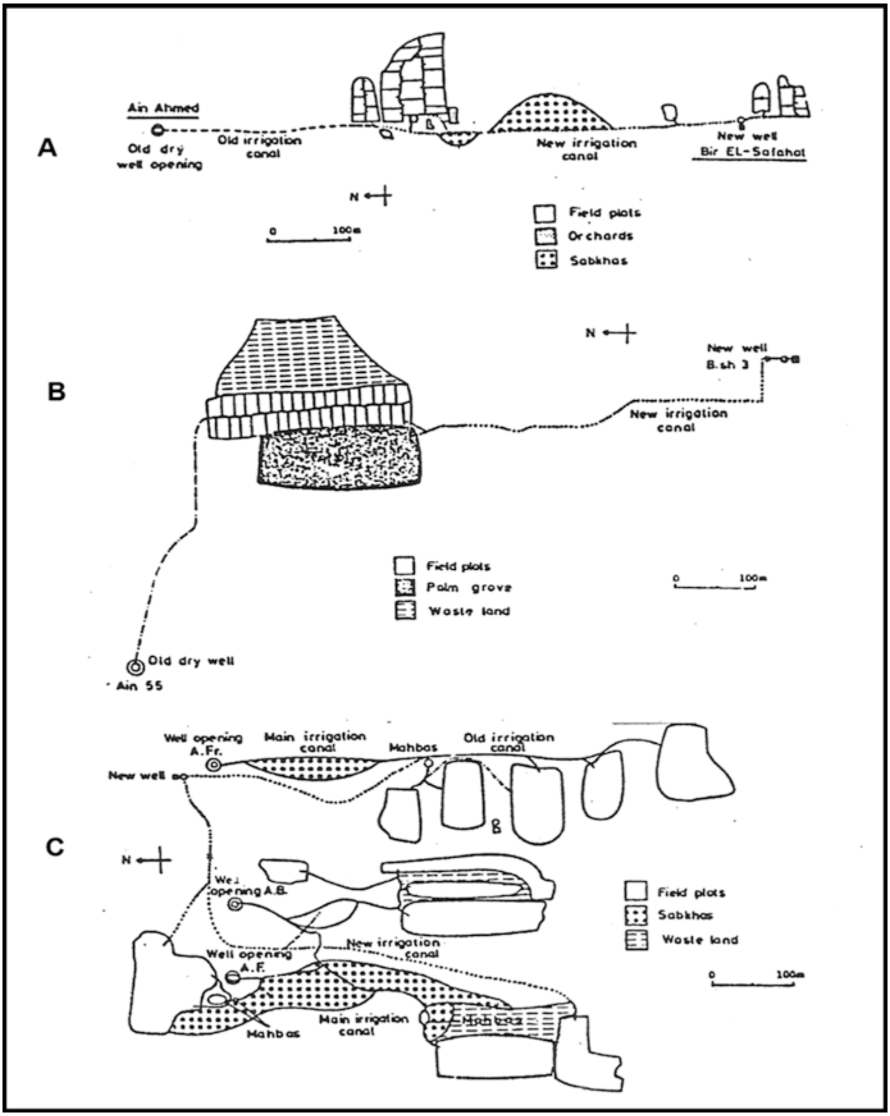

Fig. 5.12 Sketch presentations of Ain Ahmed and Bir El-Safahat (**a**), Ain 55 and Bir Sherka 3 (**b**), and Ain Farag, Ain Balal, and Ain Faheem (**c**) in Kharga Oasis

place in Dakhla and Kharga Oases of the Western Desert (New Valley Project 1959) and also on both sides of the Nile Delta (Tahrir Project 1953). Currently, in the south-eastern part of Egypt, Toshka Project is in operation. With the completion of this project (in about 2020), the water of the Nile will be transferred from the Toshka depression (southwest of Aswan) to a long canal crossing the oases of Kharga, Dakhla, and Farafra. A total of 263,051 hectares is expected to be under cultivation.

Agriculture in the oases follows the general pattern of Egyptian agriculture of summer and winter crops. Date palms (*Phoenix dactylifera* L.) and olives (*Olea*

Table 5.10 Sørensen's coefficients of floristic similarity (lower half) and the beta diversity (upper half) between the cropland ecosystems in the oases

Area of study	S	B	Fr	D	K
S		0.3	0.4	0.3	0.3
B	0.4*		0.3	0.2	0.2
Fr	0.6**	0.5**		0.3	0.3
D	0.4*	0.3*	0.5**		0.5
K	0.4*	0.3*	0.5**	0.7**	
SR	79	143	65	18	77

S Siwa, *B* Bahariya, *Fr* Farafra, *D* Dakhla, *K* Kharga, *SR* Species richness
*$p < 0.05$; **$p < 0.01$

europaea L.) are the principal orchard trees and represent the greatest source of income for the oases. In the inhabited oases, the population occupies small villages around the water resources where agriculture is practiced. The oases of the Western Desert of Egypt have the lowest population density in the country (c. 120,000 in the large five oases according to the 1990 census) compared to their area which occupies about 48% of the total area of Egypt (Abd El-Ghani 1985).

The oases of Siwa, Bahariya, Farafra, Dakhla, and Kharga belong to two structurally related groups with a different geomorphology and climate. The Siwa Oases complex and the Bahariya–northern Farafra group constitute the bulk of the oases of the Libyan Desert (El Hadidi 2000), and the oases of the Nubian Desert consist of a group of three large oases: south Farafra, Dakhla, and Kharga. The irrigation is artesian from old wells and recently dug deeper springs. Due to inefficient drainage system, extensive patches of agricultural land have become more and more saline and are abandoned.

During the early days of Holocene (12,000–10,000 years BP), it is believed that the natural vegetation of Egypt included approximately 1200 flowering plant species (El Hadidi 1993), which amounts to half of the species known at present. With the adoption of agriculture and the introduction of domesticates during the Neolithic–Predynastic period (6400–4500 years BP), an estimated 170 species are introduced and naturalized. These constitute with other native species the early weed assemblages. Following the introduction of other crop plants during Pharaonic Egypt (4500–2000 years BP), the number of adventive species is believed to have reached between 225 and 255 species. During the last two millennia, the number of weeds recorded in the flora of Egypt increased to 470 species.

Weeds of Egyptian croplands differ from season to season because of their ecological requirements. El Hadidi and Kosinová (1971) distinguished two types of field weeds: (1) winter weeds that abound in the cooler months and are associated with winter crops (e.g. broad beans, wheat, Egyptian clover, barley) and (2) summer weeds that abound in the warmer months of the year and are associated with summer crops (e.g. cotton, maize, rice). Abd El-Ghani (1981, 1985) added a third type termed "the all-the-year type" where they are biologically active throughout the year and are usually associated with perennial crops such as alfa-alfa (*Medicago sativa* L.), fruit crops, and palms.

Species diversity was unevenly distributed among taxonomic groups. Poaceae, Fabaceae, Asteraceae, Cyperaceae, and Chenopodiaceae dominated the flora, and together they comprised more than 50% of the total species diversity. These families represent the most common in the Mediterranean North African flora (Quézel 1978). Other families were conspicuously less diverse and there were 25 families with a single species. There were a suite of species-rich genera, but the majority (101% or 77.1%) of the 131 recorded genera was represented by a single species. Large genera included *Euphorbia* (five species), *Cyperus* (four species), *Avena*, *Chenopodium*, *Cuscuta*, *Medicago*, *Juncus*, and *Tamarix* (three for each). Such unequal distribution of species richness among genera was also found in the Feiran Oasis of south Sinai (Abd El-Ghani and Fahmy 1998) and in Al-Hassa Oasis of eastern Saudi Arabia (Shaltout and El-Halawany 1993).

Therophytes were the predominant life form and constituted 57% of the total flora, followed by hemicryptophytes (12%), phanerophytes (9%), chamaephytes, and geophytes (6% for each). This pattern of life-form spectrum displays a strong resemblance to that given by Abd El-Ghani and Fahmy (1998) in the Feiran Oasis, south Sinai (Egypt), and also by Olsvig-Whittaker et al. (1983) in a Negev Desert watershed at Sede Boqer, Israel. Such finding seems to be the response to a more hot and dry climate, topographic variation, human and animal interference, and short-time variation of water availability.

Five main habitat types were recognized: (i) the farmlands (H_1), represented by arable lands occupied by field crops and orchards; (ii) the fresh water irrigation canals (H_2); (iii) reclaimed lands (H_3), which include vast areas of the desert lands that have been reclaimed and are under cultivation; (iv) the waste lands (H_4), which occupy areas that were previously productive farmlands but left fallow and neglected; and (v) the water bodies (H_5), which include the fresh water streams, irrigation canals, water holes, and basins.

5.4.1.1 The Farmlands (H_1)

These represent the arable lands occupied by the field crops and the orchards and exhibit the typical ancient pattern of agriculture. Usually a 3-year crop rotation is applied in the croplands of both the Nile land and the oases. The crop succession during this period is (1) temporary Egyptian clover (or fallow fields)–cotton, (2) wheat–maize (or rice in the northern Delta), and (3) permanent Egyptian clover (or

Table 5.11 Sørensen's coefficients of floristic similarity (lower half) together with their beta diversity (upper half) between the five habitats

Habitats	H_1	H_2	H_3	H_4	H_5
H_1		0.47	0.41	0.39	0.06
H_2	0.46*		0.37	0.57	0.02
H_3	0.07	0.09		0.25	0.01
H_4	−0.26**	0.23*	−0.04		0.05
H_5	−0.03	−0.10	−0.06	0.01	
SR	143	101	42	87	14

For habitat abbreviations H_1–H_5, see text, *SR* species richness
*$p < 0.001$; **$p < 0.05$

broad beans)–maize. So, an area is usually divided into three parts in order to have all the crops in the same year (El-Khshin et al. 1980). Planting time for the winter crops is September–November, February–March for cotton, and April–May for maize and rice. The crop longevity is 5–6 months for all crops, except cotton (7–8 months). Wheat, cotton, maize, and rice receive fertilizers in the form of calcium nitrate or ammonium sulphate (about 150 kg/acre), and all crops, except broad beans, receive calcium phosphate (about 20 kg/acre for Egyptian clover and 15 kg/acre for the others). If barnyard manure is available, the amount of chemical fertilizers is usually reduced. Hand pulling and manual hoeing are the most frequent methods of weed control of all the crops, except rice. The highest species richness (alpha diversity) is recorded in this habitat (Table 5.11).

In the oases of the Western Desert, this habitat occupies the lower levels of the cultivated land where the underground water is available. Orchards occupy the higher levels and surround the crop-field areas. Date palm groves constitute the main bulk of the farmlands. Its densely shaded, cool, and humid environment encourages the growth of certain weed species. Almost pure populations of *Stellaria pallida* and/or *Euphorbia peplus* dominate the ground under the date palm orchards of Bahariya Oasis and all other oases (Abd El-Ghani 1994). It is also found that *Ambrosia maritima*, of recent introduction, grows very rapidly to form dense populations in orchards of the Egyptian oases and along the water courses of the Nile.

5.4.1.2 The Canal Banks (H_2)

This habitat comprises the embankments along the fresh water irrigation canals. Their length and width vary considerably from one site to another according to the cultivated area they irrigate. Most of the irrigation canals in the oases are lined with concrete from the terrace to the canal bed; this reduces the vegetation growth along their sides. Layering of plant species in this habitat is conspicuous. It is inhabited by some trees and shrubs (e.g. *Acacia nilotica*, *Salix subserrata*, *Ziziphus spina-christi*, *Pluchea dioscoridis*, and *Ageratum conyzoides*), subshrubs (e.g. *Atriplex nummularia*, *Persicaria salicifolia*, *Verbena officinalis*, and *Glycyrrhiza glabra*), perennial herbs (e.g. *Chenopodium ambrosioides*, *Oxalis corniculata*, *Phragmites australis*, *Sonchus maritimus*, *Samolus valerandi*, *Phyla nodiflora*, and *Silybum marianum*), and annual herbs (*Lamium amplexicaule*, *Conyza bonariensis*, *Ranunculus sceleratus*, and *Eclipta alba*). The vegetation–environment relationship of the canal banks of the Middle Delta region was the subject of El-Sheikh (1989).

5.4.1.3 The Reclaimed Lands (H_3)

This habitat includes vast areas of the desert lands that are under cultivation. Whereas the modern irrigation techniques (such as drip, sprinkle, and pivot) are used in the newly reclaimed areas, the older ones still follow the inundation type of irrigation as in the ancient alluvial land. This habitat occupies the desert boundaries of the inhabited areas and farmlands. Therefore, a number of desert plants grow and flourish under mesic conditions and behave as weeds of arable lands. Among others, *Launaea capitata*, *Zygophyllum coccineum*, *Bassia muricata*, and *Pulicaria crispa* are included. This is in accordance with the results obtained by Soliman (1996) in the newly reclaimed areas west of the Nile Delta. Several desert reclamation projects are known everywhere all over the country. In the oases of the Western Desert, the underground water irrigates the reclaimed lands, while those around the Nile Valley and its Delta use Nile water as the principal source of irrigation. Over the past decades, extensive areas of wetlands in the Nile Delta have been reclaimed to expand the agricultural land (Khedr and Hegazy 1998). Because of high water table, rice cultivation represents the major crop in these newly reclaimed lands. Wet conditions of the soil provide suitable habitat for some aquatic species such as *Lemna gibba*, *Zannichellia palustris*, *Utricularia gibba*, *Nymphaea lotus*, *Ludwigia stolonifera*, and *Potamogeton crispus* to grow and flourish.

5.4.1.4 The Waste Lands (H_4)

This habitat comprises areas that were previously productive farmlands but then become neglected and left fallow. Two aspects are identified: (1) The desertified soil areas include dried-up remains of crop plants, sand-filled irrigation canals, and traces of previous habitations. The deserted soil supports the growth of xerophytic plant communities dominated by *Alhagi graecorum, Sporobolus spicatus*, *Bassia indica,* and *Chrozophora plicata*. (2) The salinized soil areas are usually found either adjacent to the farmlands or around the irrigation canals. Soils of these areas are saturated with drainage water including a high amount of soluble matter ranges between 2% and 6%. Thus, moist and dry saline soils are, therefore, occurred. Characteristic species are *Cressa cretica, Cyperus laevigatus, Carex divisa, Frankenia pulverulenta,* and *Spergularia marina*.

5.4.1.5 The Water Bodies (H_5)

Many aquatic plants occur in the fresh water basins, reservoirs, and irrigation canals. Water hyacinth (*Eichhornia crassipes*) is a highly invasive aquatic weed native to South America that was intentionally introduced as an ornamental and now completely naturalized. It infects the waterways all over the country in the most dangerous way. The rapid spread of this weed has resulted in great economic losses to fisheries and navigation, as well as declines in native aquatic plants and threats to local biodiversity (Täckholm 1974; Hegazy et al. 1999).

According to El Hadidi (1965), *Potamogeton trichoides* has not been found outside Assiut on the Nile Valley. Probably it is more widespread in Egypt, but it may

Table 5.12 Habitat preferences of the common species (>50% occurrences) recorded from different oases

H_1	H_2	H_3	H_4	H_5
Ambrosia maritima	*Centaurium pulchellum*	*Asphodelus tenuifolius*	*Aeluropus lagopoides*	*Lemna gibba*
Avena fatua	*Chenopodium ambrosioides*	*Bassia muricata*	*Alhagi graecorum*	*Ludwigia stolonifera*
Beta vulgaris	*Conyza bonariensis*	*Launaea capitata*	*Bassia indica*	*Ottelia alismoides*
Brachypodium distachyon	*Desmostachya bipinnata*	*Launaea nudicaulis*	*Carex divisa*	*Zannichellia palustris*
Brassica nigra	*Eclipta prostrata*	*Parapholis incurva*	*Cressa cretica*	
Calendula arvensis	*Pseudognaphalium luteoalbum*	*Polygonum equisetiforme*	*Cynanchum acutum*	
Centaurea calcitrapa	*Heliotropium lasiocarpum*	*Prosopis farcta*	*Cyperus laevigatus*	
Corchorus olitorius	*Imperata cylindrica*	*Pulicaria crispa*		
Digitaria sanguinalis	*Mentha longifolia*	*Thesium humile*	*Eleocharis palustris*	
Echinochloa colona	*Oxalis corniculata*		*Juncus hybridus*	
Emex spinosa	*Panicum repens*		*Pycreus polystachyos*	
Euphorbia peplus	*Phragmites australis*		*Scirpus maritimus*	
Lolium perenne	*Phyla nodiflora*		*Spergularia marina*	
Senecio glaucus	*Samolus valerandi*		*Tamarix nilotica*	
Stellaria media	*Sonchus maritimus*			
Trifolium resupinatum	*Veronica anagallis-aquatica*			

Symbols of habitat types: H_1 farmlands (include irrigated crop fields and orchards), H_2 canal banks, H_3 reclaimed lands, H_4 waste lands (moist land and abandoned salinized field plots), and H_5 water bodies

be overlooked or misidentified by the collectors. Moreover, he suggested the relationship between the general distribution of the plant and the so-called Cacaos–Zambezian fan of bird migration route that includes Egypt within its boundaries. In this survey, few small populations of the species are recorded in the fresh water ponds of the old wells of Qara Oasis, some 30 km east of Siwa Oasis. Its occurrence represents the first record in the Egyptian oases, reaching its extreme western limit of the plant in Egypt.

Recently, *Azolla* spp. (Azollaceae, Pteridophyta) invades the irrigation canals and rice fields of the Nile Delta region. The plant was introduced from the United

Kingdom to water bodies around Mansoura town. According to El Hadidi and Fayed (1994/1995), at least five species of *Azolla* are infesting few years ago the water bodies of the northern governorates of the Nile Delta. Boulos (1999) believed that *Azolla* replaces the native *Lemna* spp. in stagnant water courses. More information about this invasive plant is still accumulating.

It was also found that certain species attain their highest ecological and sociological performance in a particular habitat; this will be referred here to as their preferential habitat (Table 5.12). The farmlands (H_1) are represented by arable land that includes field crops and orchards. They exhibit the typical ancient pattern of agriculture where usually a 3-year crop rotation is applied. Alfa-alfa (*Medicago sativa* L.) is the principal perennial fodder crop that is cultivated in the oases. This habitat occupies the lower levels of the cultivated land where the underground water is available. Orchards occupy higher levels and surround the field areas.

Canal banks (H_2) vary considerably in their length from one site to the other according to the cultivated area they irrigate. Most of the irrigation canals in the oases are lined with concrete from the terrace to the canal bed; this reduces the vegetation growth along their sides. Layering of plant species in this habitat is conspicuous.

Reclaimed lands (H_3) include vast areas of the desert that have been reclaimed and are under cultivation. Whereas the modern irrigation techniques (such as drip, sprinkle, and pivot) were used in the newly reclaimed areas, the older ones still follow the inundation type of irrigation. As this habitat occupies the desert boundaries of the inhabited areas and farmlands, a number of desert plants spread to the arable lands.

The waste lands (H_4) occupy areas that were previously productive farmlands but left fallow and neglected. These include deserted soil areas with dried-up remains of crop plants, sand-filled irrigation canals, and traces of previous habitations. The saline soil areas (not salt marshes) that found either adjacent to the farmlands or around the irrigation canals may be saturated with drainage water including a high amount (2–6%) of soluble matter (Zahran 1972).

The water bodies (H_5) include the fresh water streams, irrigation canals, water holes, and basins. In certain instances they are devoid of vegetation, while in others an extensive growth of water plants such as *Ottelia alismoides*, *Zannichellia palustris*, and *Lemna gibba* may occur.

Variation in Species Richness and β-Diversity Among the Oases

Species richness differed considerably among the five oases (Table 5.11). Bahariya Oasis was the richest in species (143), followed by Siwa (79) even if it is below the sea level. The lowest number of species was found in Dakhla Oasis (18), which represents the least affected area by the anthropogenic activities. The long history of agriculture and land use in Bahariya Oasis may contribute to its high species richness. Species richness strongly correlated with the type of bedrock at each oasis

(Spearman rank correlation coefficient $r = 0.838$, $p = 0.001$). Thus, it may be concluded that the limestone desert oases (Siwa, Bahariya, and Farafra) were richer in species than the sandstone desert oases (Dakhla and Kharga).

A considerable spatial pattern of β-diversity around wells and springs in the five studies oases was significantly correlated with the number of sites surveyed at each area ($r = 0.69$, $p = 0.001$), whereas its correlation with other variables (i.e. site bedrock, area, elevation) was weak and not significant ($p > 0.05$). Sørensen's coefficients of floristic similarity between the five habitats are generally low.

Among the significant positive relations are those between the farmlands (H_1) and the canal banks (H_2). They are the more diversified habitats with high species richness. Clearly, the floristic composition of these two habitats is closely related and characterized by the occurrence of many weed species in common. This may be due to the fact that water of irrigation canals may seep the canal borders and hence increase the soil moisture availability. Not only the reclaimed lands (H_3) and the water bodies (H_5) have the lowest similarities with other ones, but also they are the least diversified habitats. The presence of a highly dominant species in a community results in a general suppression of the less competitive species and hence a decrease in the diversity of that community (Mohler and Liebman 1987). In the present study, the low alpha diversity and species turnover of water bodies' habitat (H_5, Table 5.11) may be related to the fact that most of their species are highly specific to the aquatic habitats. This means that the species replacement or biotic change is low in this habitat (Wilson and Shmida 1984). The high disturbance of its substrate (e.g. cleaning practices and fluctuations of the water velocity) may also explain its low diversity (Grime 1973; Nilsson et al. 1991).

Spatial Distribution of Species

The diversity and species distribution in the agroecosystem of the Egyptian oases was distinguished from those in the Nile land (Abd El-Ghani and El-Sawaf 2004). Climate, particularly temperature and length of dry season, rather than precipitation were important factors in the distribution of species. Batanouny et al. (1988) showed the great variability in the distribution of the different photosynthetic types along a geographical gradient from north to the south of the country. They concluded that the oases and the Nile Valley, with high summer temperature, have a relatively high percentages (62% and 63%, respectively) of C_4 grasses, while the Nile Delta and Faiyum region, with mild temperature, have a lower percentage of C_4 grasses (59% and 51%, respectively). In this study, none of the 172 species occurred at all the 59 studied sites. However, six species, viz. *Cynodon dactylon*, *Echinochloa colona*, *Imperata cylindrica*, *Juncus rigidus*, *Phragmites australis*, and *Tamarix nilotica*, showed the highest species occurrences and have a wide ecological and sociological range of distribution where they recorded in the five oases. Forty-three species or

Table 5.13 Presence estimates of those species ($P > 10\%$) confined to a certain oasis

Species	S	B	F	K	D
Cuscuta pedicellata Ledeb.	25				
Cynanchum acutum L.	50				
Stellaria pallida (Dumort.) Piré	75				
Adiantum capillus-veneris L.		80			
Ammannia auriculata Willd.		33			
Ammannia baccifera L.		27			
Apium nodiflorum (L.) Lag.		87			
Berula erecta (Huds.) Coville		60			
Centaurea calcitrapa L.		100			
Ceratophyllum demersum L.		100			
Cuscuta planiflora Ten.		67			
Cyperus alopecuroides Rottb.		53			
Eichhornia crassipes (C. Mart.) Solms		20			
Eleocharis geniculata (L.) Roem. & Schult.		20			
Eleocharis palustris (L.) Roem. & Schult.		20			
Epilobium hirsutum L.		27			
Equisetum ramosissimum Desf.		13			
Euphorbia arguta Banks & Sol.		33			
Inula crithmoides L.		100			
Juncus fontanesii J. Gay		40			
Juncus hybridus Brot.		13			
Lemna gibba L.		100			
Marsilea minuta L.		13			
Paspalum distichum L.		40			
Persicaria lapathifolia (L.) Gray		67			
Ranunculus sceleratus L.		13			
Schoenoplectus senegalensis (Hochst ex Steud.) Palla		40			
Scirpus maritimus L.		33			
Silybum marianum (L.) Gaertn.		27			
Sonchus maritimus L.		60			
Spirodela polyrhiza (L.) Schleiden		33			
Vicia sativa L.		47			
Brachypodium distachyum (L.) P. Beauv.			33		
Ceratonia siliqua L.			25		
Euphorbia forsskaolii J. Gay			33		
Bassia muricata (L.) Asch.				33	
Doellia bovei (DC.) Anderb.				42	
Launaea fragilis (Asso) Pau				17	
Rhynchosia minima (L.) DC.				17	
Saccharum spontaneum L.				17	
Sporobolus spicatus (Vahl) Kunth				67	
Stipagrostis scoparia (Trin. and Rupr.) de Winter				50	

(continued)

Table 5.13 (continued)

Species	S	B	F	K	D
Suaeda aegyptiaca (Hasselq.) Zohary				25	
Cynodon dactylon (L.) Pers.	66	27	50	100	13
Echinochloa colona (L.) Link	33	7	33	42	13
Imperata cylindrica (L.) Raeusch.	83	47	33	100	25
Juncus rigidus Desf.	66	67	17	75	25
Phragmites australis (Cav.) Trin. ex Steud.	92	93	25	83	63
Tamarix nilotica (Ehrenb.) Bunge	42	67	33	100	63

S Siwa, *B* Bahariya, *F* Farafra, *K* Kharga, *D* Dakhla Oases

25.1% of the total recorded species demonstrated a certain degree of consistency, where they exclusively recorded in or confined to a certain study area. These species were distributed as follows: 3 in Siwa, 32 in Bahariya, 3 in Farafra, and 8 in Kharga Oasis (Table 5.13).

Interestingly, *Equisetum ramosissimum* and *Marsilea minuta* were two ferns known from certain wells in Bahariya Oasis and not elsewhere in the others oases. Their very special habitat along water channels may contribute to their very limited range of distribution. *Sphenoclea zeylanica*, indigenous to the tropics of the Old World, is of recent introduction to Egypt. Its presence may be due to anthropogenic origin, probably with rice grains introduced for cultivation (Abd El-Ghani 1988). The plant was recorded from rice cultivation in Bahariya Oasis, where it seems to reach its northern limit of distribution in the continent. *Populus euphratica*, a threatened tree not known outside Siwa Oasis, grows on the sand dunes that surround certain wells at the western stretches of Siwa Oasis. More studies should be paid to this plant.

The results proved the disappearance of some species from the flora of Egyptian oases. For this purpose, several literature were searched, in addition to present surveys, for those species whose occurrences were previously very common. The water lily, *Nymphaea caerulea* var. *aschersoniana*, is known to be endemic to Bahariya Oasis (Ascherson and Schweinfurth 1887). Collection of the plant during numerous visits made to its type locality and many others was not possible. It is unfortunate that this interesting variety is considered as extinct (Abd El-Ghani 1981). Continuous cleaning and uprooting of the plant from the springs and water channels to get more water for irrigation were the main reason for its extinction. Similar comment can be made to *Ranunculus rionii*, which can also be considered extinct from the oases of Egypt. Few populations, or sometimes individuals, of *Gossypium arboreum*, *Rostraria rohlfsii*, and *Stipagrostis vulnerans* are recorded in their characteristic habitats. They will be referred to as endangered species. In this context, *Schmidtia pappophoroides*, *Dianthus cyri*, *Diplotaxis harra*, *Ammoides pusilla*, *Ducrosia ismaelis*, and *Melilotus serratifolius* were of common occurrence but now are occasionally found in the oases. Human activities such as establishment of new settlements, road construction, digging of new wells, land reclamation, new farming processes, and overgrazing are among the main reasons of threat. *Ambrosia maritima*

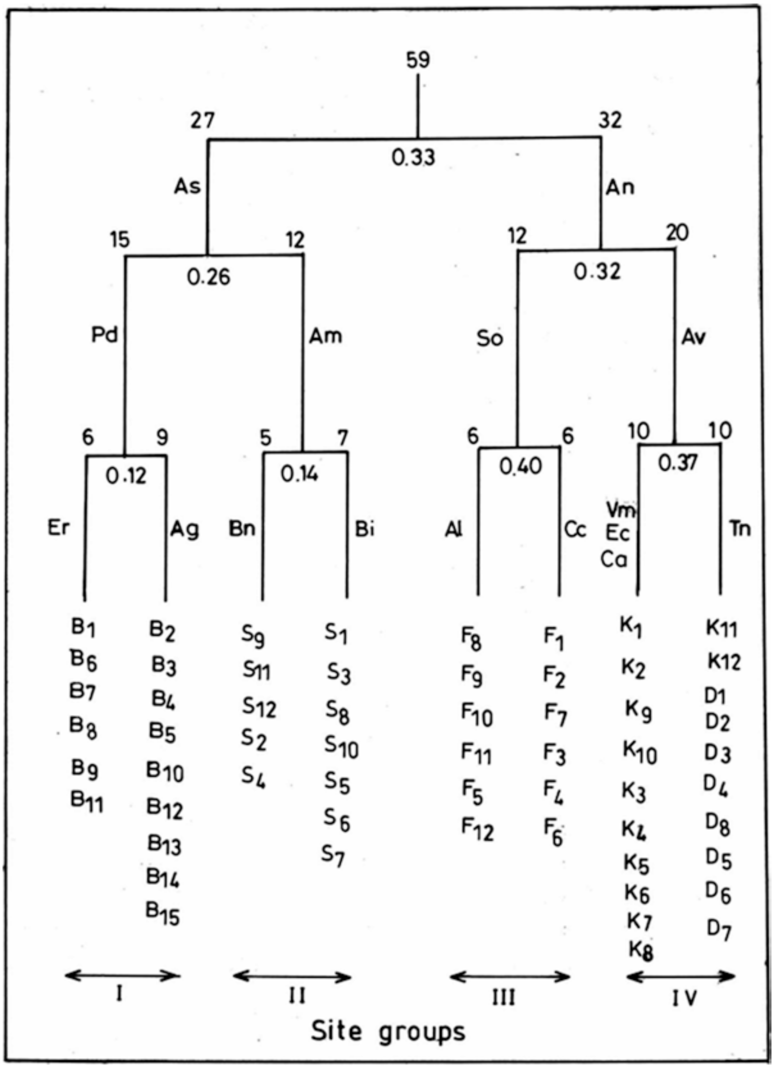

Fig. 5.13 Floristic classification dendrogram generated by TWINSPAN resulting in four site groups (*I–IV*). For abbreviation of indicator species, see Appendix; *B* Bahariya, *S* Siwa, *F* Farafra, *K* Kharga, *D* Dakhla

and *Aster squamatus* were found to dominate the habitats in the farmland ecosystem of the Egyptian oases. They grow very rapidly to form dense populations, especially in the orchards habitat that characterized by its shade, cool, and humid environment. Latter species was recently introduced into Egypt and now completely naturalized and is one of the most common invasive species in the country (Boulos and El Hadidi 1984). Further studies on the environmental correlates of species distribution in these areas are urgently recommended.

Classification and Ordination of Sites

TWINSPAN classification of the presence–absence data set of 172 species recorded in 59 sites resulted in four site groups (I–IV; Fig. 5.13), each of which could easily be linked to a certain oasis. At the first hierarchical level, site groups from Bahariya and Siwa Oases ($n = 27$) were clearly separated from those in the other oases ($n = 32$). At the left side of the dendrogram, the site groups of Bahariya (I) and Siwa (II) are clearly separated with their indicator species *Aster squamatus*, *Ambrosia maritima*, *Paspalum distichum*, *Alhagi graecorum*, *Bassia indica*, and *Brassica nigra*. The right side of the diagram represents the oasis site groups of Farafra (III) and Dakhla and Kharga (IV). *Acacia nilotica*, *Avena fatua*, *Sonchus oleraceus*, *Tamarix nilotica*, *Echinochloa colona*, and *Calendula arvensis* were the indicator species. The latter group (IV) can be inferred to as Dakhla–Kharga complex group, where they have the same origin, and their physiographic features showed high similarity.

Floristically, our study confirms the separation of the northern oases (Siwa and Bahariya) from those in the southern (Farafra, Dakhla, and Kharga). This separation is also coincides, partly, with the phytogeographical territories proposed by El Hadidi (2000) for the Western Desert, which included Siwa, Bahariya, and Farafra in the Libyan (limestone or white) Desert and the other oases (Dakhla and Kharga) in the Nubian (sandstone) Desert. Nevertheless, Farafra Oasis seems to be situated at the border between the two deserts.

Figure 5.14 shows the ordination results of the DCA analysis of the floristic data set. The 59 site scores were plotted along axes 1 (eigenvalue = 0.36) and 2 (eigenvalue = 0.16) and tend to cluster into four groups (I–IV) that resulted from TWINSPAN analysis. The sites were spread out 4.5 SD units along the first axis, expressing the floristic variation among vegetation groups and indicating a complete turnover in species composition that took place (Hill 1979). The first and second axes accounted for 13.5% and 5.8%, respectively, of the overall floristic variance. This low percentage of variance explained by the axes is attributed to the many zero values in the vegetation data set. Bahariya and Siwa Oases' site groups I and II were separated towards the negative end of DCA axis 1, while those of the other oases (groups III and IV) were separated out along the other end.

5.4.2 Habitat Types and Structure of Vegetation

5.4.2.1 The Inland Salt Marshes

Saline lands are widely distributed globally and make up about 10% of the Earth's terrestrial surface (O'Leary and Glenn 1994). Compared to studies of coastal marshes, little attention has been paid to inland saline landscapes (Adam 1990; Krügger and Peinemann 1996). The inland salt marshes of the Western Desert of Egypt are found in the form of sabkhas (Zahran 1982) around the lakes, springs, and wells of the oases, e.g. Siwa, Dakhla, Kurkur, Dungul, etc., and the depressions, e.g. Qattara, Wadi El-Natrun, El-Faiyum, etc. Being lower in level than the surrounding

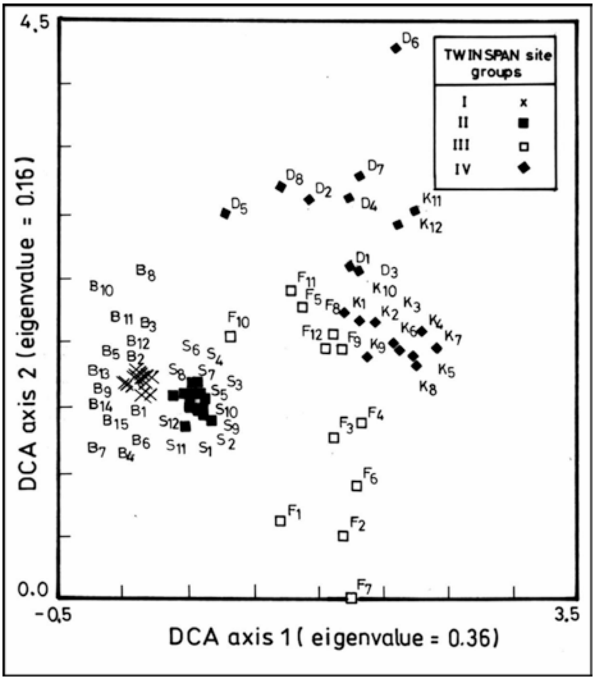

Fig. 5.14 DCA ordination of 59 sites on axes 1 and 2 as classified by TWINSPAN. For abbreviations, see Fig. 5.13

territories, the inland salt marshes are characterized by a shallow underground water table. In certain instances, the underground water is exposed forming lakes of brackish or saline water (Zahran and Girgis 1970; Zahran 1972). The formation of these salines is due to the uncontrolled spilling of water and flooding of the plains or to the water table which is being close to the ground (Migahid et al. 1960). Under the severe arid conditions of the oases and the lack of a drainage system, flooding of the soil with slightly saline artesian water increases rapidly its salinity. In contrast to the littoral salt marshes, these salines can be considered as secondary. The vegetation has a patchy structure: different patches contain different species (or sometimes one species) and even different growth forms (Abu-Ziada 1980; El Hadidi 1993).

Despite the low number of halophytes in Egypt, with 80 terrestrial plant species from 17 families (Batanouny and Abo Sitta 1977), they constitute the vegetation of extensive areas in the country. The halophytic flora is poor: mainly of perennial grasses, rushes, (dwarf-) shrubs, and some annuals which are recorded in saline environments, e.g. *Frankenia pulverulenta* L., *Lotus corniculatus* L., *Solanum nigrum* L., *Asphodelus tenuifolius* Cav., *Bassia muricata* (L.) Asch., *Anagallis arvensis* L. (s.l.), *Conyza bonariensis* (L.) Cronquist, and *Ambrosia maritima* L.

Although the autecology, synecology, and ecophysiology of several coastal salt marshes of the Western Desert of Egypt have been dealt with in a large number of publications (e.g. Ayyad and El-Ghareeb 1974, 1982; Fahmy 1986; Shaltout and

El-Ghareeb 1992; Zahran et al. 1996), the studies identifying the major environmental factors correlated with vegetation patterns in the inland salt marshes are scarce. These have attempted to elucidate, by various means, factors causing the differences in communities both within and between marshes. However, objective methodology and quantitative procedures have been applied in the present study using techniques involving classification and ordination. Recently, some studies in different parts of the country (Dargie and El-Demerdash 1991; Shaltout et al. 1995; Moustafa and Zaghloul 1996; Abd El-Ghani 1998, 1999; Springuel et al. 1997) based on multivariate approach to plant community analysis were carried out. The purpose of this study is to document and describe the plant species composition of the inland salt marshes in two geographically distant oases of the Western Desert of Egypt and to relate the species distribution patterns to some soil factors.

Surveyed Areas

Siwa Oasis

Siwa Oasis is located in the northern part of the Western Desert of Egypt, some 65 km east of the Libyan frontier and 300 km south of the Mediterranean coast. It is limited by the longitudes 25° 18′–26° 05′ E and the latitudes 29° 05′–29° 20′ N. Groundwater is one of Siwa Oasis' most valuable resource. It is tapped from the Miocene fractured limestone through c. 150 springs and flowing wells (total discharge is at least 200,000 m^3 day^{-1}). The water of Siwa springs is warm: varying between 26.5 and 30 °C. However, due to the misuse of groundwater, a continuous rise of the level of subsoil water is widespread. According to Misak et al. (1997), in 1962–1977, the rate of rise was 1.33 cm $year^{-1}$, while in 1977–1990 it measured 4.6 cm $year^{-1}$. Consequently, extensive patches are converted into salt marshes as the soils are subjected to deterioration and salinization. The oasis floor is below sea level, ranges from 0 to −18 m, and displays numerous landforms: salt marshes (sabkhas), salt lakes, and cultivated lands (orchards). The bounding uplands are represented by the northern tableland (up to +150 m) and the southern sand dunes (up to +80 m).

Twenty-five plant species (after excluding species <5% cover and single appearances) were assigned to life forms according to Raunkiaer (1937).

Vegetation

Based on the TWINSPAN outcome, Fig. 5.15 was elaborated. The TWINSPAN analysis divided the stands into seven vegetation clusters. Each cluster representing a specific plant community according to the most abundant characteristic species that reached the highest cover values. These include (A) *Arthrocnemum macrostachyum*, (B) *Cladium mariscus*, (C) *Juncus rigidus*, (D) *Alhagi graecorum*, (E) *Tamarix nilotica*, (F) *Phragmites australis*, and (G) *Cressa cretica*. Some clusters have a single characteristic species (A, B, and G), while the others have three to four species. Three clusters were dominated by a single species (A, C, and G), of which

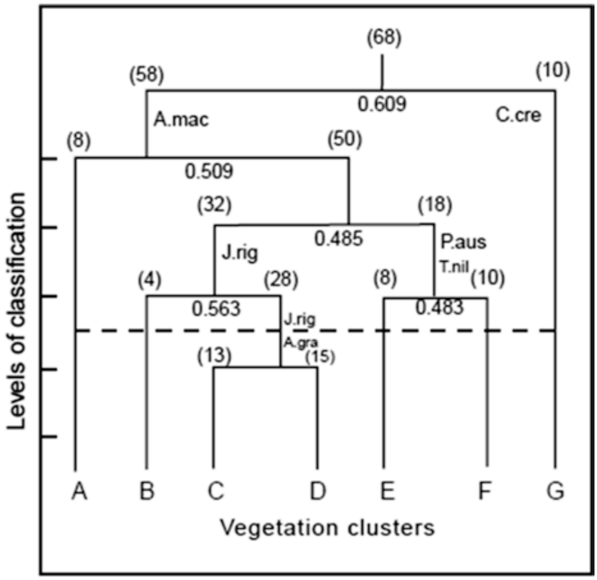

Fig. 5.15 Dendrogram of the seven vegetation clusters of the Siwa Oasis inland salt marshes generated after the application of TWINSPAN classification technique. For indicator species abbreviations, see Appendix

one is restricted to the dry–mesic habitat. No one species is recorded in all clusters. The first TWINSPAN dichotomy differentiated the 68 stands into two main groups according to soil moisture content and fine material (silt and clay) with *p* values 0.003 and 0.001, respectively. A distinct community (*Cressa cretica*) associated with the driest saline habitat is separated on the right side of the dendrogram, while the left side is still heterogeneous. At the second hierarchical level, the "wet–moist" group was split into two subgroups related to the same factors mentioned above, in addition to soil salinity (*p* values = 0.0001, 0.004, and 0.0001 for moisture content, fine material, and soil salinity, respectively). Another distinct community (*Arthrocnemum macrostachyum*) of the wettest habitat was separated. Among the relatively less "wet–moist" group, two further subdivisions, each characterized by the presence of its own vegetation, distinguish communities that differ primarily in calcareous deposits.

Vegetation–Environment Relationships

Soil characteristics of each of the seven vegetation clusters identified by TWINSPAN are summarized in Table 5.14. The mean values of the soil variables show high significant variation between clusters, except soil reaction. The soil lime content shows a significant inverse relationship with salinity, moisture content, and fine material (r = 0.297, 0.274, and 0.333, respectively). Soil salinity is significantly correlated with fine material (r = 0.370), moisture content (r = 0.359), and organic matter

Table 5.14 Means of the soil characteristics (± 1 SD) of the stands supporting the seven vegetation clusters (A–G) of Siwa Oasis derived after the application of TWINSPAN

Soil variables	Vegetation clusters A	B	C	D	E	F	G	F (ratio)	*P*
pH	7.52 ± 0.4	7.52 ± 0.3	7.61 ± 0.55	7.79 ± 0.42	7.77 ± 0.46	8.01 ± 0.33	7.43 ± 0.42	2.06	0.07
TSS (mS cm^{-1})	8.24 ± 2.01	1.7 ± 0.94	6.24 ± 2.82	4.1 ± 1.48	3.62 ± 1.58	2.12 ± 0.62	2.68 ± 0.57	15.32	0.0001
$CaCO_3$ (%)	12.36 ± 4.04	20.35 ± 2.8	18.25 ± 7.64	16.42 ± 7.9	9.91 ± 2.75	13.01 ± 4.14	14.98 ± 2.2	3.24	0.008
OM (%)	4.7 ± 3.29	0.75 ± 0.87	5.07 ± 3.25	3.44 ± 2.22	2.97 ± 1.31	3.19 ± 2.25	1.88 ± 1.18	3.03	0.012
MC (%)	15.66 ± 6.1	2.52 ± 0.77	12.06 ± 5.03	6.84 ± 5.46	4.55 ± 1.62	10.33 ± 7.37	2.80 ± 1.44	7.67	0.0001
S+C (%)	16.25 ± 6.52	9.75 ± 2.5	18.31 ± 6.68	15.07 ± 4.54	12.0 ± 2.73	13.7 ± 5.49	9.3 ± 2.5	8.17	0.005

TSS total soluble salts, *OM* organic matter, *MC* moisture content, *S+C* silt + clay

(r = 0.254). With increasing amount of fine fractions, organic matter content increases (r = 0.718). In addition, organic matter increases with moisture content (r = 0.527) which is positively correlated with soil salinity (r = 0.359) and means that the distribution patterns of organic matter and soil salinity gradually decrease from the wet–moist towards the dry–mesic communities.

The ordination diagram (Fig. 5.16) produced by DCCA that the Monte Carlo permutation test showed that both the overall effect of the environmental variables on species and the first canonical axis are significant (p = 0.01). About 64% of the cumulative percentage variance of species–environment relations is explained by axis 1 (eigenvalue 0.426) and 2 (eigenvalue 0.173). This suggests that environmental variables other than those examined in this study are likely to play a role in explaining further the distribution of vegetation in the target areas. Soil salinity, organic matter, moisture content, and fine material are higher in *Arthrocnemum macrostachyum* and *Juncus rigidus* communities than any of the other communities (significant at p = 0.0001). Both communities established on the wettest stands of the shallow depressions and form monotypic stands with high cover values (80–90%). Whereas the *Arthrocnemum* community shows the lowest number of species, the *Juncus* community is richer in species. The stands of the swampy community of *Phragmites australis* are associated with high moisture content, pH, and low levels of salinity. It usually dominates the vegetation around the wells, where it forms dense growth typical of reed swamps. This community includes species growing in both wet–moist and dry–mesic conditions (e.g. *Chenopodium murale*, *Typha domingensis*, *Echinochloa colona*, *E. crus-galli*, *Sonchus maritimus*, and *Frankenia pulverulenta*). The driest stands are occupied *by Cladium mariscus* and *Cressa cretica* with relatively high amounts of calcareous sediments.

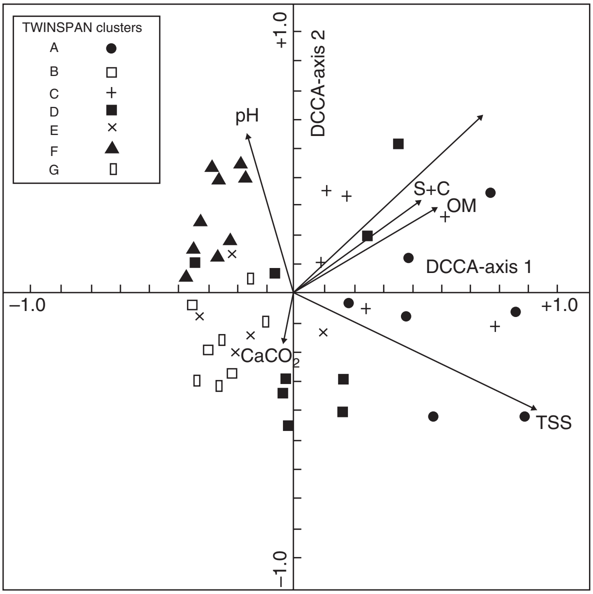

Fig. 5.16 DCCA ordination of the first two axes showing the distribution of the stands of Siwa Oasis with their TWINSPAN clusters and soil variables

Zahran and Willis (1992) report that *Cladium mariscus* is a very rare halophyte, and its domination is recorded only in Siwa Oasis where it flourishes in the marshy land about the springs where the water level is very shallow (5 cm depth). In this study, it inhabits the lime-rich saline flats far from the wells or at the feet of some sand dunes in the extreme western part of the oasis (Al-Maraqi area). The dry–mesic communities of *Alhagi graecorum* and *Tamarix nilotica* associated with flat or convex plains. As a result of the high evaporation rate, a thick crust of salt on the soil surface is formed. However, soils of the dry–mesic communities are uniformly poor in environmental characteristics.

The weighted correlations between the environmental variables and the first two axes of DCCA are given in Table 5.15. These data indicate that the distribution of plant species is most strongly influenced by soil salinity and moisture content. In addition, the weighted correlations of the first axis with organic matter and fine material are high. Axis 2 is significantly correlated with soil reaction and moisture content.

Dakhla Oasis

Dakhla Oasis is located ca. 120 km west of Kharga Oasis and about 300 km west of the Nile Valley between longitudes 28° 48′–29° 21′ E and latitudes 25° 28′–25° 44′ N. The artesian groundwater discharged to the surface through springs, shallow wells, and modern deep wells in which the depth ranges from 300 to 1220 m (Himida 1966). A serious drop of the groundwater pressure in the existing wells and consequently a drop in the discharge of the flowing wells have been emphasized (Abu-Ziada 1980). The lowest point of Dakhla Oasis is about 100 m above sea level, and its surface rises gradually towards the rim.

Twenty-nine species are recorded, representing the common plants that grow in almost all the inland salt marshes of this area. Therophytes are the most common life form and constituted 27.6% of the total flora encountered in this study, followed by chamaephytes (24.2%), geophytes and helophytes (17.2% each), and phanerophytes and hemicryptophytes (6.9% each).

Table 5.15 Weighted correlation matrix of stand ordination along the first two DCCA axes with soil variables in the study areas

	Siwa Oasis		Dakhla Oasis	
Soil variables	Axis 1	Axis 2	Axis 1	Axis 2
pH	−0.152	0.530	0.038	0.286
TSS	0.832	−0.394	0.325	−0.255
$CaCO_3$	−0.014	−0.173	−0.439	0.072
OM	0.496	0.293	0.297	−0.297
MC	0.666	0.628	0.547	0.025
Silt + clay	0.453	0.305	0.101	−0.370
Species–environment correlation	0.832	0.626	0.786	0.682
% cumulative variance	44.2	63.9	39.8	61.7

For abbreviations and units, see Table 5.14

Vegetation

Ten communities were obtained at the fourth division of the TWINSPAN classification of 89 stands and are illustrated in Fig. 5.17. These include (A) *Suaeda aegyptiaca*, (B) *Aeluropus lagopoides*, (C) *Suaeda vermiculata*, (D) *Alhagi graecorum*, (E) *Cressa cretica*, (F) *Juncus rigidus*, (G) *Tamarix nilotica*, (H) *Phragmites australis*, (I) *Typha domingensis*, and (J) *Cyperus laevigatus*. The first level in the TWINSPAN separates the stands according to the soil moisture content ($p = 0.003$) and fine material ($p = 0.005$). At the second level, further divisions correspond to additional partitioning of the moisture content, fine material, salinity, and calcareous deposits ($p = 0.002$, 0.004, 0.001, and 0.003, respectively). Lower levels distinguish communities that differ in pH and all the aforementioned soil variables.

The wet–moist communities include *Suaeda aegyptiaca* community which is widespread on waste land and which was formerly cultivated and left fallow due to salinization. The *Suaeda vermiculata* community shows similarities to that of *S. aegyptiaca* but with *Juncus rigidus* which is frequently recorded. The *Juncus rigidus* community forms thickets of dense growth. It dominates the saline flats in the saline-neglected land that were formerly under cultivation. The plant cover is dense (>80% on the average) mainly by the dominant rush. It represents one of the most common halophytic communities in Dakhla Oasis. The swampy vegetation types represented by *Phragmites australis* and *Typha domingensis* occupy the wettest stands within the study area. This habitat is characterized by a rich and continuous flow of fresh or brackish water from springs or irrigated land (Zahran and Willis 1992). Some water-loving species are recorded: *Cyperus laevigatus*, *Scirpus maritimus*, and *Cyperus rotundus*. The *Phragmites australis* community inhabits the shallow swamps that result from the flow of springs or drainage water, while *Typha*

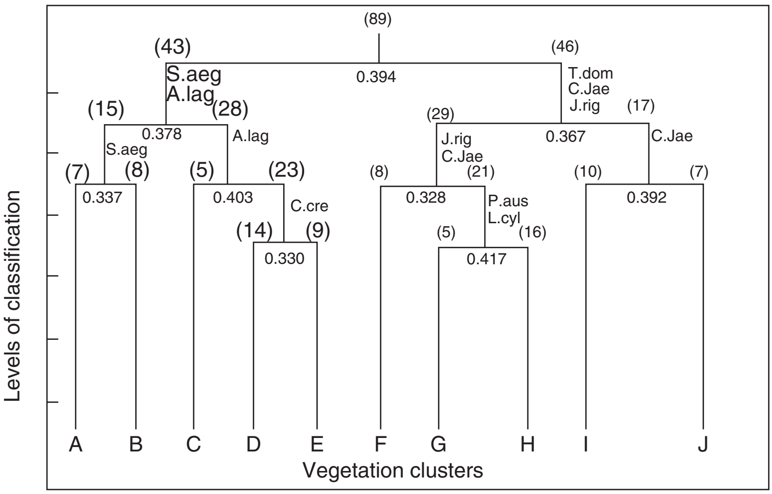

Fig. 5.17 TWINSPAN dendrogram of the 89 stands in Dakhla Oasis inland salt marshes. For indicator species abbreviations, see Appendix

domingensis community forms dense growth in the deeper water fringed with *Phragmites australis* growth towards the periphery of the swamp. Moist pastures dominated by *Cyperus laevigatus* are common in the wet saline flats associated with a shallow (or exposed) underground water, plant is severely grazed, and it forms a carpet-like growth of about 10–20 cm height.

The dry–mesic communities include *Aeluropus lagopoides*, not recorded from Siwa Oasis, and occupy the flat saline stands covered with a thin crust of salts. Whereas *Cressa cretica* community inhabits saline fallow land with occasional deposition of sheets of sand, *Alhagi graecorum* community occurs in sand plains overlying salt marsh beds, and *Tamarix nilotica* community occupies the salt marshes with deep sand deposits. The latter plant is considered one of the climax types of the salt marsh vegetation (Abu-Ziada 1980). It is subjected to destructive cutting for fuel and other household purposes in almost all of the Egyptian oases. The floristic composition of the *Cressa* community is the poorest, while those of *Alhagi* and *Tamarix* are the richest.

Vegetation–Environment Relationship

A summary of soil data for each of the ten TWINSPAN clusters is presented in Table 5.16. This reveals a narrow spectrum of soil reaction and organic matter content. The mean values of soil salinity, calcium carbonate, moisture content, and fine fractions show high significant variation between clusters. In contrast to those correlations between soil variables in Siwa Oasis (results not shown), soil reaction is significantly negatively correlated with salinity ($r = -0.215$) and organic matter ($r = -0.300$) and positively correlated with lime content ($r = 0.245$). In addition, soil salinity does not correlate with fine fractions, but positively correlated with organic matter and moisture content. The soil lime content is negatively correlated with organic matter ($r = -0.434$) and positively with fine material ($r = 0.263$), and the latter is strongly correlated with moisture content ($r = 0.534$). Therefore, calcium carbonate seems to play an important role in characterizing the dry–mesic communities from those of the wet–moist.

In Fig. 5.18 the stands are distributed along the first two DCCA axes through the environmental factors referring to relationship between communities and the factors controlling their distribution. The percent of species–environment variance accounted for by the first two axes (and their eigenvalues) are (1) 39.8 (0.306) and (2) 21.9 (0.168). The species–environment correlations are slightly higher for the DCCA axes: 0.786 and 0.682 for axes 1 and 2, respectively. This is expected as the axes in DCCA are calculated based on species and environmental variables. Correlation coefficients indicate that the measured environmental variables do account for some of the species variation. However, the eigenvalues for the DCCA axes are substantially lower than for DCA suggesting that important site variables have not been measured. The first canonical axis primarily reflects soil moisture–lime content gradient, moisture content is most strongly correlated with this axis, and soil salinity and organic matter are also correlated. A Monte Carlo permutation test suggests that the relations between vegetation variation and environmental

Table 5.16 Means of the soil characteristics (±1SD) of the stands supporting the ten vegetation clusters for Dakhla Oasis, derived from TWINSPAN analysis

	Vegetation clusters											
Soil variables	A	B	C	D	E	F	G	H	I	J	F (ratio)	*P*
pH	8.3 ± 0.5	7.9 ± 0.8	8.1 ± 0.5	8.1 ± 0.5	8.1 ± 0.4	8.2 ± 0.1	8.7 ± 0.3	8.0 ± 0.3	8.5 ± 0.0	7.8 ± 0.3	2.01	0.05
TSS	4.6 ± 1.5	4.3 ± 1.2	4.1 ± 1.4	2.3 ± 1.4	1.3 ± 1.4	3.2 ± 1.1	2.1 ± 0.7	2.3 ± 1.7	3.3 ± 4.0	4.7 ± 3.0	3.49	0.001
$CaCO_3$	28.2 ± 8.2	8.5 ± 3.2	15.3 ± 4.5	16.2 ± 5.5	17.0 ± 4.8	28.5 ± 7.9	13.8 ± 6.4	17.3 ± 8.8	11.4 ± 2.5	9.7 ± 4.4	8.49	0.0001
OM	1.6 ± 1.3	1.6 ± 1.1	1.2 ± 0.9	1.7 ± 1.4	1.1 ± 0.9	1.4 ± 0.6	0.3 ± 0.2	1.8 ± 1.7	1.5 ± 1.4	2.8 ± 2.5	1.58	0.134
MC	16.2 ± 5.5	6.4 ± 4.2	18.2 ± 7.1	6.5 ± 4.9	8.8 ± 6.3	17.8 ± 7.8	21.6 ± 7.9	7.3 ± 4.8	18.3 ± 7.3	20.5 ± 8.9	7.78	0.0001
S+C	13.7 ± 4.7	11.5 ± 4.9	11.6 ± 5.8	8.7 ± 5.1	6.7 ± 2.9	17.1 ± 5.9	12.8 ± 7.6	12.6 ± 4.3	9.2 ± 5.3	13.7 ± 6.2	2.70	0.008

For abbreviations and units, see Table 5.14

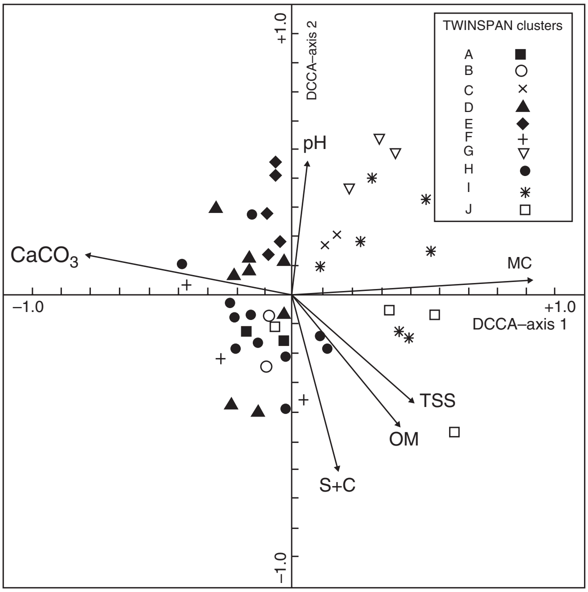

Fig. 5.18 DCCA ordination of the first two axes showing the distribution of the stands of Dakhla Oasis with their TWINSPAN clusters and soil variables

factors revealed by axis 1 are significant ($p = 0.01$). The second canonical axis reflects the gradient of soil reaction and fine fractions. Soil salinity and organic matter are inversely related to this axis.

Inspection of the DCCA diagram (Fig. 5.18) reveals that the stands of *Alhagi graecorum* and *Tamarix nilotica* occupy more of the ordination space defined by the first two axes, while *Aeluropus lagopoides* stands occupy less. Notably, most of the wet–moist communities, except that of *Suaeda aegyptiaca*, are located in the right hand side and their stands are closely associated with pH, moisture content, salinity, and fine materials. On the left-hand side of the diagram, almost all the dry–mesic communities are separated. The stands of these communities are highly affected by $CaCO_3$, pH, fine materials, and organic matter, while the stands of *Phragmites australis* and *Cressa cretica* communities are associated with soil reaction; stands of *Cyperus laevigatus*, *Typha domingensis*, and *Suaeda vermiculata* communities are affected by soil salinity and moisture content.

Concluding Remarks

1. The vegetation distribution pattern in the study areas is mainly related to gradients in salinity, soil moisture content, and fine fractions. Concentration of calcareous deposits, especially in Dakhla Oasis, is also important. Although poor in species, the vegetation is a mosaic of 12 plant communities. *Alhagi graecorum* Boiss., *Tamarix nilotica* (Ehrenb.) Bunge, *Cressa cretica* L., *Juncus rigidus* Desf., and *Phragmites australis* (Cav.) Trin. & Steud. are the ubiquitous species, indicating their wide range of ecological amplitude. Whereas communities of

Cyperus laevigatus L., *Suaeda aegyptiaca* (Hasselq.) Zohary, *Typha domingensis* (Pers.) Poir. ex Steud., *Suaeda vermiculata* Forssk. ex J.F. Gmel., and *Aeluropus lagopoides* (L.) Trin. ex Thwaites are recorded from Dakhla Oasis, the *Cladium mariscus* (L.) Pohl, and *Arthrocnemum macrostachyum* (Moric.) K. Koch. communities are recorded from Siwa Oasis. Most of these communities have analogues in the northern (Ayyad and El-Ghareeb 1982) and southern (Abu-Ziada 1980; Sheded and Hassan 1998) parts of the Western Desert of Egypt. Some of the dominant plant species are known to be of economic importance, for instance, for mats and good-quality paper (Zahran et al. 1979), sustaining animal life (Boulos 1983), sand dune fixation (Batanouny 1979), and protection from coastal erosion (Zahran 1977).

2. The life-form spectra provide information which may help in assessing the response of vegetation to variations in environmental factors. Chapman (1960) indicates that on the basis of the percentage of total species from different geographical regions, the salt marsh is fundamentally a hemicryptophyte habitat but with a tendency for chamaephytes and therophytes to be more abundant in Eastern Europe and Asia. The present study provides evidence that chamaephytes and therophyte form about 63% in most of the communities identified in the investigated areas, and their relative percentages vary from one habitat to another, with chamaephytes acquiring dominance on more saline and therophytes in less saline habitats. Most chamaephytes are succulents and/or mound-forming. The succulence is common in the vegetation of saline habitats. However, five growth forms can be distinguished: (a) rhizomatous growth form, e.g. *Juncus rigidus*, *Typha domingensis*, *Cyperus laevigatus*, and *Cladium mariscus*; (b) stoloniferous growth form as in *Aeluropus lagopoides* and *Phragmites australis*; (c) non-succulent perennial herb growth form, e.g. *Cressa cretica*; (d) non-succulent frutiscents as in *Tamarix nilotica* and *Alhagi graecorum*; and (e) succulent frutiscents as in *Arthrocnemum macrostachyum*, *Suaeda aegyptiaca*, and *Suaeda vermiculata.*
3. The distribution of the reed swamp vegetation in the two oases is remarkable: their growth is usually confined to the areas around the waterholes of the springs in the central and western parts where numerous wells and springs occur. The present study reveals that *Typha domingensis* has a very limited range of distribution in the salt marshes of Siwa Oasis and does not form a discrete community. Simpson (1932) stated that "*Typha domingensis* is more sensitive to salt than *Phragmites australis* as the latter forms well into Lake Mariut while *Typha* is present only where the Lake receives fresh water from Mahmudiya canal". Analysis of the soil samples representing swamps indicates that *Typha domingensis* and *Phragmites australis* communities are confined to levels of salinity lower than any of the other wet–moist habitat communities. Available records for the groundwater analysis indicate that the contents of the total soluble salts in the springs water of Siwa Oasis are much higher (1900–8200 ppm; Zahran 1972) than those of the Dakhla Oasis (440 ppm; Worsley 1930). This may interpret, to some extent, the formation of a well-defined community of *Typha domingensis* in the northern Oasis than in the southern. This conclusion is consistent with that of Zahran and Girgis (1970) in Wadi El-Natrun and Girgis et al. (1971) in the Moghra Oasis.

4. The distribution of species in saline and marshy habitat relates to salinity in many arid regions as has been discussed by several authors, among others Kassas (1957), Ungar (1968), Flowers (1975), Capallero et al. (1994), and Maryam et al. (1995). Ungar (1965, 1974) indicates that the distribution of inland 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) describe the interrelation of the salinity gradient and vegetation in the northern Argentinian salt marshes. Abu-Ziada (1980) also notes strong relationships between the vegetation pattern and the soil moisture–salinity gradients in the Kharga and Dakhla Oases. 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 characteristic of the Eastern Mediterranean region. In their account of the northern and eastern Mediterranean coastal salt marshes, Zahran et al. (1996) demonstrate the distribution of some halophytic species as best correlated along a gradient of a dozen of soil variables, and the most important are salinity, moisture content, soil texture, organic matter, and calcium carbonate. However, the concrete role of particular ecological factors varies between different ecosystems. In the present study, soil salinity and its variation from one habitat to another are the primary determinant of the plant community composition. Further studies may stress on the role of the annual variation in salinity and depth of the groundwater level in one hand and the zonation of the plant species as affected by these factors in the other.
5. The relationship between vegetation and environment is not unidirectional in salt marshes. In this study, the high clay, silt and organic matter, and the flatness of the marsh surface result in frequent or almost continuous waterlogging. Salinity promotes waterlogging by lowering the water vapour pressure, so depressing evaporation, and by affecting the organization of clay particles so that a largely structureless soil with a low hydraulic conductivity is produced (Long and Mason 1983). These parameters, in turn, change the species composition of plant communities. This is also in agreement with the findings of Fahmy (1986) in a salt marsh on the western Mediterranean coast of Egypt and those of Shaltout et al. (1995) in the Mediterranean region of Nile Delta. The role of soil moisture as a key element in the distribution of the plant species in the salt marshes is known in other adjacent countries: Zohary and Orshan (1949) in the Dead Sea region of Israel, El-Sheikh and Yousef (1981) in Al-Kharg springs, El-Sheikh et al. (1985) in an inland salt marsh of Al-Qassim area of Saudi Arabia, and Winter (1990) in a Jordanian saltpan of Al-Azraq Oasis.
6. The high percentage of calcareous sediments, especially in the soils of Dakhla Oasis, together with the other factors (Anderson et al. 1990) gives a number of glycophytes a competitive advantage over halophytes, as they are tolerant to salt. Girgis (1973)) suggested that the presence and relative abundance of glycophytes may be taken as a measure of the degree of halophytism in a plant community.

However, in this study, a number of glycophytes are recorded; these include *Salsola imbricata* subsp. *imbricata*, *Zygophyllum coccineum*, *Launaea capitata*, *Pulicaria crispa*, *Hyoscyamus muticus*, and *Tamarix aphylla*. Most of these species are of common occurrence in Dakhla Oasis.

7. The zonation of the salt marsh vegetation is a universal phenomenon. Concentric zonation of halophytic communities in small lakes and salt marshes of the Egyptian oases was described by Kassas (1971). Kehl et al. (1984) also describe the ring-shaped vegetation formations in NW Egypt resulting from different habitat gradients. In his account on the vegetation and flora of Qara Oasis (−70 m, on the SW edge of Qattara depression), Abd El-Ghani (1992) recognizes four concentric zones of plant communities bounding the oasis, established on previously cultivated land but now salinized or desertified.

5.4.2.2 The Saline Lakes: Wadi El-Natrun Depression

Inland saline lakes (athalassohaline) are aquatic environments with ionic proportions quite different from the dissolved salts in seawater. They are temporary bodies of water with salinities >3 gl^{-1} and lacking any connection to the marine environment (sensu Bayly 1967). Salt lakes are confined to dry regions of the world where evaporation exceeds precipitation and where they are often more abundant than fresh waters. Inland saline lakes have received increased attention in recent years due to their sensitivity to climatic change. Climatic conditions must reach a certain degree of aridity effectively to remove water by evaporation or freeze drying and so produce progressively concentrated brine. Geochemical and hydrological features are largely responsible for controlling the concentration and composition of the resulting brine (Eugester and Hardie 1978; Lent and Lyons 1995). Changes in evaporation and precipitation can affect the physical and chemical conditions in such lakes (Williams 1981; Hammer 1986; Melack 1986; Comin and Northcote 1990; Pienitz et al. 1992).

In Egypt, certain areas are lower than the sea level and constitute depressions in the desert west of Nile Delta. They include some water bodies characterized by high salinity and considered as a valuable economic resource that can be developed for better exploitation. One of these depressions is Wadi El-Natrun (23 m below sea) which considered among the important depressions in the Western Desert for land reclamation and utilization. The presence of irrigation water as underground water of suitable quality, the existence of natural fresh water springs, and the availability of some moisture contained in the sandy layers above the shallow water table southwest of the depression are the main reasons for the importance of Wadi El-Natrun region (Salem et al. 2003).

Wadi El-Natrun is characterized by small disconnected lakes in its bottom (Fig. 5.19), aligned with its general axis in the northwesterly direction except Lake El-Gaar (Zahran and Willis 2009). These lakes receive a limited supply of groundwater which seeps into the depression. Since the evaporation rate is high and the lakes lie in closed basins without outlet, the water in the lakes has a high salt con-

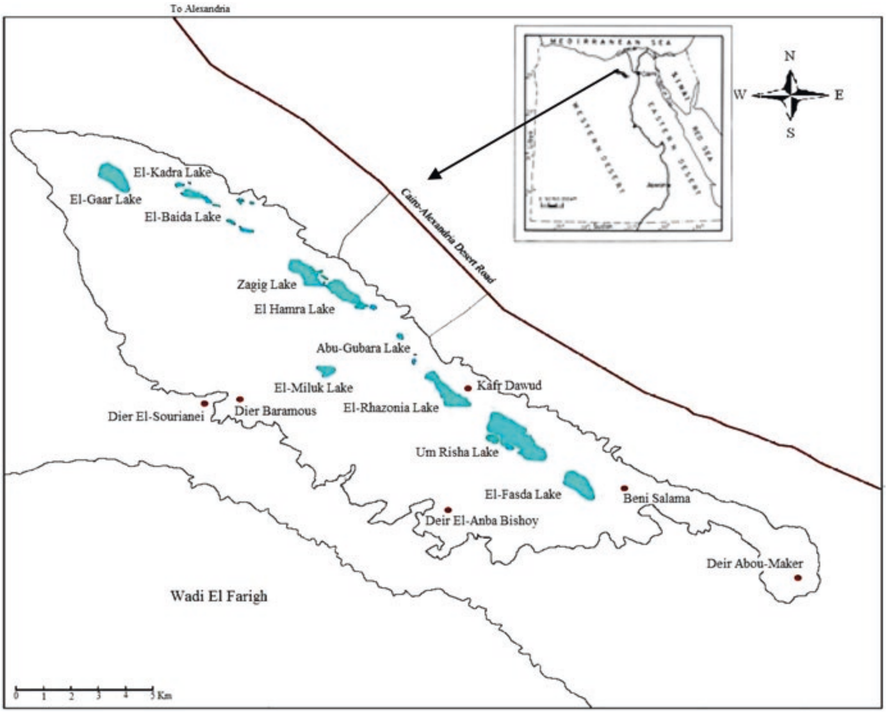

Fig. 5.19 Map of Wadi El-Natrun, showing the position of the studied lakes

centration and is susceptible to marked fluctuations in level and salinity. Although different colorations due to microbial populations are indicated by some of the lakes names (Hamra=red, Khadra=green, Beida=white), the coloration of the lakes is not constant but is subject to seasonal changes. There is a discrepancy regarding the number of lakes in Wadi El-Natrun, which ranged between 2 and 16 (Abu Al-Izz 1971).

Zahran and Willis (2009) reported the presence of eight principal lakes for a distance of about 30 km, permanent water in all or some of their parts, from south to north: El-Fasda, Um Risha, El-Rhazoniya, Abu-Gubara, El-Hamra, El Zugm, El-Baida, El-Khadra, and El-Gaar, noting that Abu-Gubara and El-Hamra form one lake in the summer. The *Natrun* occurs in solution in the lakes and forms a crust around the edges of the lakes and in deposits on their bottom. *Natrun* deposits have long been known and were used by the ancient Egyptians in the manufacture of glass, remnants of which are still found in the southern part of the depression.

Wadi El-Natrun is a narrow depression (23 m below sea level) located in the west of the Nile Delta, approximately 110 km northwest of Cairo between longitudes 30 80 20 and 30 82 90°E and latitudes 30 81 60 and 30 83 20°N (Fig. 9.10). The total area of Wadi El-Natrun is ca. 281.7 km^2, extending in a NW–SE direction. The origin of the underground water in Wadi El-Natrun is seepage from the

Nile stream, because of its proximity and low level (El-Maghraby 1990). A series of isolated saline lakes occupy the axis of the depression. The water level in the lakes fluctuates seasonally along the year rising up in winter and falling down in summer but never get dry and ranges from 16 m in Zagig Lake to 23 m in El-Gaar and El-Fasda Lakes.

The dominating land use practice is grazing and cutting. Wadi El-Natrun is a good source of forage, based on the palatable salt marsh vegetation cover (77%), and these resources are currently used sustainably by the local inhabitants. However, areas of natural forage that serve as rangelands are subjected to several types of degradation, overgrazing, removal for agriculture, and fragmentation by road network and urban sprawl (Salem et al. 2003). The Wadi can be best described as a raw grazing ecosystem for raising livestock (such as goats, sheep, cows, and camels) noting that each type of livestock has a grazing behaviour different from the other. Expanding human demand and economic activities are putting constantly increasing pressure on land and other particular natural resources in the area creating suboptimal use and even destruction.

5.4.2.3 Floristic Variations

Data were collected from seven lakes and were permanently visited to study the vegetation and floristic composition around these lakes. Table 5.17 demonstrated the floristic analysis of the 25 species of vascular plants from 22 stands associated with the studied seven lakes in the study area and distributed as follows: 1 tree, 4 annuals, and 21 perennial herbs. The latter included *Juncus acutus*, *J. rigidus*, and *Cyperus laevigatus* var. *laevigatus* as the common species. It is obvious that the desert outskirt surrounding the lakes favour the growth of some perennials such as *Phragmites australis*, *Imperata cylindrical*, *Alhagi graecorum*, and *Desmostachya bipinnata*. Furthermore, the saline feature of this habitat enabled some salt-tolerant species to grow and flourish such as *Typha domingensis*, *Typha elephantina*, and *Spergularia marina*. Among the less common species, *Sonchus maritimus*, *Panicum turgidum*, and *Cynodon dactylon* were noticed. Five species were occasionally recorded (recorded in one stand) and/or very modestly represented. These included xerophytic species such as *Sporobolus spicatus* and *Centropodia forskaolii* and water-loving species such as *Zannichellia palustris*, *Berula erecta*, and *Samolus valerandi*.

Four species (*Juncus acutus*, *J. rigidus*, *Cyperus laevigatus* var. *laevigatus*, and *Phragmites australis* subsp. *australis*) were constantly recorded around the seven lakes which exhibited wide ecological and sociological ranges. On the other hand, eight species were confined to only one lake (narrowest sociological range) where *Panicum turgidum* and *Centropodia forskaolii* were confined to El-Gaar Lake, *Samolus valerandi* and *Apium crassipes* to El-Hamara Lake, *Sporobolus spicatus* and *Digitaria sanguinalis* to Um Risha Lake, *Solanum elaeagnifolium* to El-Zaqiq Lake, and the water-loving plant *Zannichellia palustris* to El-Beda Lake.

Table 5.17 Variations in floristic composition of the 22 stands around the studied seven lakes in Wadi El-Natrun

	El-Beds		El-Gaar		E1-Hamara		El-Zaqiq		El-Rhazonia		Um Risha		El-Fasda		T	
Species	t/4	F	t/4	F	t/3	F	t/3	F	t/3	F	t/3	F	t/2	F	22	P (%)
Trees and shrubs																
Tamarix	3	75	0	0	0	0	0	0	2	67	0	0	0	0	5	23
Perennials																
Juncus acutus	3	75	3	75	3	100	2	67	3	100	3	100	2	100		86
J. rigidus	4	100	4	100	2	67	3	100	2	67	1	33	2	100	18	82
Cyperus laevigatus var. *laevigatus*																
	3	75	3	75	3	100	2	67	2	67	2	67	1	50	16	73
Phragmites australis subsp. *australis*																
	2	50	2	50	1	33	3	100	1	33	2	67	1	50	12	55
Typha domingensis	0	0	1	25	2	67	3	100	2	67	1	33	2	100	11	50
Imperata cylindrica	1	25	2	50	2	67	2	67	0	0	1	33	1	50	9	40
Alhagi graecorum	3	75	1	25	0	0	0	0:	2	67	2	67	0	0	8	36
Desmostachya bipinnata	2	50	1	25	0	0	2	67	0	0	2	67	0	0	7	32
Typha elephantina	1	25	3	75	1	33	0	0	0	0	0	0	1	50	6	27
Aeluropus littoralis	0	0	2	50	0	0	0	0	1	33	1	33	1	50	5	23
Spergularia marina	1	25	0	0	0	0	1	33	1	33	0	0	1	50	4	18
Arundo donax	1	25	1	25	0	0	1	33	1	33	0	0	0	0	4	18
Sonchus maritimus	0	0	1	25	2	67	0	0	0	0	0	0	0	0	3	14
Panicum turgidum	0	0	3	75	0	0	0	0	0	0	0	0	0	0	3	14
Cynodon dactylon	1	25	0	0	0	0	0	0	1	33	i	53	;	0	3	14
Zannichellia palustris	1	25	0	0	0	0	0	0	0	0	0	0	0	0	1	5
Sporobolus spicatus	0	0	0	0	0	0	0	0	0	0	1	33	0	0	1	5

(continued)

Table 5.17 (continued)

	El-Beds		El-Gaar		E1-Hamara		El-Zaqiq		El-Rhazonia		Um Risha		El-Fasda		T	
Species	t/4	F	t/4	F	t/3	F	t/3	F	t/3	F	t/3	F	t/2	F	22	P (%)
Samolus valerandi	0	0	0	0	1	33	0	0	0	0	0	0	0	0	1	5
Centropodia forskaolii	0	0	1	25	0	0	0	0	0	0	0	0	0	0	1	5
Apium crassipes	0	0	0	0	1	33	0	0	0	0	0	0	0	0	1	5
Annuals																
Polypogon monspeliensis	1	25	0	0	1	33	1	33	0	0	0	0	1	50	4	18
Senecio glaucus																
subsp. *coronopifolius*	0	0	0	0	0	1	33	0	0	1	33	0	0	4	9	
Solanum elaeagnifolium	0	0	0	0	0	0	1	33	0	0	0	0	0	0	1	5
Digitaria sanguinalis	0	0	0	0	0	0	0	0	0	0	1	33	0	0	1	5

t number of studied stands in each lake, *T* grand total of studied stands, *F* frequency percentages, *P*(%) performance

5.4.2.4 Classification of the Vegetation

Based on their frequency values, classification of the recorded 25 species from 22 stands around the 7 lakes resulted in 5 vegetation groups (A–E), named after the dominant and highly frequent species. Based on the cluster analysis outcome, the dendrogram in Fig. 5.20 was elaborated, and the characteristic species of each group was displayed in Table 5.18. Clearly, pH, percentages of coarse sand, and silt showed significant differences between the identified vegetation groups (Table 5.19).

Group A. *Juncus rigidus–Desmostachya bipinnata–Typha elephantina–Arundo donax* Group

It is characterized by the dominance of *Juncus rigidus* and *Desmostachya bipinnata* together with *Typha elephantina* and *Arundo donax* in stands 115 and 116 which located in El-Gaar and El-Baida Lakes. Among the associated species, *Tamarix nilotica*, *Alhagi graecorum*, *Panicum turgidum*, *Cyperus laevigatus* var. *laevigatus*, and *Imperata cylindrica* can be enumerated. *Centropodia forskaolii* showed a certain degree of fidelity to this group. Organic matter, fine sand, coarse sand, pH, and bicarbonate attained their highest values in this group and have the lowest mean value for electric conductivity (Table 5.19).

Group B. *Typha domingensis* Group

This group (12 species) characterized the three stands (111, 118, and 120) from Um Risha, El-Rhazoniya, and Zagig Lakes on high soil contents of salinity, sulphates, and ions of Ca, Mg, Na, K, and Cl. *Typha domingensis* was the characteristic species, while the common associated species *Alhagi graecorum*, *Juncus rigidus*, *Juncus acutus*, *Cyperus laevigatus* var. *laevigatus*, *Phragmites australis* subsp. *australis*, *Desmostachya bipinnata*, *Arundo donax*, and *Cynodon dactylon* were recorded. *Digitaria sanguinalis* and *Senecio glaucus* subsp. *coronopifolius* were confined to this group.

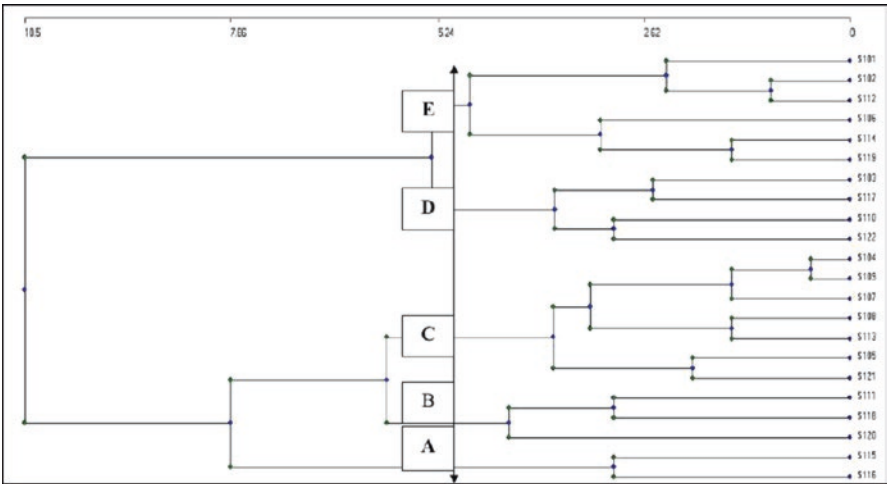

Fig. 5.20 Cluster analysis of the 22 stands around the studied seven lakes of Wadi El-Natrun; *A–E* are the five separated vegetation groups

Table 5.18 Presence percentages of the dominant and associated species within the five vegetation groups in lake habitat of Wadi El-Natrun

Species	Vegetation groups A	B	C	D	E
Group size	2	3	7	4	6
Species present in all groups					
	50	66.6	100	75	50
Juncus rigidus	100	66.6	85.7	50	100
Species present in four groups					
Desmostachya bipinnata	100	66.6	28.5	25	0
Juncus acutus	0	66.6	100	100	100
Phragmites australis var. *australis*	0	66.6	57	75	50
Typha domingensis	0	100	28.5	25	83.3
Species present in three groups					
Aeluropus littoralis	0	33.3	42.8	0	16.6
Alhagi graecorum	50	66.6	71.4	0	0
Imperata cylindrica	50	0	0	100	66.6
Species present in two groups					
Arundo donax	100	66.6	0	0	0
Cynodon dactylon	0	66.6	0	25	0
Panicum turgidum	50	0	0	0	33.3
Polypogon monspeliensis	0	0	14.2	0	50
Sonchus maritimus	0	0	0	25	33.3
Spergularia marina	0	0	28.5	0	33.3
Tamarix nilotica	50	0	57	0	0
Typha elephantina	100	0	0	0	66.6
Species present in one groups					
Centropodia forskaolii	50	0	0	0	0
Senecio glaucus subsp. *coronopifolius*	0	66.6	0	0	0
Digitaria sanguinalis	0	33.3	0	0	0
Berula erecta	0	0	0	25	0
Samolus valerandi	0	0	0	25	0
Solanum elaeagnifolium	0	0	0	25	0
Sporobolus spicatus	0	0	0	25	0
Zannichellia palustris	0	0	0	25	0

It is interested to note the complete absence of *Typha elephantina*.

Group C. *Juncus acutus*–*Cyperus laevigatus* var. *laevigatus* Group

This group is characterized by *Juncus acutus* and *Cyperus laevigatus* var. *laevigatus* in seven stands from five lakes (El-Baida, El-Rhazoniya, El-Gaar, El-Fasda, and Um Risha) with soil rich in NH_4^+ and clay contents. *Juncus rigidus* and *Alhagi graecorum* were the co-dominant species of this group (F = 85.7% and 71.4%, respectively). Among the associated species, *Tamarix nilotica*, *Phragmites australis* subsp. *australis*, and *Aeluropus littoralis* were recorded. The complete absence of *Typha elephantina*, *Arundo donax*, *Panicum turgidum*, *Imperata cylindrica*,

Table 5.19 Mean values, standard deviations (±SD), and ANOVA F-values of the soil variables, in the stands representing the five vegetation groups obtained by cluster analysis

Soil variables		Mean±SD	Vegetation groups					F-ration	*P*
			A	B	C	D	E		
pH		7.7 ± 0.008	7.75 ± 0.00	7.65 ± 0.03	7.68 ± 0.009	7.72 ± 0.01	7.694 ± 0.008	5.295	0.006*
EC		2.13 ± 0.46	0.50 ± 0.01	3.71 ± 2.4	2.30 ± 0.84	2.31 ± 1.03	1.56 ± 0.37	0.791	0.547
$CaCO_3$	(meqL^{-1})	16.74 ± 1.94	2.93 ± 2.16	11.46 ± 5.27	18.22 ± 3.94	18.60 ± 3.7	21.00 ± 2.27	2.235	0.108
Ca^{+2}	(meqL^{-1})	3.63 ± 0.58	2.65 ± 0.00	5.13 ± 2.48	4.49 ± 1.21	3.11 ± 1.66	2.56 ± 0.41	0.675	0.618
Mg^{+2}	(meqL^{-1})	1.38 ± 0.21	O.89 ± 0.00	1.94 ± 0.15	1.49 ± 0.40	1.30 ± 0.62	1.184 ± 0.46	0.421	0.791
Na^{+}	(meqL^{-1})	27.46 ± 6.18	4.16 ± 0.24	47.66 ± 3.19	29.56 ± 1.15	31.12 ± 1.40	2023 ± 5.41	0.769	0.560
K^{+}	(meqL^{-1})	1.18 ± 0.85	0.12 ± 0.01	6.49 ± 6.25	0.36 ± 0.11	0.49 ± 0.09	0.31 ± 0.08	1.768	0.182
HCO_3^-	(meqL^{-1})	0.94 ± 0.096	1.18 ± 0.04	0.68 ± 0.14	0.94 ± 0.15	0.87 ± 0.15	1.03 ± 0.29	0.425	0.788
Cl^-	(meqL^{-1})	22.76 ± 4.43	3.11 ± 0.67	35.59 ± 2.06	24.05 ± 8.55	25.24 ± 9.72	19.75 ± 5.73	0.746	0.574
SO_4^{-2}	(meqL^{-1})	9.51 ± 2.91	3.54 ± 0.89	21.62 ± 1.67	10.93 ± 4.71	9.91 ± 6.72	3.51 ± 0.72	0.995	0.437
NH_4^+	(meqL^{-1})	42.41 ± 8.99	44.59 ± 2.40	3.5.48 ± 1.09	58.31 ± 2.71	34.30 ± 4.85	32.00 ± 7.45	0.349	0.841
NO_3^-	(meqL^{-1})	1.16 ± 4.72	20.58 ± 6.86	3.49 ± 3.12	1.41 ± 6.64	49.73 ± 3.08	45.71 ± 2.20	1.249	0.328
OM	(%)	5.01 ± 1.61	6.554 ± 6.21	2.17 ± 1.29	6.14 ± 2.56	3.36 ± 1.75	5.69 ± 4.98	0.192	0.939
FS	(%)	28.2 ± 4.55	64.90 ± 2.60	32.90 ± 1.77	21.27 ± 5.74	25.80 ± 1.09	23.30 ± 7.33	2.195	0.113
CS	(%)	9.85 ± 1.52	23.90 ± 2.60	12.06 ± 5.92	7.68 ± 1.53	10.00 ± 3.47	6.50 ± 1.73	3.881	0.020**
Silt	(%)	28.34 ± 2.44	6.25 ± 0.45	26.23 ± 1.05	31.80 ± 2.02	29.65 ± 6.43	31.85 ± 2.97	3.069	0.045**
Clay		33.87 ± 3.83	495 ± 0.45	29.13 ± 1.29	39.24 ± 6.33	34.55 ± 7.94	39.16 ± 6.40	1.919	0.153

CS coarse sand, *EC* electric conductivity, *FS* fine sand, *OM* organic matter
*$P \leq 0.01$; **$P \leq 0.05$

Centropodia forskaolii, *Cynodon dactylon*, *Senecio glaucus* subsp. *coronopifolius*, and *Digitaria sanguinalis* can also be noticed.

Group D. *Juncus acutus–Imperata cylindrica* Group

This is the most diversified (15 species) among the recognized groups. It is characterized by the dominance of *Juncus acutus* and *Imperata cylindrica* in four stands (103, 117, 110, and 122) on soil rich in NO_3^- content (49.73 ± 3.08). The dominant species showed their highest abundance in this group, together with *Cyperus laevigatus* var. *laevigatus* and *Phragmites australis* subsp. *australis.* Sporadic species were *Typha domingensis*, *Desmostachya bipinnata*, *Sonchus maritimus*, and *Cynodon dactylon*. Five species showed a degree of consistency to this group: *Zannichellia palustris*, *Sporobolus spicatus*, *Samolus valerandi*, *Berula erecta*, and *Solanum elaeagnifolium were not recorded in this group*.

Group E. *Juncus rigidus–Juncus acutus* Group

This group comprised 13 species from 6 stands inhabiting soil rich in $CaCO_3$ content, where *Juncus rigidus* and *J. acutus* were the dominant species. *Typha domingensis* was the most common species. Associated species included *Imperata cylindrica* and *Typha elephantina.* Occasionally recorded species (present in only one stand; $P = 16.6\%$) was *Aeluropus littoralis*. Notably, *Arundo donax*, *Centropodia forskaolii*, *Desmostachya bipinnata*, *Tamarix nilotica*, *Alhagi graecorum*, *Cynodon dactylon*, *Senecio glaucus* subsp. *coronopifolius*, *Digitaria sanguinalis*, *Zannichellia palustris*, *Sporobolus spicatus*, *Samolus valerandi*, *Berula erecta*, and *Solanum elaeagnifolium*.

5.4.2.5 Ordination of Stands

Principal Component Analysis (PCA) scatter plot showed the segregation of the five groups along the first two axes (Fig. 5.21). Stands of group (A) occupied the highest position in the ordination plan. This group was dominated with *Juncus rigidus*, *Desmostachya bipinnata*, *Typha elephantina*, and *Arundo donax.* Stands of the vegetation groups (D) and (E) which dominated with *Juncus acutus*, *J. rigidus*, and *Imperata cylindrica* occupied the positive side of axis 1, while stands of the vegetation groups (B) and (C) that dominated with *Typha domingensis*, *Juncus acutus*, and *Cyperus laevigatus* var. *laevigatus* occupied the other negative end.

5.4.2.6 Soil–Vegetation Relationships

The relationships between the results of vegetation and soil analyses using redundancy analysis (RDA) with the five vegetation groups (A–E) were shown in Fig. 5.22. This biplot diagram showed similar pattern of ordination obtained from the floristic PCA, with most of the sites remaining in their respective cluster group. It can be noted that stands of group C were affected by ammonia; stands of groups

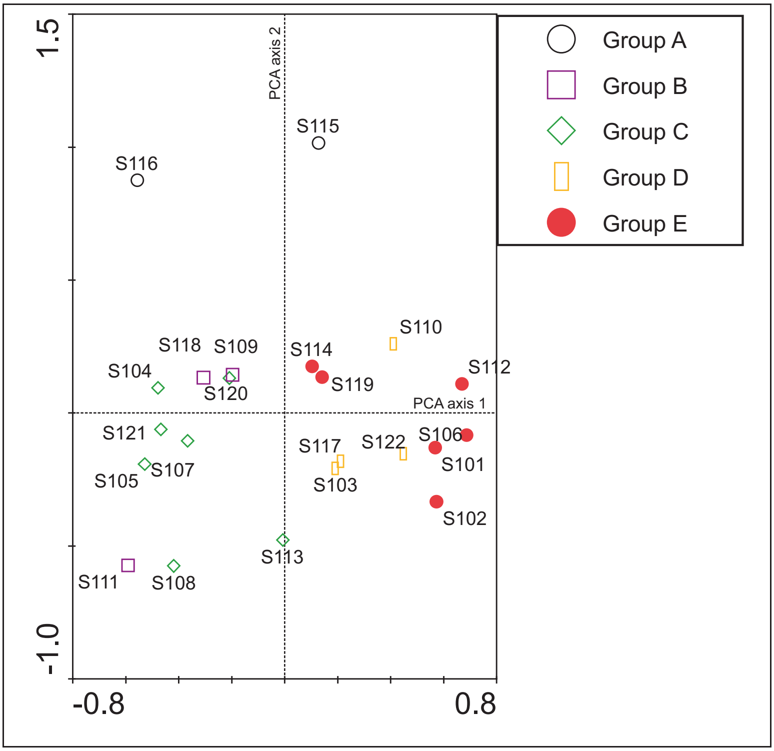

Fig. 5.21 Principal Component Analysis (PCA) scatter plot along the first two axes for the 22 stands around the lakes in Wadi El-Natrun, with the vegetation groups (*A*–*E*) superimposed

D and E were correlated with $CaCO_3$, while those of group C were affected by SO_4^{-2} and Ca^{+2}. While some stands of groups D and E showed high relation to pH, other stands of groups C and E were correlated with HCO_3. Two stands of group A exhibited high correlation to organic matter and coarse sand.

The successive decrease of eigenvalues (Table 5.20) of the four RDA axes (0.140, 0.115, 0.090, and 0.077 for axes 1, 2, 3, and 4, respectively) suggests a well-structured data set. The species–environment correlations were high for the four axes, explaining 67.5 % of the cumulative variance. These results suggested an association between vegetation and the measured soil variables presented in the biplot. The inter-set correlations resulted from RDA of the examined soil variables were shown in Table 5.20. Axis 1 was positively correlated with $CaCO_3$ and negatively correlated with Ca, SO_4, and NO_3. This axis 1 can be interpreted as $CaCO_3$–NO_3 gradient. Axis 2 was positively correlated with coarse sand and negatively correlated with $CaCO_3$, Ca^{+2}, K^+, Cl^-, SO_4^{-2}, and NO_3^-. This axis 2 can be interpreted as coarse sand–Cl^- gradient. A test for significance with an unrestricted Monte Carlo permutation test found the F-ratio for the eigenvalue of RDA axis 1 and the trace statistics to be significant ($p = 0.03$).

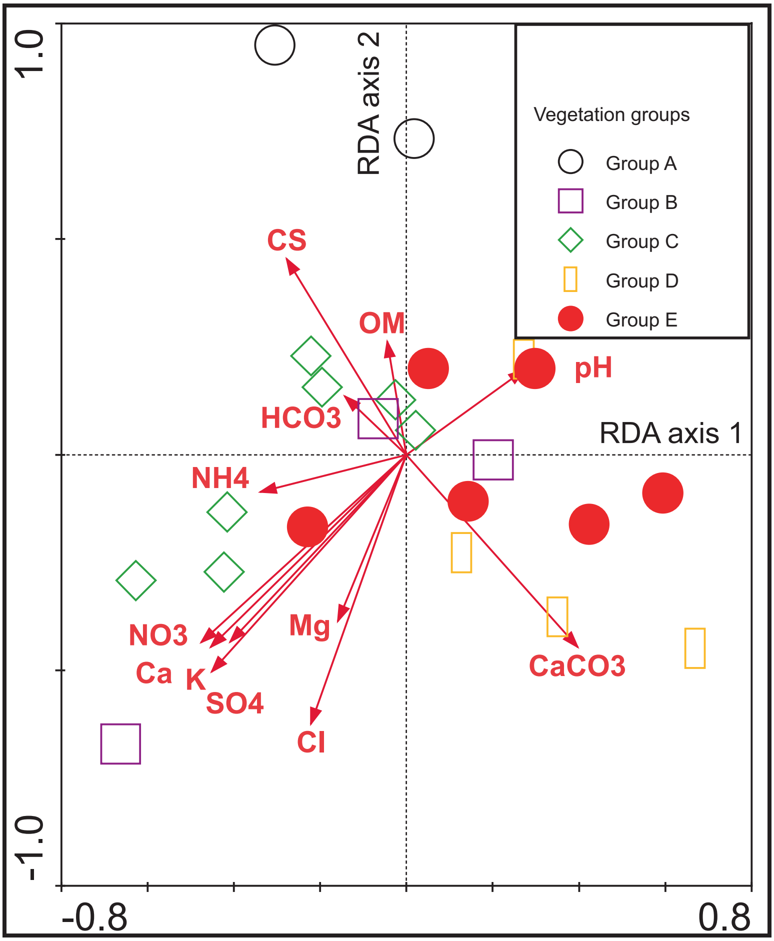

Fig. 5.22 The RDA ordination biplot along the first two axes, showing the distribution of 22 stand around the lakes, with the examined soil variables

5.4.2.7 Concluding Remarks

1. In total, 25 species were recorded and represented the species composition around the inland saline lakes in this study. The fewer number of species (mostly salt-tolerant) may be attributed to the high soil salinity around the lakes. Such salinity stress on floristic diversity in the study area and related areas was documented (Shaltout and El-Ghareeb 1992; Shaltout et al. 1997; Omer 2004; Li et al. 2008).
2. Application of multivariate analysis techniques (classification and ordination) to the floristic composition and soil features around the lakes yielded five vegetation groups (communities): (A) *Juncus rigidus–Desmostachya bipinnata–Typha*

Table 5.20 Redundancy analysis results showing the inter-set correlations of the soil variables, together with eigenvalues and species–environment correlation of the studied lakes

Axes	Ax1	Ax2	Ax3	Ax4
Eigenvalues	0.140	0.115	0.090	0.077
Species–environment correlations	0.919	0.925	0.908	0.900
pH	0.2502	0.1810	0.1022	−0.3335
$CaCO_3$	0.3642*	−0.4118*	0.0441	0.0138
Ca^{++}	−0.4156*	−0.4111*	0.1721	−0.0030
Mg^{++}	−0.1451	−0.3553	0.1832	0.2313
K^+	−0.3746	−0.4002*	0.3008	0.1211
HCO_3^-	−0.1303	0.1241	0.1457	−0.1695
Cl^-	−0.2034	−0.5756	0.0193	−0.0251
SO_4^-	−0.4139*	−0.4642*	0.1316	0.0028
NH_4^+	−0.3099	−0.0797	0.0857	0.2808
NO_3^-	−0.4366*	−0.4016*	0.1485	−0.0157
O.M	−0.0406	0.2415	0.0377	0.3828
CS	−0.2549	0.4188*	−0.0798	−0.0461

For abbreviations and units, see Table 5.19
*$P \leq 0.05$

elephantina–Arundo donax, (B) *Typha domingensis*, (C) *Juncus acutus–Cyperus laevigatus* var. *laevigatus*, (D) *Juncus acutus–Imperata cylindrica*, and (E) *Juncus rigidus–Juncus acutus*. None of the obtained vegetation groups has analogues in other former studies. Despite the difference in their dominating species, these communities are undoubtedly having the same floristic composition of the previously recorded communities. This difference may be related to the method of vegetation analysis that followed in each study. The significant role of abiotic factors that controlling the distribution of halophytes in saline habitats was studied by Ungar (1998), Sanchez et al. (1998), Bouzille et al. (2001), and Isacch et al. (2006).

3. Redundancy analysis (RDA) of the present data set demonstrated the effect of edaphic factors on the spatial distribution of plant communities around the lakes. $CaCO_3$, Ca^{++}, K^+, SO_4^-, NO_3^-, and coarse sand were of significant variations ($p < 0.05$) among the five vegetation groups (communities). RDA axis 1 can be inferred as $CaCO_3$–NO_3 gradient, while RDA axis 2 showed a gradient of sand and Cl^- gradient. These results were inconsistent with those of El-Sawaf and Emad El-Deen (2000). On the contrary, around the inland saline lakes in Dakhla and Siwa Oases of the western Desert (Abd El-Ghani 2000a), 12 halophytic plant communities linked to two main habitats (wet–moist and dry–mesic) were identified, with few communities were in common with Wadi El-Natrun salines. *Alhagi graecorum*, *Tamarix nilotica*, *Cressa cretica*, *Juncus rigidus*, and *Phragmites australis* were the most common in the two oases. Whereas communities of *Cyperus laevigatus*, *Suaeda aegyptiaca*, *Suaeda vermiculata*, *Typha domingensis*, and *Aeluropus lagopoides* were

recorded from Dakhla Oasis, *Cladium mariscus* and *Arthrocnemum macrostachyum* communities were recorded from Siwa Oasis. The most important edaphic variables affecting the distribution and structure of the plant communities were salinity, moisture content, and fine fractions, yet $CaCO_3$ content seems to be more effective in the Dakhla Oasis. 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 characteristic of the Eastern Mediterranean region.

4. From a phytosociological point of view, Boulos et al. (1974) recorded pure community of *Typha elephantina* existed under the conditions of deep fresh water (total soluble salts c. 2000 ppm) around El-Gaar Lake. *Typha domingensis* replaced *T. elephantina* when the total soluble salts reached 4000 ppm coupled with basin elevation. More accumulation of sand on the bank encouraged *Phragmites australis* to grow. Simpson (1932) stated that *Typha domingensis* is more sensitive to salt than *Phragmites australis* as the latter forms well into Lake Mariut, while *Typha* is present only where the lake receives fresh water from Mahmudiya canal. El-Sawaf and Emad El-Deen (2000) recognized the disappearance of *Typha* species from El-Hamra Lake where *Phragmites australis* was scattered among the *Juncus acutus* plants as well as higher elevations, near the road. They also recognized three distinct communities around the lakes: (A) *Juncus rigidus–Tamarix nilotica* community, inhabited soil with relatively high contents of Cl^-, Na^+, SO_4^-, pH, and EC with high silt content and low sand, related to the fairly saline habitats. (B) *Phragmites australis–Typha elephantina* community inhabiting swampy lands (border of the lakes) where there is a rich and continuous feed of fresh brackish water. Soils showed low content of Cl^-, Na^+, and SO_4^-, relatively high organic matter and silt, and low values of EC and sand. (C) *Nitraria retusa–Sporobolus spicatus* community, inhabited soil with low content of Cl^-, Na^+, and SO_4^-, relatively high organic matter and silt, and low values of EC and sand. Boulos et al. (1974) reported that *Juncus acutus* communities were scattered among *Cyperus laevigatus* were they distributed as contour lines parallel to the lake bank, and both species decreased in number and vigour by increasing the ground surface until they disappeared. In the present study, *Typha elephantina* was represented in vegetation group (A), with fewer individuals. It is recommended that conservation measures should be taken to protect and secure the remaining populations throughout Wadi El-Natrun which represents its type locality from extinction (Boulos 2009).
5. Two species, *Zygophyllum album* and *Nitraria retusa*, deserve special comments. In Egypt, *Zygophyllum album* is a species of wide ecological amplitude. It was recognized by several habitats of the country, such as in the littoral salt marches (Kassas and Zahran 1967), in the inland desert, in the wadis of the limestone habitat (Kassas and Girgis 1964), and in the sand dunes of the oases

of the Western Desert of Egypt (Zahran 1962). In Wadi El-Natrun (Zahran and Girgis 1970), recognized *Zygophyllum album* community abounds in the sand formations west of the lakes (e.g. El-Hamara and El-Rhazonia Lakes) further than area occupied by *Sporobolus spicatus* community and in water runnels lined with sand deposits and dissecting the gravel deposits where the salinity is lower. El-Sawaf and Emad El-Deen (2000) recorded *Zygophyllum album* just as associated species to community of *Nitraria retusa–Sporobolus spicatus*. *Nitraria retusa* forms one of the main scrubland types along the northern part of the Red Sea littoral of Egypt and is also common in the wadis of the limestone desert east of the Nile. Zahran and Girgis (1970) recorded *Nitraria retusa* in some of the principal wadis to the west of El-Hamra Lake and on terraces east of El-Khadra and El-Gaar lakes. Boulos et al. (1974) reported that *Nitraria retusa* dominated with increased salinity on the surface soil layer, where the underground water table was deep. In this study, it is a point of importance to recognize the disappearance of *Zygophyllum album* and *Nitraria retusa* around the studied lakes.

6. The zonation of salt marsh vegetation is a universal phenomenon (Winter 1990; Krüger and Peinemann 1996; Apaydin et al. 2009). Concentric zonation of halophytic communities around small lakes and salt marshes of the Egyptian oases was described by Kassas (1971). Kehl et al. (1984) also described the ring-shaped vegetation formations in NW Egypt resulting from different habitat gradients. In his account on the vegetation and flora of Qara Oasis, Abd El-Ghani (1992) recognizes four concentric zones of plant communities bounding the oasis. The zonation patterns of the littoral salt marsh vegetation are mainly influenced by the tidal phenomena (Kassas and Zahran 1967). Zahran and Girgis (1970) recognized seven salt marsh zones of plant communities around middle lakes (El-Hamara, Zugm, Zagig, El-Baida, and El-Khadra) of Wadi El-Natrun: swamps of *Typha elephantina* and *Phragmites australis*, *Cyperus laevigatus* and *Juncus acutus* complex (wet salt marsh), *Sporobolus spicatus* community, *Desmostachya bipinnata* community, *Zygophyllum album* community, *Nitraria retusa* community, and a community of *Tamarix* sp., where the last five community revealed as the dry salt marsh. He also recognized the mosaic pattern of the vegetation which means that the plant life is affected by several interacting factors with no single dominant factor.
7. In Wadi El-Natrun, the lakes occupy the central part of this depression and bordered by salines which may harbour different plant communities (Hussein 1980). While the conditions though different, yet vegetational zonation is controlled by seasonal fluctuations of water level in the lakes and hence that of water table: shallow in wet season and deeper in dry season. Under the prevalent arid climate, evaporation causes the accumulation of salts at the ground surface forming crusts. The other important factor is relief (Chapman 1960). El-Sawaf and Emad El-Deen (2000) revealed that most of the soils were rich in silt and clay and poor in sand. The soil physical and chemical characteristics are apparently one of the main factors influencing the plant cover, distribution, and also the zonal pattern of the vegetation types (Zahran 1977).

Appendix

Names and abbreviations of the species displayed in Figs. 5.2, 5.3, and 5.5.

Acacia tortilis (Forsk.) Hayne subsp. *raddiana* (Savi) Brenan	A rd
Alhagi graecorum Boiss.	A gr
Anabasis articulata (Forssk.) Moq.	A ar
Astragalus trigonus DC.	A tr
Atriplex leucoclada Boiss.	A lu
Calligonum polygonoides L. subsp. *comosum* (L'Her.) Soskov	C cm
Calotropis procera (Ait.) W.T. Aiton	C pr
Capparis spinosa L. var. *aegyptia* (Lam.) Boiss.	C sp
Carduncellus mareoticus (Delile) Hanelt	C mr
Citrullus colocynthis (L.) Schrad.	C cl
Cornulaca monacantha Delile	C mo
Deverra tortuosa (Desf.) DC.	D tr
Ephedra alata Decne.	E al
Fagonia arabica L.	F ar
Fagonia bruguieri DC.	F br
Fagonia indica Burm.f.	F in
Farsetia aegyptia Turra	F ag
Farsetia ramosissima E. Fourn.	F rm
Helianthemum lippii (L.) Dum. Cours.	H lp
Heliotropium digynum (Forssk.) C. Chr.	H dg
Herniaria hemistemon J. Gay	H he
Hyoscyamus muticus L.	H mu
Imperata cylindrica (L.) Raeusch.	I cy
Launaea nudicaulis (L.) Hook.f.	L nu
Monsonia nivea (Decne.) Webb	M nv
Nitraria retusa (Forssk.) Asch.	N rt
Phoenix dactylifera L.	P df
Prosopis farcta (Banks & Sol.) Macbr.	P fr
Pulicaria crispa (Forssk.) Oliv.	P cr
Pulicaria incisa (Lam.) DC.	P in
Randonia africana Coss.	R af
Salsola imbricata Forssk. subsp. *imbricata*	S im
Salsola villosa Schult.	S vr
Sarcocornia fruticosa (L.) A.J. Scott	S fr
Stipagrostis plumosa (L.) Munro ex T. Anderson	S pl
Tamarix nilotica (Ehrenb.) Bunge	T ni
Traganum nudatum Delile	T nd
Zilla spinosa (L.) Prantl subsp. *biparmata* (O.E. Schulz) Maire & Weiller	Z bi
Zilla spinosa (L.) Prantl subsp. *spinosa*	Z sp
Zygophyllum coccineum L.	Z co

Abbreviations of Plant Names in Fig. 5.13

Ag	*Alhagi graecorum* Boiss.
Al	*Aeluropus lagopoides* (L.) Trin. ex Thwaites
Am	*Ambrosia maritima* L.
An	*Acacia nilotica* (L.) Delile
As	*Aster squamatus* (Spreng.) Hieron.
Av	*Avena fatua* L.
Bi	*Bassia indica* (Wight) A.J. Scott.
Bn	*Brassica nigra* (L.) Koch
Ca	*Calendula arvensis* L.
Cc	*Ceratonia siliqua* L.
Ec	*Echinochloa colona* (L.) Link
Er	*Eichhornia crassipes* (C. Mart.) Solms
Pd	*Paspalum distichum* L.
So	*Sonchus oleraceus* L.
Tn	*Tamarix nilotica* (Ehrenb.) Bunge
Vm	*Vicia monantha* Retz.

Photo Gallery

Photo 5.1 Part of the white desert between Dakhla and Farafra Oases

Photo 5.2 A salt lake of Siwa Oasis. Note the kersheve (salinized soil) in the foreground, date palm trees, and tamarisks in the background

Photo 5.3 General view of the typical structure of an oasis (Bahariya Oasis). Note the salinized land located between the bounding desert (background) and the date palm orchards (foreground)

Photo 5.4 Part of the bounding (adjoining) desert outside Dakhla Oasis. Note the growth of tamarisks (*Tamarix nilotica*) forming hillocks

Photo 5.5 General view of the bounding desert outside Bahariya Oasis, showing the cushions of *Pulicaria undulata*

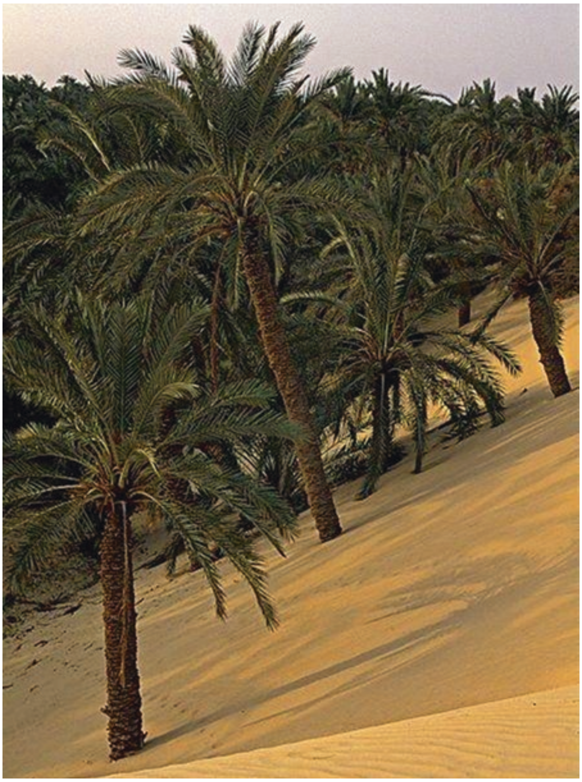

Photo 5.6 Sand dune movement towards the farmlands, showing buried date palm trees with sand in Bahariya Oasis

Photo 5.7 General view of an old well of Kharga Oasis marked by date palm trees

Photo 5.8 The main well opening surrounded by reeds (*Phragmites australis*) and date palm trees in Farafra Oasis

Photo 5.9 General view of the reclaimed areas in Qara Oasis

Photo 5.10 An exposed irrigation canal in Bahariya Oasis. The canal banks are covered with *Trifolium resupinatum* (foreground)

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Chapter 6
The Sinai Desert

Abstract The Sinai Peninsula is currently recognized as one of the central regions for biodiversity in the Middle East by the World Conservation Union. It is rich both in the number of species and the high percentage of endemics. The roughness in geomorphology leads to differentiation of enormous number of microhabitats and landforms which resulted in relatively high diversity in ecosystems and flora. The most conspicuous inhabited oasis in south Sinai is Feiran Oasis which is considered as the largest receiving amounts of runoff water from the drainage system of Wadi Feiran. The small size of Feiran Oasis, the limited water resources, the rapid development due to increased touristic and population pressures, as well as the present serious socio-economic situation may cause the destruction of the remaining natural habitats in the near future. Recently, it is subjected to severe destruction and dryness of a great deal of its characteristic date palm orchards habitat. Out of the 33 species which recorded for the first time from Feiran Oasis, 13 were invading xerophytes, growing in fields and orchards, and behaving as field weeds. Floristic analysis, species distribution, and soil–vegetation correlations in Wadi Solaf, W. El-Akhdar, and W. Romana (as inland wadis) were compared to W. Kid (a coastal wadi). In the eastern sector of Central Sinai, plant communities and vegetation analysis were performed along four tracks (unpaved and unaccessible roads): Nekhel–Al-Qasimia, Al-Qasimia–Al-Kuntella, Al-Kuntella–Al-Thamad, and Nekhel–Al-Malha.

6.1 General

Sinai is of great interest from a biological point of view. Because of its geographic location at the junction of three continents and the climatic changes throughout its history, the Sinai Peninsula is currently recognized as one of the central regions for biodiversity in the Middle East by the World Conservation Union (Ayyad et al. 2000). The plant life of the Sinai Peninsula has been a subject of interest, which attracted many botanists and explorers (Batanouny 1985). The area of the Sinai Peninsula (61,000 km^2) is about 6% of that of Egypt. More than half the peninsula is between the Gulfs of Aqaba and Suez.

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Sinai represents one of the main phytogeographical regions of Egypt; several studies were published on plant ecology of Sinai. The first phytosociological study was by (Zohary (1946)) who studied the vegetation along three transects across Sinai. Hassib (1951) described the distribution of plant communities in Egypt including Sinai. Halevy and Orshan (1972) studied the distribution of *Acacia* trees as related to environmental factors in Negev and Sinai, whereas Danin (1978) compared species diversity of Sinai with other desert areas of the world. The Sinai Peninsula is rich both in the number of species and the high percentage of endemics. Boulos (1995) lists 1,262 taxa of vascular plants known from Sinai, or 56.2% of the flora of Egypt is represented in Sinai; the number of native and naturalized taxa known from Egypt is 2,247 (2,094 species and 153 infraspecific taxa). On the other hand, the endemic taxa known from Sinai are 36 out of 70, or 51.4% of those known from Egypt (Boulos 1997).The phytogeographical concept of Eig (1932–1933), which was basically adopted by most workers for several decades, identifies four regions represented in the Sinai Peninsula: the Mediterranean region, the Saharo–Sindian, the Irano–Turanian, and the Sudano–Deccanian.

Three regions may be distinguished in the Sinai Peninsula according to their geomorphological features (Zahran and Willis 1992 and several others): northern, central, and southern.

6.2 Surveyed Areas of South Sinai

6.2.1 The Inland Wadis

The southern part of Sinai Peninsula, which is triangular mass of mountains with 28,438 km^2 in surface area, is formed of igneous and metamorphic rocks. This mass of mountains is intensively rugged and dissected by a complicated system of deep wadis (Moustafa and Klopatek 1995), some of which reach a considerable length (e.g. Wadi Feiran and W. Zaghar) and some are shorter, narrower, and steeper and represent tributaries of the main wadis (e.g. Wadi El-Arbaein). This roughness in geomorphology leads to differentiation of enormous number of microhabitats (Batanouny 1965) and landforms which resulted in relatively high diversity in ecosystems and flora. The vegetation is characterized by sparseness of plant cover of semishrubs, restricted to wadis or growing on slopes of rocky hills and in sand fields, and paucity of trees (Danin 1986). South Sinai mountains represent a great harbour of endemism (Moustafa 1990) where the area has wetter climate than most of Sinai and characterized by having large outcrops of smooth-faced rocks which support rare species (Danin 1972, 1978, 1983).

South Sinai is an arid to extremely arid region, characterized by an ecological uniqueness due to its diversity in landforms, geologic structures, and climate that resulted in a diversity in vegetation types, which is characterized mainly by the sparseness and dominance of shrubs and subshrubs and the paucity of trees (Moustafa and Klopatek 1995; Helmy et al. 1996) and a variation in soil properties (Ramadan 1988; Kamh et al. 1989; Abd El Wahab 1995). Human impacts of settled societies and nomadic Bedouin groups have been recorded in south Sinai (Moustafa et al. 1999).

The mountainous region of southern Sinai probably contains a greater biodiversity than in the rest of Egypt. A large section of the area was declared a protectorate in 1996, centred upon the town of St. Catherine (1,600 m a.s.l.). From the mountain of St. Catherine, at 2,641 m a.s.l., the highest point in Egypt and marking the watershed of the peninsula, wadi systems drain eastwards towards the Gulf of Aqaba and westwards towards the Gulf of Suez.

6.2.1.1 Wadi Feiran (Feiran Oasis)

The most conspicuous inhabited oasis in south Sinai is Feiran Oasis. It is considered by Zahran and Willis (1992) as the largest receiving considerable amounts of runoff water from the drainage system of Wadi Feiran.

During the last 60 years, studies on the ecology, flora, vegetation–soil environmental relationships, and phytogeography of the Sinai Peninsula have been carried out. However, the flora and vegetation of Feiran Oasis were inadequately described (Prof. A. Danin; personal communication). The author had the opportunity to visit Feiran Oasis during 1995 and 1996. The area seems to be subjected to some pressures which can be observed from the state of its natural habitats 1 year to the next, besides the comparatively drier environmental conditions which prevail south Sinai. According to the information given by Feiran's Sheikh (Sheikh Salem Mansour) and other inhabitants as well as the nuns of Wadi Feiran Nunnery, the last 4 years to our work were almost rainless, and the digging of four new deep wells by the Water Resources' Authorities to cover the touristic and military water supply is greatly affecting the underground water level and consequently has a negative effect on both irrigation and farmlands. Therefore, the main goals of the present work are to study the current situation of the flora and vegetation of Feiran Oasis and monitor the impact of the recent human activities on different habitats.

Wadi Feiran (28° 30′ – 28° 47′N and 33° 33 – 34°E) is the longest and broadest wadi in south Sinai: *ca* 59-km long and rises from the high mountains surrounding the Monastery of St. Catherine in the south at about 2,500–750 m above sea level at Feiran Oasis in the west (Fig. 6.1). It is a small depression located at about 43-km east of the mouth of Wadi Feiran and appears as a deep, fertile extension of the wadi surrounded by high red mountains of igneous and metamorphic rocks (Kassim 1983) and extends over a distance of 10 km with a dense growth of plants with groves of date palms. Abundant groundwater and deep sand–clay deposits (wadi terrace) as well as the natural protection of the locality against wind favour the utilization of the oasis as a productive site to cultivate some fruit trees and crops.

Said (1990) notes that the fossil groundwater of Feiran Oasis originated from ancient lakes which were formed as a result of the blocking of water courses by resistant porphyry dikes. Kassim (1983) and Zahran and Willis (1992) report two main water resources in south Sinai: (1) scanty rainfall on the mountains 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 underground in rock crevices. It may be obtained by digging wells with an average water table ranging between 17 and 25 m in old wells and 35–40 m in the new; (2) snow which covers

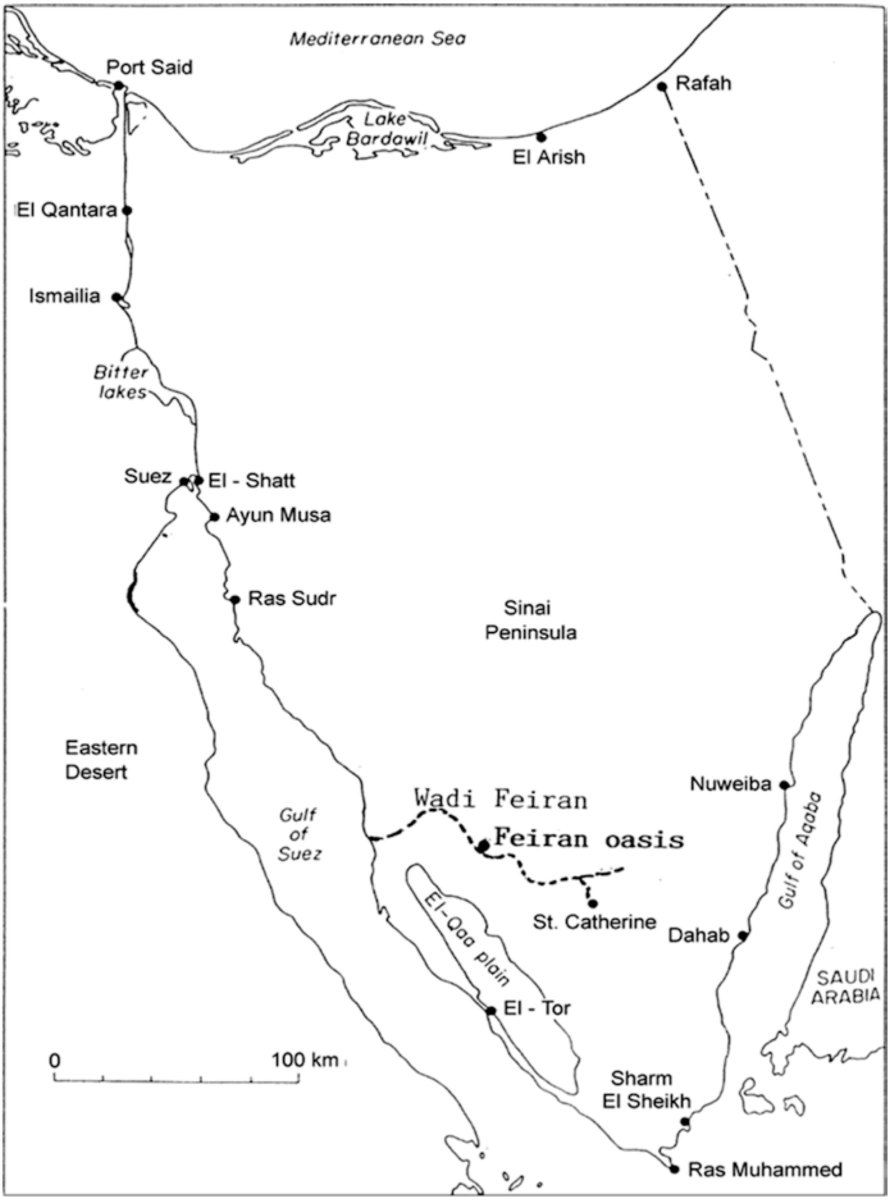

Fig. 6.1 Map of Sinai, showing the location of Wadi Feiran

the high mountain summits in winter is an effective water resource, and when it melts by the onset of warm months, it runs down the mountain slopes and adds to the sources of wadis. These substantial resources of fresh water have made the development of such oasis-like areas possible in some wadis.

According to Ayyad and Ghabour (1986), Feiran Oasis lies in the hyperarid southern zone with hot summer, mild winter, and winter rainfall. Available meteorological information (1970–1994) of St. Catherine station shows that the mean annual precipitation is 45-mm year^{-1}. The high mountains (1,500–2,624 m) receive more precipitation (*ca* 100-mm year^{-1}) as rain and snow (Danin 1983). Moustafa and Zaghloul (1996) report the mean air temperature (1982–1991) ranges from 5.4 to 25.1 °C with the lowest in January and February and the highest in July and August. At St. Catherine Mountain, mean monthly temperature ranges from −1 to 2 °C in winter and 17 to 19 °C in summer. Monthly mean relative humidity ranges between 33.3% in May and June and 57.9% in February.

Feiran Oasis is located in El Hadidi's (1980) "mountainous Sinai proper," a phytogeographic region of Egypt. Although the perennial vegetation is generally sparse, spectacular spring displays of wildflowers occur during rainy years. In the study area, two different ecosystems are usually distinguished: (A) the bounding desert and (B) the cultivated areas; each comprises a number of habitats. Growth forms in these ecosystems extend along a wide range from trees to tiny annuals and habitat ranges from hydrophytic to arid. The major ecosystems are described below.

A. The bounding desert (desert outskirts) is represented by the surrounding mountains as well as a part of Wadi Feiran. Qualitative analysis of the sparse xerophytic plant cover surrounding Feiran Oasis reveals that it includes mountainous vegetation and Wadi bed vegetation.

   (i) Mountainous vegetation: This type of vegetation is restricted to the mountainous rocky slopes along both sides of the main Wadi bed. Few scattered trees of *Moringa peregrina* and *Acacia tortilis* subsp. *raddiana* are growing on gullies and rocky crevices. Soil and plant debris accumulate in these fissures, retaining water and forming a fertile substratum through which plant roots penetrate. Shrubs of *Ochradenus baccatus* and *Capparis sinaica* are recorded from the same habitat.

   (ii) Wadi bed vegetation: The main Wadi bed is covered by boulders and stone fragments. Growth of xerophytic plants occurs on sand/clay matrix deposited in spaces between the rocks. Common associates include, among others, *Achillea fragrantissima*, *Artemisia herba-alba*, *Stipagrostis plumosa*, *Teucrium decaisnei*, *Gymnocarpos decanter*, and *Onopordum ambiguum.* Eight species have been recorded from the same area but in low frequencies, namely, *Zygophyllum simplex*, *Anabasis articulata*, *Aerva javanica*, *Haloxylon salicornicum*, *Schismus barbatus*, *Hyoscyamus muticus*, *Zilla spinosa*, and *Citrullus colocynthis.* This analysis shows that ephemeral and perennial plant growth occurs mixed together in Wadi Feiran and the water catchments, a community dependent on the rainfall (precipitation-dependent permanent contracted vegetation), where no perennial groundwater or any other permanent water supply is available. In their account on the vegetation and environment in the bed of Wadi el-Sheikh and its tributaries (including Wadi Feiran), El-Ghareeb and Shabana (1990) concluded that the vegetation is dominated by *Artemisia judaica*, *Zilla spinosa*, *Fagonia terristris* var. *boveana*, and *Lygos raetam.* Meanwhile, soil moisture and soil fertility are the main factors influencing the distribution of the vegetation.

B. The cultivated areas (farmlands) where agriculture has been practiced for millenia. As noted in the other oases of the Western Desert of Egypt (Abd El-Ghani 1981, 1985, 1992), agriculture is mainly dependent on underground water which is available from wells or springs. A total of 15 wells in Feiran Oasis exist of which 9 are dried up. The remaining six are feebly flowing (dug 8–10 years ago) and are located in the northern and southern boundries of the oasis. Consequently, a number of scattered "small oases" are established. The cultivated areas are usually surrounded by *Casuarina* sp., *Tamarix aphylla*, and/or *Eucalyptus rostrata* trees to provide protection from invading sand and wind. Several parts of this ecosystem are now exploited by the Bedouin to cultivate narcotic plants (e.g. marijuana and bango), thus violating the law. The following habitats are recognized:

1. The water hole (well opening), the main water resource, unlike other oases of the Western Desert of Egypt, is located inside the farmlands where the water remains unexposed. In general, there is no marked plant growth in the well opening, but *Cynodon dactylon*, *Phragmites australis*, *Tamarix nilotica*, and *Cyperus rotundus* grow around it.
2. The reservoir "Arabic–Khazzan", a large storage pond connected with the water hole through a culvert. The discharged water is stored in the pond and discharged through several irrigation rubber pipes to be distributed into the cultivated areas. The plant growth in this habitat is composed mainly of green algae (e.g. *Chara* sp.), some hydrophytes (e.g. *Elodea* sp.), and often *Phragmites australis.* The pattern of irrigation in the newly dug wells is different, where it is carried out by a number of irrigation canals as in most oases of the Western Desert of Egypt, so that the canal bank vegetation is well established.
3. The crop fields are represented by some patches between the trees and are usually located in the centre of this ecosystem. The main winter crops include barley (*Hordeum vulgare*), broad beans (*Vicia faba*), wheat (*Triticum vulgare*) and maize (*Zea mays*), eggplant (*Solanum melongena*), and muskmelon (*Cucumis melo*) as summer crops. Alfalfa (*Medicago sativa*) is widely cultivated in the oasis as a perennial forage crop. The associated weeds are *Chenopodium murale*, *Malva parviflora*, *Sonchus oleraceus*, *Euphorbia peplus*, *Portulaca oleracea*, and *Amaranthus graecizans.*
4. The orchards, mostly of date palm trees *Phoenix dactylifera*, comprise the most conspicuous element in Feiran Oasis. Several other fruit trees are cultivated, e.g. olives (*Olea europaea*), vine (*Vitis vinifera)*, and pomegranate (*Punica granatum*). Due to the continuous depletion and shortage of water resources in Feiran Oasis, the date palm orchards may be classified into three main groups: (i) old orchards, the worthiest, where most of the old wells are dried up and many orchards are now either dried up or neglected; (ii) orchards established 8–10 year ago, with wells providing insufficient water discharge; and (iii) new orchards with adequate water discharge from deep wells dug during the last 4 years, where mats of *Oxalis corniculata*, *Cynodon dactylon*,

Alhagi graecorum, and *Zygophyllum simplex* usually occupy the ground between the date palm trees. Several associates of weedy and xerophytic species are recorded.

A total of 70 taxa of vascular plants (49 dicots and 21 moncots) are recorded, belonging to 63 genera and 26 families. Largest families are Gramineae (20 taxa), Chenopodiaceae, Compositae, and Euphorbiaceae, four each. Thirty-three species are recorded for the first time from Feiran Oasis. Thirteen out of these newly recorded taxa are invading xerophytes, growing in fields and orchards, and behaving as field weeds. This replacement may be attributed to the dry conditions which prevail for the last 4 years. A full species list with their habitats is presented in the Appendix.

Table 6.1 shows a group of 11 species comprising the most common weeds of arable lands in Egypt (El-Hadidi and Kosinová 1971); these are also recorded in Feiran Oasis. Another three species were intensively recorded by Vivi Täckholm's group during their visit to the study area in 1961 (notes from the herbarium sheets in CAI and CAIM): *Parietaria alsinifolia* Delile, *Rostraria pumila* (Desf.) Tzvelev, and *Samolus valerandi* L. Yet, almost none of these taxa have been recorded by the authors in the present study. This also confirms the environmental changing gradient during the last three decades (El-Hadidi et al. 1970).

The life-form spectrum of Feiran Oasis resembles the adjacent desert flora where therophytes are most frequent and constitute 45.1% of the recorded species, followed by hemicryptophytes and chamaephytes (19.5% and 14.6%, respectively). The remaining 20.7% are belonging to phanerophytes, geophytes, and parasites. This pattern of life-form spectrum displays a strong resemblance to that given by Olsvig-Whittaker et al. (1983) in a Negev Desert watershed at Sede Boqer, Israel. The distribution of these major life forms in relation to environment of Israel has also been viewed by Danin and Orshan (1990). In contrast, a comparison of the life-form spectra of other oases of the Western Desert of Egypt (Abd El-Ghani 1981, 1985) and the central part of the Hijaz Mountains of Saudi Arabia (Abd El-Ghani 1997) with the study area shows that the former areas include more chamaephytes than hemicryptophytes and geophytes. This reversed situation seems to be a response to a more hot and dry climate, topographic variation, human and animal interference, and short-time variation of water availability.

Analysis of the floristic data revealed that Cosmopolitan, Palaeotropical, and Pantropical taxa constitute 33% of the total recorded taxa of Feiran Oasis.The contribution of the three aforementioned chorological types in the flora of other oases of the Western Desert of Egypt was very highly represented: 51.6%, 49%, and 48.4% in Kharga, Bahariya, and Farafra Oases, respectively. This indicates that the floristic structure of the study area is relatively simple as compared with other oases of the Western Desert of Egypt, being more affected by human disturbances. Pure (monoregional) Mediterranean element is very modestly represented (1.2%); otherwise it is represented as bi- or pluriregional species (26.81%). Notably, the Saharo–Arabian element forms the main bulk (39%) of the total species in Feiran Oasis. In contrast, monoregional Sudano–Zambezian element is not represented. Thus the shrub layer is composed mainly of Saharo–Arabian with Irano–Turanain and/or

Table 6.1 Floristic composition of Feiran Oasis in 1939, in the 1960s, and in 1995–1996
+ = recorded, − = not recorded

Taxon	Drar 1939	Taeckholm 1961 El-Hadidi (1967) El-Hadidi et al. (1970)	Presend study 1995–96
Cuscuta planiflora Ten.	–	–	+
Cynanchum acutum L.	–	–	+
Cyperus rotundus L.	–	–	+
Dactyloctenium aegyptium (L.) Wild.	–	–	+
Digitaria sanguinalis (L.) Scop.	–	–	+
Eragrostis pilosa (L.) P. Beauv.	–	–	+
Euphorbia heterophylla L.	–	–	+
Forsskaolea tenacissima L.	–	–	+
Hyoscyamus muticus L.	–	–	+
Imperata cylindrica (L.) Raeusch.	–	–	+
Malva parviflora L.	–	–	+
Ochradenus baccatus Delile	–	–	+
Orobanche cernua Loefl.	–	–	+
Oryzopsis miliacea (L.) Asch. and Schweinf.	–	–	+
Oxalis corniculata L.	–	–	+
Panicum turgidum Forssk.	–	–	+
Phalaris minor Retz.	–	–	+
Solanum nigrum L.	–	–	+
Sonchus oleraceus L.	–	–	+
Tamarix aphylla (L.) H. Karst	–	–	+
Stipagrostis plumosa (L.) munro ex T. Anderson	–	–	+
Zygophyllum simplex L.	–	–	+
Alhagi graecorum Boiss.		+	+
"*Artemisia herba-alba* Asso"	–	+	+
Brachypodium distachyon (L.) P. Beauv.	–	+	+
Chrozophora tinctoria (L.) Raf.	–	+	+
Conyza bonariensis (L.) Cronq.	–	+	+
Echinochloa colona (L.) Link	–	+	+
Erucaria hispanica (L.) Druce	–	+	+
Hordeum murinum subsp. *leporinum* (Link) Arcang.	–	+	+
Lotus creticus L.	–	+	+
Panicum repens L.	–	+	+
Peganum harmala L.	–	+	+
Phragmites australis (Cav.) Trin. ex Steud.	–	+	+
Portulaca oleraces L.	–	+	+
Schismus barbatus (L.) Thell.	–	+	+
Setaria verticillata (L.) P. Beauv.	–	+	+
Sisymbrium irio L.	–	+	+
Spergularia marina (L.) Griseb.	–	+	+
Tamarix nilotica (Ehrenb.) Bunge	–	+	+
Withania somnifera L.	–	+	+
Zilla spinosa (L.) Prantl	–	+	+
Ziziphus spina-christi L.	–	+	+
Ammi majus L.	+	–	+
Avena sterilis L.	+	–	+
Lolium rigidum Gaudin	+	–	+

Taxon	Drar 1939	Taeckholm 1961 El-Hadidi (1967) El-Hadidi & al (1970)	Presend study 1996-96
Mentha longifolia subsp. *typhoides* (Briq.) Harley	+	–	+
Tribulus terrestris L.	+	–	+
Anagallis arvensis L.	+	+	+
Chenopodium murale L.	+	+	+
Convolvulus arvensis L.	+	+	+
Cynodon dactylon (L.) Pers.	+	+	+
Euphorbia peplus L.	+	+	+
Melilotus indicus (L.) All.	+	+	+
Polypogon monspeliensis (L.) Desf.	+	+	+
Polypogon viridis (Gouan) Breistr.	+	+	+
Silene nocturna L.	+	+	+
Sisymbrium orientale L.	+	+	+
Suaeda aegyptiaca (Hasselq.) Zohary	+	+	+

Sudano–Zambezian focus of distribution. This result is inconsistent with those given by Danin and Plitmann (1987) in their work on the phytogeographical territories of Israel and Sinai. In conclusion, Saharo–Arabian plants are known to be a good indicator for desert environmental conditions, while Mediterranean species stand for more mesic environs.

The present status of the flora of Feiran Oasis has a little similarity with weed flora of southern Sinai. Of the 156 species recorded by El-Hadidi et al. (1970) and the 70 in this study, only 32 are in common. The index of similarity is therefore 28.3%. The other five species are in common with those collected by Drar 1939. On the other hand, the weed flora of Egypt enumerated by El-Hadidi and Kosinová (1971) shows much greater affinity with the recently recorded flora of Feiran Oasis; the index of similarity being 54.6%. The low similarity is a conclusive proof of the worthy environmental conditions that dominate the area under review and the markedly different farming activities that were used during the last decades. Yet, the introduction of new crop seeds by the Bedouin, especially from the Nile Valley and Delta, may explain its high similarity with the weed flora of Egypt.

It can be also added that the small size of Feiran Oasis, the limited water resources, the rapid development due to increased touristic and population pressures, as well as the present serious socio-economic situation may cause the destruction of the remaining natural habitats in the near future.

Feiran Oasis is subjected to severe destruction and dryness of a great deal of its characteristic date palm orchards' habitat. The increasing population, scarce precipitation, and digging of some new deep wells were greatly affecting the underground water level and consequently have a negative effect on both irrigation and farmlands. A descriptive analysis of the weed assemblages associated with date palm orchards of Feiran Oasis and assessing the relationships between these assemblages and some soil characteristics and human interference are examined. A sketch of the orchards is shown in Fig. 6.2, which represents a field drawing rather than a map to scale.

The studied 34 phytosociological releves are fused in the dendrogram (Fig. 6.3) at an Euclidean distance of 1.44. The dendrogram structure suggests the existence of two main vegetation units: the former includes vegetation type A and the latter for vegetation types B and C. The resulting structured table is presented in Table 6.2, in which the stands are ordered according to their sequence in the dendrogram. The vegetation types identified in the study area are *Zygophyllum simplex–Hordeum murinum* in the old orchards, *Polypogon monspeliensis–Malva parviflora* in the mature orchards, and *Bidens pilosa–Conyza bonariensis* in the young orchards.

The largest cluster A includes the 17 old date palm orchards with high soil percentage of boulders, stones, and coarse sand and low salinity level (Table 6.3). Dominated species are *Zygophyllum simplex* and *Hordeum murinum.* This type of vegetation is characterized by the occurrence of many xerophytic species (18 out of 33), among others, *Citrullus colocynthis*, *Aerva javanica*, *Tamarix nilotica*, and *Haloxylon persicum.*

Community B is characterized by the dominance of *Bidens pilosa* and *Conyza bonariensis.* Some hygrophilous species occur in this community, e.g. *Cyperus rotundus*, *Mentha longifolia* subsp. *typhoides*, and *Phragmites australis*. This type of vegetation inhabits the seven studied young orchards with high content of fine material, organic matter, and soil moisture.

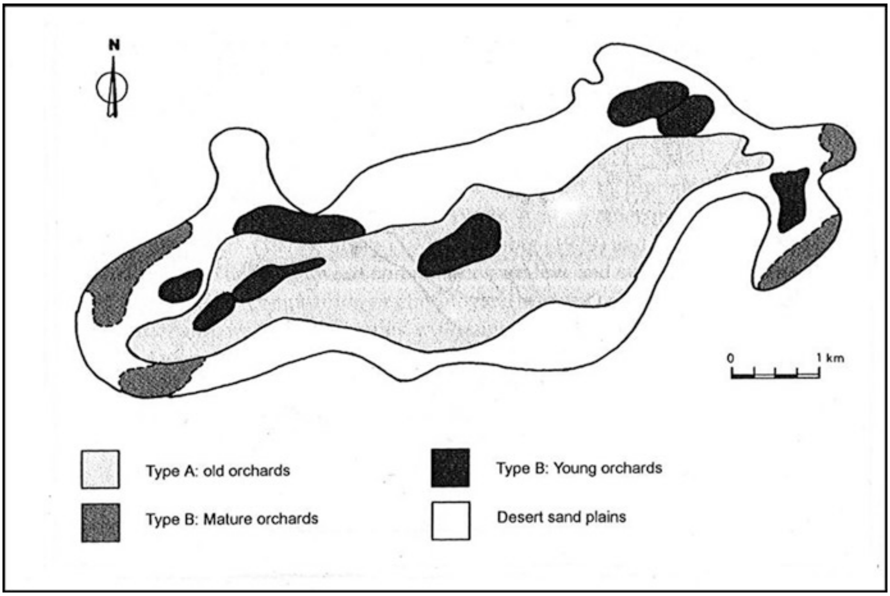

Fig. 6.2 Diagrammatic sketch of Wadi Feiran, showing the distribution of the different types of date palm orchards

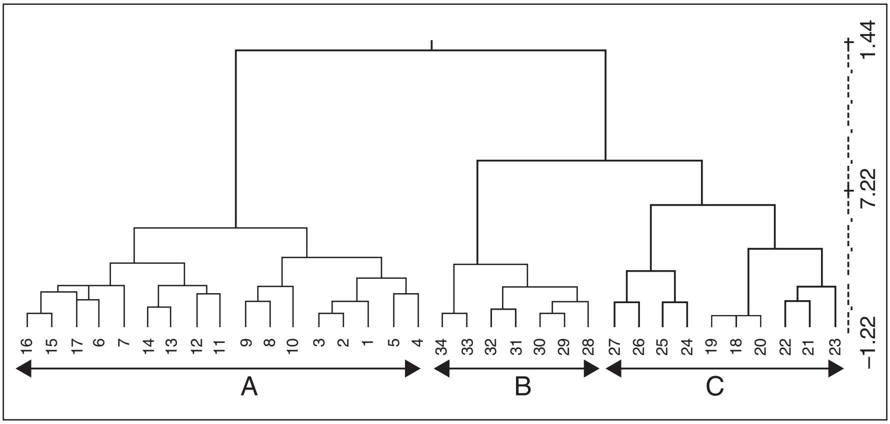

Fig. 6.3 Dendrogram resulting from cluster analysis of 34 stands of date palm orchards in Wadi Feiran, showing their separation into three distict vegetation types (*A*–*C*)

Community C inhabits the ten mature orchards with high soil pH and low percentage of fine sediments. Differential species with the highest cover values are *Polypogon monspeliensis* and *Malva parviflora*. Both vegetation types B and C are floristically separated from A by the presence of a number of species, e.g. *Anagallis arvensis*, *Mentha longifolia*, *Sisymbrium irio*, *Alhagi graecorum*, and *Tribulus terristris*.

Table 6.2 Phytosociological table ordered according to their sequence in the dendrogram of stands (Fig. 6.3)

Vegetation type	A	B	C
Stand number	111 1111 1 65767432198032154	3333322 4321098	2222112222 7654980213
Aerva javanica (Burm.f.) Juss.ex Schult.	3122112 1 21 3		
Ammi majus L.	4 2		
Brachypodium distachyum (L.) P. Beauv.	3 24 5 342		
Calotropis procera (Ait) W. T. Aiton	2 2		
Caylusea hexagyna (Forssk.) M. L. Green	4 425		
Citrullus colocynthis L.	5 35 3		
Cleome amblyocarpa Barratte & Murb.	3313 2 42		
Fagonia boveana (Hadidi) Hadidi & Garf	2 2 1		
Forsskaolea tenacissima L.	4 32		
Haloxylon persicum Bunge	2 3 12 3		
Hyoscyamus muticus L.	4 33		
Indigofera arabica Jaub. & Spach	142 32		
Orobanche cernua Loefl.	2 1		
Panicum repens L.	111 5 232 4		
Peganum harmala L.	1 11		
Polypogon viridis (Gouan) Breistr.	34 25 43		
Spergularia marina (L.) Griseb.	32 1 31		
Stipagrostis plumosa Munro ex Anderson	32 3 22		
Tamarix nilotica (Ehrenb.) Bunge	46 3 6 4		
Zygophyllum simplex L.	8896965 76427 47		
Bassia indica (Wight) A. J. Scott		2 14	
Bidens pilosa L.		7465334	
Cynanchum acutum L.		133	
Digitaria sanguinalis (L.) Scop.		25	
Phragmites australis (Cav.) Trin ex Steud.		555	
Capparis sinaica Veill.			2 3 3
Ochradenus baccatus Delile			44313
Portulaca oleracea L.			36756
Cuscuta planiflora Ten.	2 2	4	
Echinochloa colona (L.) Link	22 62 54	5 42	
Eragrostis pilosa (L.) P. Beauv.	2 3 2	345	
Hordeum murinum L.	44576263 9 7987	4 3	
Imperata cylindrica (L.) Raeusch.	2 33	3	
Setaria verticillata (L.) P. Beauv.	2 2	34 44	
Alhagi graecorum Boiss.		4 2	256
Anagallis arvensis L.		3	35 1 1
Conyza bonariensis (L.) Cronquist		6788657	5
Melilotus indicus (L.) All.		5	45
Mentha longifolia (L.) Huds. subsp. *typhoides*		4 546	4 4
Phalaris minor Retz.		231	4 3
Sisymbrium irio L.		5 63	44 4
Solanum nigrum L.		45	1 2
Tribulus terristris L.		213	54 13
Amaranthus graecizans L.	5 52 4	6	4 4 2

Table 6.2 (continued)

Amaranthus lividus L.	3 624 53		4635
Avena sterilis L.	2 332 3		44
Chenopodium album L.	1 2 2 3		333 4
Chrozophora tinctoria (L.) Raf.	54 2 33		3
Cleome chrysantha Decne.	54		43 2
Cucumis prophetarum L.	352		14 332
Cyperus rotundus L.	21	2434	42 1 1
Dactyloctenium aegyptium (L.) Willd.	3 476 5	54	2 4545
Malva parviflora L.	2 2	5 4	4556978687
Panicum turgidum Forssk.	3 1 3 2 2		42 5 44
Polypogon monspeliensis (L.) Desf.	11 3 2	31	56 679769
Sonchus oleraceus L.	3212		46
Chenopodium murale L.	774 586 867	58 45	57 77
Convolvulus arvensis L.	74965234678788679	9967887	5688989679
Cynodon dactylon (L.) Pers.	434652 369		878675
Euphorbia peplus L.	46769788587688967	6985679	779656 747
Oxalis corniculata L.	6884875	6879644	5 89 7

Table 6.3 Mean values and ±SD for soil characteristics and diversity indices for three vegetation types resulting from numerical classification

Soil variables		Vegetation types		
		A	B	C
Number of stands		17	7	10
Boulders + stones	(%)	67.64 ± 6.08	39.84 ± 4.98	51.43 ± 7.56
Coarse sand	(%)	46.30 ± 3.98	38.83 ± 3.90	40.18 ± 2.75
Fine sand	(%)	51.90 ± 4.20	59.62 ± 6.21	57.16 ± 5.33
Silt + clay	(%)	1.80 ± 0.78	2.4 ± 1.03	1.33 ± 0.67
Soil moisture	(%)	1.53 ± 1.01	1.92 ± 0.97	1.75 ± 1.13
$CaCO_3$	(%)	0.06 ± 0.09	0.07 ± 0.03	0.06 ± 0.01
Organic matter	(%)	1.72 ± 1.04	3.31 ± 0.54	2.61 ± 1.4
pH		7.95 ± 0.90	7.81 ± 1.01	8.3 ± 0.34
HCO_3 (meq l^{-1})		0.37 ± 1.98	0.21 ± 0.55	1.75 ± 1.87
Electric conductivity (mS cm^{-1})		0.18 ± 0.07	0.41 ± 0.05	0.29 ± 0.12
Species richness		32	27	28
Shannon–Wiener index (H')		1.44	1.38	1.41

The results of performed PCA are demonstrated in Fig. 6.4. The clustering of stands obtained by the classification method is still recognizable in the ordination results. The first PCA ordination axis was primarily a soil texture gradient which positively correlates significantly with boulders, stones, and coarse sand and is negatively correlated with fine sand, soil moisture, and organic matter. PCA axis 1 also correlates positively with species richness and species diversity (Table 6.4). Axis 2 was negatively correlated with coarse sand and electric conductivity.

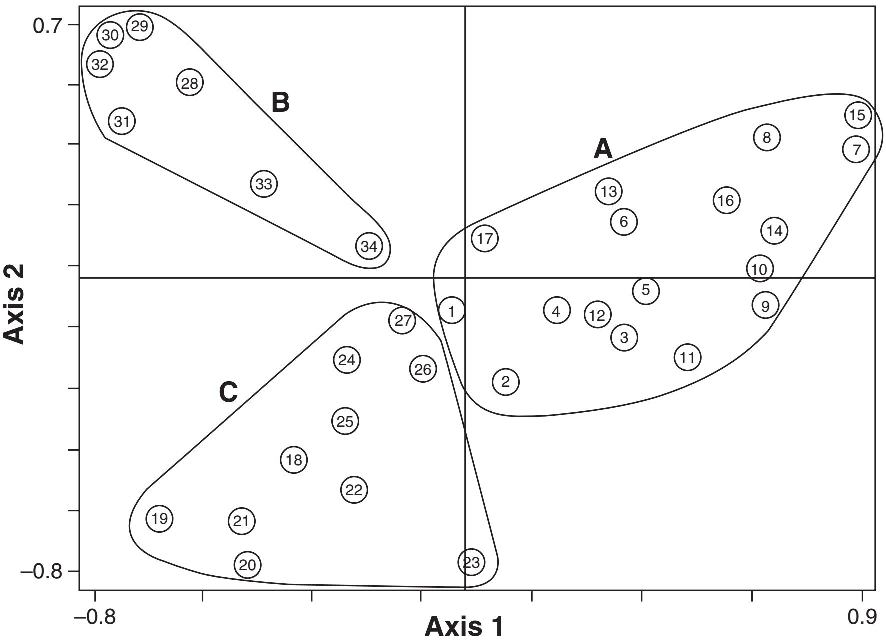

Fig. 6.4 PCA ordination diagram on the first (29.6%) and the second (18.6%) axes, showing the position of the three vegetation types (*A*–*C*)

Table 6.4 Correlation coefficients (*r*) between the soil factors of the sampled stands and their positions along the first two axes of PCA ordination

Soil factors		PCA 1	PCA 2
(a) Soil characters			
Boulders + stones		0.41**	0.24
Coarse sand		0.48***	–0.63***
Fine sand		–0.47**	0.01
Silt + clay		–0.06	0.23
Soil moisture	(%)	–0.52***	0.12
$CaCO_3$		0.15	0.14
Organic matter		–0.39*	–0.33
pH		–0.25	0.15
HCO_3^- (meq l^{-1})		–0.23	0.09
Electric conductivity (mS cm^{-1})		–0.01	–0.54***
(b) Diversity indices			
Species richness		0.59***	–0.21
Species diversity (H´)		0.64***	–0.13

Significance levels: *=$p < 0.05$; **=$p < 0.01$; ***=$p < 0.001$

Community A from date palm orchards with low salinity levels and high content of soil boulders and stones is floristically more diverse (9.7 species m^{-2}) than the other types, followed by community C (6.4 species m^{-2}) inhabiting orchards with low silt and clay content. The least diversified is type B (4.1 species m^{-2}) that characterizes young orchards with high soil moisture and organic matter contents. Shannon–Weaver index (H') shows a similar trend between the three vegetation types (1.44, 1.41, and 1.38 for communities A, C, and B, respectively).

6.2.1.2 Wadi Solaf, W. El-Akhdar, and W. Romana

These wadis are located in St. Catherine area, between latitudes 28°30′ and 29°00′N and longitudes 33°30′ and 34°00′E (Fig. 6.5).

Floristic Analysis and Spatial Distribution

A total of 116 species (45 annuals and 71 perennials) belonging to 95 genera and 37 families were recorded (Table 6.5). The largest families were Asteraceae, Brassicaceae, Fabaceae, Zygophyllaceae (18, 14, 10, and 8 species, respectively); Boraginaceae, Caryophyllaceae, and Chenopodiaceae (six species for each); and Poaceae (five species). They constituted 62.93% of the recorded species and represent most of the floristic structure in the inland wadis of south Sinai. Nineteen families were represented by only one species. The largest genera were *Fagonia* (six species) and *Astragalus* (five species).

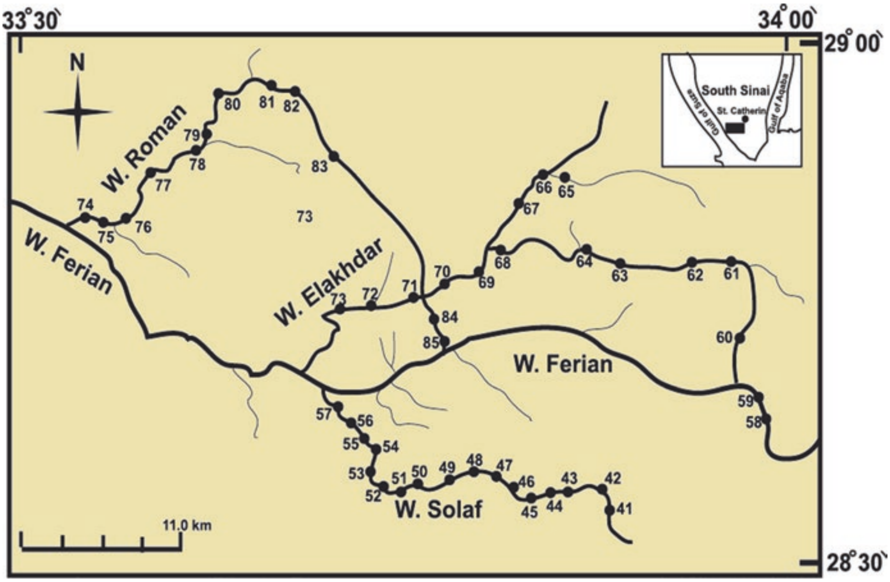

Fig. 6.5 Location map of the inland wadis and numbers of the studied stands

Table 6.5 Floristic composition, presence value, life forms, and chorology of the recorded species in the studied areas

Species	Duration	Chorotypes	Life forms	*P* (%)
Acanthaceae				
Blepharis edulis (ForssK.) Pers.	Per	SA	H	7.06
Aizoaceae				
Aizoon canariense L.	Ann	M+SA+IT	Th	4.71
Amaranthaceae				
Aerva javanica (Burm. F.) Juss.ex Schult.	Per	SA	Ch	12.9
Apiaceae				
Deverra tortuosa (Desf.) DC.	Per	SA	Ch	1.18
Pimpinella cretica Poir.	Ann	M	Th	1.18
Asclepiadaceae				
Caralluma europaea (Guss.) N. E. Br.	Per	M	H	1.18
Pergularia tomentosa L.	Per	SA	Ch	9.41
Asphodelaceae				
Asphodelus tenuifolius Cav.	Ann	M+SA+IT	Th	7.06
Asteraceae				
Achillea fragrantissima (Forssk.) Sch. Bip.	Per	SA+IT	Ch	5.88
Anthemis melampodina Delile	Ann	SA	Th	1.18
Artemisia judaica L	Pre	SA	Ch	41.2
Carduncellus eriocephalus Boiss.	Per	SA	H	1.18
Carthamus nitidus Boiss.	Ann	IT+SA	Th	1.18
Centaurea aegyptiaca L.	Per	SA	H	4.71
Centaurea sinaica DC.	Ann	SA	Th	2.35
Crepis micrantha Czerep.	Ann	M+IT	Th	1.18
Echinops spinosus L.	Per.	SA+IT	H	2.22
Filago desertorum Pomel	Ann	SA+IT	Th	3.53
Iphiona scabra DC.	Per	SA	Ch	2.35
Launaea capitata (Spreng.) Dandy	Ann	SA	Th	3.53
Nauplius graveolens (Forssk.) Wiklund	Per	SA	H	5.88
Pulicaria incisa (Lam.) DC.	Per	SA	H	7.06
Pulicaria undulata (L.) C. A. Mey.	Per	SA	H	15.3
Senecio flavus (Decne.) Sch. Bip.	Ann	SA	Th	1.18
Seriphidium herba-album	Per	M+SA+IT	Ch	8.24
Volutaria lippii (L.) Cass. Ex Maria	Ann	M+SA	Th	1.18
Boraginaceae				
Anchusa hispida Forssk.	Ann	SA+IT	Th	1.18
Echium angustifolium Mill.	Per	SA	H	1.18
Echium rauwolfii Delile	Ann	SA	Th	1.18
Heliotropium arbainense Fresen.	Per	SA	Ch	9.41
Paracaryum intermedium (Fresen.) Lipsky	Ann	SA+IT	Th	1.18
Trichodesma africanum (L.) R. Br.	Ann	SA+SZ	Ch	4.71
Brassicaceae				
Diplotaxis acris (Forssk.) Boiss.	Ann	SA	Th	1.18

(continued)

Table 6.5 (continued)

Species	Duration	Chorotypes	Life forms	*P* (%)
Diplotaxis harra (Forssk.) Boiss.	Per	SA	H	25.9
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.	Per	SA	Th	3.53
Farsetia aegyptia Turra	Per	SA	Ch	3.53
Matthiola arabica Boiss.	Per	SA	H	5.88
Matthiola longipetala (Vent.) DC.	Ann	M+SA+IT	Th	2.35
Morettia philaeana (Delile) DC.	Ann	SA	H	15.3
Moricandia nitens (Viv.) Durand & Barratte	Per	SA	Ch	1.18
Moricandia sinaica (Boiss.) Boiss.	Per	SA	Ch	2.35
Savignya parviflora (Delile) Webb	Ann	SA	Th	1.18
Schimpera arabica Hochst. & Steud. ex Boiss.	Ann	SA	Th	1.18
Schouwia purpurea (Forssk.) Schweinf.	Ann	SA	Th	1.18
Sisymbrium erysimoides Desf.	Ann	M+SA+SZ	Th	1.18
Zilla spinosa (L.) Prantl	Per	SA	Ch	50.6
Caesalpiniaceae				
Senna italica Mill.	Per	Sa+SZ	H	1.18
Capparaceae				
Capparis spinosa L.	Per	M+SA+IT	Ch	8.24
Caryophyllaceae				
Gymnocarpos decanter Forssk.	Per	SA	Ch	7.06
Gypsophila capillaris (Forssk.) C. Chr.	Per	M+SA	H	10.6
Paronychia arabica (L.) DC.	Per	SA+IT	Th	1.18
Polycarpaea repens (Forssk.) Asch. & Schweinf.	Per	SA	Th	1.18
Polycarpaea robbairea (Kuntze) Greuter & Burdet	Ann.	SA	Th	2.22
Silene arabica Boiss.	Ann	SA+IT	Th	1.18
Chenopodiaceae				
Agatophora alopecuroides (Delile) Fenzl ex Bunge	Per	SA	Ch	1.18
Anabasis articulata (Forssk.) Moq.	Per	SA+IT	Ch	35.3
Anabasis setifera Moq.	Per	SA+IT	Ch	5.88
Chenopodium murale L.	Ann	Cosm	Th	1.18
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	Per	SA+IT	Ch	17.6
Suaeda sp.	Per	SA	Ch	1.18
Cistaceae				
Helianthemum lippii (L.) Dum.Cours.	Per	SA	Ch	1.18
Cleomaceae				
Cleome amblyocarpa Barratte & Murb.	Ann	SA	Th	11.8
Cleome droserifolia (Forssk.) Delile	Per	SA+IT	H	2.22
Cucurbitaceae				
Citrullus colocynthis (L.) Schrad.	Per	M+SA+IT	H	22.4

(continued)

Table 6.5 (continued)

Species	Duration	Chorotypes	Life forms	*P* (%)
Cucumis prophetarum L.	Per	SA	H	4.71
Dipsacaceae				
Scabiosa palaestina L.	Ann	M+IT	Th	2.35
Ephedraceae				
Ephedra pachyclada Boiss	Per	IT	Ph	1.18
Euphorbiaceae				
Chrozophora oblongifolia (Delile) Spreng.	Per	SZ	Ch	2.35
Euphorbia retusa Forssk.	Per	SA	H	7.06
Fabaceae				
Astragalus eremophilus Boiss.	Ann	SA	Th	2.35
Astragalus sieberi DC.	Per	SA	Ch	3.53
Astragalus spinosus (Forssk.) Muschl.	Per	SA+IT	Ch	1.18
Astragalus trigonus DC.	Per	SA	Ch	1.18
Astragalus vogelii (Webb) Bornm.	Ann	SA	Th	4.71
Crotalaria aegyptiaca Benth.	Per	SZ	H	1.18
Lotononis platycarpa (Viv.) Pic.Serm.	Per	SA+SZ	Th	7.06
Retama raetam (Forssk.) Webb & Berthel.	Per	SA+IT	Ph	32.9
Tephrosia purpurea (L.) Pers.	Per	SA	Ch	2.35
Trigonella stellata Forssk.	Ann	M+SA+IT	Th	1.18
Geraniaceae				
Erodium oxyrhynchum M. Bieb.	Per	SA+IT	H	9.41
Erodium pulverulentum (Boiss.) Batt.	Ann	SA+IT	Th	10.6
Monsonia nivea (Decne.) Webb	Per	SA	H	2.35
Lamiaceae				
Lavandula coronopifolia Poir.	Per	SA	Ch	4.71
Stachys aegyptiaca Pers.	Per	M+SA	H	2.35
Malvaceae				
Malva parviflora L.	Ann	M+ES+IT	Th	1.18
Mimosaceae				
Acacia tortilis (Forssk.) Hayne	Per	SA+SZ	Ph	17.6
Nuradaceae				
Neurada procumbens L.	Ann	M+SA+IT	Th	3.53
Orobanchaceae				
Orobanche cernua Loefl.	Per	M+SA+IT	P	3.53
Papaveraceae				
Glaucium corniculatum (L.) Rudolph	Ann	M+IT	Th	2.35
Peganaceae				
Peganum harmala L.	Per	M+ES+IT	H	14.1
Plantaginaceae				
Plantago ovata Forssk.	Ann	M+SA+IT	Th	1.18
Poaceae				
Aristida adscensionis L.	Per	Pan	Th	4.71

(continued)

Table 6.5 (continued)

Species	Duration	Chorotypes	Life forms	*P* (%)
Bromus catharticus Vahl	Ann	M+ES+IT	Th	1.18
Lolium rigidum Gaudin	Ann	M+ES+IT	Th	1.18
Schismus arabicus Nees	Ann	M+SA+IT	Th	7.06
Stipagrostis plumosa (L.) Munro ex T. Anderson	Per	M+SA+IT	H	3.53
Polygonaceae				
Rumex vesicarius L.	Ann	M+SA+IT	Th	1.18
Resedaceae				
Caylusea hexagyna (Forssk.) M. L. Green	Ann	SA	Th	2.35
Ochradenus baccatus Delile	Per	SA	Ph	21.2
Reseda pruinosa Delile	Ann	SA	Th	41.2
Rubiaceae				
Crucianella ciliata Lam.	Ann	IR	Th	1.18
Scrophulariaceae				
Kickxia acerbiana (Boiss.) Täckh. & Boulos	Per	SA	Ch	4.71
Scrophularia deserti Delile	Per	SA	H	1.18
Varbascum sinaiticum Benth.	Per	M+IT	H	2.35
Solanaceae				
Hyoscyamus boveanus (Dunal) Asch. & Schweinf.	Per	SA	H	5.88
Hyoscyamus pusillus L.	Ann	SA	Th	1.18
Lycium shawii Roem. & schult.	Per	SA	Ph	9.41
Urticaceae				
Forsskaolea tenacissima L.	Per	SA+SZ	H	14.1
Zygophyllaceae				
Fagonia arabica L.	Per	SA	Ch	29.4
Fagonia bruguieri DC.	Per	SA+IT	H	3.53
Fagonia glutinosa Delile	Per	SA	H	4.71
Fagonia mollis Delile	Per	SA	Ch	38.8
Fagonia schimperi Presl	Per	SA	H	1.18
Fagonia thebaica Boiss.	Per	SA	Ch	2.35
Tribulus pentandrus Forssk.	Ann	SA+SZ	Th	2.35
Zygophyllum simplex L.	Ann	SA+SZ	Th	1.18

P%, presence values, *Per* perennials, *Ann* annuals, *Ph* phanerophytes, *H* hemicryptophyte, *Ch* chamaephytes, *Th* therophytes, *G* geophytes, *P* parasites, *SA* Saharo–Arabian, *SZ* Sudano–Zambezian, *IT* Irano–Turanian, *ES* Euro–Siberian, ME Mediterranean, *Cosm* Cosmopolitan, *Pan* Pantropical

Therophytes (41.38%) constituted the largest number of species (48 species). Chamaephytes ranked second (26.72%), followed by phanerophytes (4.31%) and hemicryptophytes (26.72%). *Orobanche cernua* was the only recorded parasite. Chorological analysis revealed that 59 species (51% of the total recorded species) were monoregional in being native to Saharo–Arabian chorotype. About 42% of the recorded species are biregional and pluriregional extending their distribution all over the Saharo–Arabian, Sudano–Zambezian, Irano–Turanian, and Mediterranean regions. Being part of Saharo–Arabian region, the Saharo–Arabian chorotype (bi- and pluriregional) constitutes 27% and 12% of the recorded species, respectively. Thus it forms the major component of the floristic composition of this study.

The three studied wadis shared 37 species or about 31.9% of the total recorded species (116) in the three inland wadis (Table 6.6). Among the recorded species, *Acacia tortilis*, *Aerva javanica*, and *Retama raetam* (trees); *Anabasis articulata*,

Table 6.6 Comparison between the presence percentages (P%) of recorded species in the three inland wadis (W.=wadi)

Species	W. Romana	W. Al-Akhdar	W. Solaf
Species present in three wadis (%)			
Acacia tortilis	66.67	18.75	23.53
Achillea fragrantissima	16.67	6.25	11.76
Aerva javanica	58.33	18.75	5.88
Aizoon canariense	8.33	12.50	5.88
Anabasis articulata	58.33	87.50	52.94
Anabasis setifera	8.33	6.25	17.65
Aristida adscensionis	16.67	6.25	5.88
Artemisia judaica	25.00	93.75	100
Asphodelus tenuifolius	16.67	18.75	5.88
Blepharis edulis	25.00	12.50	5.88
Capparis spinosa	33.33	6.25	11.76
Citrullus colocynthis	58.33	43.75	29.41
Cleome amblyocarpa	8.33	43.75	11.76
Cucumis prophetarum	16.67	6.25	5.88
Diplotaxis harra	41.67	50.00	52.94
Erodium oxyrhynchum	8.33	37.50	5.88
Fagonia arabica	75.00	62.50	35.29
Fagonia glutinosa	8.33	6.25	11.76
Fagonia mollis	58.33	81.25	76.47
Forsskaolea tenacissima	50.00	25.00	11.76
Gymnocarpos decanter	25.00	12.50	5.88
Gypsophila capillaris	8.33	37.50	11.76
Haloxylon salicornicum	16.67	25.00	52.94
Heliotropium arbainense	33.33	12.50	11.76
Hyoscyamus boveanus	8.33	6.25	17.65
Launaea capitata	8.33	6.25	5.88
Lavandula coronopifolia	16.67	6.25	5.88
Morettia philaeana	33.33	31.25	23.53
Ochradenus baccatus	58.33	25.00	41.18
Peganum harmala	33.33	18.75	29.41
Pulicaria incisa	16.67	18.75	5.88

(continued)

Table 6.6 (continued)

Species	W. Romana	W. Al-Akhdar	W. Solaf
Pulicaria undulata	41.67	25.00	23.53
Reseda pruinosa	83.33	62.50	88.24
Retama raetam	41.67	62.50	76.47
Seriphidium herba-album	8.33	25.00	11.76
Trichodesma africanum	8.33	6.25	11.76
Zilla spinosa	91.67	100	94.12
Species present in two wadis (%)			
Astragalus sieberi	8.33	12.50	0
Fagonia bruguieri	16.67	6.25	0
Kickxia acerbiana	25.00	6.25	0
Lotononis platycarpa	25.00	18.75	0
Moricandia sinaica	8.33	6.25	0
Stachys aegyptiaca	8.33	6.25	0
Tephrosia purpurea	8.33	6.25	0
Astragalus vogelii	0	6.25	17.65
Farsetia aegyptia	0	12.50	5.88
Glaucium corniculatum	0	6.25	5.88
Centaurea aegyptiaca	0	12.50	11.76
Erodium pulverulentum	0	31.25	23.53
Euphorbia retusa	0	31.25	5.88
Matthiola arabica	0	12.50	17.65
Nauplius graveolens	0	25.00	5.88
Orobanche cernua	0	12.50	5.88
Schismus arabicus	0	31.25	5.88
Euphorbia retusa	0	31.30	5.88
Centaurea sinaica	8.33	0	5.88
Chrozophora oblongifolia	8.33	0	5.88
Lycium shawii	58.33	0	5.88
Pergularia tomentosa	58.33	0	5.88
Species present in one wadi (%)			
Cleome droserifolia	16.67	0	0
Fagonia thebaica	16.67	0	0
Caralluma europaea	8.33	0	0
Crotalaria aegyptiaca	8.33	0	0
Echium angustifolium	8.33	0	0
Hyoscyamus pusillus	8.33	0	0
Lolium rigidum	8.33	0	0
Polycarpaea repens	8.33	0	0
Silene arabica	8.33	0	0
Suaeda sp.	8.33	0	0
Volutaria lippii	8.33	0	0
Zygophyllum simplex	8.33	0	0
Eremobium aegyptiacum	0	18.75	0
Filago desertorum	0	18.75	0

(continued)

Table 6.6 (continued)

Species	W. Romana	W. Al-Akhdar	W. Solaf
Neurada procumbens	0	18.75	0
Stipagrostis plumosa	0	18.75	0
Astragalus eremophilus	0	12.5	0
Monsonia nivea	0	12.5	0
Anthemis melampodina	0	6.25	0
Astragalus trigonus	0	6.25	0
Bromus catharticus	0	6.25	0
Carduncellus eriocephalus	0	6.25	0
Carthamus nitidus	0	6.25	0
Chenopodium murale	0	6.25	0
Crepis micrantha	0	6.25	0
Crucianella ciliata	0	6.25	0
Diplotaxis acris	0	6.25	0
Echinops spinosus	0	6.25	0
Echium rauwolfii	0	6.25	0
Ephedra pachyclada	0	6.25	0
Fagonia schimperi	0	6.25	0
Helianthemum lippii	0	6.25	0
Malva parviflora	0	6.25	0
Moricandia nitens	0	6.25	0
Paracaryum intermedium	0	6.25	0
Paronychia arabica	0	6.25	0
Pimpinella cretica	0	6.25	0
Savignya parviflora	0	6.25	0
Schimpera arabica	0	6.25	0
Senecio flavus	0	6.25	0
Senna italica	0	6.25	0
Trigonella stellata	0	6.25	0
Caylusea hexagyna	0	0	11.76
Matthiola longipetala	0	0	11.76
Tribulus pentandrus	0	0	11.76
Varbascum sinaiticum	0	0	11.76
Agatophora alopecuroides	0	0	5.88
Anchusa hispida	0	0	5.88
Astragalus spinosus	0	0	5.88
Deverra tortuosa	0	0	5.88
Plantago ovata	0	0	5.88
Polycarpaea robbairea	0	0	5.88
Rumex vesicarius	0	0	5.88
Scabiosa palaestina	0	0	5.88
Schouwia purpurea	0	0	5.88
Scrophularia deserti	0	0	5.88
Sisymbrium erysimoides	0	0	5.88

Capparis spinosa, *Ochradenus baccatus*, *Haloxylon salicornicum*, *Heliotropium arbainense*, *Zilla spinosa*, and *Seriphidium herba-album* (shrubs); *Blepharis edulis*, *Citrullus colocynthis*, *Cucumis prophetarum*, *Erodium oxyrhynchum*, and *Morettia philaeana* (perennial herbs); and *Asphodelus tenuifolius*, *Aristida adscensionis*, *Gypsophila capillaris*, *Launaea capitata*, *Diplotaxis harra*, and *Reseda pruinosa* (annuals) can be mentioned. Fifty-seven species showed a degree of consistency to a certain wadi and distributed as follows: 12 species showed consistency to Wadi Romana, 30 species to W. Al-Akhdar, and 15 species in Wadi Solaf.

Classification of Vegetation

Application of classification using cluster analysis to the floristic data of the inland wadis yielded five vegetation groups (Fig. 6.6). Nine species were recorded with variable presence values in all the five groups. Apart from *Diplotaxis harra*, all the remaining eight species were among the most common trees and shrubs of the

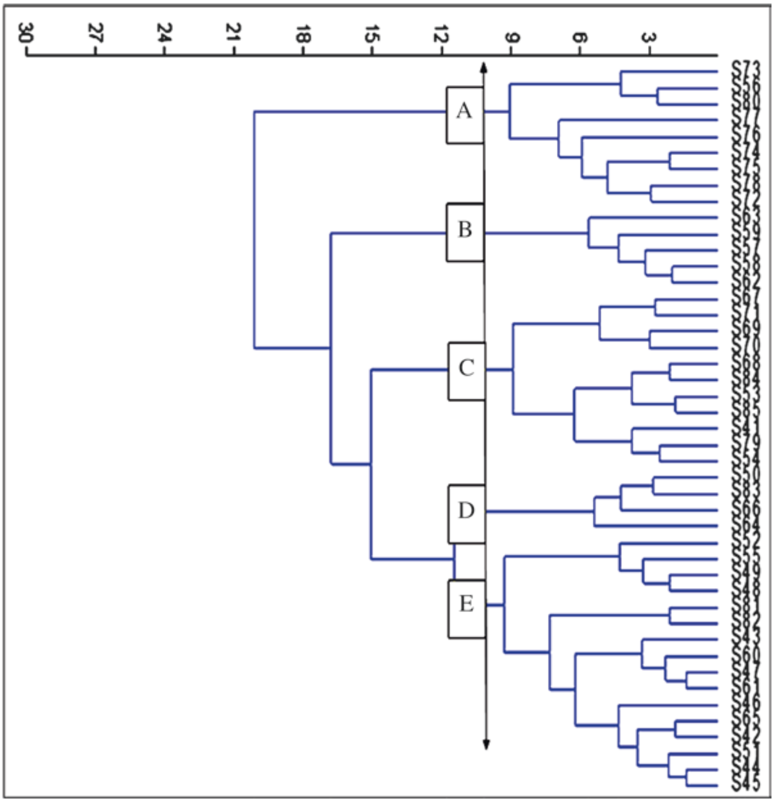

Fig. 6.6 Dendrogram showing cluster analysis of the studied 45 stands of the inland wadis, with the five vegetation groups (*A*–*E*)

Egyptian deserts such as *Anabasis articulata*, *Artemisia judaica*, *Fagonia arabica*, *Haloxylon salicornicum*, *Retama raetam*, and *Zilla spinosa*.

Three ubiquitous (have a wide ecological range of distribution) were recorded: *Zilla spinosa*, *Reseda pruinosa*, and *Fagonia mollis* have the highest presence values (P = 50.6%, 41.2%, and 38.8%, respectively). On the other hand, *Reseda pruinosa* showed the highest presence estimate among annuals (P = 41.18%). Seventy-one species or about 61% of the total recorded species were perennials and demonstrated a certain degree of constancy.

Significant differences in the examined soil variables within the separated vegetation groups were demonstrated in Table 6.7. Electric conductivity, total soluble salts, gravel, clay, sodium, and calcium showed clear significant differences between groups at $p < 0.05$.

Group (A). *Zilla spinosa* Group

It is the most diversified among the separated vegetation groups. It comprised of 70 species recorded from ten stands, with the lowest average species richness of 4.7 ± 5.5 species stands^{-1} and Shannon–Wiener diversity index of 1.07 ± 0.98 (Table 6.7). Stands of this group inhabited soil rich in its electric conductivity, total soluble salts, fine sand, clay, Na, and Mg and low in silt and chloride contents. Sporadic species included were represented by 34 species or about 48.6% of the recorded species of this group, among others, *Caralluma europaea*, *Crotalaria aegyptiaca*, *Gymnocarpos decanter*, *Moricandia sinaica*, *Schimpera arabicam*, and *Volutaria lippii*. Co-dominant associated species (P = 90–80%) included *Acacia tortilis*, *Aerva javanica*, *Fagonia arabica*, *Reseda pruinosa*, and *Forsskaolea tenacissima*. Eighteen species showed certain degree of fidelity to this group, among others, *Fagonia thebaica*, *Crotalaria aegyptiaca*, *Caralluma europaea*, *Hyoscyamus pusillus*, *Paracaryum intermedium*, *Senecio flavus*, and *Zygophyllum simplex*.

Group (B). *Artemisia judaica–Zilla spinosa* Group

This group was the least diversified among the recognized groups. It comprised of 39 species recorded from five stands, with average species richness of 12.7 ± 4.1 species stands $^{-1}$ and Shannon–Wiener diversity index of 2.5 ± 0.3. It inhabited soil with the highest levels of gravel, coarse sand, and Na and lowest levels of potassium. Sporadic species comprised 24 species (or about 61.5% of the recorded species of this group) which included, among others, *Anabasis setifera*, *Crucianella ciliata*, *Haloxylon salicornicum*, *Morettia philaeana*, *Orobanche cernua*, *Pimpinella cretica*, and *Retama raetam*. Co-dominant associated species that have presence values ranging from 60% to 80% were *Anabasis articulata*, *Diplotaxis harra*, *Euphorbia retusa*, *Seriphidium herba-album*, *Erodium oxyrhynchum*, *Fagonia mollis*, and *Nauplius graveolens*. Among the consistent species to this group, *Anchusa hispida*, *Astragalus trigonus*, *Ephedra pachyclada, Paronychia Arabica*, and *Trigonella stellata* can be mentioned.

Group (C). *Artemisia judaica* Group

This group comprised 56 species recorded from seven stands, with an average species richness of 10.7 ± 3.3 species stand^{-1} and Shannon–Wiener diversity index of

Table 6.7 Mean values, standard deviations (±), and ANOVA values of the soil variables in the vegetation groups (A–E) of the inland wadis

Soil factors	Total mean		Vegetation groups A	B	C	D	E	P
EC	mS cm^{-1}	17.9 ± 8.8	19.6 ± 4.3	14.6 ± 4.6	24.1 ± 12.8	14.1 ± 4.6	14.2 ± 7.05	0.034*
TSS	mgl^{-1}	3.4 ± 1.7	3.8 ± 0.8	2.8 ± 0.9	4.6 ± 2.4	2.7 ± 0.9	2.7 ± 1.3	0.034*
Gravel		10.8 ± 9.2	9.5 ± 5.7	19.6 ± 10.7	6.0 ± 2.8	17.7 ± 23.3	10.5 ± 5.6	0.033*
CS		8.4 ± 5.3	8.4 ± 5.5	12.692	53 ± 2.1	10.9 ± 8.6	8.5 ± 3.6	0.089
FS	(%)	36.1 ± 12.6	38.0 ± 12.4	34.0 ± 9.6	30.4 ± 16.1	33.4 ± 12.1	40.3 ± 10.3	0.359
Silt		11.7 ± 5.1	9.7 ± 3.8	10.0 ± 5.7	11.1 ± 5.8	12.4 ± 7.8	13.8 ± 4.3	0.318
Clay		33.0 ± 19.5	34.3 ± 18.0	23.7 ± 22.3	47.2 ± 22.4	25.7 ± 19.6	26.8 ± 12.3	0 05*
Na		0.4 ± 0.7	0.2 ± 0.4	0.4 ± 0.9	0.4 ± 0.6	1.5 ± 1.1	0.3 ± 0.6	0.022*
K		0.02 ± 0.02	0.03 ± 0.02	0.01 ± 0.005	0.03 ± 0.02	0.02 ± 0.02	0.03 ± 0.03	0.82
Ca	(mgl^{-1})	0.1 ± 0.05	0.1 ± 0.02	0.1 ± 0.03	0.1 ± 0.07	0.1 ± 0.04	0.1 ± 0.03	0.032*
Mg		0.06 ± 0.04	0.05 ± 0.02	0.06 ± 0.01	0.07 ± 0.05	0.05 ± 0.02	0.05 ± 0.03	0.661
Cl		0.6 ± 0.2	0.5 ± 0.1	0.6 ± 0.08	0.7 ± 0.2	0.6 ± 0.03	0.6 ± 0.3	0.373
SO_4		0.001 ± 0.007	0.001 ± 0.001	0.001 ± 0.0	0.001 ± 0.008	0.001 ± 0.008	0.001 ± 0.005	0.95
SR		11.4 ± 6.5	4.7 ± 5.5	12.7 ± 4.1	10.7 ± 3.3	13.7 ± 2.5	21.2 ± 4.4	0.001**
H′		2.2 ± 0.89	1.07 ± 0.98	2.5 ± 0.3	2.3 ± 0.3	2.6 ± 0.2	3.0 ± 0.2	0.001**

EC Electric conductivity, *TSS* Total soluble salts, *CS* Coarse sand, *FS* Fine sand, *SR* Species richness, and *H´* Shannon–Wiener index
* = $p < 0.05$

2.3 ± 0.3. The seven stands of this group are characterized by soil with the highest electric conductivity, total soluble salts, clay, Na, and Mg and the lowest contents of coarse and fine sand. Sporadic species were represented by 29 species (about 52% of the total number of species in this group) and included, among others, *Achillea fragrantissima*, *Astragalus spinosus*, *Carduncellus eriocephalus*, *Filago desertorum*, *Lycium shawii*, *Lavandula coronopifolia*, *Savignya parviflora*, and *Varbascum sinaiticum*. Co-dominant associated species (P = 81.8–72.7%) included *Fagonia glutinosa*, *Reseda pruinosa*, *Zilla spinosa*, *Anabasis articulata*, *Citrullus colocynthis*, and *Retama raetam*. Eleven species were consistent to this group, among others, *Fagonia glutinosa*, *Astragalus spinosus*, *Malva parviflora*, *Polycarpaea robbairea*, *Rumex vesicarius*, and *Scabiosa palaestina*.

Group (D). *Anabasis articulata–Artemisia judaica–Fagonia mollis* Group

The 46 species in this group were recorded from seven stands, with average species richness of 13.7 ± 2.5 species stand^{-1} and Shannon diversity index of 2.6 ± 0.2. The low number of studied stands in this group was due to rugged topography and limited accessibility. The stands of this group inhabited soil with high content of coarse sand and silt and lowest contents of electric conductivity, total soluble salts, and sodium. Thirty sporadic species (65.2% of species in this group) were recorded that included, among others, *Acacia tortilis*, *Agatophora alopecuroides*, *Centaurea sinaica*, *Chenopodium murale*, *Gypsophila capillaries*, *Lolium rigidum*, *Lotononis platycarpa*, and *Schismus arabicus*. Co-dominant associated species that have presence values more than 75% included *Zilla spinosa*, *Citrullus colocynthis*, *Diplotaxis harra*, *Erodium pulverulentum*, and *Gymnocarpos decanter*. Twelve species showed a certain degree of consistency to this group and included *Stachys aegyptiaca*, *Agatophora alopecuroides*, *Bromus catharticus*, *Crepis micrantha*, *Plantago ovata*, *Scrophularia deserti*, and *Senna italica*.

Group (E). *Fagonia mollis–Zilla spinosa* Group

The group size (15 stands) was the largest among the separated vegetation groups. Forty-three species was recorded, with average species richness of 21.2 ± 4.4 species stands^{-1} and Shannon–Wiener diversity index of 3.0 ± 0.2. The stands of this group inhabited soil with the highest content of fine sand and silt and low contents of total soluble salts, gravel, and coarse sand. Sporadic species included 17 species, of which *Aizoon canariense*, *Asphodelus tenuifolius*, *Capparis spinosa*, *Deverra tortuosa*, *Helianthemum lippii*, *Pergularia tomentosa*, *Schouwia purpurea*, and *Varbascum sinaiticum* were included. Co-dominant associated species with presence values of 73.3–80% included, among others, *Artemisia judaica*, *Reseda pruinosa*, and *Retama raetam*. Consistent species to this group included, among others, *Matthiola longipetala*, *Tribulus pentandrus*, and *Silene arabica*.

Stand Ordination

Application of Principal Component Analysis (PCA) as an ordination technique resulted in the segregation of the five vegetation groups, with most of their stands within, along the first two axes with eigenvalues of 0.131 and 0.073 for axes 1 and 2,

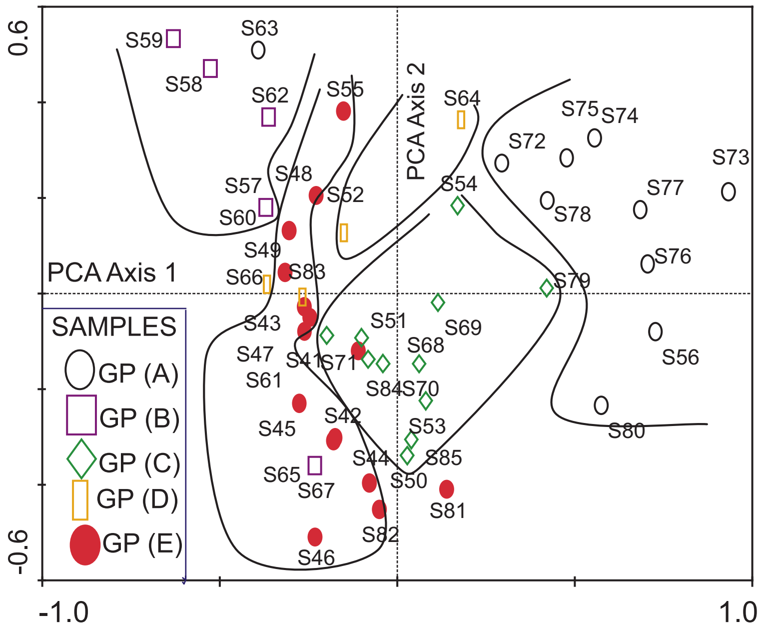

Fig. 6.7 PCA diagram showing the distribution of the 45 stands of the inland wadis within their vegetation groups

respectively (Fig. 6.7). The first two axes explained 20.4% of the total variation in species data, which may be attributed to the many zero in the vegetation data matrix. Stands of group (A) were separated along the positive end of the PCA axis 1, while those of groups (B) and (E) were separated along its negative end. On the other hand, stands of groups (C) and (D) demonstrated an intermediate position between both ends of PCA axis 1.

Soil–Vegetation Relationships

The relationship between the vegetation and soil variables was studied using Canonical Correspondence Analysis (CCA). Figure 6.8 showed the CCA ordination biplot with vegetation groups (A–E) and the examined soil variables. It can be noted that stands of groups (A) and (E) were highly correlated with fine sand. On the other hand, stands of group (B) were highly associated with gravel and coarse sand. Similar comments can be added to stands of group (C) that related to electric conductivity, total soluble salts, and clay.

The species–environment correlations (Table 6.8) were higher for the first three axes, explaining 68.4% of the cumulative variance. These results suggested an association between vegetation and the measured soil parameters presented in the biplot. CCA axis 1 was highly positively correlated with gravel and highly negatively

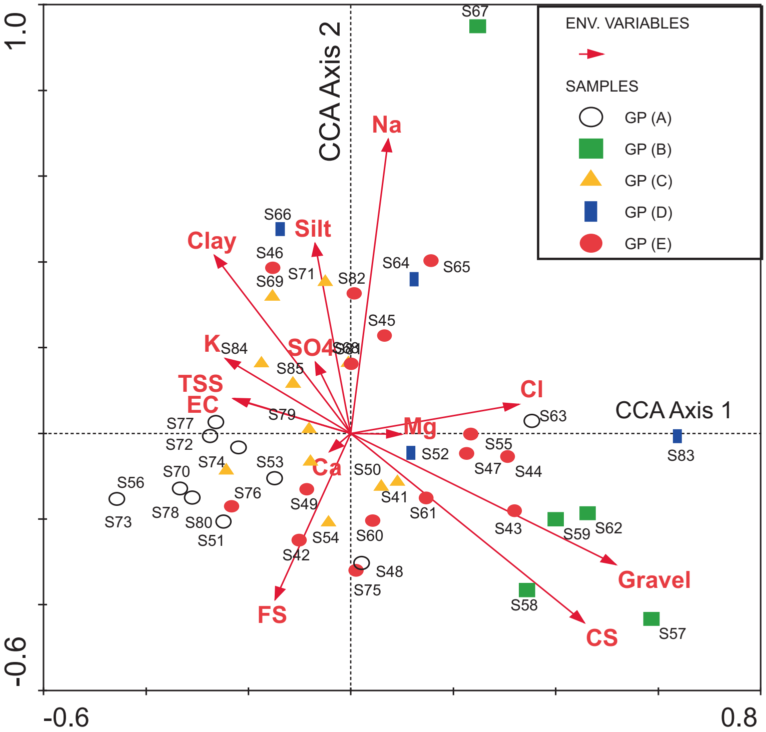

Fig. 6.8 Canonical Correspondence Analysis (*CCA*) biplot of axes 1 and 2 showing the distribution of the 45 stands of the inland wadis, together with their vegetation groups and soil variables

Table 6.8 The results of ordination for the three CCA axes, inter-set correlation of the soil variables, together with eigenvalues and species–environment correlation in the inland wadis

Axes	Ax1	Ax2	Ax3
Eigenvalues	0.307	0.284	0.221
Species–environment correlations	0.899	0.938	0.945
EC	−0.20	0.07	0.01
TSS	−0.20	0.08	0.01
Gravel	0.46	−0.29	−0.14
CS	0.41	−0.41	−0.18
FS	−0.13	−0.36	0.19
Silt	−0.06	0.41	0.35
Clay	−0.24	0.39	−0.10
Na	0.06	0.64	−0.03
K	−0.22	0.16	−0.18
Ca	−0.04	−0.04	−0.30
Mg	0.09	−0.001	−0.06
Cl	0.29	0.06	0.27
SO_4	−0.06	0.15	0.27

Table 6.9 Correlation coefficients between soil factors and diversity indices of inland wadis

Soil factors	Diversity index	
	Species richness (SR)	Shannon–Wiener (H′)
EC	0.079	0.116
TSS	0.079	0.116
Gravel	−0.099	−0.059
CS	−0.102	−0.070
FS	0.025	−0.002
Silt	0.040	0.005
Clay	0.048	0.046
Na	0.091	0.074
K	−0.136	−0.159
Ca	0.215	0.247*
Mg	−0.143	−0.129
Cl	−0.287*	−0.314*
SO_4	0.087	0.065

* $p < 0.05$

correlated with clay. So this axis can be interpreted as gravel–clay gradient. CCA axis 2 was highly positively correlated with sodium and highly negatively with coarse sand. Thus, this axis can be interpreted as sodium–coarse sand gradient. A test for significance with an unrestricted Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be highly significant ($P = 0.008$).

Diversity Versus Soil Factors

The effects of environmental variables on species richness and Shannon diversity index (Table 6.9) indicated that species richness was significantly negatively correlated with chlorides, while the Shannon diversity index showed significant negative correlation with chlorides and positively correlated with calcium.

6.2.2 The Coastal Wadis

From the mountain of St. Catherine, at 2,641 m, the highest point in Egypt and marking the watershed of the peninsula, wadi systems drain eastwards towards the Gulf of Aqaba and westwards towards the Gulf of Suez. Although southern Sinai is classified as "very arid" (Zahran and Willis 1992), there is in fact a great deal of water draining down the wadis, sometimes as violent and destructive flash floods, but under normal circumstances most of the water is underground, occasionally surfacing to produce short sections of freely flowing permanent water. Sparse vegetation occurs everywhere, but the wet areas are particularly rich with plants and consequently with insects and other animals.

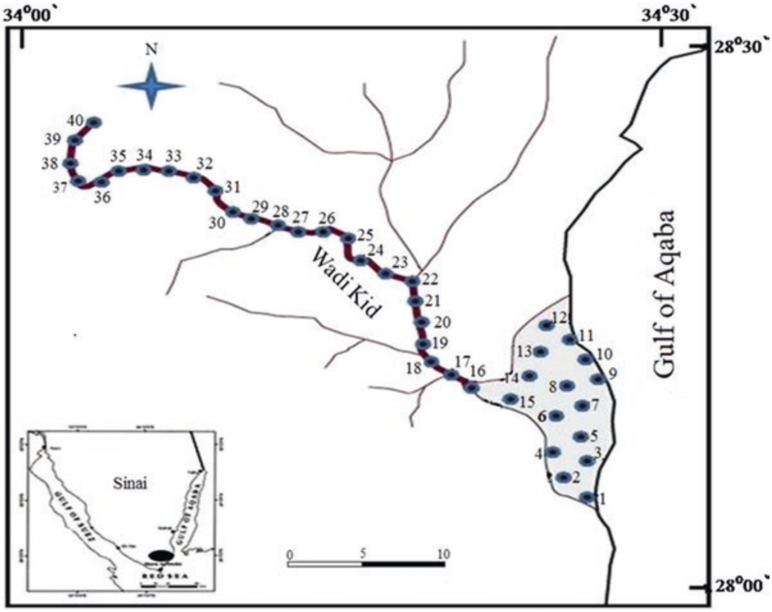

Fig. 6.9 Location map of the studied stands in Wadi Kid

6.2.2.1 Wadi Kid

Wadi Kid is a main basin which drains to the Gulf of Aqaba (Fig. 6.9), located between longitudes 34°09′ and 34°27′E and latitudes 28° 04′ and 28° 21′, with an elevation range between 17 and 636 m above sea level. It is a long wadi, located about 50 km north to Sharm El Sheikh city, and extends for about 50 km, surrounded by different types of granitic and volcanic mountains. The width of the main wadi ranges between 50 and 100 m, and in some areas turned into vast plains. This wadi can be divided into two main parts, the upstream part and the downstream part. The upstream part is mainly gravel with surface cobbles. The downstream part of the wadi is covered mainly with rocks (cobbles and stones) with a coarse sand strips near the foothills.

Floristic Analysis

A total of 69 species (22 annuals and 47 perennials) belonging to 57 genera and 33 families are recorded. The largest families were Asteraceae and Zygophyllaceae (eight and seven species, respectively); Caryophyllaceae (five species); Boraginaceae, Brassicaceae, and Fabaceae (four species for each); and Geraniaceae, Resedaceae, and Poaceae (three species for each). They constituted 59.4% of the recorded species and represent most of the floristic structure in south Sinai desert. Twenty families are represented by only one species. The largest genera were *Fagonia* and *Zygophyllum*, three species for each (Table 6.10).

Table 6.10 Floristic composition, presence value, life forms, and chorology of the recorded species in the studied area of Wadi Kid in the south Sinai, Egypt

Species	Duration	Chorology	L.F	*P%*
Acanthaceae				
Blepharis edulis (ForssK.) Pers.	Per	SA	H	7.5
Aizoaceae				
Aizoon canariense L.	Ann	M+SA+IT	Th	23
Amaranthaceae				
Aerva javanica (Burm. F.) Juss.ex Schult.	Per	SA	Ch	23
Asclepiadaceae				
Pergularia tomentosa L.	Per	SA	Ch	5
Solenostemma argel (Delile) Hayne	Per	SA	Ph	2.5
Asphodelaceae				
Asphodelus tenuifolius Cav.	Ann	M+SA+IT	Th	27.5
Asteraceae				
Artemisia judaica L.	Per	SA	Ch	17.5
Echinops hussonii Boiss.	Per	SA+SZ	H	5
E. spinosus L.	Per	SA+IT	H	10
Iphiona mucronata (Forssk.) Asch. & Schweinf.	Per	SA	Ch	7.5
I. scabra DC.	Per	SA	Ch	38
Picris cyanocarpa Boiss.	Ann	SA	Th	2.5
Pulicaria incisa (Lam.) DC.	Per	SA	H	25
P. undulata (L.) C. A. Mey.	Per	SA	H	35
Avicenniaceae				
Avicennia marina (Forssk.) Vierh.	Per	SA	Ph	7.5
Boraginaceae				
Arnebia hispidissima (Lehm.) DC.	Ann	SA	Th	5
Heliotropium arbainense Fresen.	Per	SA	Ch	5
H. digynum (Forssk.) C. Chr.	Per	SA	Ch	2.5
Trichodesma africanum (L.) R. Br.	Ann	SA+SZ	Ch	13
Brassicaceae				
Brassica tournefortii Gouan	Ann	M+SA+IT	Th	2.5
Diplotaxis harra (Forssk.) Boiss.	Per	SA	H	13
Schouwia purpurea (Forssk.) Schweinf.	Ann	SA	Th	73
Zilla spinosa (L.) Prantl	Per	SA	Ch	48
Capparaceae				
Capparis spinosa L.	Per	M+SA+IT	Ch	2.5
Caryophyllaceae				
Gypsophila capillaris (Forssk.) C. Chr.	Per	M+SA	H	2.5
Polycarpaea repens (Forssk.) Asch. & Schweinf.	Per	SA	Th	7.5
P. robbairea (Kuntze) Greuter & Burdet	Ann	SA	Th	13
Silene linearis Decne.	Ann	SA	Th	2.5
Chenopodiaceae				

(continued)

Table 6.10 (continued)

Species	Duration	Chorology	L.F	*P%*
Salsola baryosma (Roem. & Schult.) Dandy	Per	SA	Ch	2.5
Atriplex halimus L.	Per	M+SA	Ph	13
Cleomaceae				
Cleome amblyocarpa Barratte & Murb.	Ann	SA	Th	10
C. droserifolia (Forssk.) Delile	Per	SA+IT	H	5
Cucurbitaceae				
Citrullus colocynthis (L.) Schrad.	Per	M+SA+IT	H	38
Cucumis prophetarum L.	Per	SA	H	5
Euphorbiaceae				
Chrozophora oblongifolia (Delile) Spreng.	Ann	M+IT	Th	10
Fabaceae				
Astragalus spinosus (Forssk.) Muschl.	Per	SA+IT	Ch	2.5
A.vogelii (Webb) Bornm.	Ann	SA	Th	10
Lotononis platycarpa (Viv.) Pic.Serm.	Ann.-Per.	SA+SZ	Th	10
Retama raetam (Forssk.) Webb & Berthel.	Per	SA+IT	Ph	10
Geraniaceae				
Erodium oxyrhynchum M. Bieb.	Per	SA+IT	H	5
E. pulverulentum (Boiss.) Batt.	Ann	SA+IT	Th	2.5
Monsonia nivea (Decne.) Webb	Per	SA	H	25
Lamiaceae				
Teucrium polium L.	Per	SA	Ch	5
Mimosaceae				
Acacia tortilis (Forssk.) Hayne	Per	SA+SZ	Ph	40
Nitrariaceae				
Nitraria retusa (Forssk.) Asch.	Per	SA	Ph	10
Nuradaceae				
Neurada procumbens L.	Ann	M+SA+IT	Th	5
Orobanchaceae				
Orobanche cernua Loefl.	Per	M+SA+IT	P	2.5
Peganaceae				
Peganum harmala L.	Per	M+ES+IT	H	5
Plumbaginaceae				
Limonium pruinosum (L.) Chaz.	Per	SA	H	7.5
Poaceae				
Bromus catharticus Vahl	Ann	M+ES+IT	Th	5
Panicum turgidum Forssk.	Per	M+SA	Ge	20
Stipagrostis plumosa (L.) Munro ex T. Anderson	Per	M+SA+IT	H	45
Polygonaceae				
Calligonum polygonoides L.	Per	SA+IT	Ph	25
Rumex vesicarius L.	Ann	M+SA+IT	Th	13
Resedaceae				

(continued)

Table 6.10 (continued)

Species	Duration	Chorology	L.F	*P*%
Caylusea hexagyna (Forssk.) M. L. Green	Ann	SA	Th	23
Ochradenus baccatus Delile	Per	SA	Ph	18
Reseda pruinosa Delile	Ann	SA	Th	35
Rhamnaceae				
Zizyphus spina-christi (L.) Desf.	Per	M+SA+IT+SZ	Ph	7.5
Salvadoraceae				
Salvadora persica L.	Per	SA+SZ	Ph	13
Scrophulariaceae				
Kickxia scoparia	Per	SA+SZ	Ch	5
Solanaceae				
Hyoscyamus boveanus (Dunal) Asch. & Schweinf.	Per	SA	H	2.5
Urticaceae				
Forsskaolea tenacissima L.	Per	SA+SZ	H	48
Zygophyllaceae				
Fagonia arabica L.	Per	SA	Ch	43
F. mollis Delile	Per	SA	Ch	30
F. schimperi Presl	Per	SA	H	5
Tribulus pentandrus Forssk.	Ann	SA+SZ	Th	28
Zygophyllum album L.	Per	M+SA+IT	Ch	5
Z. coccineum L.	Per	SA	Ch	60
Z. simplex L.	Ann	SA+SZ	Th	68

P% presence values, *Per* perennials, *Ann* annuals, *L.F* life form, *Ph* phanerophytes, *H* hemicryptophyte, *Ch* chamaephytes, *Th* therophytes, *G* geophytes, *P* parasites, *SA* Saharo–Arabian, *SZ* Sudano–Zambezian, *IT* Irano–Turanian, *ES* Euro–Siberian, *ME* Mediterranean

Figure 6.10 shows the life forms of the recorded species according to Raunkiaer (1937). The 69 recorded species were represented in five different life forms. Therophytes (31%) constitute the largest number of species (21 species). Chamaephytes have high value of 26% including 18 species, phanerophytes have 10 species representing about 14% of the flora, and hemicryptophytes represent about 26% of the flora with 18 species. Geophytes were represented by one species, namely, *Panicum turgidum*, and parasites were represented by one species, namely, *Orobanche cernua*.

Chorological Affinities

Results of the total chorological analysis of the surveyed flora (Fig. 6.11) revealed that 36 species (53% of the total recorded species) are monoregional in being native to Saharo–Arabian chorotype. About 47% of the recorded species are biregional and pluriregional extending their distribution all over the Saharo–Arabian, Sudano–Zambezian, Irano–Turanian, and Mediterranean regions. Being part of

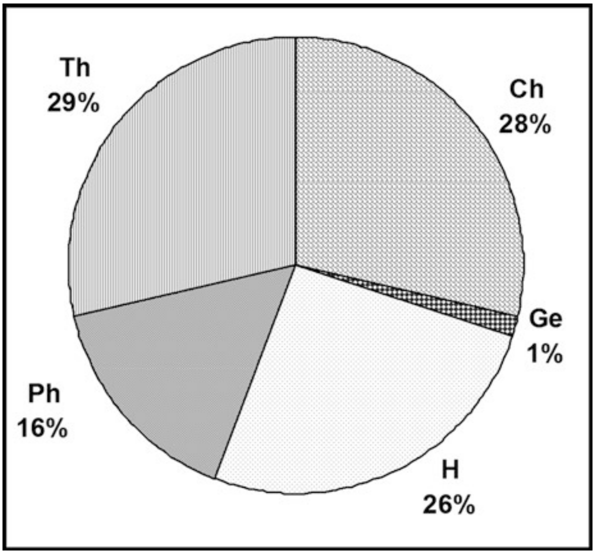

Fig. 6.10 Life-form spectrum of the recorded species in the study area. *H* hemicryptophytes, *Ge* geophytes, *Ch* chamaephytes, *Th* therophytes, *Ph* phanerophytes

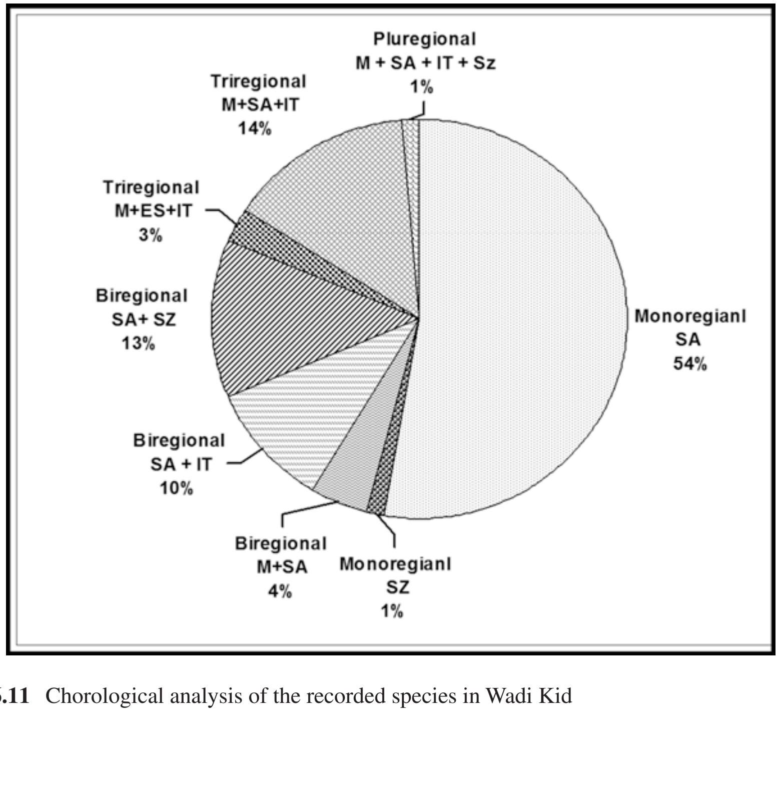

Fig. 6.11 Chorological analysis of the recorded species in Wadi Kid

Saharo–Arabian region, the Saharo–Arabian chorotype (bi- and pluriregional) constitutes 27% and 16% of the recorded species, respectively. Thus it forms the major component of the floristic composition of this study.

Classification of Vegetation

Application of classification using cluster analysis to the floristic data of Wadi Kid yielded five vegetation groups (Fig. 6.12). Ten species were recorded with variable presence values in the five groups. It included one tree (*Acacia tortilis*), shrubs (e.g. *Fagonia arabica*, *Schouwia purpurea*, *Zilla spinosa*, and *Zygophyllum coccineum*), and annuals (e.g. *Zygophyllum simplex*).

Group (A). *Nitraria retusa–Salvadora persica–Zygophyllum simplex* Group
It is the largest among the separated vegetation groups. It comprised of 33 species recorded from 11 stands, with the lowest species richness of 4.7 ± 5.4 species stands^{-1} and Shannon–Wiener diversity index of 1.07 ± 0.98. Stands of this group

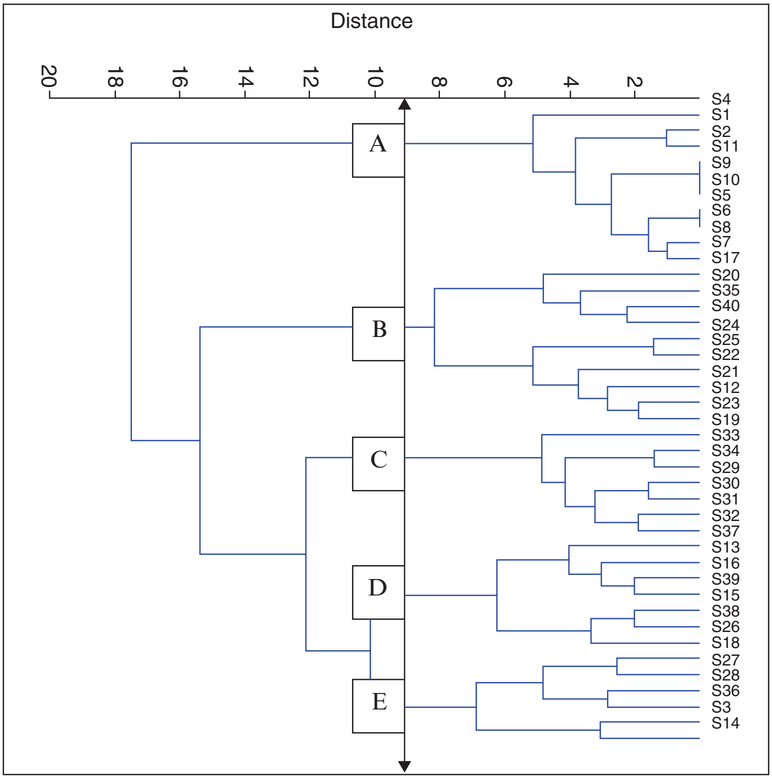

Fig. 6.12 Dendrogram showing cluster analysis of the studied 40 stands of Wadi Kid, with the five vegetation groups (*A*–*E*)

inhabited soil rich in its electric conductivity, total soluble salts, chlorides, coarse sand, fine sand, silt, and other cations such as Na, K, Ca, and Mg. Sporadic species (species recorded in one stand only) were represented by 24 species or about 73% of the recorded species of this group, among others, *Acacia tortilis*, *Astragalus spinosus*, *Blepharis edulis*, *Panicum turgidum*, *Diplotaxis harra*, *Teucrium polium*, and *Zilla spinosa*. Co-dominant associated species included *Avicennia marina*, *Limonium pruinosum* (P = 27.3% for each), and *Zygophyllum album* (P = 18.2%). Six species showed consistency to this group: *Nitraria retusa*, *Avicennia marina*, *Limonium pruinosum*, *Zygophyllum album*, *Astragalus spinosus*, and *Brassica tournefortii* (Table 6.11).

Table 6.11 Floristic composition in the vegetation groups of coastal wadis

	Vegetation groups				
Species	A	B	C	D	E
Total number of stands	11	10	7	7	5
Total number of species	33	45	25	37	43
Acacia tortilis	9.1	70	42.8	28.6	60
Fagonia arabica	9.1	60	28.6	14.3	60
Forsskaolea tenacissima	9.1	70	28.6	57.1	100
Monsonia nivea	27.3	10	42.8	14.3	40
Reseda pruinosa	9.1	40	14.3	71.4	60
Schouwia purpurea	9.1	90	100	100	100
Stipagrostis plumosa	9.1	30	85.7	71.4	60
Zilla spinosa	9.1	70	57.1	42.8	80
Zygophyllum coccineum	27.3	40	100	85.7	80
Zygophyllum simplex	36.4	60	100	71.4	100
Aerva javanica		20	28.6	14.3	80
Asphodelus tenuifolius	9.1	50		57.1	10
Calligonum polygonoides		10	14.3	71.4	60
Caylusea hexagyna	9.1	40		14.3	60
Citrullus colocynthis		60	14.3	57.1	80
Echinops spinosus		10	14.3	28.6	10
Fagonia mollis		30	85.7	71.4	40
Iphiona scabra		10	57.1	57.1	100
Pulicaria incisa	9.1	20		71.4	80
Pulicaria undulata		70	57.1	14.3	10
Rumex vesicarius	9.1	20		14.3	10
Tribulus pentandrus		10	71.4	14.3	80
Aizoon canariense	9.1	60			40
Artemisia judaica		30		28.6	40
Astragalus vogelii	9.1	10			60
Atriplex halimus	9.1	20			40
Blepharis edulis	9.1	10			10

(continued)

Table 6.11 (continued)

Species	Vegetation groups				
	A	B	C	D	E
Chrozophora oblongifolia		10	14.3		40
Diplotaxis harra	9.1	30		14.3	
Lotononis platycarpa		10		14.3	40
Panicum turgidum	9.1			42.8	80
Polycarpaea robbairea	18.2		28.6		10
Trichodesma africanum	9.1			28.6	40
Arnebia hispidissima		10		14.3	
Bromus catharticus	9.1		14.3		
Cleome amblyocarpa			14.3		40
Cleome droserifolia				14.3	40
Cucumis prophetarum		10			10
Heliotropium arbainense		10			10
Iphiona mucronata		30		14.3	
Kickxia scoparia	9.1		14.3		
Neurada procumbens		10		14.3	
Ochradenus baccatus				57.1	40
Pergularia tomentosa				14.3	10
Polycarpaea repens		10			10
Retama raetam	9.1	30			
Salvadora persica	36.4				10
Teucrium polium	9.1				10
Ziziphus spina-christi		10			40
Nitraria retusa	36.4				
Avicennia marina	27.3				
Limonium pruinosum	27.3				
Zygophyllum album	18.2				
Astragalus spinosus	9.1				
Brassica tournefortii	9.1				
Erodium oxyrhynchum		20			
Capparis spinosa		10			
Erodium pulverulentum		10			
Fagonia bruguieri		10			
Hyoscyamus boveanus		10			
Picris cyanocarpa		10			
Solenostemma argel		10			
Echinops hussonii			14.3		
Heliotropium digynum			14.3		
Peganum harmala				28.6	
Fagonia schimperi				14.3	
Gypsophila capillaries				14.3	
Salsola imbricata subsp. *imbricat*				14.3	
Silene linearis					10

Group (B). ***Schouwia purpurea*** **Group**

This group was the most diversified among the recognized groups. It comprised of 45 species recorded from ten stands, with average species richness of 12.7 ± 4.1 species stands^{-1} and Shannon–Wiener diversity index of 2.5 ± 0.3. It inhabited soil with the lowest salinity (electric conductivity and total soluble salts) and lowest levels of calcium contents. Sporadic species comprised 21 species (or about 47% of the recorded species of this group) which included, among others, *Calligonum polygonoides*, *Chrozophora oblongifolia*, *Echinops spinosus*, *Hyoscyamus boveanus*, *Iphiona scabra*, *Solenostemma argel*, and *Zizyphus spina-christi*. Co-dominant associated species that have presence values ranging from 60% to 70% were *Acacia tortilis*, *Forsskaolea tenacissima*, *Pulicaria undulata*, *Zilla spinosa*, *Aizoon canariense*, *Citrullus colocynthis*, *Fagonia arabica*, and *Zygophyllum simplex*. Consistent species to this group included *Erodium oxyrhynchum*, *Capparis spinosa*, *Erodium pulverulentum*, *Fagonia bruguieri*, *Hyoscyamus boveanus*, *Picris cyanocarpa*, and *Solenostemma argel.*

Group (C). ***Schouwia purpurea–Zygophyllum coccineum–Zygophyllum simplex*** **Group**

This was the least diversified (25 species) among the recognized vegetation groups, with an average species richness of 10.7 ± 3.3 species stand^{-1} and Shannon–Wiener diversity index of 2.3 ± 0.3. The seven stands of this group inhabited soil with the highest clay content (higher than the total mean) and high sodium and chloride contents and lowest contents of gravel, coarse sand, fine sand, and silt. Sporadic species included ten species, among others, *Bromus catharticus*, *Cleome amblyocarpa*, *Echinops hussonii*, *Heliotropium digynum*, and *Kickxia scoparia.* Co-dominant associated species (P = 85.7–57.1%) included *Fagonia mollis*, *Stipagrostis plumosa*, *Tribulus pentandrus*, *Iphiona scabra*, *Pulicaria undulata*, and *Zilla spinosa*. Two species (*Echinops hussonii* and *Heliotropium digynum*) showed consistency to this group.

Group (D). ***Schouwia purpurea–Zygophyllum coccineum*** **Group**

The 37 species in this group were recorded from seven stands, with average species richness of 13.7 ± 2.5 species stand^{-1} and Shannon diversity index of 2.6 ± 0.2. The stands of this group inhabited soil with lower content of sodium and chlorides (Table 6.12). Seventeen sporadic species (*ca* 46% of species in this group) were recorded which included among others, *Aerva javanica*, *Cleome droserifolia*, *Fagonia schimperi*, *Iphiona mucronata*, *Pergularia tomentosa*, and *Salsola imbricata* subsp. *imbricata.* Co-dominant associated species that have presence values ranging between 71.4% and 57.1% included *Calligonum polygonoides*, *Fagonia mollis*, *Stipagrostis plumosa*, *Citrullus colocynthis*, *Asphodelus tenuifolius*, and *Ochradenus baccatus*. Four species showed a certain degree of consistency to this group and included *Peganum harmala*, *Fagonia schimperi*, *Gypsophila capillaries*, and *Salsola imbricata* subsp. *imbricata.*

Table 6.12 Mean values, standard deviations (STD), and ANOVA values of the soil variables in the vegetation groups (A–E) of Wadi Kid

Soil factors		Total mean	Vegetation groups					P
			A	B	C	D	E	
EC		145.2 ± 345.0	449.3 ± 588.4	20.83 ± 17.9	38.7435.3	34.0 ± 33.9	29.4 ± 29.2	0.016*
TSS		27.9 ± 67.9	86.3 ± 11.9	3.9 ± 3.4	7.4 ± 6.8	6.5 ± 6.5	5.6 ± 5.6	0.016*
Gravel	(%)	5.2 ± 6.0	6.6 ± 6.3	5.3 ± 8.1	3.1 ± 3.9	3.4 ± 4.0	7.7 ± 5.3	0.585
CS	(%)	6.15 ± 9.9	12.9 ± 17.1	4.1 ± 3.6	2.4 ± 2.3	3.1 ± 3.5	4.9 ± 2.8	0.121
FS	(%)	27.1 ± 19.3	35.8 ± 25.6	29.3 ± 19.2	15.9 ± 13.3	21.0 ± 12.3	28.0 ± 13.8	0.253
Silt	(%)	18.3 ± 8.2	22.01 ± 10.9	17.8 ± 5.6	15.4 ± 8.5	16.6 ± 6.0	17.6 ± 8.3	0.505
Clay		43.2 ± 24.0	22.7 ± 19.9	43.5 ± 23.1	63.1 ± 21.1	55.8 = 17.6	41.8 = 12.6	0.002**
Na		0.8 ± 2.6	2.7 ± 4.7	0.10 ± 0.1	0.10 ± 0.1	0.07 ± 0.06	0.04 ± 0.02	0.102
K		0.1 ± 0.3	0.4 ± 0.5	0.01 ± 0.004	0.01 ± 0.007	0.01 ± 0.004	0.02 ± 0.03	0.028*
Ca		0.8 ± 1.5	2.2 ± 2.3	0.19 ± 0.1	0.2 ± 0.1	0.3 ± 0.3	0.3 ± 0.40	0.002**
Ma		0.2 ± 0.4	0.7 ± 0.7	0.07 ± 0.04	0.1 ± 0.09	0.1 ± 0.1	0.07 ± 0.02	0.002**
Cl		9.01 ± 21.5	30.01 ± 33.7	1.06 ± 0.5	1.3 ± 1.1	0.9 ± 0.5	0.8 ± 0.2	0.002**
SO_4		0.003 ± 0.001	0.005 ± 0.001	0.003 ± 0.001	0.003 ± 0.001	0.003 ± 0.001	0.003 ± 0.001	0.010*
SR		11.4 ± 6.5	4.7 ± 5.4	12.7 ± 4.1	10.7 ± 3.3	13.7 ± 2.5	21.2 ± 4.4	0.001**
H′		2.2 ± 0.89	1.07 ± 0.98	2.5 ± 0.3	2.3 ± 0.3	2.6 ± 0.2	3.0 ± 0.2	0.001**

EC Electric conductivity, *TSS* Total soluble salts, *CS* Coarse sand, *FS* Fine sand, *SR* Species richness, and *H′* Shannon–Wiener index
**= $p < 0.01$, *= $p < 0.05$

Group (E). *Forsskaolea tenacissima–Iphiona scabra–Schouwia purpurea–Zygophyllum simplex* **Group**

The group size of this group was represented by five stands that included 43 species. The average species richness was the highest among the recognized groups with 21.2 ± 4.4 species stands^{-1} and Shannon–Wiener diversity index of 3.0 ± 0.2. The stands of this group inhabited soil with the highest content gravel and lowest content of sodium, magnesium, and chlorides. Sporadic species included 13 species, of which *Cucumis prophetarum*, *Heliotropium arbainense*, *Pergularia tomentosa*, *Salvadora persica*, and *Silene linearis* were included. Co-dominant associated species with presence values of 80% included among others *Aerva javanica*, *Citrullus colocynthis*, *Pulicaria incisa*, *Panicum turgidum*, *Tribulus pentandrus*, and *Zilla spinosa.* One species (*Silene linearis*) showed consistency to this group.

Stand Ordination

Application of Principal Component Analysis (PCA) to the vegetation data of the coastal wadis (Fig. 6.13) revealed the segregation of the five vegetation groups along PCA axis 1 (eigenvalue 0.294) and PCA axis 2 (eigenvalue 0.074). The cumulative percentage variance of species data of the first two PCA axes was 36.8%. Stands of group (A) separated along the negative side of PCA axis 1, while those of group (E) separated along its positive end. In the meantime, stands of group (B) separated along the positive end of PCA axis 2, and those of group (C) separated along its negative end.

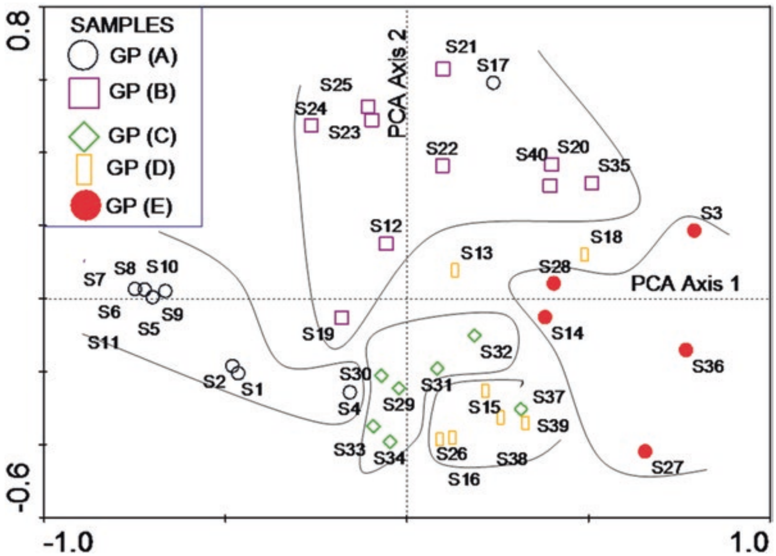

Fig. 6.13 PCA diagram showing the distribution of the 40 stands of the coastal wadis within their vegetation groups

Soil–Vegetation Relationships

Significant differences in the examined soil variables within the separated vegetation groups were demonstrated in Table 6.12. Clay, calcium, magnesium, chlorides, electric conductivity, total soluble salts, potassium, and sulphates showed clear significant differences between groups at $p < 0.01$ and $p < 0.05$, respectively.

The relationship between the vegetation and soil variables was studied using Canonical Correspondence Analysis (CCA). Figure 6.14 showed the CCA ordination biplot with vegetation groups (A–E) and the examined soil variables. It can be noted that stands of group (A) were highly correlated with calcium, potassium, and coarse sand. On the other hand, the remaining vegetation groups (B–E) cannot be easily differentiated and tend to clump together.

The species–environment correlations were higher for the first three axes, explaining 75.5% of the cumulative variance. These results suggested an association between vegetation and the measured soil parameters presented in the biplot. The inter-set correlations that resulted from Canonical Correspondence Analysis (CCA) of the examined soil variables were displayed in Table 6.13.

CCA axis 1 was highly positively correlated with chlorides and highly negatively correlated with clay. So this axis can be interpreted as chloride–clay gradient. CCA axis 2 was highly positively correlated with coarse sand and highly negatively with

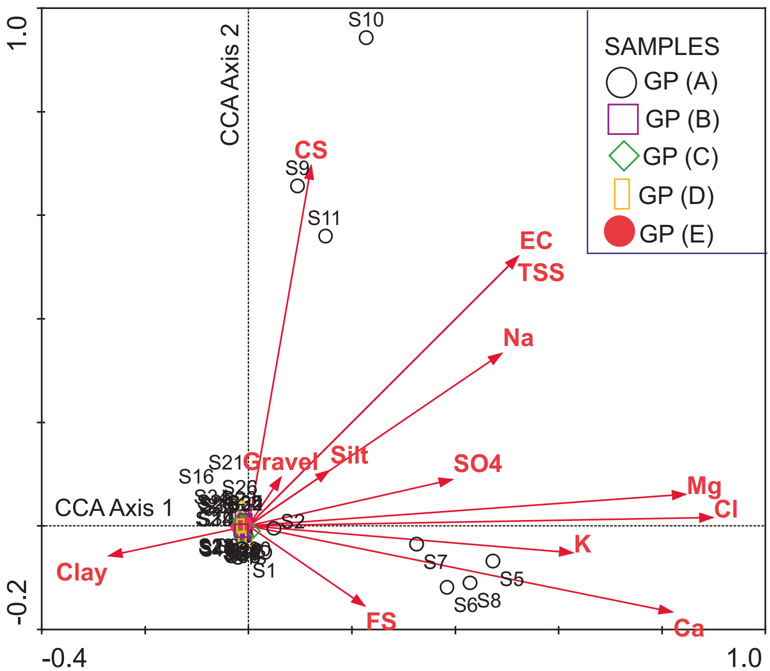

Fig. 6.14 Canonical Correspondence Analysis (CCA) biplot of axes 1 and 2 showing the distribution of the 40 stands of the coastal wadis, together with their vegetation groups and soil variables

Table 6.13 The results of ordination for the four CCA axes, inter-set correlations of the soil variables, together with eigenvalues and species–environment correlation in Wadi Kid

Axes	Ax1	Ax2	Ax3
Eigenvalues	0.930	0.895	0.224
Species—environment correlations	0.988	0.950	0.861
EC	0.5144	0.4936	0.1234
TSS	0.5144	0.4936	0.1235
Gravel	0.0611	0.0883	0.1104
CS	0.1195	0.6597	0.0070
FS	0.2210	−0.1462	−0.0814
Silt	0.1530	0.1005	−0.0005
Clay	−0.2656	−0.0548	0.0401
Na	0.4824	0.3160	−0.0186
K	0.6184	−0.0491	0.3792
Ca	0.8082	−0.1578	0.0883
Mg	0.8337	0.0580	−0.0599
Cl	0.8858	0.0154	−0.1479
SO_4	0.3881	0.0848	0.2263

Table 6.14 Correlation coefficients between soil factors and diversity indices

	Diversity index	
Soil factors	Species richness (SR)	Shannon–Wiener (H′)
EC	−0.500**	−0.667**
TSS	−0.500**	−0.667**
Gravel	−0.094	−0.197
CS	−0.386*	−0.621**
FS	0.015	0.051
Silt	−0.251	−0.369*
Clay	0.258	0.394*
Na	−0.428**	−0.576**
K	−0.424**	−0.469**
Ca	−0.487**	−0.474**
Mg	−0.570**	−.663**
Cl	−0.531**	−0.609**
SO4	−0.638**	−0.677**

*=$p < 0.01$, *=$p < 0.05$

fine sand. Thus, this axis can be interpreted as coarse sand–fine sand gradient. A test for significance with an unrestricted Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be significant ($P = 0.05$).

The results of species diversity (species richness and Shannon–Wiener index) were illustrated in Table 6.14. It was clear that both species richness and Shannon index showed significant differences between the recognized vegetation groups. Regarding the effect of soil variables on the species diversity, both species diversity measures showed high significant positive correlation (0.913) to each other. Species richness (SR) showed significant negative correlations with EC, TSS, CS, Na, K, Ca, Mg, Cl, and SO_4. Shannon–Wiener diversity index showed significant negative correlation with EC, TSS, CS, silt, Na, K, Ca, Mg, Cl, and SO_4 and positively correlated with clay.

Concluding Remarks

1. The natural conditions and geographical position of the Sinai Peninsula make it a very distinctive region. The Sinai Desert is a desert of the "Saharan type" (McGinnies et al. 1968) linking Asia with Africa and constitutes a transition between the Egyptian Deserts and those of the Middle East. It is an interesting phytogeographic area as it borders the Mediterranean, Irano–Turanian, Saharo–Arabian, and Sudanese regions (Zohary 1973). Besides, the great diversity of climate with mean annual precipitation decreases from about 100 mm in the north, near the Mediterranean, to 5–30 mm in the south (Danin 1978); rock and soil types make the existence of some 900 species and 200–300 associations possible (Danin 1986). Whereas in the northern part of the peninsula is covered with sand and in the central part limestone hills and gravel plains predominate, the landscape of the southern region is characterized by a variety of landforms which display varied environmental and vegetation spectra. The major landforms include plains, wadis, oases and springs, salt marshes, and sand dunes. Southern Sinai, however, has an intricate complex of high, very rugged, igneous, and metamorphic mountains that represent the highest peaks in Egypt, among others, Gebel Katherina (2,641 m), Gebel Musa (2,285 m), and Gebel Serbal (2,070 m).
2. 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 forms the major component of the floristic structure where it was represented by more than 50% in both the coastal and the inland wadis. 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 absence of the endemic species in this study 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 the absence

of endemic families. Most of the endemic species in Sinai is confined to the mountain region (El-Hadidi 1967).

3. 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 lead to variation of the distributional behaviour of the plant associations of the study area. In terms of classification, the plant communities that characterize the coastal wadis were substantially differing from those characterizing the inland wadis. The identified five vegetation groups of Wadi Kid (coastal wadis) included (A) *Nitraria retusa–Salvadora persica–Zygophyllum simplex*, (B) *Schouwia purpurea*, (C) *Schouwia purpurea–Zygophyllum coccineum–Zygophyllum simplex*, (D) *Schouwia purpurea–Zygophyllum coccineum*, and (E) *Forsskaolea tenacissima–Iphiona scabra–Schouwia purpurea–Zygophyllum simplex.* Apart from group (A), *Schouwia purpurea* had the highest presence values (90–100%) in the other four vegetation groups.
4. In the Sinai Peninsula, mangrove swamps are absent from the whole stretch of the eastern coast of the Gulf of Suez (as in the western coast). However, at the cap of the Sinai Peninsula where the Suez Gulf meets the Aqaba Gulf at Ras Muhammad, there is a shallow and narrow lagoon extending from the Gulf of Suez landwards. This lagoon provides a suitable site for the growth of mangal vegetation. Zaghloul (1997) conducted a detailed study of Wadi Kid (south Sinai), who distinguished three main parts: the upstream, the mainstream, and the downstream; each has its specific community types that resembled the structure of the identified vegetation groups in this study. However, their records were devoid of *Avicennia marina.* Therefore, the record of this species in Wadi Kid (along the Red Sea coast) in this study can be considered a new site for the distribution range of this species in Egypt. 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. 1990) 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.
5. According to Kassas and Girgis (1964), 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). Further studies on the biogeography and conservation biology of the aforementioned plants in the country are strongly recommended.
6. The present study reveals that stands of group (E) of the lowland channels of Wadi Kid (coastal wadis) that have the lowest salinity levels have the highest species richness (21.2 ± 4.4 species stands^{-1}). This may explain the high contri-

bution of annuals in this group. The highly salinized soil with deep fine sediments (group A) dominated by *Nitraria retusa*, *Salvadora persica*, and *Zygophyllum simplex* has the lowest species richness (4.7 ± 5.4 species stands^{-1}). These results are in line with those of Abd El-Ghani and Amer (2003) in El-Qaa plain of south Sinai. In this study, both species diversity measures showed high significant positive correlation (0.913) to each other. Species richness (SR) showed significant negative correlations with EC, TSS, CS, Na, K, Ca, Mg, Cl, and SO_4. Shannon–Wiener diversity index showed significant negative correlation with EC, TSS, CS, silt, Na, K, Ca, Mg, Cl, and SO_4 and positively correlated with clay.

7. Comparing the floristic compositions in two coastal wadis (Wadi Kid and El-Qaa plain) yielded 55 species in common and 52.6% floristic similarity according to Sørensen coefficient. This relatively high similarity may be related to the comparable soil characters of both landforms. Due to the agricultural practices in El-Qaa plain (Abd El-Ghani and Amer 2003), several weed species were recorded such as *Brachypodium distachyon*, *Cynodon dactylon*, *Malva parviflora*, *Senecio flavus*, *Sonchus oleraceus*, *Spergularia marina*, and *S. diandra*. Other salt-tolerant species were exclusively and/or confined to El-Qaa plain such as *Atriplex halimus*, *Halocnemum strobilaceum*, *Halogeton alopecuroides*, *Halopeplis perfoliata*, *Limonium axillare*, *Suaeda monoica*, and *Tamarix nilotica*. Certain psammo-xerophytic species showed a degree of fidelity to El-Qaa plain and included *Artemisia monosperma*, *Convolvulus hystrix*, *C. lanatus*, *Cornulaca monacantha*, *Salsola tetrandra*, *Traganum nudatum*, and *Zygophyllum dumosum*.
8. The soil–vegetation relationships of the coastal wadis revealed that electric conductivity, total soluble salts, coarse sand, sodium, potassium, calcium, magnesium, and chlorides were the most important soil factors along the first two axes of Canonical Correspondence Analysis (CCA). Whereas gravel, coarse sand, fine sand, silt, clay, sodium, and chlorides were the controlling soil variables along the first two axes of Canonical Correspondence Analysis. This is in accordance with the results in the present study and other relevant works such as those of Yair et al. (1980), El-Ghareeb and Shabana (1990), Abd El-Ghani (1998, 2000b), and Abd El-Ghani and Amer (2003). According to Helmy et al. (1996), who studied the distribution behaviour of seven common shrubs and trees growing in southern Sinai (viz. *Retama raetam*, *Acacia tortilis*, *Moringa peregrina*, *Nitraria retusa*, *Crataegus sinaica*, *Salvadora persica*, and *Lycium shawii*) in relation to physical environmental factors, altitude, nature of soil surface, soil texture and salinity are the most important factors controlling the distribution of woody plant communities in southern Sinai. In the same direction, Mashaly (2006) pointed out that moisture content, sand fraction, sodium cations, electric conductivity, and chloride contents were the most important soil factors controlling the distribution of halophytic species in south Sinai. In this study, while the contents of calcium carbonate, magnesium, calcium cations, total nitrogen, silt, clay fractions, and pH were the most effective soil factors affecting the distribution of xerophytic species. These findings are also in agreement with the results obtained from this study.

6.2.3 *The Isthmic Desert*

The Isthmic Desert is one of the least phytosociologically studied regions and subregions of Egypt. It lies between Sinai proper (S) and the Mediterranean region (Eastern Mediterranean coastal region (Mp) as well as north of Wadi Tumilat) (Täckholm 1974). It occupies the north of Sinai and extends to El-Igma plateau in southern Sinai; El Hadidi and Fayed (1994/1995) excluded the area north of Wadi Tumilat from the traditional concept of Di. The Isthmic Desert and Sinai proper (S) were combined by Boulos (1995) into one phytogeographic region called Entire Sinai (S). Floristic studies of the Isthmic Desert were carried out by many authors (Zohary 1944; Boulos 1960; Gibali 1988, 2000). Taxonomic studies were carried out by Ahmed and Marzouk (1997) and Kenawy (2005), who selected many species from a small area within this desert. Previous vegetation studies in Di included those by Shmida and Orshan (1977) on Gebel El-Maghara and El-Kady and El-Shourbagy (1994) on 70 km of Wadi El-Arish; both works covered limited areas. Using GIS techniques, Marie (2001) provided detailed distribution maps for all the species in the central part of the Isthmic Desert (in central Sinai Peninsula and parts of the Ismailia, Suez, and Sharqia governorates), thus overlooking the eastern reaches of the Isthmic Desert bordering on Palestine. Furthermore, the extensive field data collected by Marie (2001) was neither subjected to critical statistical analysis nor to some of the modern computer programs designed specifically for detection of plant communities (such as TWINSPAN, DECORANA, etc.).

6.2.3.1 Surveyed Area: The Eastern Sector of Central Sinai

The surveyed area lies between latitudes 29° 11′ S–30° 40′ N and longitudes 33° 40′ W–34° 45′ E. The main cities included within the study area were “Nekhel” (lat. 29° 53′ N, long. 33° 45′ E), “Al-Thamad” (lat. 29° 40′ N, long. 34° 18′ E), “Ras An-Naqab” (lat. 29° 37′ N, long. 34°48′ E), “Al-Hasana” (lat. 30° 28′ N, long. 33° 37′ E), “Al-Qasimia” (lat. 30° 40′ N, long. 34° 22′ E), and “Al-Kuntella” (lat. 30° 0′ N, long. 34° 41′ E). A total of 46 georeferenced sites were distributed along the whole area starting from Nekhel and extending in various directions (Fig. 6.15). Plant communities and vegetation analysis were performed along four tracks (unpaved and unaccessible roads): Nekhel–Al-Qasimia, Al-Qasimia–Al-Kuntella, Al-Kuntella–Al-Thama), and Nekhel–Al-Malh), where 19 sites were selected for investigation. The lack of guiding maps and strict security measures hindered the running of more excursions to the study area.

Vegetation Analysis

A total of 109 species belonging to 34 families were recorded from the study area. TWINSPAN was used to classify the 46 sites into five groups (000, 001, 010, 011, and 1) at the third level of classification (Fig. 6.16, Table 6.15).

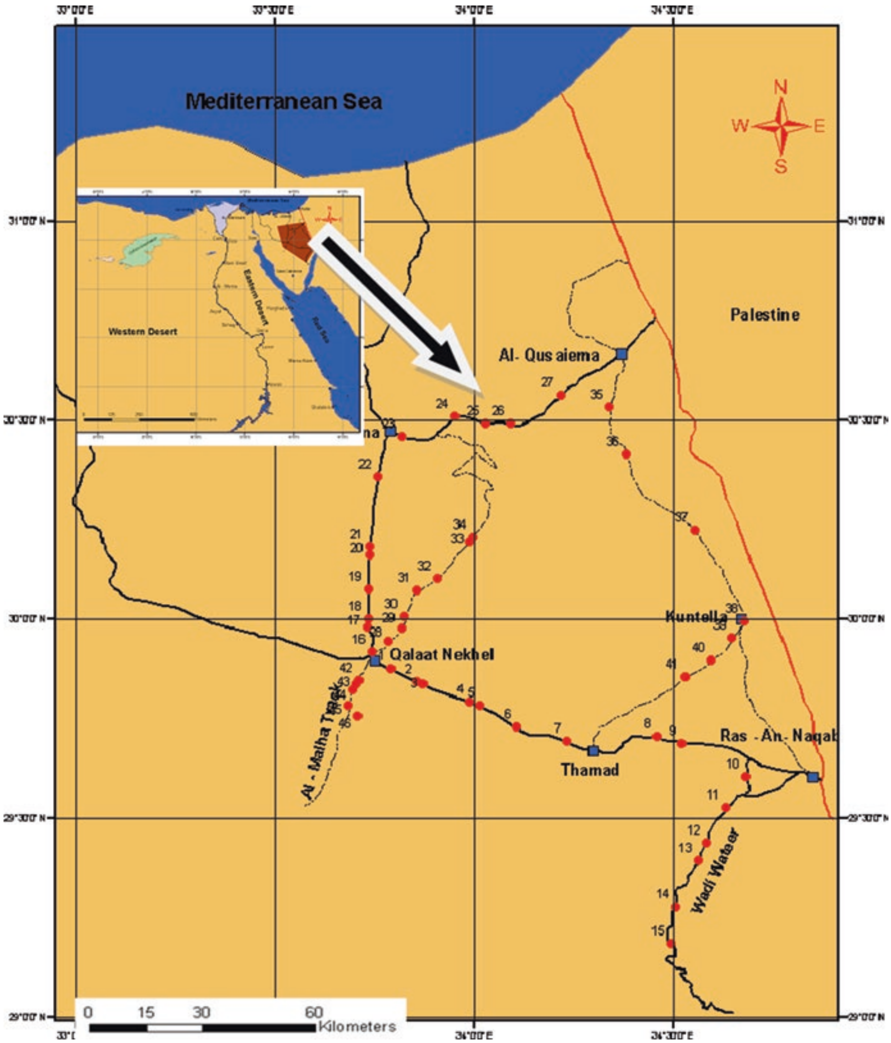

Fig. 6.15 Location map of the 46 studied sites in the Isthmic Desert

Group 000 The dominant species were *Zygophyllum album* and *Tamarix nilotica*. The six sites which represent this group were located in the western sector of the study area. This group was characterized by silt, clay, and fine sand (Table 6.16). Both species and soil factors were highly significant to axis 2 in the positive direction and related to axis 1 in the negative direction except silt and clay. The six sites had the highest importance value to *Z. album* or *T. nilotica*, or at least it had one of them present as a dominant; also referring to the soil variables, sites No. 24, 25, and 28 had the highest content of fine sand in the study area, and also sites No.16, 27, and 29 had high content of silt and clay.

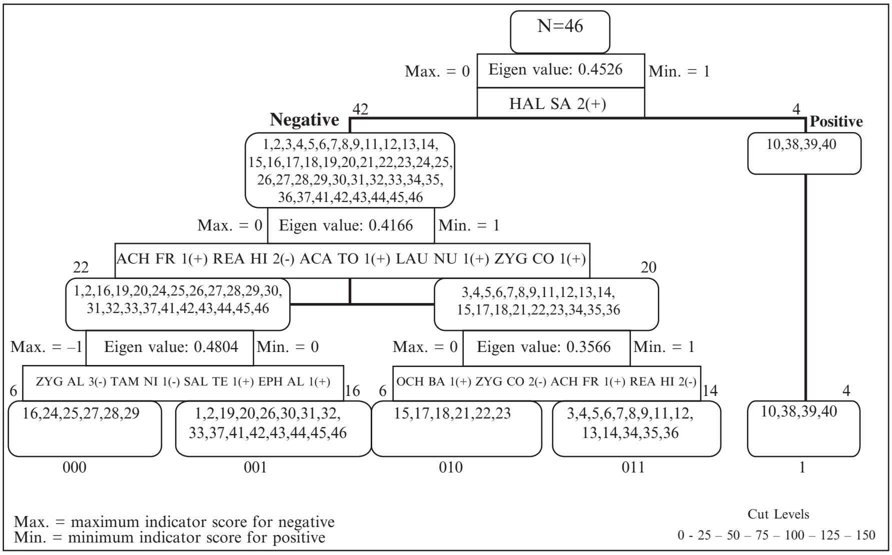

Fig. 6.16 TWINSPAN classification diagram of the 46 sites with their groups

Table 6.15 Constancy classes (I–V) and the mean importance value (IV) within the five TWINSPAN groups rounded to the nearest integer are given for each species

TWINSPAN groups	000	001	010	011	1
Group size	6	16	6	14	4
No. of species	28	46	41	88	16
Zygophyllum album L.f.	108.V	8.I	1.I	–	–
Tamarix nilotica (Ehrenb.) Bunge	54.III	8.I	–	4.I	–
Retama raetam (Forssk.) Webb & Berthel. subsp. *raetam*	44.III	44.III	16.I	51.III	133.V
Reaumuria hirtella Jaub. & Spach var. *palaestina* (Boiss.) Zohary & Danin	28.II	41.III	47.III	14.I	–
Zilla spinosa (L.) Prantl subsp. s*pinosa*	27.II	23.II	29.II	63.IV	13.I
Artemisia monosperma Delile	27.II	8.I	8.I	–	–
Fagonia mollis Delile var. *mollis*	18.I	7.I	15.I	17.I	4.I
Tamarix aphylla (L.) H. Karst.	18.I	–	9.I	5.I	–
Haloxylon scoparium Pomel	13.I	39.II	12.I	8.I	–
Anabasis articulata (Forssk.) Moq.	12.I	52.III	4.I	5.I	5.I
Argemone mexicana L.	6.I	–	–	–	–
Thymelaea hirsuta (L.) Endl.	5.I	–	–	1.I	–
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	4.I	–	–	4.I	133.V
Cornulaca monacantha Delile	4.I	–	–	–	–
Phoenix dactylifera L.	3.I	–	–	–	–
Ochradenus baccatus Delile	3.I	8.I	–	14.I	3.I
Heliotropium digynum (Forssk.) Asch.ex C.Chr.	3.I	–	–	0.I	–
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss. var. *aegyptiacum*	3.I	–	–	–	–
Atriplex leucoclada Boiss. var. *inamoena* (Aellen) Zohary	3.I	27.II	–	11.I	–
Erodium glaucophyllum (L.) L'Hér.	3.I	v	1.I	–	–
Peganum harmala L.	2.I	–	–	5.I	6.I
Pulicaria undulata (L.) C. A. Mey. subsp. *undulata*	2.I	4.I	2.I	5.I	–

Table 6.16 The mean ± standard deviation (SD) of the soil variables for the five vegetation groups of the study area

Soil variables		TWINSPAN groups					Mean ± SD	F-ratio
		000	001	010	011	1		
Gravel		7.88 ± 3.66	22.32 ± 5.23	21.21 ± 6.07	28.35 ± 4.85	8.71 ± 6.88	21.34 ± 2.73	1.967
CS		6.29 ± 2.59	13.52 ± 2.12	17.08 ± 4.72	19.37 ± 2.85	14.12 ± 5.66	14.87 ± 1.49	2.115*
FS		76.52 ± 7.22	56.75 ± 5.12	47.82 ± 6.5	41.74 ± 5.26	64.97 ± 7.62	54.31 ± 3.17	4.123**
Silt	(%)	8.82 ± 2.62	7.03 ± 1.11	10.44 ± 4.15	9.93 ± 2.97	11.76 ± 4.21	9.01 ± 1.20	0.423
Clay		0.49 ± 0.13	0.38 ± 0.10	0.44 ± .091	0.62 ± 0.15	0.43 ± 0.17	0.48 ± 0.06	0.580
Moisture		0.82 ± 0.21	0.82 ± 0.14	1.73 ± 1.1	0.96 ± 0.16	0.92 ± 0.19	1.06 ± 0.16	0.711
OC		0.36 ± 0.04	0.35 ± 0.02	0.37 ± 0.01	0.35 ± 0.01	0.53 ± 0.04	0.37 ± 0.01	5.163**
CO^{-}_{3}		5.70 ±. 0.15	5.83 ± 0.03	5.89 ± 0.02	5.71 ± 0.11	5.85 ± 0.02	5.79 ± 0.04	0.736
Cl		0.10 ± 0.04	0.07 ± 0.01	0.20 ± 0.11	0.06 ± 0.02	0.08 ± 0.01	0.09 ± 0.02	2.192*
TSS ppm		421.6 ± 163.6	373.1 ± 68.6	743.3 ± 328.5	260.7 ± 66.6	277.5 ± 43.9	385.2 ± 58.3	1.782
SO^{-}_{4} ppm		139.9 ± 59.1	199.1 ± 64	167.8 ± 77.4	90.4 ± 27.6	90 ± 46.2	144.7 ± 27.3	0.744
EC (mS cm^{-1})		0.81 ± 0.3 1	0.71 ± 0.13	1.41 ± 0.62	0.50 ± 0.13	0.53 ± 0.08	0.74 ± 0.11	1.771
pH		7.58 ± 0.08	7.70 ± 0.05	7.60 ± 0.01	7.71 ± 0.05	7.72 ± 0.08	7.68 ± 0.03	0.780
Ca^{2+}mg 100 ml^{-1}		5.97 ± 2.48	6.19 ± 1.52	9.38 ± 3.70	4.48 ± 1.24	4.35 ± 0.79	5.90 ± 0.87	0.800
Mg^{2+} mg 100 ml^{-1}		0.72 ± .0.38	0.63 ± 0.18	0.90 ± 0.44	0.31 ± 0.11	0.75 ± 0.13	0.59 ± 0.10	0.938
Na^{+} ml mol^{-1}		5.08 ± 0.99	5.58 ± 0.59	9.68 ± 3.81	4.57 ± 0.50	4.50 ± 0.25	5.65 ± 0.59	2.095*
K^{+} ml mol^{-1}		0.05 ± 0.02	0.91 ± 0.03	0.11 ± 0.05	0.08 ± 0.02	0.30 ± 0.03	0.10 ± 0.02	6.442**

CS Coarse sand, *FS* Fine sand, *TSS* Total soluble salts, *EC* Electric conductivity, *OC* Organic carbon
** = $P < 0.01$, * = $P < 0.1$

Group 001 The dominant species were *Salsola tetrandra* and *Ephedra alata*, and it was characterized by gravel and carbonate content; both species and soil factors had high significance to axis 2 in the negative direction; also it was related to axis 1 in the negative direction except gravel. However carbonate content is related to axis 1 in the negative direction; it was in the borderline to positive direction. This result revealed that the carbonate content was an insignificant factor. The 16 sites either have the highest importance value to *S. tetrandra* or *E. alata* or at least the site had one of them present. Soil variables play a role in the distribution of sites on the graph ordination as of site 1 which has low carbonate content, and also it has *Zygophyllum album* as a dominant species so it appears near the group 000 in the graph which is characterized by *Z. album*.

Group 010 The dominant species were *Reaumuria hirtella* and *Zygophyllum coccineum*. Soil variables in this group play a role in the site distribution but individually. *Z. coccineum* is related to axis 1 and axis 2 in the positive direction, but it is more related to axis 2; however *R. hirtella* is related to axis 1 and axis 2 in the negative direction but it is more related to axis 1. The six sites either had the highest importance value to *R. hirtella* or *Z. coccineum* or at least the site had one of them. The six sites which represent the group were site No. 15 (Ra's An-Naqab-Wadi Wateer road), sites No. 17–18 and 21–22 (Nekhel-Al-Hasana road), and site No.23 (Al-Hasana–Al-Qasimia road). All of the sites were related to the west side except site No.15.

Group 011 The dominant species were mainly *Achillea fragrantissima*, *Ochradenus baccatus*, and *Zygophyllum coccineum*. Soil variables in this group play a role in the sites distribution but individually. *A. fragrantissima*, *O. baccatus*, and *Z. coccineum* were related to axis 1 in the positive direction and axis 2 in the negative direction except *Z. coccineum* (Fig. 6.17). The distribution of sites was depending on the presence of *A. fragrantissima*, *O. baccatus*, and Z. *coccineum* or at least the presence of one of them.

Group 1 The dominant species were *Haloxylon salicornicum* and *Retama raetam* with the highest values of K+ and OC; both species and soil factors had the highest significance value in the positive direction with axis 1. *H. salicornicum* and *R. raetam* had the highest importance values in the four sites of this group. *H. salicornicum*, *R. raetam*, K+, and OC were related to axis 2 in the positive direction (Fig. 6.17, Table 6.17).

Results of constancy classes showed the five groups of TWINSPAN and the efficacy of each species within each group (Table 6.15) according to the mean importance value (MIV) of each species within the group. *Zygophyllum album* (MIV = 108.V) is followed by *Tamarix nilotica* (MIV = 54.III) and *Retama raetam* (MIV = 44.III) as the most effective species in the group 000. In group 001, the most effective species were *Anabasis articulata* (MIV = 52.III) followed by *Retama raetam* (MIV = 44.III) and *Reaumuria hirtella* (MIV = 41.III). Group 010 results showed that the most effective species were *Zygophyllum coccineum* (MIV = 108.V) followed by *Reaumuria hirtella* (MIV = 47.III). Group 011 results revealed that the most effective species were *Zilla spinosa* (MIV = 63.IV) and *Retama raetam*

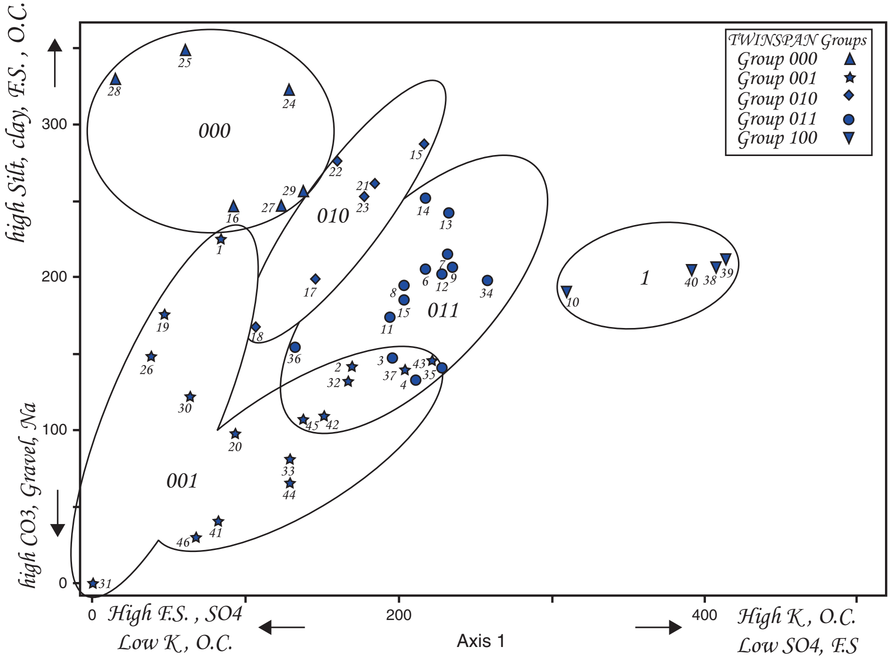

Fig. 6.17 DCA scatterplot of the studied 19 sites, together with their TWINSPAN groups

Table 6.17 Pearson's (r) correlations of the soil variables with ordination axes of DCA. For abbreviations and units, see Table 6.16

Soil variables	Axis 1	Axis 2	Axis 3
Gravel	0.039	–0.187	0.134
CS	0.175	–0.084	0.113
FS	–0.178	0.132	–0.164
Silt	0.164	0.173	–0.009
Clay	0.043	0.143	–0.046
Moisture	–0.044	–0.04	-0.031
TSS	–0.165	–0.023	0.126
EC	–0.165	–0.024	0.125
pH	0.366	–0.072	-0.139
OC	0.414	0.101	0.192
CO_3^-	–0.003	–0.199	0.174
Cl^-	–0.09	0.011	0.161
SO_4^-	–0.23	–0.078	–0.039
Ca^{2+}	–0.15	0.006	0.061
Mg^{2+}	–0.074	–0.035	–0.032
Na^+	–0.157	–0.14	0.162
K^+	0.454	0.007	–0.046

(MIV = 51.III). Group 1 results showed that the most effective species were *Retama raetam* (MIV = 133.V) and *Haloxylon salicornicum* (MIV = 133.V), followed by *Acacia tortilis* subsp. *raddiana* (MIV = 32.II). From these results, *Retama raetam* seemed to be the most effective species along the whole area, as it was present as dominant or co-dominant in four groups out of five groups (Table 6.15).

Appendix

Species list and their habitats recorded in Feiran Oasis. The taxa preceded by an (*) are recorded for the first time in Feiran Oasis. B1 = around the water whole, B2 = the reservoir, B3 = the crop fields, and B4 = the orchards.

Dicotyledons

Amaranthaceae

**Aerva javanica* (Burm.f.) Juss. ex Schult.

Habitat: B3 and B4; April 1995 and Oct. 1996.

Distribution: N and tropical Africa, SW Asia to India.

**Amaranthus graecizans* L.

Habitat: B3 and B4; April 1995 and Oct. 1996.

Distribution: S Europe, Central Asia, to Arabia.

**Amaranthus lividus* L.

Habitat: B4; Oct. 1996.

Distribution: Eurasia, N and tropical Africa.

Apiaceae

Ammi majus L.

Habitat: occasional in B3 and B4; April 1995.

Distribution: Mediterranean region.

Asclepiadaceae

**Calotropis procera* (Ait.) W.T. Aiton

Habitat: B4; Oct. 1996.

Distribution: E Africa extending through Egypt and Arabia to India.

**Cynanchum acutum* L.

Habitat: B4; Oct. 1996.

Distribution: S Europe, N Africa, Middle East to India.

Asteraceae

Artemisia herba-alba Asso

Habitat: B4; April 1995 and Oct. 1996.

Distribution: W Irano–Turanian region.

**Bidens pilosa* L.

Habitat: B4; Oct. 1996.

Distribution: native to S America, naturalized in SW Europe, introduced into N Africa.

Conyza bonariensis (L.) Cronquist

Habitat: B3 and B4; April 1995 and Oct. 1996.

Distribution: native to S America, naturalized in almost throughout the world.
**Sonchus oleraceus* L.
Habitat: B3 and B4; April 1995 and Oct. 1996.
Distribution: Cosmopolitan.
Brassicaceae
Erucaria hispanica (L.) Druce
Habitat: B4; April 1995.
Distribution: SE Europe, N Africa, Middle East to W and C Asia.
Sisymbrium irio L.
Habitat: B4; April 1995 and Oct. 1996.
Distribution: S Europe, N Africa, Middle East to India, N America, and Australia.
Sisymbrium orientale L.
Habitat: occasional in B4; April 1995 and Oct. 1996.
Distribution: Mediterranean extended to the Irano–Turanian region.
Zilla spinosa (L.) Prantl.
Habitat: invading B4; April 1995 and Oct. 1996.
Distribution: N Africa, Middle East to Arabia.
Caryophyllaceae
Silene nocturna L.
Habitat: B3 and B4; Oct. 1996.
Distribution: Mediterranean and introduced elsewhere.
Spergularia marina (L.) Griseb.
Habitat: B1 and B3; Oct. 1996.
Distribution: Cosmopolitan.
Chenopodiaceae
**Bassia muricata* (L.) Asch.
Habitat: B4; Oct. 1996.
Distribution: Saharo–Arabian region.**Chenopodium album* L.
Habitat: B3 and B4; Oct. 1996.
Distribution: Cosmopolitan.
Chenopodium murale L.
Habitat: B3 and B4; April 1995 and Oct. 1996.
Distribution: Cosmopolitan.
Suaeda aegyptiaca (Hasselq.) Zohary
Habitat: B4; Oct. 1996.
Distribution: Saharo–Arabian region.
Cleomaceae
**Cleome chrysantha* Decne.
Habitat: B4; Oct. 1996.
Distribution: N and tropical Africa to Arabia and Iran.
Convolvulaceae
Convolvulus arvensis L.
Habitat: B3 and B4; April 1995 and Oct. 1996.
Distribution: Cosmopolitan.

**Cuscuta planiflora* Ten.
Habitat: occasional in B3 and in B4; Oct. 1996.
Distribution: mainly S Mediterranean extended to N Africa and Arabia.
Cucurbitaceae
**Cucumis prophetarum* L. subsp. *prophetarum*
Habitat: B4; April 1995 and Oct. 1996.
Distribution: Senegal eastwards in the desert regions to Pakistan and India.
Euphorbiaceae
* *Chrozophora brocchiana* Vis.
Habitat: occasional in B3 and in B4; Oct. 1996.
Distribution: Central and Southern Sahara.
Chrozophora tinctoria (L.) Raf.
Habitat: B4; Oct. 1996.
Distribution: Mediterranean, N Africa, Middle East to India.
**Euphorbia heterophylla* L.
Habitat: B4; Oct. 1996.
Distribution: Pantropical, originating from C America.
Euphorbia peplus L.
Habitat: B3 and B4; April 1995 and Oct. 1996.
Distribution: Cosmopolitan.
Fabaceae
Alhagi graecorum Boiss.
Habitat: B2, B3, and B4; April 1995 and Oct. 1996.
Distribution: S Mediterranean, N Africa, Middle East to S Iran.
Lotus creticus L.
Habitat: B3 and B4; April 1995.
Distribution: widespread throughout the Mediterranean region.
Melilotus indicus (L.) All.
Habitat: B3 and B4; April 1995 and Oct. 1996.
Distribution: Mediterranean region.
Lamiaceae
Mentha longifolia (L.) Huds. subsp. *typhoides* (Briq.) Harley
Habitat: B2 (new wells), B3, and B4; April 1995 and Oct. 1996.
Distribution: most of Europe to north and tropical parts of the world.
Malvaceae
**Malva parviflora* L.
Habitat: occasional in B3 and in B4; April 1995 and Oct. 1996.
Distribution: SW Mediterranean, N and tropical Africa to E and Central Asia.
Orobanchaceae
**Orobanche cernua* Loefl.
Habitat: B3 and occasional in B4; Oct. 1996.
Distribution: S Europe, N Africa extended eastwards to Pakistan.
Oxalidaceae

**Oxalis corniculata* L.
Habitat: B4; April 1995 and Oct. 1996.
Distribution: Cosmopolitan.
Portulacaceae
Portulaca oleracea L.
Habitat: B3 and occasional in B4; April 1995 and Oct. 1996.
Distribution: Cosmopolitan.
Primulaceae
Anagallis arvensis L.
Habitat: B3 and B4; April 1995.
Distribution: Cosmopolitan.
Resedaceae
**Caylusea hexagyna* (Forssk.) M.L. Green
Habitat: B4; Oct. 1996.
Distribution: E Africa to Arabia.
**Ochradenus baccatus* Delile
Habitat: B4; April 1995 and Oct. 1996.
Distribution: N and tropical Africa eastwards to Iran and Pakistan.
Rhamnaceae
Ziziphus spina-christi L.
Habitat: B1; April 1995 and Oct. 1996.
Distribution: native of tropical Africa, introduced and cultivated elsewhere.
Solanaceae
**Hyoscyamus muticus* L.
Habitat: B4; April 1995 and Oct. 1996.
Distribution: N and tropical Africa to Arabia and NW India.
**Solanum nigrum* L.
Habitat: B3 and B4; April 1995.
Distribution: Cosmopolitan.
Withania somnifera (L.) Dunal
Habitat: B4; Oct. 1996.
Distribution: N and E Africa to India through Arabia.
Tamaricaceae
**Tamarix aphylla* (L.) Karst.
Habitat: occasional in B1 and B4; April 1995 and Oct. 1996.
Distribution: Saharo–Arabian region extended to Irano–Turanian and Sudano–Zambezian regions.
Tamarix nilotica (Ehrenb.) Bunge
Habitat: B1, occasional in B3 and B4; April 1995 and Oct. 1996.
Distribution: N Africa, E Mediterranean extending to E and S Arabian region.
Urticaceae
**Forsskaolea tenacissima* L.
Habitat: invading B4; Oct. 1996.
Distribution: North Africa to India and Pakistan through Arabia.

Zygophyllaceae
Peganum harmala L.
Habitat: B4; Oct. 1996.
Distribution: Mediterranean region, SW Asia, N America to Australia.
Tribulus terrestris L.
Habitat: B4; Oct. 1996.
Distribution: S Europe, N Africa to Middle East and India.
**Zygophyllum simplex* L.
Habitat: B4; April 1995 and Oct. 1996.
Distribution: N and tropical Africa to S and W Asia.
Monocotyledons
Cyperaceae
**Cyperus rotundus* L.
Habitat: B1, B2 (new wells), and B3; April 1995 and Oct. 1996.
Distribution: Pantropical, subtropical in arid regions.
Poaceae
Avena sterilis L.
Habitat: B4; April 1995.
Distribution: Mediterranean region to Arabia.
Brachypodium distachyon (L.) P. Beauv.
Habitat: B4; April 1995 and Oct. 1996.
Distribution: Mediterranean region, SW and Central Asia.
Cynodon dactylon (L.) Pers.
Habitat: B1, B2 (new wells), B3, and B4; April 1995 and Oct. 1996.
Distribution: Pantropical.
**Dactyloctenium aegyptium* (L.) Willd.
Habitat: B2 (new wells), B3, and occasional in B4; Oct. 1996.
Distribution: NE Africa to NW India.
**Digitaria sanguinalis* (L.) Scop.
Habitat: B3 and 4; April 1995 and Oct. 1996.
Distribution: warm temperate regions.
Echinochloa colona (L.) Link
Habitat: B2 (new wells), B3, and B4; Oct. 1996.
Distribution: tropical and subtropical areas.
**Eragrostis pilosa* (L.) P. Beauv.
Habitat: B4; Oct. 1996.
Distribution: throughout tropical and warm temperate Old World.
Hordeum murinum L. subsp. *leporinum* (Link) Acrang
Habitat: occasional in B3 and in B4; Oct. 1996.
Distribution: Mediterranean region, Middle East to NW India, N America, and Australia.
**Imperata cylindrica* (L.) Raeusch.
Habitat: B2 (new wells), B3, occasional in B4; April 1995 and Oct. 1996.
Distribution: Mediterranean and tropical regions.

Lolium rigidum (L.) Goudin
Habitat: B3; April 1995.
Distribution: Mediterranean region, Middle East to Central Asia.
**Oryzopsis miliacea* (L.) Asch. & Schweinf.
Habitat: B4; April 1995 and Oct. 1996.
Distribution: S Europe to Middle East.
Panicum repens L.
Habitat: occasional in B1 and in B3; Oct. 1996.
Distribution: tropical Africa to Arabia.
**Panicum turgidum* Forssk.
Habitat: invading B4; April 1995 and Oct. 1996.
Distribution: N and NE Africa to SW Asia.
**Phalaris minor* Retz.
Habitat: B3; Oct. 1996.
Distribution: Mediterranean region to SW Asia.
Phragmites australis (Cav.) Trin. ex Steud.
Habitat: B1, B2 (new wells), occasional in B3 and B4; April 1995 and Oct. 1996.
Distribution: circum-Mediterranean, Arabia, Iran, Senegal to Kenya.
Polypogon monspeliensis (L.) Desf.
Habitat: B3 and B4; April 1995 and Oct. 1996.
Distribution: Mediterranean region to NW India through Arabia.
Polypogon viridis (Gouan) Breistr.
Habitat: B3 and B4; April 1995 and Oct. 1996.
Distribution: Mediterranean and Central Asia, East Africa; introduced into many temperate regions of the world.
Schismus barbatus (L.) Thell.
Habitat: occasional in B4; April 1995.
Distribution: Mediterranean region to N and E India, introduced to many parts of the world.
Setaria verticillata (L.) P. Beauv.
Habitat: occasional in B3 and B4; April 1995 and Oct. 1996.
Distribution: Cosmopolitan.
**Stipagrostis plumosa* (L.) Munro ex T. Anderson
Habitat: occasional in B3; April 1995 and Oct. 1996.
Distribution: Mediterranean region to SW Asia.

Photo Gallery

Photo 6.1 Part of the coastal vegetation in Sharm El-Sheikh (south Sinai), showing hillocks of *Limoniastrum monopetalum* (June 19, 2010)

Photo 6.2 A mangrove of *Avicennia marina* at Sharm El-Sheikh (south Sinai, June 19, 2010)

Photo 6.3 The desert vegetation of Wadi Al-Akhdar (south Sinai, June 23, 2010), showing the dominance of *Haloxylon salicornicum*

Photo 6.4 Part of Wadi Al-Akhdar (south Sinai, June 23, 2010), showing a stand dominated with *Zilla spinosa*

Photo 6.5 *Citrullus colocynthis* and *Haloxylon salicornicum* forming the desert vegetation in Wadi el-Sheikh (south Sinai, June 21, 2010)

Photo 6.6 Hillocks of *Salvadora persica* growing in the vicinity of Sharm El-Sheikh (south Sinai, June 19, 2010)

Photo 6.7 Part of Wadi Feiran (Feiran Oasis) in south Sinai, showing the flourishing date palm orchards (May 1998)

Photo 6.8 The date palm orchards of Wadi Feiran (Feiran Oasis) in south Sinai suffering from severe drought conditions due to loss of water (April 2010)

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Chapter 7
Human Impacts

Abstract Urbanization, land reclamation, and road construction are the major human impacts on the desert ecosystem. These man-made habitats represent species-rich environments due to habitat heterogeneity and diverse disturbances. New urban industrial cities were examined in terms of their synanthropic vegetation in the distinguished five main habitats (from inner city towards surroundings): lawns, home gardens, public gardens, waste lands, and desert outskirts. The soil–vegetation relationships in each of the recognized habitat were investigated. Distribution patterns of weed species in the cultivations of desert-reclaimed lands along the northern sector of the Nile Valley were studied. The weed flora of that sector was compared to other relevant studies in adjacent desert-reclaimed lands. The application of redundancy analysis (RDA) demonstrated the effect of edaphic factors on the spatial distribution of weed communities revealed that soil organic matter, coarse sand, fine sand, silt, and soil saturation point were of significant variations among the separated vegetation (site) groups. Vegetation analysis and species composition and chorological affinities along desert roads in the Eastern Desert using multivariate techniques were demonstrated. The allocation of each of the separated vegetation groups was displayed on the studied roads.

7.1 General

Desert ecosystems of the world have in recent times been subjected increasingly to untested contacts with humans and their characteristic activities. Within the past 60 years, there has been heavy use of desert scrub communities for land reclamation, recreational purposes, and different construction projects. All have modified the physical characteristics of soil and altered the composition of desert scrub vegetation and changing floristic composition. Human impact was recognized as the most important influence on the composition of the flora and vegetation. This impact had a dominant environmental factor in the arid environments of the world, particularly in the Middle East for thousands of years (Zohary 1983).

Urbanization produces fundamental changes in the desert ecosystem. These changes include vegetation removal, construction of infrastructure (roads and utility

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rights-of-ways, etc.), introduction of exotic flora and fauna species, stabilization of stream channels, increased human presence, and changes in disturbance regimes. Disruption of natural disturbance regimes by conversion of desert ecosystem to urban habitats and stabilization of channel banks can lead to changes within remnant habitat patches (Pickett and White 1985; Brown 1991). Urbanization imposes a different hydrologic regime on channels and riparian systems relative to pre-urbanization condition. Changes in hydrologic regime due to human activities have been correlated to changes plant species, sediment routing, and channel form (Ehrenfeld 2000; Inoue and Nakagoshi 2001).

Roads traversing the desert, paved and/or unpaved, are water harvesting systems that redistribute rainwater from the road surface to its edges, and this runoff pattern produces an "edge effect", wherein a very lush strip of vegetation forms along the road edge (Frenkel 1970; Johnson et al. 1975). Johnson et al. (1975) compared road edge vegetation with that of adjacent control desert shrub and concluded that all measures of productivity were much higher for roadside perennials for an unpaved road; edges had higher density, greater percent ground cover, and greater aboveground biomass due especially to development of larger, fuller shrub canopies.

Land reclamation. For a very arid country like Egypt, the prime factor which makes land productive is water. Fortified by increased and more reliable water availability that was made possible by the construction of the high dam (in Aswan) and assisted by technological development, it has been possible both to intensify cultivation in the old lands and to expand agricultural activities in the new areas by reclaiming deserts (Biswas 1993). Land reclamation in the Egyptian context means converting desert areas to agricultural land and rural settlements. This is done primarily by "adding water", i.e. by extending the water canals from existing agricultural land into the desert, but also by working with the soil, by ploughing in manure in order to enhance its fertility, and finally by providing the infrastructure for making new villages. The principal purpose was and still is to increase agricultural production through horizontal expansion and "overcome Egypt's overwhelmingly unfavourable population to land ratio" (Springborg 1979). Since the early 1960s, vast areas in the Egyptian deserts (western, eastern, and Sinai) were subjected to land reclamation, private and government schemes (Soliman 1989). Land reclamation of desert plains took place along the Nile region, around Kom Ombo near Aswan (New Nubia Project), and on both sides of the Nile Delta (Tahrir and Nubariya Projects to the west and Salhiya Project to the east). Not surprisingly, 61% of the priority reclaimable land through the Nile waters is located on the fringes of the Delta region. In parts of these areas, where soil is loamy in nature, wheat can be cultivated relatively successfully (Biswas 1993).

Man-made habitats, as in reclaimed desert lands, represent species-rich environments (Wittig 2002) due to habitat heterogeneity, frequent and diverse disturbances creating mosaics of different successional stages, and immigration of alien species (Pyšek et al. 2002). This human interference causes the weedy species to replace the wild plant species in these reclaimed areas (Baessler and Klotz 2006), which are considered as transitional habitats between the old cultivated land and desert. The invasive species in the new agricultural lands cause serious problems that require attention to be paid to the negative impacts of plant invasions on ecosystems and gene pools

(Hegazy et al. 1999). Arable land is not only disturbed with varying frequency, intensity, and predictability but has been directly created by disturbance associated with agriculture since the Neolithic period (Holzner and Immonen 1982). Disturbance can be described in terms of crop management but is difficult to quantify as it may interact with environmental factors (Pyšek and Lepš 1991; Dale et al. 1992; Salonen 1993; Erviö et al. 1994; Andersson and Milberg 1998; Hallgren et al. 1999).

7.2 Desert Urbanization

7.2.1 Surveyed Areas

7.2.1.1 New Urban–Industrial Cities

In Egypt, the new cities are considered the natural extension of different governorates. The essential purpose for the establishment of these cities is the creation of new civilized centres, achieving community stability and economic prosperity, redistribution of population far from Nile Delta narrow strip, establishment of new attraction areas outside the existing cities and villages, and curbing the urban infringement upon cultivated areas. No investigation took place in the satellite cities around Cairo, which are still growing and exhibit very special conditions. In order to fill this gap of knowledge, the present study was conducted in four, new, mainly industrial cities: 6th of October, El-Sadat, Burg El-Arab, and 10th of Ramadan (Fig. 7.1).

According to Shata and El-Fayoumy (1967), the northern part of the Western Desert can be distinguished into the following physiographic provinces (Fig. 7.2): Edku–Mariut coastal plain, Nile Delta flood plain, El-Tahrir gravelly plain, Mariut table land, and Abu Roash–El-Heneishat structural plains. Table 7.1 summarizes the general information and climatic features of the studied cities.

Fig. 7.1 Location map showing the four studied cities (·): 6th October, El-Sadat, Burg El-Arab, and 10th Ramadan

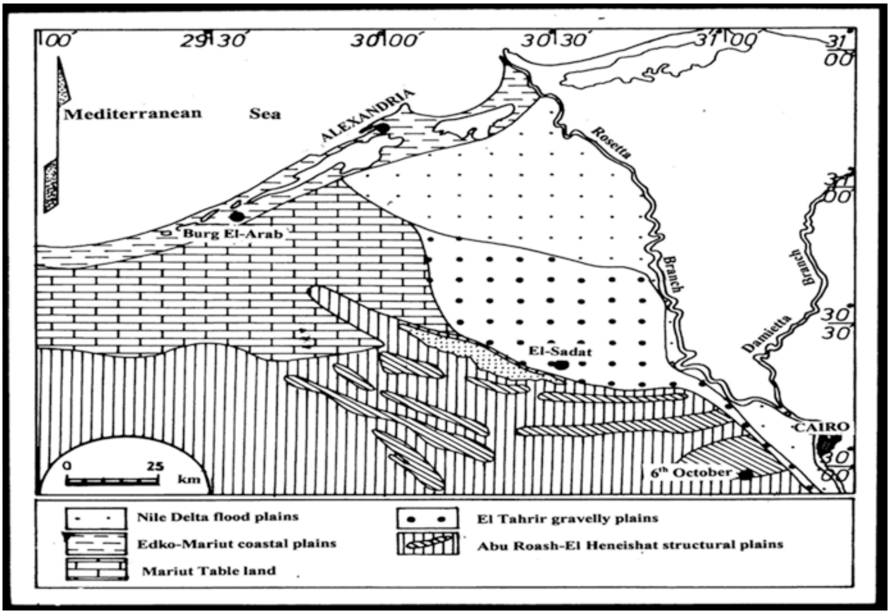

Fig. 7.2 Physiographic provinces of the area west of the Nile Delta of Egypt where 6th October, El-Sadat, and Burg El-Arab cities are located (After Shata and El-Fayoumy 1967)

Spatial Distribution of Species Within Cities

Altogether, 305 species of the vascular plants constituted the main synanthropic flora in the present investigation, and the total number of species varied among the studied cities: 171 in Burg El-Arab, 157 in 10th Ramadan, 144 in Sadat, and 132 in 6th October (Table 7.2).

Generally, 45 ubiquitous species were recorded in the four cities (e.g. *Cynodon dactylon*, *Cenchrus ciliaris*, *Malva parviflora*, *Sonchus oleraceus*, *Portulaca oleracea*, and *Conyza bonariensis*). On the other hand, each city was characterized by a certain number of species (preferential or characteristic) that are not recorded in others. Twenty-three species were confined to 6th October city (e.g. *Stipagrostis hirtigluma*, *Monsonia nivea*, *Trianthema triquetra*, *Malva sylvestris*, and *Cutandia dichotoma*), 24 in Sadat (e.g. *Artemisia monosperma*, *Haplophyllum tuberculatum*, *Convolvulus hystrix*, *Epilobium hirsutum*, and *Cuscuta pedicellata*), 73 in Burg El-Arab (e.g. *Suaeda vermiculata*, *Thymelaea hirsuta*, *Centaurea alexandrina*, *Enarthrocarpus strangulates*, and *Erucaria microcarpa*), and 30 in 10th Ramadan (e.g. *Pergularia tomentosa*, *Forsskaolea tenacissima*, *Retama raetam*, *Silene rubella*, and *Citrullus colocynthis*). The largest families that formed the main bulk of the recorded flora were Poaceae, Asteraceae, Fabaceae, and Chenopodiaceae, followed by Euphorbiaceae, Brassicaceae, Cyperaceae, Apiacee, and Solanaceae (Table 7.3). The contribution of annual species to the total number of species was remarkable, where they dominated (more than 50% of the total flora) the floristic

Table 7.1 Summary of general information and climatic features of the study cities

	General information of study areas					Climatic features (means 2000–2006)			
City	Year of establishment	Total area (acre)	Built-up area (acre)	Inhabitants	Distance from Cairo (km)	Temperature (°C)	Rainfall (mm)	Relative humidity (%)	Evaporation (mm day^{-1})
6th October	1979	86,400	66,700	250,0000	32	22.4	9.4	51.7	4.7
Sadat	1977	119,000	23,000	750,000	93	21.6	26.0	74.9	4.8
Burg El-Arab	1979	47,400	26,000	570,000	200	21.3	165.5	77.0	4.1
10th Ramadan	1977	95,000	23,000	500,000	46	23.7	40.1	60.3	4.6

Table 7.2 Preferential synanthropic species with their presence values (*P%*) recorded in only one city, together with those occurring in all studied cities
Oct **6th October,** *Sad* **Sadat,** *Burg* **Burg El-Arab,** *Ram* **10th Ramadan**

Species	Oct	Sad	Burg	Ram
Stipagrostis hirtigluma (Steu.ex Trin &Rupr.) De Winter	12.2			
Chloris virgata Sw.	10.2			
Monsonia nivea (Decne.) Webb	10.2			
Sorghum halepense (L.) Pers.	6.1			
Cornulaca monacantha Delile	4.1			
Launaea fragilis (Asso) Pau	4.1			
Trianthema triquetra Willd.	4.1			
Citrullus vulgaris L.	2			
Coronopus squamatus (Forssk.) Asch.	2			
Cutandia dichotoma (Forssk.) Batt. & Trab.	2			
Hibiscus esculentus L.	2			
Ifloga spicata (Forssk.) Sch. Bip.	2			
Launaea spinosa (Forssk.) Sch. Bip. ex Kuntze	2			
Linum usitatissimum L.	2			
Lycopersicon lycopersicum (L.) Karst. ex Farw.	2			
Malva sylvestris L.	2			
Mentha piperita L.	2			
Neurada procumbens L.	2			
Paspalidium geminatum (Forssk.) Stapf	2			
Spergularia marina (L.) Bessler	2			
Stipagrostis scoparia (Trin. & Rupr.) De Winter	2			
Traganum nudatum Delile	2			
7Triticum aestivum L.	2			
Artemisia monosperma Delile		29.7		
Helianthemum lippii (L.) Dum. Cours.		13.5		
Haplophyllum tuberculatum (Forssk.) Juss.		10.8		
Astragalus spinosus (Forssk.) Muschl.		8.1		

Convolvulus hystrix Vahl	5.4	
Eucalyptus camaldulensis Dehnh.	5.4	
Setaria viridis (L.) P. Beauv.	5.4	
Trianthema portulacastrum L.	5.4	
Allium cepa L.	2.7	
Bolboschoenus glaucus (Lam.) S.G.Smith	2.7	
Cassia fistula L.	2.7	
Caylusea hexagyna (Forssk.) M. L. Green	2.7	
Clerodendrum acerbianum (Vis.) Benth & Hook. f.	2.7	
Cuscuta pedicellata Ledeb.	2.7	
Epilobium hirsutum L.	2.7	
Euphorbia forsskaolii J. Gay	2.7	
Euphorbia indica Lam.	2.7	
Lotus hebranicus Hochst. ex Brand	2.7	
Morus alba L.	2.7	
Plantago notata Lag.	2.7	
Sida alba L.	2.7	
Urtica urens L.	2.7	
Vitex agnus-custus L.	2.7	
Zygophyllum aegyptium Hosny	2.7	
Suaeda vermiculata Forssk. ex. J. F.Gmel.		40
Atriplex lindleyi Moq. subsp. *inflata* (F.Mull.) P.G.Wilson		26.7
Atriplx halimus L.		24.4
Eryngium creticum Lam.		24.4
Thymelaea hirsuta (L.) Endl.		24.4
Echium angustifolium Mill.		20
Centaurea alexandrina Delile		17.8
Nicotiana glauca R.C. Graham		17.8
Achillea santolina L.		13.3
Asphodelus aestivus Bort.		13.3
Brassica tournefortii Gouan		13.3
Calendula arvensis L.		11.1

(continued)

Table 7.2 (continued)

Fagonia cretica L.		11.1	
Ficus elastica Roxb.ex Hornem.var. *decora*		11.1	
Salsola kali L.		11.1	
Silybum marianum (L.) Gaertn.		11.1	
Xanthium spinosum L.		11.1	
Emex spinosa (L.) Campd.		8.9	
Linaria albifrons (Sm.) Spreng.		8.9	
Lycium europaeum L.		8.9	
Phagnalon rupestre (L.) DC.		8.9	
Arisarum vulgare Targ.Tozz.		6.7	
Chiliadenus montanus (Vahl) Brullo		6.7	
Convolvulus althaeoides L.var. *pedatus* Choisy		6.7	
Enarthrocarpus strangulatus Boiss.		6.7	
Filago desertorum Pomel		6.7	
Globularia arabica Jaub. & Spach.		6.7	
Herniaria hemistemon J.Gay.		6.7	
Marrubium alysson L.		6.7	
Noaea mucronata (Forssk.) Asch. & Schweinf.		6.7	
Peganum harmala L.		6.7	
Phyla nodiflora (L.) Greene		6.7	
Polygonum equisetiforme Sm.		6.7	
Rostraria cristata (L.) Tzvelev		6.7	
Thymus capitatus (L.) Link		6.7	
Trifolium repens L.		6.7	
Adonis dentata Delile		4.4	
Arnebia decumbens (Vent.) Coss. & Kralik		4.4	
Atriplex leucoclada Boiss.		4.4	
Centaurea glomerata Vahl		4.4	
Cynara cornigera Lindl.		4.4	
Eleusine indica (L.) Gaertn.		4.4	
Juncus rigidus Desf.		4.4	
Parapholis incurva (L.) C.E.Hubb.		4.4	

Plantago crypsoides Boiss.		4.4	
Salvia lanigera Poir.		4.4	
Vicia monantha Retz.		4.4	
Vicia sativa L.		4.4	
Xanthium strumarium L.		4.4	
Acacia saligna (Labill.) H.Wendl.		2.2	
Astragalus caprinus L.		2.2	
Atriplex dimorphostegia Kar. &Kir.		2.2	
Brachypodium distachyum (L.) P. Beauv.		2.2	
Ceratonia siliqua L.		2.2	
Chenopodium glaucum L.		2.2	
Crepis micrantha Czerep		2.2	
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.		2.2	
Erodium laciniatum (Cav.) Willd.		2.2	
Erucaria microcarpa Boiss.		2.2	
Hedypnois rhagadioloides (L.) F.W.Schmidt		2.2	
Helianthus annus L.		2.2	
Iphiona scabra DC.		2.2	
Leopoldia comosa (L.) Parl.		2.2	
Ludwigia stolonifera (Guill. & Perr.) P.H.Raven		2.2	
Medicago laciniata (L.) Mill.		2.2	
Onopordum alexandrinum Boiss.		2.2	
Pennisetum glaucum (L.) R. Br.		2.2	
Picris longirostris Sch.Bip.		2.2	
Plantago albicans L.		2.2	
Ranunculus marginatus d'Urv.		2.2	
Reaumuria hirtella Jaub.& Spach		2.2	
Silene nocturna L.		2.2	
Tamarix aphylla (L.) Karst.		2.2	
Aerva javanica (Burm.f.) Juss. ex Schult			10.3
Pergularia tomentosa L.			10.3

(continued)

Table 7.2 (continued)

Chrozophora oblongifolia (Delile) Spreng.				8.6
Forsskaolea tenacissima L.				8.6
Retama raetam (Forssk.) Webb & Berthel. subsp. *Raetam*				6.9
Cleome amblyocarpa Barratte & Murb.				3.5
Eragrostis tef (Zucc.) Trott.				3.5
Hibscus sabdariffa L.				3.5
Rosa sp.				3.5
Agave americana L. subsp. *americana*				1.7
Aloe vera L.				1.7
Arachis hypogaea L.				1.7
Chrozophora tincotoria (L.) Raf.				1.7
Citrullus colocynthis (L.) Schrad.				1.7
Enterolobium contortisiliqum (Vell.) Morong.				1.7
Ficus carica L.				1.7
Fimbristylis bisumbellata (Forssk.) Bubani				1.7
Hibiscus trionum L.				1.7
Ipomoea batatas L.				1.7
Ipomoea carnea Jacq.				1.7
Jacaranda mimosifolia D.Don				1.7
Mangifera indica L.				1.7
Musa nana Lour.				1.7
Petroselinum crispum (Mill.) A. W. Hill				1.7
Psidium guajava L.				1.7
Pulicaria arabica (L.) Cass.				1.7
Silene rubella L. var. *rubella*				1.7
Solanum melongena L.				1.7
Vicia faba L.				1.7
Zygophyllum coccineum L.				1.7
Amaranthus lividus L.	32.6	43.2	6.7	27.6
Anagallis arvensis L. var. *arvensis*	10.2	5.4	11.1	5.1
Anagallis arvensis L. var. *caerulea*	6.1	2.7	8.9	12.1
Bassia indica (Wight) A. J. Scott	55.1	67.6	15.6	15.5

Beta vulgaris L. subsp. *maritima* (L.) Arcang.	4.1	2.7	13.3	3.5
Bidens pilosa L.	18.4	8.1	11.1	22.4
Bromus catharticus Vahl	12.2	21.6	8.9	13.8
Cenchrus ciliaris L.	44.9	45.9	11.1	48.3
Chenopodium murale L.	30.6	24.3	26.7	17.2
Convolvulus arvensis L.	14.3	43.2	40	17.2
Conyza bonariensis (L.) Cronquist	38.8	45.9	26.7	34.5
Cynanchum acutum L. subsp. *acutum*	44.9	37.8	6.7	22.4
Cynodon dactylon (L.) Pers.	65.3	62.2	44.4	56.9
Cyperus rotundus L.	8.2	29.7	13.3	17.2
Deverra tortuosa (Desf.) DC.	8.2	35.1	24.4	5.1
Digitaria sanguinalis (L.) Scop.	16.3	24.3	4.4	19.1
Echinochloa colona (L.) Link	18.4	27.1	20	10.3
Eragrostis pilosa (L.) Beauv.	30.6	40.5	8.9	39.7
Erodium glaucophyllum (L.) L'Hèr.	6.1	2.7	4.4	3.5
Euphorbia hirta L.	2	5.4	2.2	6.9
Euphorbia peplus L.	8.2	10.8	4.4	10.3
Ficus nitida Thunb.	24.5	5.4	15.6	15.5
Imperata cylindrica (L.) Raeusch.	22.4	48.7	31.1	20.7
Launaea amal-aminae N. Kilian	12.2	2.7	4.4	12.1
Launaea nudicaulis (L.) Hook. f.	36.7	37.8	13.3	32.8
Lolium perenne L.	6.1	2.7	11.1	3.5
Lotus glaber Mill.	8.2	10.8	24.4	12.1
Malva parviflora L.	20.4	48.7	46.7	32.8
Medicago polymorpha L.	6.1	13.5	4.4	17.2
Melilotus indicus (L.) All.	12.2	8.1	17.8	5.1
Oxalis corniculata L.	8.2	16.2	4.4	13.8
Phoenix dactylifera L.	20.4	8.1	13.3	3.5
Phragmites australis (Cav.) Trin. ex Steud.	24.5	18.9	2.2	3.5
Plantago lagopus L.	4.1	35.1	22.2	24.1
Plantago major L.	16.3	21.6	17.8	24.1
Pluchea dioscoridis (L.) DC.	18.4	27.1	8.9	22.4

(continued)

Table 7.2 (continued)

Polypogon monspeliensis (L.) Desf.	8.2	16.2	4.4	8.6
Portulaca oleracea L.	28.6	48.7	11.1	20.7
Ricinus communis L.	6.1	2.7	8.9	5.1
Rumex dentatus L.	2	5.4	2.2	1.7
Senecio glaucus L.	26.5	16.2	8.9	10.3
Sisymbrium irio L.	10.2	10.8	6.7	19.1
Sonchus oleraceus L.	44.9	27.1	31.1	32.8
Trifolium resupinatum L.	18.4	18.9	6.7	20.7
Zea mays L.	6.1	2.7	4.4	1.7

Table 7.3 Number of species in major species-rich families in the four cities

	Species rich families			
City	Poaceae	Asteraceae	Fabaceae	Chenopodiaceae
6th October	35	16	9	8
Sadat	30	15	14	6
Burg El-Arab	24	35	16	12
10th Ramadan	31	16	16	7

City	Urbanized area (%)	Inhabitants	Number of species
Sadat	19	750,000	144
10th Ramadan	24	500,000	157
Burg El-Arab	56	570,000	171
6th October	77	2,500,000	132

structure in the cities of 6th October and Burg El-Arab cities. On the contrary, perennials dominated Sadat and 10th Ramadan cities which can be attributed to the extensive un-urbanized desert areas, where perennial vegetation dominated, which surround both of the latter cities.

The number of species in European cities has been well documented. Species numbers of vascular plants correlated strongly with population size and less strongly with the area of cities (Pyšek 1993). In small- and medium-sized towns, between 530 and 560 species of ferns and flowering plants were usually found. Between 650 and 730 species were found in cities with 100,000–200,000 inhabitants, 900 and 1.000 species in cities with populations ranging from 250,000 to 400,000, and cities with more than a million inhabitants, the number of species usually exceeds 1.300 (Klotz 1990). In this study, apart from 6th October city, our results are inconsistent with results of Pyšek (1989, 1993, 1998) and Wittig (1991) in central Europe (see the table below), where they demonstrated significant correlations between town and city size and species and plant community richness. The greater the spatial extent of a town/city, the more diverse will be its flora.

Variation in Vegetation Structure Within Cities

The 22 vegetation groups (Fig. 7.3) were identified after the application of TWINSPAN to the presence values of species in the four cities, each of a definite floristic and habitat characteristic. They were also clearly separated along the first two axes of DCA, forming two major divisions along the inner city-surrounding deserts gradient.

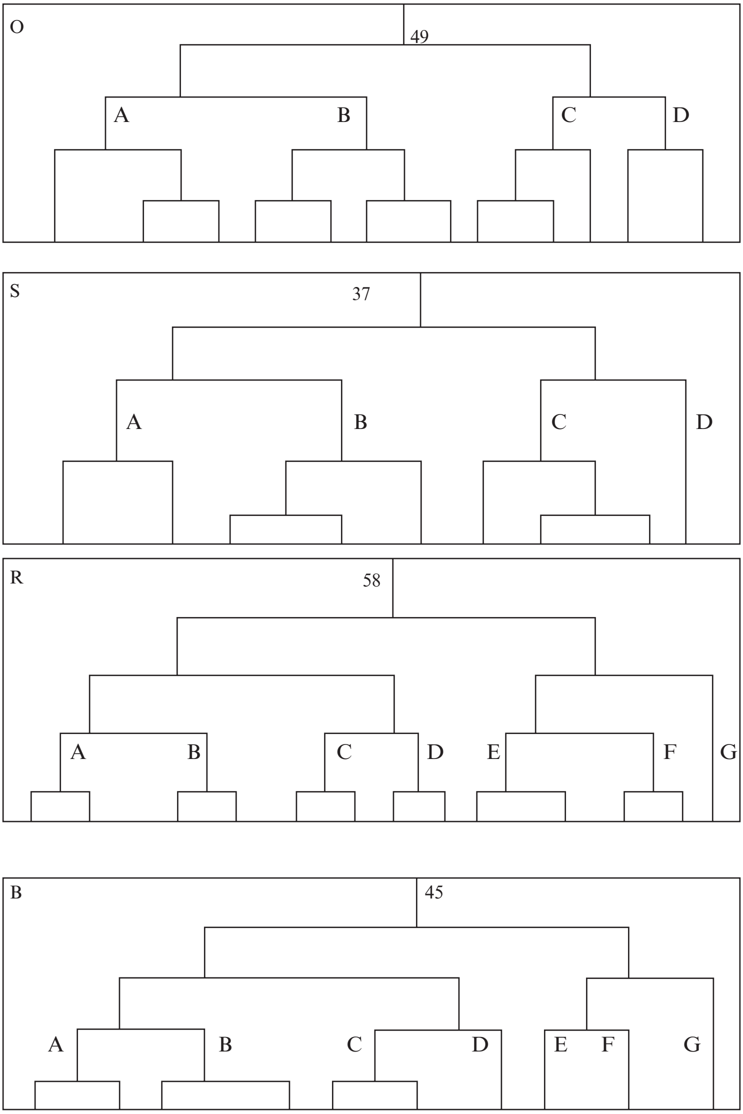

Fig. 7.3 The 22 vegetation groups (**a**–**g**) yielded after the application of TWINSPAN for classification of vegetation in the four cities: *O* 6th October, *S* Sadat, *R* 10th Ramadan, *B* Burg El-Arab

Some of these groups were recorded in other surrounding deserts of urban environments such as *Calligonum polygonoides–Centropodia forsskaolii–Pulicaria undulata* group that inhabits landscape vegetation outside Bahariya Oasis (Abd El-Ghani 1981) and Faiyum region (Abd El-Ghani 1985), *Suaeda vermiculata* group and *Asphodelus aestivus–Deverra tortuosa–Gymnocarpos decandrus–Thymelaea hirsuta* group that live in the western Mediterranean region (Bornkamm and Kehl 1990; Shaltout and El-Ghareeb 1992; Shaltout et al. 1994), *Hyoscyamus muticus–Aerva javanica* group around the urbanized areas of Feiran Oasis (Abd El-Ghani 1998), and the *Alhagi graecorum* group in the outskirts of the Nile Delta region (Shaltout and Sharaf El-Din 1988; Shaltout and El-Sheikh 2002).

The lower number of both species and communities in the inner town has been documented in other studies (Kunick 1974; Sundik-Wójcikowska 1987; Pyšek and Pyšek 1988; Kowarik 1990). This pattern is usually being explained by higher habitat diversity in peripheral areas which reflect more variable human impact creating more heterogeneous environments. In the four industrial cities under investigation, it was found that this pattern was partially reversed, i.e. the inner town included lower number of communities (referred to in this study as vegetation groups) and the highest number of species. This finding is in accordance with that of Mandák et al. (1993) who attributed the higher number of species and communities in the inner town to the area available to vegetation, assuming its importance when analyzing the spatial pattern of species and vegetation (in terms of phytosociological units) diversity. In the view point of Mandák et al. (1993), when the diversity of flora and vegetation is related to the area available, it appears that more species and communities are concentrated per unit area in the town centre than in both industrial and peripheral zones. This may reflect that (a) the vegetation in both latter zones is provided with more space which makes it possible to form large stands and (b) the diversity expressed in absolute terms (i.e. the total number of species or communities in a given zone) is, to large extent, a function of the area available (Pyšek 1993). On the contrary to European cities, it may be concluded that the extensive anthropogenic disturbances such as ploughing, mowing, burning, grazing, and treading by livestock in the inner city zone were the main factors that increased its species diversity than the peripheral zone where these disturbances were negligible.

Floristic Diversity of the Urban Habitats

The urban ecosystem includes a wide variety of habitats, from the inner city to the surrounding outskirts. In larger cities of the Nile Delta region of Egypt, Shaltout and El-Sheikh (2002) distinguished eight ruderal habitats that included demolished houses, abandoned fields, wet and dry refuse areas, graveyards, railway yards, motor roads, and railways. In European cities such as Szcezin (NW Poland), large parts were occupied by parks, cemeteries, gardens, lawns, railroads, harbour areas, and avenues with greenery belts (Ziarnek 2007). On the other hand, the vegetation of the city of Durham (North Carolina, USA) mainly occurred in lawns and roadsides (Bornkamm 1975). Changes in the composition of flora on the inner city-surroundings gradient have been repeatedly reported, and an increase in the occurrence of aliens and decrease in the proportion of natives is very common (Kunick 1974; Sukopp and Werner 1983; Kowarik 1990; Pyšek and Pyšek 1991). In this study, the flora across particular habitats was not remarkably different. One hundred and sixty five stands were stratified to cover five main urban habitats (from inner city towards surroundings): lawns, home gardens, public gardens, waste lands, and desert outskirts. The habitat richest in species was waste lands (172 species). Otherwise, the total number of species amounted to 104 in the lawns and 113 home gardens, to 123 in the desert and 133 in the public gardens (see Appendix). Generally, the recorded synanthropic flora within the five main urban habitats can be classified into (1) cultivated plant species that included ornamentals, hedges, shade plants, fodder plants, vegetables, and fruits; (2) canal banks, salinized areas, and wetland plants; (3) xerophytic plants of the outskirting desert; and (4) weeds of arable lands.

Species Distribution Within Habitats

Five main urban habitats (from inner city towards outskirts) were distinguished: lawns, home gardens, public gardens, waste lands, and desert outskirts. The most species-rich habitat was the waste lands (172 species), while the total number of species varied from 104 in the lawns and 113 home gardens to 123 in the desert and 133 in the public gardens (Table 7.4). Annuals constituted the main bulk of the flora. They showed remarkable occurrence (>50% of the flora) in home gardens (60.2%), followed by public gardens (55.6%) and lawns (52.9%). Perennial herbs and woody

Table 7.4 Summary of the floristic structure in the five habitats

Habitats	D	HG	L	WL	PG
Total number of stands	28	23	26	49	39
Total number of species	123	113	104	172	133
(I) Growth forms					
(i) Annuals	43 (35.0)	68 (60.2)	55 (52.9)	80 (46.5)	74 (55.6)
(ii) Perennial herbs	41 (33.3)	25 (22.1)	33 (31.7)	50 (29.1)	34 (25.6)
(iii) Woody perennials	39 (31.7)	20 (17.7)	16 (15.4)	42 (24.4)	25 (18.8)
(II) Species-rich families					
Asteraceae	23	12	12	26	16
Poaceae	19	27	28	28	31
Chenopodiaceae	12	5	5	13	6
Fabaceae	6	11	10	12	14
Brassicaceae	5	5	NS	8	6
Euphorbiaceae	NS	NS	5	7	8
Zygophyllaceae	4	8	NS	NS	NS
Boraginaceae	4	NS	NS	NS	NS
Cyperaceae	NS	NS	5	NS	NS
Convolvulaceae	NS	NS	NS	5	NS
Apiaceae	NS	NS	NS	5	NS

Figures between parentheses are the percentages of the total
NS not significant numbers, *D* desert, *HG* home gardens, *L* lawns, *WL* waste lands, *PG* public gardens

perennials dominated in the desert habitat (33.3% for the former and 31.7% for the latter) than in any other habitats. Asteraceae, Poaceae, Chenopodiaceae, and Fabaceae were the most species-rich families, and their species were represented in all habitats. These families constituted >50% of the recorded flora in the lawns and public gardens habitat and equally represented in the desert and home gardens. Species of some families showed notable presence in certain habitats, e.g. Zygophyllaceae in the desert and home gardens, Boraginaceae in the desert, Cyperaceae in lawns, and Convolvulaceae and Apiaceae in the waste lands.

In the desert habitat, *Bassia indica*, *Aizoon canariense*, *Bassia muricata*, *Senecio glaucus*, and *Zygophyllum simplex* were among the most important annuals. Whereas *Launaea nudicaulis*, *Hyoscyamus muticus*, *Polycarpaea repens*, *Stipagrostis plumosa*, and *Cynanchum acutum* subsp. *acutum* were among the common perennial herbs, *Deverra tortuosa*, *Tamarix nilotica*, *Farsetia aegyptia*, and *Pulicaria undulata* were the most important woody perennials. In the home gardens, among the most important recorded annuals were *Eragrostis pilosa*, *Conyza bonariensis*, *Malva parviflora*, *Sonchus oleraceus*, and *Bidens pilosa*. As for perennial herbs, *Cynodon dactylon*, *Cenchrus ciliaris*, and *Plantago major* were the most important. Among the important woody perennials were *Ficus nitida*, *Dodonaea viscosa*, *Nerium oleander*, and *Phoenix dactylifera*. For the lawns, *Conyza bonariensis*, *Portulaca oleracea*, *Malva parviflora*, *Amaranthus lividus*, and *Plantago lagopus* were of common annuals. *Cynodon dactylon*, *Cyperus rotundus*, *Cenchrus ciliaris*, and *Convolvulus arvensis* were among the most important perennial herbs, and *Nerium oleander* and *Delonix regia* were the most common woody perennials. In the waste lands, *Bassia indica*, *Sonchus oleraceus*, *Conyza bonariensis*, *Malva parviflora*, *Chenopodium murale*, and *Amaranthus lividus* were the most important annuals. Perennial herbs included, among others, *Launaea nudicaulis*, *Cynodon dactylon* and *Imperata cylindrica*, *Cenchrus ciliaris*, and *Cynanchum acutum* subsp. *acutum*. Woody perennials exhibited xerophytic nature such as *Tamarix nilotica*, *Pluchea dioscoridis*, *Deverra tortuosa*, and *Farsetia aegyptia*. Among the most common annuals in the public gardens, *Eragrostis pilosa*, *Conyza bonariensis*, *Malva parviflora*, *Plantago lagopus*, *Amaranthus lividus*, and *Sonchus oleraceus* occurred. Whereas *Cynodon dactylon*, *Cenchrus ciliaris*, *Convolvulus arvensis*, *Dichanthium annulatum*, and *Plantago major* were the most important perennial herbs, and *nitida*, *Delonix regia*, *Nerium oleander oleander*, *Phoenix dactylifera*, and *Pluchea dioscoridis* were the important woody perennials.

This study recorded 24 common species that inhabited the five distinct habitats (Table 7.5). The most common were *Malva parviflora*, *Eragrostis pilosa*, *Portulaca oleracea*, *Bassia indica*, *Dichanthium annulatum*, and *Cenchrus ciliaris.* However, 111 species were found to occur in only one habitat and distributed as follows: 26 in the desert (where the most common were *Asphodelus aestivus*, *Gymnocarpos decanter*, *Salvia aegyptiaca*, *Arisarum vulgare*, and *Cornulaca monacantha*), 26 in the public gardens (e.g. *Capsella bursa-pastoris*, *Polygonum bellardii*, and *Spergularia marina*), 18 in the home gardens (e.g. *Hibscus sabdariffa*, *Zea mays*, *Coronopus squamatus*, and *Ipomoea carina*), 29 in the waste lands (e.g. *Atriplex halimus*, *Xanthium strumarium*, *Peganum harmala*, *Ludwigia stolonifera*, and *Zygophyllum coccineum*),

Table 7.5 Characteristic species of each habitat, together with their presence percentages and ubiquitous species that occurred in all the recognized five habitats
WL **waste lands,** *L* **lawns,** *HG* **home gardens,** *PG* **public gardens,** *D* **desert**

Species	WL	L	HG	PG	D	
Nicotiana glauca R.C. Graham	10.2					Cultivated
Linaria albifrons (Sm.) Spreng.	8.2					Dryland xerophytes
Peganum harmala L.	6.1					Dryland xerophytes
Sorghum halepense (L.) Pers.	6.1					Weeds of arable lands
Opuntia ficus-indica (L.) Mill	4.1					Cultivated
Veronica anagallis-aquatica L.	4.1					Wetland
Xanthium strumarium L.	4.1					Weeds of arable lands
Atriplex leucoclada Boiss.	2					Dryland xerophytes
Ceratonia siliqua L.	2					Cultivated
Chrozophora tincotoria (L.) Raf.	2					Dryland xerophytes
Citrullus colocynthis (L.) Schrd.	2					Dryland xerophytes
Citrullus vulgaris L.	2					Cultivated
Convolvulus althaeoides L. var. *pedatus* Choisy	2					Weeds of arable lands
Cynara cornigera Lindl.	2					Dryland xerophytes
Erodium laciniatum (Cav.) Willd.	2					Dryland xerophytes
Fimbristylis bisumbellata (Forssk.) Bubani	2					Wetland
Ifloga spicata (Forssk.) Sch. Bip.	2					Dryland xerophytes
Ipomoea batatas L.	2					Cultivated
Lotus hebranicus Hochst. ex Brand	2					Weeds of arable lands
Ludwigia stolonifera (Guill. & Perr.) P. H. Raven	2					Wetland
Mangifera indica L.	2					Cultivated
Marrubium alysson L.	2					Dryland xerophytes
Morus alba L.	2					Cultivated
Musa nana Lour.	2					Cultivated
Picris longirostris Sch. Bip.	2					Dryland xerophytes
Plantago crypsoides Boiss.	2					Dryland xerophytes
Pulicaria arabica (L.) Cass.	2					Dryland xerophytes
Rostraria cristata (L.) Tzvelev	2					Weeds of arable lands
Zygophyllum coccineum L.	2					Dryland xerophytes
Oryzopsis miliacea (L.) Asch. & Schweinf.		7.7				Weeds of arable lands
Allium cepa L.		3.8				Cultivated
Bolboschoenus glaucus (Lam.) S. G. Smith		3.8				Wetland
Emex spinosa (L.) Campd.		3.8				Weeds of arable lands
Euphorbia indica Lam.		3.8				Weeds of arable lands
Hibiscus trionum L.		3.8				Weeds of arable lands
Linum usitatissimum L.		3.8				Cultivated
Ranunculus marginatus d'Urv.		3.8				Weeds of arable lands
Setaria viridis (L.) P. Beauv.		3.8				Weeds of arable lands
Silybum marianum (L.) Gaertn.		3.8				Weeds of arable lands
Triticum aestivum L.		3.8				Cultivated
Urtica urens L.		3.8				Weeds of arable lands
Vitex agnus-custus L.		3.8				Cultivated

(continued)

Table 7.5 (continued)

Zea mays L.			17.4			Cultivated
Capsicum frutescense L.			8.7			Cultivated
Hibscus sabdariffa L.			8.7			Cultivated
Rosa sp.			8.7			Cultivated
Agave americana L. subsp. *americana*			4.4			Cultivated
Aloe vera L.			4.4			Cultivated
Arachis hypogaea L.			4.4			Cultivated
Coronopus squamatus (Forssk.) Asch.			4.4			Weeds of arable lands
Faba vulgaris L.			4.4			Cultivated
Ficus carica L.			4.4			Cultivated
Hibiscus esculentus L.			4.4			Cultivated
Ipomoea carnea Jacq.			4.4			Cultivated
Mentha piperita L.			4.4			Cultivated
Petroselinum crispum (Mill.) A. W. Hill			4.4			Cultivated
Psidium guajava L.			4.4			Cultivated
Raphanus sativus L.			4.4			Cultivated
Solanum melongena L.			4.4			Cultivated
Trifolium alexandrinum L.			4.4			Cultivated
Platycladus orientalis (Lufi) Franco				10.2		Cultivated
Cassia nodosa Roxb.				7.7		Cultivated
Trifolium repens L.				7.7		Weeds of arable lands
Capsella bursa-pastoris (L.) Medik.				5.1		Weeds of arable lands
Cassia fistula L.				5.1		Cultivated
Enterolobium contortisiliqum (Vell.) Morong.				5.1		Cultivated
Eragrostis tef (Zucc.) Trott.				5.1		Weeds of arable lands
Polygonum bellardii All.				5.1		Dryland xerophytes
Amaranthus hybridus L.				2.6		Weeds of arable lands
Brassica nigra (L.) Koch				2.6		Weeds of arable lands
Chenopodium glaucum L.				2.6		Weeds of arable lands
Clerodendrum acerbianum (Vis.) Benth. & Hook. f.				2.6		Cultivated
Cutandia dichotoma (Forssk.) Batt. & Trab.				2.6		Dryland xerophytes
Euphorbia forsskaolii J. Gay				2.6		Weeds of arable lands
Glebionis coronaria (L.) Tzvelev				2.6		Dryland xerophytes
Jacaranda mimosifolia D.Don				2.6		Cultivated
Launaea spinosa (Forssk.) Sch. Bip. ex Kuntze				2.6		Dryland xerophytes
Lycopersicon lycopersicum (L.) Karst. ex Farw.				2.6		Cultivated
Malva sylvestris L.				2.6		Weeds of arable lands
Paspalidium geminatum (Forssk.) Stapf				2.6		Wetland
Pennisetum glaucum (L.) R. Br.				2.6		Weeds of arable lands
Sida alba L.				2.6		Weeds of arable lands
Silene rubella L. var. *rubella*				2.6		Weeds of arable lands
Spergularia marina (L.)Bessler				2.6		Wetland
Trianthema portulacastrum L.				2.6		Weeds of arable lands

Asphodelus aestivus Bort.					17.9	Dryland xerophytes
Gymnocarpos decander Forssk.					17.9	Dryland xerophytes
Salvia aegptiaca L.					14.3	Dryland xerophytes
Globularia arabica Jaub. & Spach.					10.7	Dryland xerophytes
Lycium europaeum L.					10.7	Dryland xerophytes
Phagnalon rupestre (L.) DC.					10.7	Dryland xerophytes
Thymus capitatus (L.) Link					10.7	Dryland xerophytes
Arisarum vulgare Targ.Tozz.					7.1	Dryland xerophytes
Arnebia decumbens (Vent.) Coss.& Kralik					7.1	Dryland xerophytes
Centaurea glomerata Vahl					7.1	Dryland xerophytes
Cornulaca monacantha Delile					7.1	Dryland xerophytes
Astragalus caprinus L.					3.6	Dryland xerophytes
Caylusea hexagyna (Forssk.) M. L. Green					3.6	Weeds of arable lands
Crepis micrantha Czerep					3.6	Dryland xerophytes
Enarthrocarpus strangatulus Boiss.					3.6	Dryland xerophytes
Epilobium hirsutum L.					3.6	Wetland
Filago desertorum Pomel					3.6	Dryland xerophytes
Iphiona scarbra DC.					3.6	Dryland xerophytes
Medicago laciniata (L.) Mill.					3.6	Weeds of arable lands
Mesembryanthemum nodifiorum L.					3.6	Dryland xerophytes
Neurada procumbens L.					3.6	Dryland xerophytes
Plantago notata Lag.					3.6	Dryland xerophytes
Reaumuria hirtella Jaub. & Spach					3.6	Dryland xerophytes
Stipagrostis scoparia (Trin. & Rupr.) De Winter					3.6	Dryland xerophytes
Traganum nudatum Delile					3.6	Dryland xerophytes
Zygophyllum aegyptium Hosny					3.6	Dryland xerophytes
Amaranthus graecizans L.	4.1	3.8	4.4	5.1	3.6	Weeds of arable lands
Amaranthus lividus L.	20.4	46.2	34.8	43.6	3.6	Weeds of arable lands
Bassia indica (Wight) A. J. Scott	57.1	34.6	17.4	33.4	39.3	Dryland xerophytes
Cenchrus ciliaris L.	38.8	50	60.9	53.9	10.7	Weeds of arable lands
Chenopodium album L.	2	3.8	4.4	7.7	3.6	Weeds of arable lands
Convolvulus arvensis L.	10.2	50	30.4	46.2	3.6	Weeds of arable lands
Conyza bonariensis (L.) Cronquist	26.5	53.8	65.2	51.3	10.7	Weeds of arable lands
Cynanchum acutum L. subsp. *acutum*	38.8	19.2	43.5	25.6	21.4	Dryland xerophytes
Cynodon dactylon (L.) Pers.	40.8	100	87	82.1	3.6	Weeds of arable lands
Cyperus rotundus L.	6.1	53.8	21.7	18	3.6	Wetland
Dichanthium annulatum (Forssk.) Stapf	14.3	26.9	17.4	46.2	3.6	Wetland
Digitaria sanguinalis (L.) Scop.	12.2	26.9	26.1	25.6	3.6	Weeds of arable lands
Echinochloa colona (L.) Link	6.1	30.8	21.7	28.2	3.6	Weeds of arable lands
Eragrostis pilosa (L.) P. Beauv.	14.3	23.1	73.9	64.1	3.6	Weeds of arable lands
Imperata cylindrica (L.) Raeusch.	40.8	26.9	17.4	41	10.7	Weeds of arable lands
Launaea amal-aminae N. Kilian	10.2	15.8	4.4	7.7	3.6	Dryland xerophytes
Launaea nudicaulis (L.) Hook. f.	55.1	7.7	17.4	18	46.4	Dryland xerophytes
Malva parviflora L.	24.5	50	52.2	48.7	3.6	Weeds of arable lands
Phoenix dactylifera L.	8.2	7.7	21.7	18	3.6	Cultivated
Pluchea dioscoridis (L.) DC.	32.6	11.5	17.4	18	21.4	Wetland
Polypogon monspeliensis (L.) Desf.	12.2	11.5	13	7.7	3.6	Weeds of arable lands
Portulaca oleracea L.	8.2	53.8	39.1	38.5	7.1	Weeds of arable lands
Senecio glaucus L.	14.3	15.4	21.7	12.8	14.3	Weeds of arable lands
Sonchus oleraceus L.	28.6	42.3	52.2	43.6	7.1	Weeds of arable lands

and 14 in the lawns (e.g. *Emex spinosa*, *Oryzopsis miliacea*, *Silybum marianum*, and *Acacia saligna*). Annuals dominated (more than 50%) the floristic composition of the cultivated (managed) areas such as home gardens (68 out of 113) and public gardens (74 out of 133). This is not surprising considering the great variety and often high intensity of disturbance due to agricultural activities like ploughing, mowing, cutting, weeding, and hoeing. Compared to other life forms, the occurrence of annuals was most conspicuously related to human impact. In this context, it can be mentioned that neither the trampling nor the level of disturbance, i.e. the factors directly acting on vegetation, was found to be related to the zone of urbanization (Pyšek et al. 2003). Hence, a conclusion may be drawn that the generally accepted pattern of the spatial distribution of flora is not as pronounced in a small industrial cities as in large cities. This is in accordance with the results of Mandák et al. (1993), who studied the distribution pattern of flora and vegetation in small industrial town of Czech Republic.

Vegetation Structure of the Urban Habitats

The present study recognized five main habitats that were represented in the studied cities: desert, waste lands, home gardens, public gardens, and lawns. Two more habitats, the farmlands and the salinized areas, were excluded as they were either only occasionally represented or differ strongly. The structure of the vegetation within each of the recognized habitat was represented by a number of vegetation groups, each dominated with one or more species.

The 26 vegetation groups that identified by TWINSPAN were demonstrated in the DCA (Detrended Correspondence Analysis, Fig. 7.4) and described as follows:

In the desert habitats: (A) *Asphodelus aestivus–Deverra tortuosa–Thymelaea hirsuta*, (B) *Anabasis articulata*, (C) *Tamarix nilotica*, and (D) *Forsskaolea tenacissima*

In the waste lands: (A) *Thymelaea hirsuta–Linaria albifrons*, (B) *Cynodon dactylon–Malva parviflora–Polypogon monspeliensis–Sonchus oleraceus*, (C) *Bassia indica–Launaea nudicaulis*, (D) *Convolvulus lanatus–Deverra tortuosa–Launaea nudicaulis*, (E) *Imperata cylindrica–Alhagi graecorum*, and (F) *Atriplex halimus–Atriplex lindleyi* subsp. *inflata–Suaeda vermiculata–Typha domingensis*

In the home gardens: (A) *Cynodon dactylon*, (B) *Conyza bonariensis–Cynodon dactylon–Sonchus oleraceus*, (C) *Cynodon dactylon–Eragrostis pilosa*, (D) *Bidens pilosa–Eragrostis pilosa*, and (E) *Dactyloctenium aegyptium–Portulaca oleracea*

In the lawns: (A) *Cynodon dactylon-Portulaca oleracea*, (B) *Cynodon dactylon–Nerium oleander–Plantago lagopus*, (C) *Cynodon dactylon*, and (D) *Hordeum murinum–Melilotus indicus–Trifolium resupinatum*

In the public gardens: (A) *Bassia indica–Plantago major*, (B) *Cenchrus ciliaris–Digitaria sanguinalis*, (C) *Cynodon dactylon*, (D) *Oxalis corniculata–Plantago lagopus*, (E) *Malva parviflora–Sisymbrium irio*, (F) *Sonchus oleraceus–Cynodon dactylon*, and (G) *Dactyloctenium aegyptium–Leptochloa fusca–Phragmites australis*

Remarkably, the *Asphodelus aestivus–Deverra tortuosa–Thymelaea hirsuta* group was confined to the desert habitat of Burg El-Arab city; *Thymelaea hirsuta–Linaria albifrons* and *Atriplex halimus–Atriplex lindleyi* subsp. *inflata–Suaeda vermiculata–Typha domingensis* groups in the waste lands of Burg El-Arab city; *Conyza*

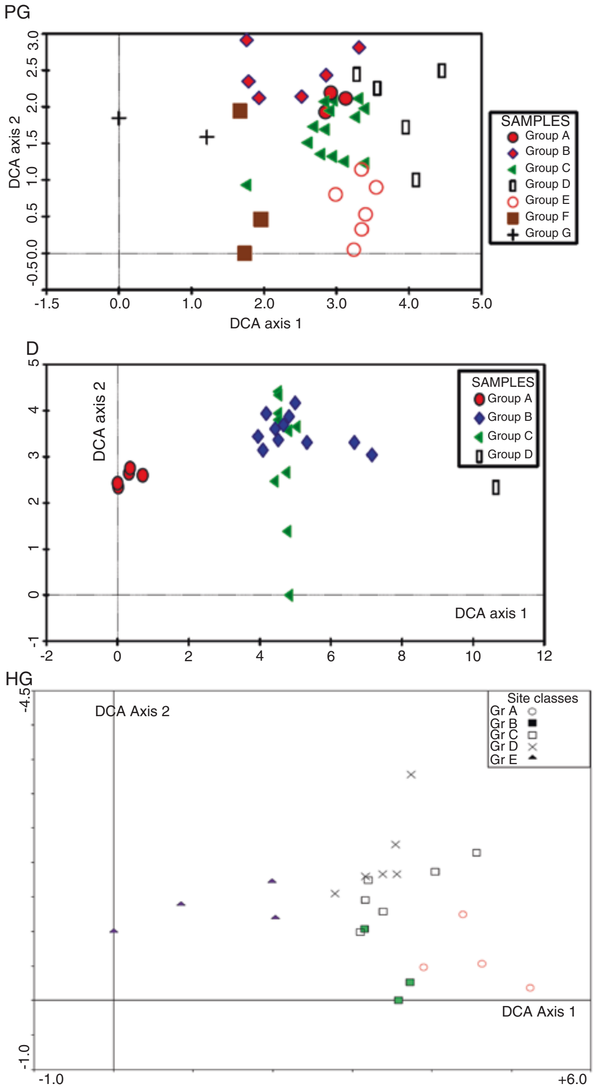

Fig. 7.4 Detrended Correspondence Analysis (*DCA*) ordination diagram for the five main habitats recognized in the studied four cities showing the identified 26 vegetation groups: *PG* public gardens, *D* desert, *HG* home gardens, *L* lawns, and *WL* waste lands

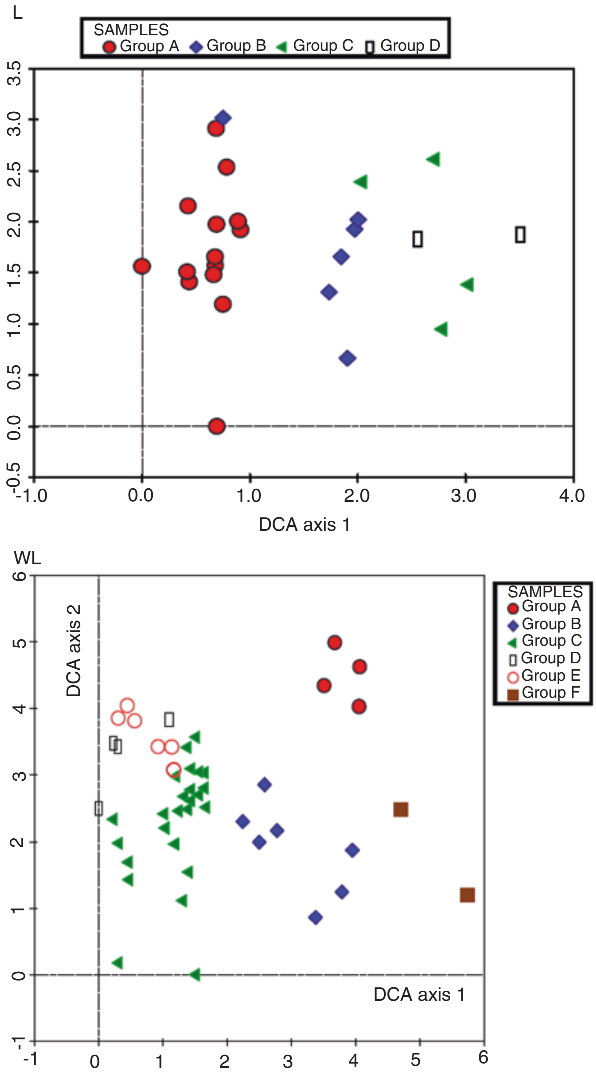

Fig. 7.4 (continued)

bonariensis–Cynodon dactylon–Sonchus oleraceus group in the home garden habitat of 10th Ranadan city; *Cynodon dactylon* group in the lawns of Burg El-Arab city; *Bassia indica–Plantago major* group in the public gardens of Burg El-Arab city; *Oxalis corniculata–Plantago lagopus* group in the public gardens of 10th Ramadan city; and *Sonchus oleraceus–Cynodon dactylon* and *Dactyloctenium aegyptium–Leptochloa fusca–Phragmites australis* groups in the public gardens of 6th October city. Comparable vegetation groups were also recognized in the orchards of Siwa Oasis (Abd El-Ghani 1994) and in the date palm orchards of Feiran Oasis (Abd El-Ghani 1998). Yet, different vegetation groups were recognized by El-Sheikh et al.

(2004) in the gardens and flowerbeds of El-Qanatir Public Park (south Nile Delta). In addition, the species richness of the urban habitats in the studied cities (11–22 species stands^{-1}) was nearly the same as in the Nile Delta region (11–19 species stands^{-1}; Shaltout and El-Sheikh 2002) but higher than that of the weed communities of the common crops in the agricultural land of the Nile Delta (8–12 species stands^{-1}; Shaltout and El-Fahar 1991). In this study, the most common recorded weeds in the lawns, home gardens, and public gardens habitats were inconsistent with those of Egypt (El Hadidi and Kosinova 1971; Boulos and El Hadidi 1994). Apparently, the preponderance of weed flora in the aforementioned habitats was noticed. A slight difference from this framework was reported by Danin et al. (1982) who analysed the synanthropic flora of ten new settlements in NE Sinai. They demonstrated that *Conyza canadensis*, *Conyza bonariensis*, *Amaranthus gracilis*, *Digitaria sanguinalis*, and *Portulaca oleracea* subsp. *nitida* were the most common weeds in those areas. The synanthropic flora of NE Sinai displayed a greater similarity to the weed flora of new settlements on the Gulf of Aqaba than to that of the Bedouin and monastery gardens of the S Sinai mountain range and to that of Egypt.

Open spaces in the urban habitats such as the sides of motor roads and railways allow colonizing plants to invade and provide opportunities for spreading species to penetrate deeply into the desert zone (e.g. *Desmostachya bipinnata* groups at the borders of the Nile Delta; *Tamarix nilotica* groups at the borders of the Oases; *Dichanthium annulatum, Cyperus alopecuroides*, *Alhagi graecorum,* and *Imperata cylindrica* at the borders of 10th Ramadan city). Indications exist also for a reverse trend. Some desert plants managed to invade the urban habitats (e.g. *Hyoscyamus muticus*, *Zilla spinosa*, *Cornulaca monacantha*, *Artemisia monosperma*, *Deverra tortuosa*, *Bassia muricata*, and *Pulicaria undulata*) at the borders of the study cities. A similar result was reported by Shaltout and El-Sheikh (2002) in the Nile Delta. It can be also mentioned that these high-stressed microsites (Grime 1979) are places with low competition, which allow these plants to get established. Under such circumstances, the impact of urban habitats such as motor roads and railways creates mixed vegetation which has been identified as anthropogenous–azonal (Holzapfel and Schmidt 1990).

Home (domestic) gardens, lawns, and public gardens were extremely rich in plant species (Thompson et al. 2003), especially weeds of arable lands (Abd El-Ghani and El-Sawaf 2004). Numerous investigations which examined agroforestry systems particularly focusing on home gardens were in tropical areas. These have received attention as potential models for an ecologically sustainable system (Lamont et al. 1999). Despite their importance, home gardens have not been previously studied in Egypt. Several studies concluded that home garden structures vary greatly, without identifiable patterns (Caballero 1992, 1994). Concerning the gardens examined in this study, the horizontal ordering of plant species appears to be much more random, and this is in accordance with the study of Rico-Gray et al. (1990) in tropical regions. In physiognomic terms, the structure of the home gardens resembled to a great extent that of neighbouring cultivated lands. The vertical structure of many gardens described in the literature is often complex, but quite variable. Albuquerque et al. (2005) studied the home gardens of Alagoinha in

Northeastern Brazil and described the importance of home garden plants as they used for food and fruit production as well as medicinal products. This is not the case in our gardens (either home or public), which are principally used for shading (e.g. *Cassia nodosa*, *Delonix regia*, *Ficus nitida*, *Tecoma stans*, and *Schinus terebinthifolius*), decorative (e.g. *Rosa* sp., *Ficus elastica*, *Thevetia peruviana*, *Nerium oleander*, and *Ipomoea carnea*), and hedge functions (e.g. *Sesbania sesban*, *Dodonaea viscosa*, *Hibiscus rosa-sinensis*, *Acokanthera oblongifolia*, and *Lantana camara*). Yet, rarely medicinal plants (e.g. *Aloe vera, Ricinus communis, Cassia fistula*) and fruit trees (e.g. *Phoenix dactylifera*, *Psidium guajava*, and *Olea europaea*) occurred (see Appendix). However, it is important to emphasize that the difference between the results of other studies such as those of Rico-Gray et al. (1990) in the home gardens of Mexico and Millat-e-Mustafa et al. (1996) in the home gardens of Bangladesh and those found here supported the argument that home garden structure varies in different regions (Soewarwoto et al. 1985; Albuquerque et al. 2005). With the application of multivariate methods with presence–absence data, Millat-e-Mustafa et al. (1996) established the existence of different floristic patterns in the home gardens of Bangladesh. Also, Albuquerque et al. (2005) recognized four groups of home gardens based on relative abundance and dominant species. In the present investigation, five main vegetation groups were identified after the application of multivariate techniques; *Cynodon dactylon*, *Conyza bonariensis*, *Eragrostis pilosa*, *Bidens pilosa*, *Portulaca oleracea*, and *Sonchus oleraceus* constituted the framework of these groups. Most of the recorded species were reported as common winter, summer, and all-the-year weeds of arable lands in Egypt (Abd El-Ghani 1985; Abd El-Ghani and Amer 1990; Abd El-Ghani and El-Bakry 1992).

Given the very heavy use that many lawns and parks experience, it is not surprising that trampling is one of the major variables affecting their composition (Whitney 1985). *Poa annua*, *Lolium perenne*, *Trifolium repens*, *Matricaria matricarioides*, *Polygonum aviculare*, *Juncus tenuis*, and *Plantago major* are all relatively cosmopolitan species that have been associated with heavily compacted sites around the world. Bates (1935) and Davies (1938) have discussed many of these communities in Great Britain. Horikawa and Miyawaki (1954) have outlined their occurrence in Japan, while Tüxen (1950) has indicated many of the same trample plant species in the *Lolium perenne–Plantago major* association of the more inclusive *Polygonum aviculare* alliance of Western Europe. In the present work, the three identified groups of *Cynodon dactylon* (*Cynodon dactylon–Portulaca oleracea*, *Cynodon dactylon–Nerium oleander–Plantago lagopus*, and *Cynodon dactylon*) separated in the lawn habitats were located in heavily trampled areas.

Based on their mean presence percentages, the Sørensen's coefficient of similarity between the five main habitats was shown in Table 7.6 and Fig. 7.5. At the first hierarchical level, the habitats were clustered into two main groupings: the first included public gardens, home gardens, and lawns. These can be called "managed ecosystems" that show strong cultural influence. The high amenity values accorded many of these areas make them more artificial and ornamental of any of the other communities of the urban ecosystems. The desert and waste land habitats formed the second grouping because both habitats have similar number of species, 26 and

Table 7.6 Sørensen's coefficient of similarity between the five main habitats

Habitats	W	L	HG	PG
W				
L	0.497			
HG	0.5	0.612*		
PG	0.51	0.638*	0.677*	
D	0.638*	0.347	0.322	0.326

W waste land, *L* lawns, *HG* home gardens, *PG* public gardens, *D* desert
*Significant at 1%

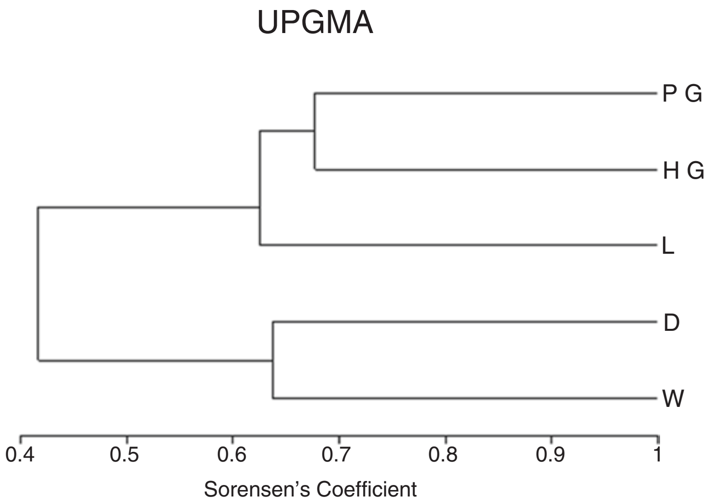

Fig. 7.5 Cluster analysis of the five habitats based on Sørensen's coefficient of similarity. For habitat abbreviations, see Table 7.6

29 respectively, and only 3 common species with relatively high values of percentage of presence. This high similarity between both habitats may indicate the high disturbance of desert habitats.

Soil Characteristics of the Habitats

Table 7.7 summarizes the significant differences in soil features of the five habitats. Differences in fine sand, medium sand, and sulphate contents were insignificant. The highest number (8) of soil variables with significant differences was in the waste land habitats, followed by the desert (7) and the public gardens (6). Silt, clay, organic matter, carbonates, and carbon contents showed significant differences among the five habitats. On the other hand, coarse sand and bicarbonates and total soluble salts showed significant differences in the lawns, desert, and waste lands, respectively. Regarding the species diversity indices, species richness was highly significant ($P = 0.007$) in the public gardens and Shannon's index ($P = 0.021$) with the desert habitat.

Table 7.7 ANOVA *P* values of soil variables, species richness (SR), and Shannon's index (H′) in the stands representing the groups obtained by TWINSPAN in all habitats

Soil variables	D	HG	L	WL	PG
C	0.001**	0.003**	0.111	0.001**	0.003**
Clay	0.004**	0.046*	0.572	0.001**	0.035*
$CaCO_3$	0.001**	0.23	0.003**	0.001**	0.001**
OM	0.001**	0.003**	0.111	0.001**	0.003**
Silt	0.003**	0.009**	0.901	0.017*	0.144
Cl	0.574	0.307	0.405	0.001**	0.050*
MC	0.034*	0.421	0.092	0.001**	0.103
pH	0.112	0.591	0.011*	0.136	0.001**
CS	0.227	0.503	0.001**	0.08	0.148
HCO_3	0.039*	0.72	0.987	0.731	0.242
TSS	0.293	0.39	0.629	0.030*	0.204
FS	0.404	0.379	0.137	0.172	0.527
MS	0.463	0.426	0.092	0.332	0.162
SO_4	0.835	0.244	0.461	0.193	0.335
SR	0.199	0.957	0.059	0.357	0.007**
H′	0.021*	0.952	0.439	0.314	0.082

D desert, *HG* home gardens, *L* lawns, *WL* waste lands, *PG* public gardens, *MC* moisture content, *pH* soil reaction, *TSS* total soluble salts, *Cl* chlorides, CO_3 total carbonates, HCO_3 bicarbonates, SO_4 sulphates, *C* organic carbon, *OM* organic matter, *CS* coarse sand, *MS* medium sand, *FS* fine sand

*$P \leq 0.05$ and **$P \leq 0.01$

Soil–Vegetation Relationships of the Habitats

The relationship between the vegetation and soil variables was studied using Canonical Correspondence Analysis (CCA). Figure 7.6 showed the CCA ordination biplots for the studied habitats with their TWINSPAN vegetation groups and the examined soil variables. The inter-set correlations resulted from Canonical Correspondence Analysis (CCA) of the examined soil variables in different habitats were displayed in Table 7.8.

The Desert Habitat

The species–environment correlations for the four axes explained 52% of the cumulative variance. CCA axis 1 was positively correlated with total carbonates, organic carbon, organic matter, clay, silt, and bicarbonates and negatively with coarse sand. So this axis can be interpreted as total carbonates–coarse sand gradient (Table 7.8). CCA axis 2 was positively correlated with moisture content and negatively with chlorides. Thus, this axis can be interpreted as moisture content-chlorides gradient. Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be significant ($P = 0.05$).

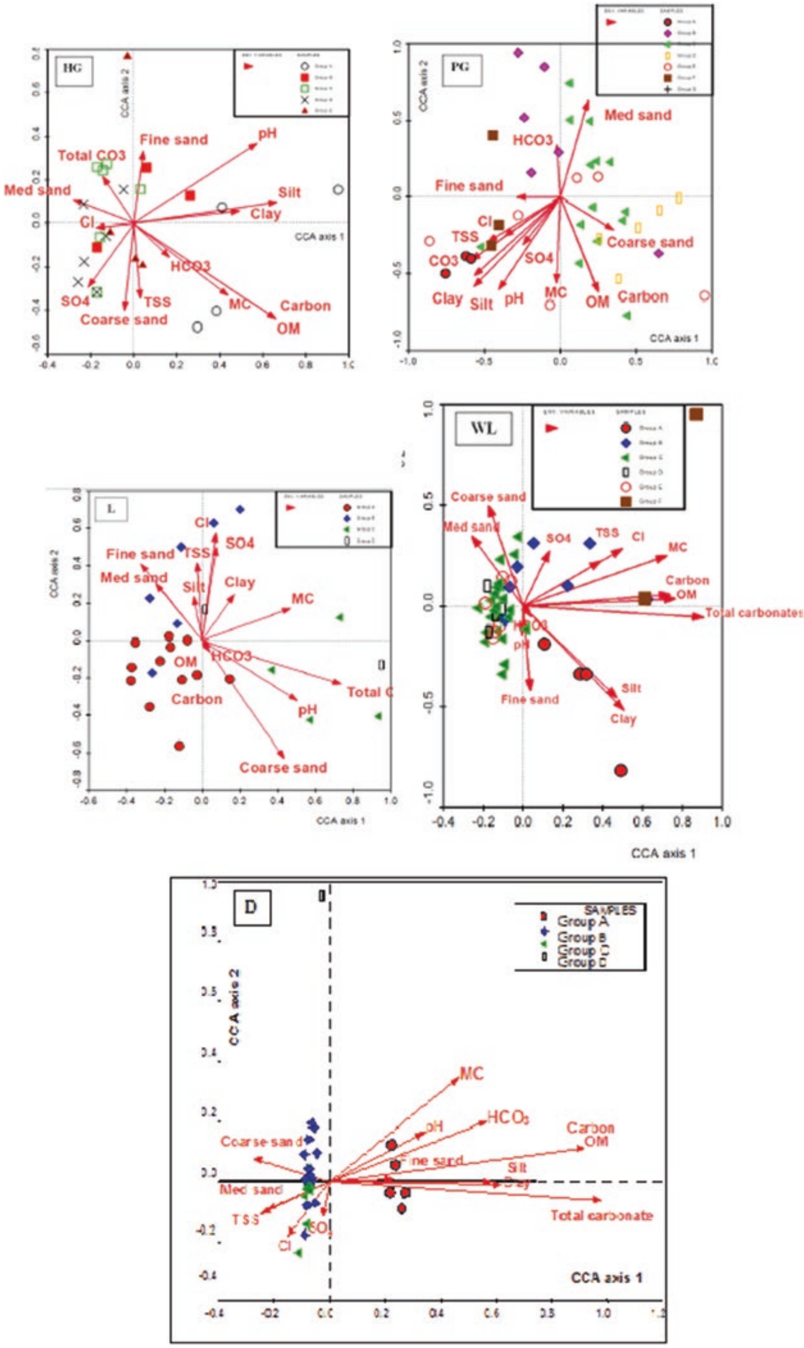

Fig. 7.6 CCA biplots of axes 1 and 2 showing the distribution of stands of the habitats, together with their TWINSPAN groups and soil variables. *D* desert, *HG* home gardens, *L* lawns, *WL* waste lands, *PG* public gardens

Table 7.8 Inter-set correlation of CCA for the soil variables, together with eigenvalues and species–environment correlation in the five habitats

Habitats	D		HG		WL		L		PG	
Axes	1	2	1	2	1	2	1	2	1	2
Eigenvalues	0.85	0.66	0.46	0.39	0.66	0.49	0.43	0.35	0.34	0.27
Species–environment correlations	1.00	0.91	0.98	0.94	0.98	0.94	0.98	0.95	0.96	0.87
pH	0.34	0.15	0.56	0.35	−0.01	−0.13	0.49	−0.30	−0.39	−0.52
MC	0.47	0.32	0.43	−0.31	0.71	0.24	0.46	0.16	−0.03	−0.49
TSS	−0.23	−0.09	0.03	−0.32	0.39	0.21	−0.03	0.40	−0.46	−0.25
Cl	−0.15	−0.17	−0.17	−0.02	0.49	0.27	0.08	0.48	−0.35	−0.22
CO_3	0.98	−0.06	−0.14	0.20	0.89	−0.05	0.72	−0.22	−0.56	−0.36
HCO_3	0.57	0.18	0.16	−0.15	0.04	−0.05	0.04	−0.03	−0.02	0.30
SO_4	−0.02	−0.11	−0.21	−0.28	0.13	0.26	0.07	0.54	−0.24	−0.27
C	0.92	0.10	0.65	−0.42	0.73	0.05	0.04	−0.06	0.24	−0.54
OM	0.92	0.10	0.65	−0.41	0.75	0.03	0.04	−0.06	0.24	−0.54
CS	−0.28	0.07	−0.04	−0.38	−0.17	0.47	0.43	−0.60	0.33	−0.19
MS	−0.25	−0.10	−0.28	0.10	−0.25	0.33	−0.24	0.29	0.17	0.55
FS	0.23	0.01	0.04	0.31	0.04	−0.40	−0.32	0.39	−0.27	0.00
Silt	0.59	0.00	0.65	0.09	0.46	−0.43	−0.04	0.22	−0.55	−0.51
Clay	0.62	−0.01	0.48	0.05	0.50	−0.49	0.17	0.23	−0.54	−0.45

D desert, *HG* home gardens, *WL* waste lands, *L* lawns, *PG* public gardens

The Waste Lands Habitat

The species–environment correlations explained 47.7% of the cumulative variance for the first four axes. CCA axis 1 was positively highly correlated with total carbonates, organic matter, organic carbon, and moisture content and negatively with medium sand. This axis can be defined as total carbonates–medium sand gradient. CCA axis 2 was positively correlated with coarse sand and negatively with clay, silt, and fine sand. Thus, this axis can be defined as coarse sand–clay gradient. Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be significant ($P = 0.002$).

The Home Gardens Habitat

The species–environment correlations explained 59.7% of the cumulative variance for the first four axes CCA axis 1 was positively correlated with silt, organic matter, organic carbon, pH, clay, and moisture content and negatively with medium sand. So this axis can be defined as silt–medium sand gradient. CCA axis 2 was positively correlated with pH and negatively with organic carbon and organic matter. Thus, this axis can be defined as pH–organic carbon gradient. Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be significant ($P = 0.05$).

The Lawns Habitat

The species–environment correlations explained 45.9% of the cumulative variance for the first four axes. CCA axis 1 was positively correlated with carbonates, pH, and moisture content and negatively with fine sand, so this axis can be defined as carbonates–fine sand gradient. CCA axis 2 was positively correlated with sulphates, chlorides, total soluble salts, and fine sand and negatively with coarse sand. Thus, this axis can be defined as sulphates–coarse sand gradient. Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be significant ($P = 0.02$).

The Public Gardens Habitat

The species–environment correlations for the four axes explained 46.2% of the cumulative variance. CCA axis 1 was positively correlated with coarse sand and negatively with total carbonates, silt, clay, total soluble salts, and chlorides. So this axis can be defined as coarse sand–total carbonates gradient. CCA axis 2 was positively correlated with medium sand and negatively with organic matter, organic matter, pH, silt, moisture content, and clay. Thus, this axis can be defined as medium sand–organic matter gradient. Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 was found to be significant ($P = 0.004$).

7.3 General Remarks

1. Environmental factors that determined plants species distribution in the urban habitats were scarcely studied. In this study, the application of Canonical Correspondence Analysis (CCA) revealed that soil carbonates (CO_3)–sand content was the principal gradient along which the vegetation groups of the desert, waste land, lawns, and public garden habitats were distributed, whereas contents of sand and silt affected the home gardens. Other gradients vary from one habitat to the other: moisture content– chloride in the desert, sand–clay in waste lands, pH–organic matter in home gardens, sulphates–sand in lawns, and organic matter–sand in public gardens.
2. Comparing the soil of the vegetation types at the borders of the Nile Delta with those inside it, Shaltout and El-Sheikh (2002) indicated that silt, organic matter, phosphorus, and nitrogen increased, while sand decreased with increased urbanization from the borders of the Nile Delta towards its middle. They suggested that, at the border, the desert soil merges gradually with the agricultural land of the Nile Delta, where the middle is pure agricultural land. The discharge of

organic and inorganic refuses such as dumps, rubbish heaps, debris from buildings, garden refuses, vegetal refuses from kitchens and shops, and solid refuses from factories is a possible cause for increasing nutrient supply in the urban habitats of the four cities under study. The trampling of soil in the densely populated urban habitats leads to destruction of soil structure (Frenkel 1970). As suggested by Shaltout et al. (1999), the urban vegetation is favoured where disturbance, nutrient, and water resources are more abundant. Holzapfel and Schmidt (1990) reported that this relationship may be reversed under more humid conditions.

3. Results of this study support the idea that plant species composition in urban waste lands is mainly driven by soil nutrient content, soil moisture, and soil pH. Urban soils are actually enriched with dirt and construction rubble (mainly cement, bricks, and mortar), which leads to an increase in alkalinity (Sukopp et al. 1979). After demolition of buildings, sites are typically graded as a slightly domed area of rubble set into matrix of fine material, which is dominated by lime-based mortar which leads to neutral to alkaline soils, pH values typically 6.5–8.0 (Wildlife Trust for Birmingham and the Black Country 2000). Such observations were also reported by Godefroid et al. (2007) when studying the role of soil microclimatic variables in the distribution patterns of the urban waste land flora in Brussels (Belgium). Similarly, this study also exhibited the role of pH in the vegetation of urban habitats. Soils of the studies cities were slightly alkaline (pH = 7.5–8.2) and were significantly correlated with the vegetation in lawns and public gardens habitats (i.e. inner city zone). On the contrary, the soil moisture exhibited significant variation in the vegetation of the desert and waste lands habitats (city outskirts).

7.4 Desert Reclamation

7.4.1 Surveyed Area: Along the Northern Sector of the Nile Valley

This area is one of the most recently reclaimed areas in Egypt. It is located within the territories of four governorates: Cairo, Giza, Fayium, and Beni Suef. It comprises the reclaimed desert lands extending on both sides (eastern and western) of the Nile Valley between 29° 04′ and 29° 42′N and 31° 3′ and 31° 23′E (Fig. 7.7). The eastern part of the study area represents a part of Helwan–Kuraymat and Assiut eastern desert roads crossing the Eastern Desert parallel to the Nile Valley and extends for about 80 km (the distance between site 7, farthest to the north, and site 17, farthest to the south). This part will be referred to in this study as the eastern transect. The western part represents a part of Assiut western desert road crossing the Western Desert parallel to the Nile Valley and extends for about 31 km (the distance between site 1, the farthest to the north and site 5, the farthest to the south). This part will be referred to as the western transect.

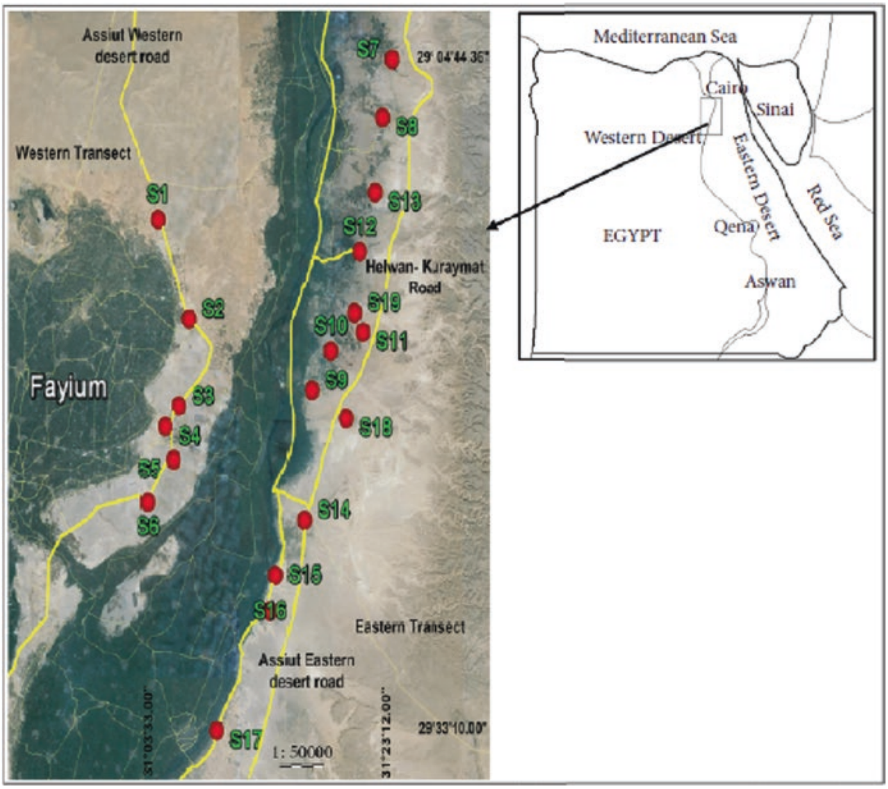

Fig. 7.7 Map showing the location of the 19 studied sites in the study area (scale 1:50,000)

7.4.1.1 Floristic Composition

A total of 150 species of the vascular plants belonged to 125 genera in 33 families were recorded (Table 7.9). The most species-rich families were Poaceae (31 species) and Asteraceae (23 species), followed by Brassicaceae (13 species), Chenopodiaceae (12 species), Fabaceae (12 species), and Zygophyllaceae (5). Other families were represented in different ways. Five families, Boraginaceae, Caryophyllaceae, Euphorbiaceae, Lamiaceae, and Polygonaceae, were represented by four species each. Amaranthaceae, Asclepiadaceae, and Convolvulaceae were represented by three species each. Monospecific families (13 families) such as Urticaceae, Solanaceae, Resedaceae, Portulacaceae, Malvaceae, Tiliaceae, and Primulaceae constituted less than 42% of the total recorded families. The main bulk (98) of the genera was represented by one species. Generally, the family size is small: 28 families have less than 10 species and only 5 families have more than 10 species. Genera with highest number of species included *Chenopodium*, *Amaranthus*, *Coronopus*, *Zygophyllum*, and *Euphorbia* (three species each). Another 12 genera were represented by two species, among others, *Rumex*, *Brassica*, *Medicago*, *Tamarix*, *Heliotropium*, *Launaea*, *Phalaris*, and *Setaria.*

Table 7.9 Number of species with their percentages and the total number of genera included in each family

Family	Number of genera	Total number of species	% of the total
Poaceae	28	31	20.6
Asteraceae	21	23	15.3
Brassicaceae	10	13	8.6
Chenopodiaceae	9	12	8
Fabaceae	9	12	7.3
Zygophyllaceae	3	5	3.3
Boraginaceae	4	4	2.7
Caryophyllaceae	4	4	2.7
Euphorbiaceae	2	4	2.7
Lamiaceae	3	4	2.7
Polygonaceae	3	4	2.7
Amaranthaceae	1	3	2
Asclepiadaceae	3	3	2
Convolvulaceae	3	3	2
Capparaceae	2	2	1.3
Cyperaceae	1	2	1.3
Geraniaceae	2	2	1.3
Plantaginaceae	1	2	1.3
Tamaricaceae	1	2	1.3
Apiaceae	2	2	1.3
Families with one species	13	13	8.6
Total number	125	150	

Annuals constituted the main bulk of the total flora, where 100 species (about 67% of the total) were recorded, in addition to 33 perennials and 11 margin species and 6 trees. The total number of recorded species varied from one agroecosystem to another: 118 in the orchards and 129 in the croplands. Typical desert annuals included *Cotula cinerea*, *Neurada procumbens*, *Schismus barbatus*, *Ifloga spicata*, *Trichodesma africanum*, and *Zygophyllum simplex.* Trees and shrubs included 29 species, mostly of desert habitats such as *Calotropis procera*, *Farsetia aegyptia*, *Deverra tortuosa*, *Haloxylon salicornicum*, and *Zygophyllum coccineum.* Certain halophytic shrubs that characterized the salt-affected soils were also recorded such as *Suaeda monoica*, *Tamarix nilotica*, and *Zygophyllum album.*

General Distribution Patterns of Species

Figure 7.8 displayed the distribution patterns of the recorded species in the study area. Two ubiquitous (omnipresent) species were *Cynodon dactylon* and *Sonchus oleraceus* that can be included among the all-the-year weeds. None of the summer and winter weeds were recorded in this category. Common species included ten winter weeds, four summer weeds, and three all-the-year weeds. As for desert plant

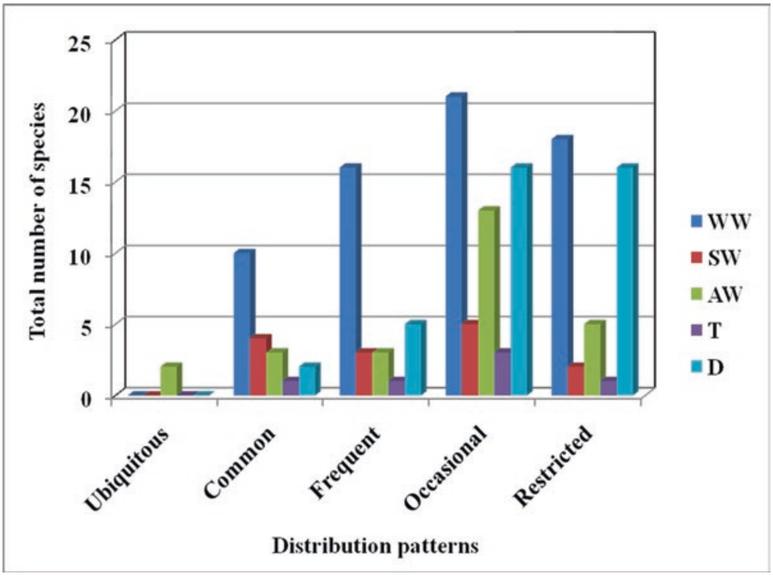

Fig. 7.8 Distribution patterns of the recorded species in their different categories. *WW* winter weeds, *SW* summer weeds, *AW* all-the-year weeds, *T* trees, *D* desert species

species and trees, *Bassia indica* for the former and *Tamarix nilotica* for the latter were included in both categories. Both species inhabited wide range of habitats such as cultivated lands, waste lands, canal banks, salt-affected lands, and edges of cultivations. Certain species exhibited variations in their presence percentages from eastern and western transects. Twenty-nine frequent species were included, of which 16 were winter weeds, while all-the-year and summer weeds were represented by almost equal number of species (3 species).

The newly reclaimed areas and their adjacent fringes (borders) provide habitat for rich populations of several desert plants that were sparse elsewhere. Invasion of desert plant species into the cultivated lands is noticeable as the number of desert plant species increases gradually from one category to another. Six desert plant species were not represented in the western transect such as *Trichodesma africanum*, *Schismus barbatus*, *Cleome amblyocarpa*, *Stachys aegyptiaca*, *Heliotropium bacciferum*, and *Capparis spinosa.* Eight species characterized the western transect and not found in the eastern one such as *Cornulaca monacantha*, *Rostraria cristata*, *Galinsoga parviflora*, and *Trigonella hamosa.*

7.4.1.2 The Weed Flora of the Present Study and Adjacent Desert-Reclaimed Lands

To assess the floristic relationships between the weed flora of the reclaimed lands in this study with those in other adjacent areas in Minya Province to the south (El-Amry 1981) and Tahrir area to the north (Soliman 1989), a comparison was elaborated.

Altogether 308 species were enumerated, of which 202 species were recorded in the reclaimed lands of El-Tahrir area, 186 in Minya Province, and 150 in the reclaimed lands of this study. It revealed that 72 species were of common occurrence in the three areas. On the other hand, 62 species were confined to Minya Province, 60 species to Tahrir area, and 28 to the reclaimed areas of the present study.

Desert perennials (herbs, shrubs, or trees) constituted the main bulk of the recorded flora. For example, *Fagonia bruguieri*, *Faidherbia albida*, and *Salsola imbricata* subsp. *imbricata* were confined to the reclaimed lands in Minya Province, whereas *Artemisia monosperma*, *Astragalus spinosus*, *Atractylis carduus*, *Centropodia forsskaolii*, *Moltkiopsis ciliata*, *Convolvulus lanatus*, and *Xanthium strumarium* in the reclaimed lands of El-Tahrir area, and *Anabasis setifera*, *Calotropis procera*, *Haloxylon salicornicum*, *Heliotropium bacciferum*, *Ochradenus baccatus*, *Pergularia tomentosa*, and *Stachys aegyptiaca* in the reclaimed lands of the present study.

It can also be noted that some species known from the Nile lands characterized the reclaimed lands of Minya Province (e.g. *Acacia nilotica* subsp. *nilotica*, *Ageratum conyzoides*, *Ammannia auriculata*, *Cyperus alopecuroides*, *C. articulates*, *Myriophyllum spicatum*, *Persicaria senegalensis*, *Potamogeton pectinatus*, *Saccharum spontaneum* var. *aegyptiacum*, and *Salix mucronata*). While certain species known from the Mediterranean region were consistent to the reclaimed lands of El-Tahrir area (e.g. *Allium roseum* var. *tourneauxii*, *Astragalus peregrinus* subsp. *peregrines*, *Bromus diandrus*, *Dipcadi erythraeum*, *Ononis serrata*, and *Picris asplenioides*).

Thirty-six species were found in the reclaimed lands of both Minya Province and El-Tahrir area, among which are *Calligonum polygonoides* subsp. *comosum*, *Chrozophora plicata*, *Hyoscyamus muticus* as perennials and *Brachiaria eruciformis*, *Dichanthium annulatum*, *Lolium temulentum*, *Senecio vulgaris*, and *Veronica anagallis-aquatica* as weed species. This comparison showed also that 34 species were in common between the reclaimed lands of El-Tahrir area and this study, among which are *Deverra tortuosa* and *Panicum turgidum* as perennials. The present study area shared 16 species with those of Minya Province, of which *Capparis aegyptia*, *Echinops spinosus*, *Salsola vermiculata* var. *villosa*, *Sporobolus spicatus*, and *Tamarix nilotica* were perennials and *Cuscuta pedicellata and Leptochloa fusca* were among the recorded weeds.

7.4.1.3 Crop–Weed Relationships

Table 7.10 summarizes the performance of each species within the studied six crops. Performance (P) was calculated as the total number of fields where species recorded divided by the total number of monitored fields. The total number of species varied from one crop to another: the highest was 105 species in olive, and the lowest was 56 in wheat. Twenty-three species were recorded in all the six crops (widest sociological ranges of species). Certain species exhibited high performance in one (or more) crop than the others, e.g. *Cichorium endivia* in clover fields ($P = 89\%$) where its records in other crops ranged between 3% and 45%. *Tamarix nilotica* and the desert perennials *Zygophyllum coccineum* and *Alhagi graecorum* fare well or at

Table 7.10 Sociological range of species recorded in the studied orchards and crops

	Species	Olive		Vineyard		Clover		Wheat		Tomato	Maize			Total	
GF		37	%	22	%	18	%	11	%	10	%	15	%	113	P(%)
I—Species present in all crops															
a	*Cynodon dactylon*	27	73	18	82	11	61	5	45	4	40	9	60	74	65
a	*Sonchus oleraceus*	23	62	11	50	14	78	8	73	5	50	9	60	70	62
w	*Chenopodium murale*	12	32	7	32	16	89	7	64	1	10	9	60	52	46
w	*Malva parviflora*	12	32	5	23	12	67	6	55	3	30	9	60	47	42
w	*Conyza bonariensis*	18	49	7	32	6	33	1	9	2	20	11	73	45	40
da	*Bassia indica*	23	62	5	23	3	17	2	18	3	30	7	47	43	38
w	*Senecio glaucus* subsp. *coronopifolius*	21	57	7	32	4	22	2	18	1	10	5	33	40	35
t	*Tamarix nilotica*	20	54	4	18	2	11	1	9	8	80	3	20	38	34
a	*Convolvulus arvensis*	8	22	1	5	7	39	5	45	4	40	8	53	33	29
w	*Anagallis arvensis* var. *caerulea*	8	22	2	9	10	56	6	55	1	10	6	40	33	29
w	*Melilotus indicus*	7	19	3	14	10	56	6	55	1	10	3	20	30	27
w	*Cichorium endivia*	1	3	1	5	16	89	5	45	1	10	5	33	29	26
dp	*Alhagi graecorum*	10	27	6	27	4	22	1	9	5	50	2	13	28	25
dp	*Zygophyllum coccineum*	15	41	4	18	1	6	1	9	6	60	1	7	28	25
w	*Polypogon monspeliensis*	9	24	5	23	7	39	4	36	2	20	1	7	28	25
ms	*Phragmites australis*	15	41	2	9	4	22	2	18	2	20	2	13	27	24
s	*Echinochloa colona*	5	14	3	14	8	44	1	9	2	20	6	40	25	22
ms	*Imperata cylindrical*	13	35	7	32	1	6	1	9	1	10	1	7	24	21
s	*Dactyloctenium aegyptium*	6	16	6	27	3	17	2	18	2	20	4	27	23	20
w	*Euphorbia peplus*	4	11	3	14	6	33	4	36	2	20	1	7	20	18
a	*Solanum nigrum*	6	16	4	18	1	6	1	9	1	10	3	20	16	14
s	*Amaranthus graecizans*	4	11	2	9	1	6	1	9	3	30	5	33	16	14
w	*Phalaris minor*	4	11	2	9	3	17	3	27	1	10	1	7	14	12
II—Species present in 5 crops															
dp	*Launaea nudicaulis*	30	81	13	59	3	17			8	80	4	27	58	51

(continued)

Table 7.10 (continued)

	Species	Olive		Vineyard		Clover		Wheat		Tomato		Maize		Total	
GF		37	%	22	%	18	%	11	%	10	%	15	%	113	P(%)
a	*Cynanchum acutum*	23	62	15	68	4	22			3	30	6	40	51	45
s	*Amaranthus viridis*	5	14	10	45	6	33			1	10	7	47	29	26
s	*Cenchrus biflorus*	9	24	6	27	1	6			1	10	4	27	21	19
s	*Portulaca oleracea*	6	16	3	14	3	17			3	30	6	40	21	19
w	*Avena fatua*	3	8			7	39	4	36	3	30	3	20	20	18
w	*Bidens pilosa*	3	8	7	32	3	17	2	18			1	7	16	14
w	*Rumex vesicarius*	4	11			4	22	2	18	1	10	4	27	15	13
w	*Symphyotrichum squamatus*	6	16	3	14	1	6	1	9			4	27	15	13
a	*Cyperus rotundus*	4	11	4	18	3	17			1	10	2	13	14	12
w	*Euphorbia helioscopia*	2	5	1	5	5	28	5	45	1	10			14	12
w	*Reichardia tingitana*	8	22	3	14	1	6			1	10	1	7	14	12
w	*Digitaria sanguinalis*	7	19	2	9	1	6			1	10	2	13	13	12
w	*Eruca sativa*	2	5	1	5	1	6			3	30	5	33	12	11
w	*Medicago intertexta* var. *ciliaris*	4	11	1	5	2	11	2	18			3	20	12	11
w	*Plantago lagopus*	4	11			2	11	2	18	2	20	2	13	12	11
w	*Brassica tournefortii*	2	5	1	5	3	17	3	27	2	20			11	10
ms	*Pluchea dioscoridis*	2	5	1	5	3	17	1	9			1	7	8	7
III—Species present in 4 crops															
t	*Calotropis procera*	10	27	1	5					2	20	2	13	15	13
w	*Lolium perenne*	3	8			5	28	3	27			4	27	15	13
w	*Emex spinosa*	3	8			5	28	3	27			1	7	12	11
da	*Cotula cinerea*	8	22	1	5					1	10	1	7	11	10
w	*Chenopodium album*			1	5	3	17	4	36			3	20	11	10
w	*Hordeum murinum* subsp. *leporinum*					1	6	7	64	1	10	1	7	10	9
w	*Oxalis corniculata*	1	3	4	18			2	18			3	20	10	9

(continued)

Table 7.10 (continued)

	Species	Olive		Vineyard		Clover		Wheat		Tomato	Maize			Total	
GF		37	%	22	%	18	%	11	%	10	%	15	%	113	P(%)
da	*Zygophyllum simplex*	6	16	1	5					1	10	1	7	9	8
dp	*Fagonia arabica*	5	14			1	6			2	20	1	7	9	8
s	*Setaria verticillata*	3	8	2	9	1	6					3	20	9	8
s	*S. viridis*	4	11	1	5	2	11					1	7	8	7
ms	*Spergularia marina*	3	8			1	6	2	18	1	10			7	6
da	*Matthiola longipetala* subsp. *livida*	3	8			1	6	1	9	2	20			7	6
s	*Amaranthus hybridus*			1	5	2	11	1	9			3	20	7	6
w	*Poa annua*			1	5	3	17	2	18	1	10			7	6
s	*Corchorus olitorius*	1	3	1	5					1	10	2	13	5	4
w	*Ammi majus*					2	11	1	9	1	10	1	7	5	4
w	*Vicia sativa*	1	3			2	11	1	9			1	7	5	4
IV—Species present in 3 crops															
dp	*Stipagrostis plumosa*	8	22							6	60	3	20	17	15
dp	*Ochradenus baccatus*	9	24							3	30	3	20	15	13
da	*Neurada procumbens*	6	16							1	10	2	13	9	8
ms	*Polygonum bellardii*					4	22			1	10	3	20	8	7
w	*Beta vulgaris*					4	22	3	27	1	10			8	7
w	*Melilotus messanensis*					4	22	1	9			2	13	7	6
w	*Pseudognaphalium luteoalbum*					2	11	2	18	3	30			7	6
ms	*Pennisetum divisum*	3	8	1	5					1	10			5	4
w	*Raphanus sativus*					2	11	2	18	1	10			5	4
w	*Sisymbrium irio*	1	3	2	9	2	11							5	4
ms	*Cyperus laevigatus*	1	3	1	5	2	11							4	4
dp	*Iphiona mucronata*	2	5	1	5							1	7	4	4
da	*Cleome amblyocarpa*	2	5	1	5					1	10			4	4

(continued)

Table 7.10 (continued)

	Species	Olive		Vineyard		Clover		Wheat		Tomato		Maize		Total	
GF		37	%	22	%	18	%	11	%	10	%	15	%	113	P(%)
dp	*Stachys aegyptiaca*	2	5	1	5							1	7	4	4
w	*Lathyrus sativus*					2	11	1	9	1	10			4	4
w	*Phalaris paradoxa*	1	3			1	6	2	18					4	4
a	*Geranium dissectum*	1	3							1	10	1	7	3	3
ms	*Paspalidium geminatum*					1	6	1	9			1	7	3	3
da	*Schismus barbatus*	1	3			1	6					1	7	3	3
s	*Eragrostis pilosa*	1	3			1	6					1	7	3	3
V—Species present in 2 crops															
dp	*Launaea mucronata* subsp. *cassiniana*	12	32							1	10			13	12
da	*Trichodesma africanum*	5	14							4	40			9	8
w	*Lamium amplexicaule*					8	44	1	9					9	8
dp	*Pulicaria undulata* subsp. *undulata*	6	16							2	20			8	7
dp	*Haloxylon salicornicum*	4	11							3	30			7	6
t	*Phoenix dactylifera*	5	14							2	20			7	6
dp	*Citrullus colocynthis*	5	14							1	10			6	5
ms	*Mentha longifolia*					5	28	1	9					6	5
da	*Ifloga spicata*	4	11	1	5									5	4
t	*Ricinus communis*	3	8									2	13	5	4
w	*Urtica urens*			4	18	1	6							5	4
a	*Sorghum virgatum*					3	17	1	9					4	4
a	*Leptochloa fusca*	1	3	2	9									3	3
da	*Savignya parviflora*	2	5							1	10			3	3
dp	*Heliotropium bacciferum*	2	5	1	5									3	3
dp	*Heliotropium digynum*	2	5									1	7	3	3

Table 7.10 (continued)

	Species	Olive		Vineyard		Clover		Wheat		Tomato		Maize		Total	
GF		37	%	22	%	18	%	11	%	10	%	15	%	113	P(%)
dp	*Monsonia nivea*	1	3									2	13	3	3
dp	*Polycarpaea repens*	1	3									2	13	3	3
t	*Sesbania sesban*	2	5			1	6							3	3
w	*Anchusa aggregata*	2	5							1	10			3	3
dp	*Achillea fragrantissima*	1	3							1	10			2	2
dp	*Anabasis setifera*	1	3							1	10			2	2
dp	*Capparis spinosa*					1	6			1	10			2	2
dp	*Deverra tortuosa*	1	3									1	7	2	2
dp	*Farsetia aegyptia*	1	3									1	7	2	2
dp	*Gymnocarpos decandrus*	1	3									1	7	2	2
dp	*Pergularia tomentosa*	1	3									1	7	2	2
dp	*Pulicaria inuloides*	1	3							1	10			2	2
dp	*Zilla spinosa*	1	3							1	10			2	2
dp	*Zygophyllum album*	1	3							1	10			2	2
S	*Echinochloa cruss-galli*			1	5							1	7	2	2
T	*Tamarix tetragyna*					1	6	1	9					2	2
w	*Medicago polymorpha*					1	6					1	7	2	2
w	*Mentha sativa*					1	6					1	7	2	2
w	*Plantago major*					1	6					1	7	2	2
w	*Rostraria cristata*	1	3			1	6							2	2
VI—Species present in one crop															
ms	*Atriplex lindleyi* subsp. *inflata*	1	3											1	1
dp	*Sporobolus spicatus*	1	3											1	1
dp	*Cornulaca monacantha*	1	3											1	1

Figures are number of fields where species was recorded. Growth form categories: *w* winter weeds, *s* summer weeds, *a* all-the-year weeds, *da* desert annuals, *dp* desert perennials, *t* trees, and *ms* margin species

P(%) = performance

least common in tomato fields (P = 80%, 60%, and 50%, respectively), while their records are 9% in wheat fields. The desert species *Calotropis procera*, *Cotula cinerea*, and *Zygophyllum simplex* were absent in the records of winter crops. The winter weeds *Hordeum murinum* subsp. *leporinum* and *Ammi majus* were not recorded in the orchards.

Thirty-five species were confined to only one assemblage (narrowest sociological range) and distributed as follows: 12 species in olive orchards, 7 species in vineyards, 11 species in clover farmlands, 2 species in wheat farmlands, 2 species in maize, and 1 species in tomato farmlands. All species of this category showed low or very low performances except for *Brassica nigra*, *Trigonella stellata*, and *Rumex dentatus* that recorded 36% in wheat, 32% in vineyards, and 28% in clover cultivations, respectively. It is obvious that desert species of this category were confined to one of the orchards (eight species) except *Echinops spinosus* that was recorded in maize farmlands.

Application of cluster analysis (Fig. 7.9) to the presence percentages of each species in each crop resulted in four floristic groups (A–D). Group (A) included species

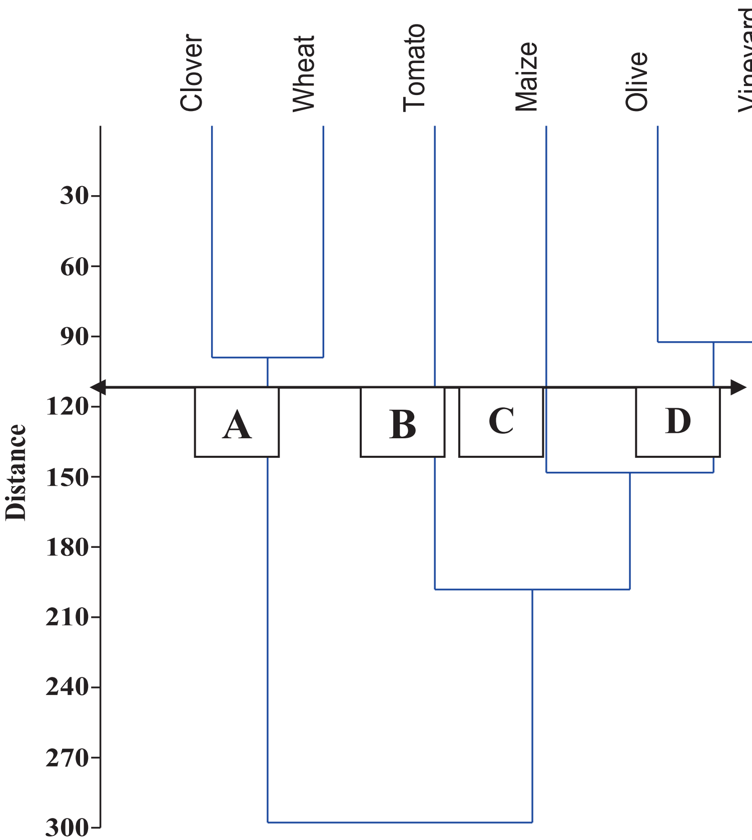

Fig. 7.9 Dendrogram resulting from cluster analysis of the six crops based on species frequency. A–D are the vegetation groups

of clover and wheat (winter crops), group (B) included tomato (winter/summer crop), group (C) included those of maize (summer crop), and group (D) included species of olive and vineyard orchards.

7.4.1.4 Classification of Vegetation

The TWINSPAN classification of the presence percentages of the recorded 150 species in 19 studied sites resulted in four site (vegetation) groups (Fig. 7.10). The first TWINSPAN dichotomy differentiated the 19 sites into two main clusters (1 and 2) according to soil pH ($p = 0.008$), bicarbonates ($p = 0.002$), and ammonia ($p = 0.03$). At the second hierarchical level, the first cluster was separated into two distinct groups (A and B), and the second was separated into two other groups (C and D) related to silt content ($p = 0.02$) and sulphates ($p = 0.04$). Each site group will be referred to as vegetation group and named after the dominants with the highest presence percentages (P %): group A, *Cynanchum acutum–Launaea nudicaulis* (70 species) in sites 5, 6, and 8; group B, *Launaea nudicaulis–Cynodon dactylon* (74 species) included sites 7, 15, 16, and 18 along the eastern transect; group C, *Cynodon dactylon–Sonchus oleraceus–Chenopodium murale* (102 species) from sites 1, 2, 3, and 4 along the western transect and sites 11, 12, 13, and 14 along the eastern transect; and group D, *Sonchus oleraceus–Cichorium endivia* (88 species) from sites 9, 10, 17, and 19 along the eastern transect. Twenty-seven species were recorded in all the four separated groups, whereas nine species showed consistency to group (A), 17 to group (B), 12 to group (C), and 8 to group (D).

These groups were clearly separated along the first two axes of the DCA (Fig. 7.11). The 19 sites were plotted along axis 1 (eigenvalue = 0.414) and axis 2 (eigenvalue = 0.252) and tended to cluster into four vegetation groups (A–D) that resulted from TWINSPAN analysis. The sites were spread out at three SD units along the first axis, expressing reasonable floristic variations among vegetation groups. The four DCA axes explained 30.8% of the total variation in species data.

7.4.1.5 Soil Characteristics of the Vegetation Groups

Table 7.11 demonstrated that organic matter, coarse sand, fine sand, silts, and soil saturation point were of significant variations ($p < 0.05$). Sites of group (A) had the highest amounts of fine sand (60.9 ± 3.1) with the highest levels of electric conductivity (39.7 ± 8.4) and ions of Cl (460.2 ± 104.0), Na (457.4 ± 102.5), Ca (66.0 ± 18.0), K (4.9 ± 1.1), NH_4 (50.3 ± 12.7), and NO_3 (98.3 ± 26.4). The mean total number of species/site (species richness) reached its maximum in this group (41.7 ± 7.3) and Shannon's diversity index (3.5 ± 0.1) as well. Sites of group (B) had the lowest soil content of electric conductivity (7.3 ± 1.9) and ions of Cl (66.3 ± 22.1), SO_4 (19.3 ± 4.0), Na (67.1 ± 21.5), and K (1.4 ± 0.5). Its species diversity measurements also showed the lowest among the other recognized groups. Soil of group (C)

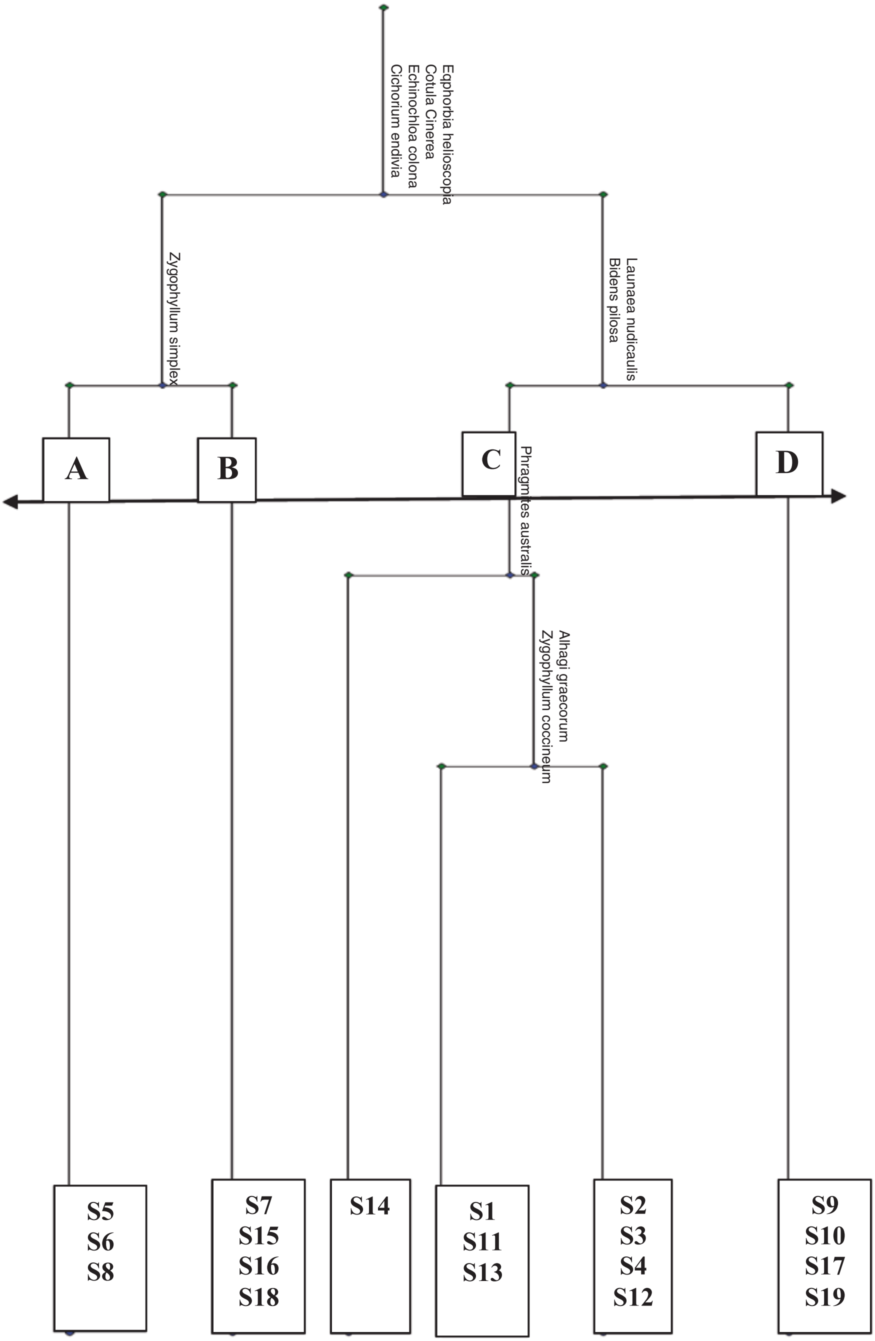

Fig. 7.10 TWINSPAN dendrogram of the 19 studied sites based on their species presence values. A–D are the four separated TWINPAN vegetation groups

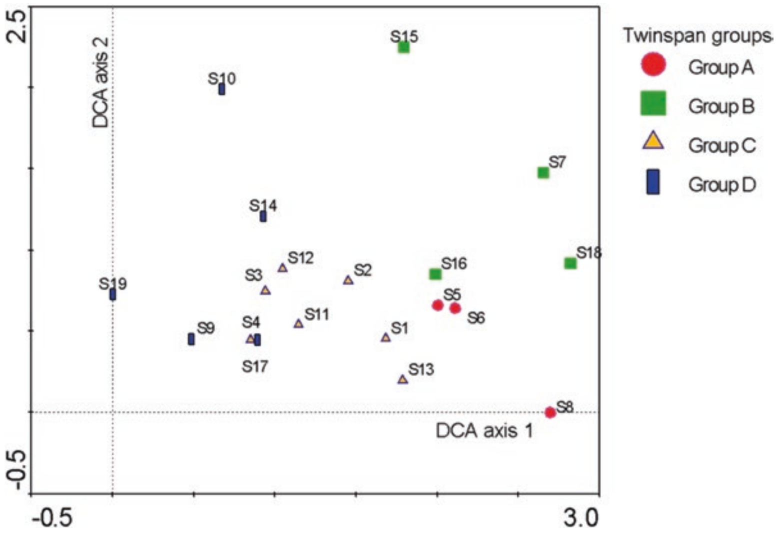

Fig. 7.11 DCA ordination diagram for the 19 sites on the first two axes with the TWINSPAN vegetation groups (A–D) superimposed

Table 7.11 Mean values and standard errors (±SE) of the soil variables in the sites representing the vegetation groups (A–D) obtained by TWINSPAN

Soil variables		TWINSPAN vegetation groups A	B	C	D	F-ratio
Total number of sites		3	4	8	4	
pH		7.6 ± 0.1	7.7 ± 0.03	7.7 ± 0.03	7.7 ± 0.04	2.02
EC (Mmohs/cm)		39.7 ± 8.4	7.3 ± 1.9	23.1 ± 10.0	12.9 ± 11.2	1.37
OM		0.15 ± 0.04	0.3 ± 0.1	0.22 ± 0.1	0.92 ± 0.4	3.38*
CS		20.7 ± 0.8	22.9 ± 1.5	21.5 ± 0.6	13.3 ± 3.0	7.47*
FS	(%)	60.9 ± 3.1	54.8 ± 1.6	56.8 ± 1.8	50.6 ± 4.4	1.96
Silt		10.0 ± 0.9	12.4 ± 1.4	10.7 ± 0.8	22.6 ± 4.2	7.92*
Clay		8.2 ± 2.5	10.0 ± 1.1	10.2 ± 1.2	13.8 ± 2.3	1.48
HCO_3		1.6 ± 0.2	1.6 ± 0.3	1.6 ± 0.2	1.5 ± 0.3	0.98
Cl		460.2 ± 104.0	66.3 ± 22.1	208 ± 86.5	153.1 ± 142.0	1.93
SO_4		86.0 ± 11.6	19.3 ± 4.0	88.8 ± 51.4	21.0 ± 17.2	0.69
Ca		66.0 ± 18.0	12.8 ± 3.3	57.4 ± 29.9	15.1 ± 12.1	0.91
Mg	(Meq/l)	19.6 ± 4.3	5.9 ± 1.8	22.6 ± 13.0	4.0 ± 3.0	0.69
Na		457.4 ± 102.5	67.1 ± 21.5	215.2 ± 92.1	154.9 ± 142.4	1.76
K		4.9 ± 1.1	1.4 ± 0.5	3.2 ± 0.9	1.7 ± 1.4	1.64
NH_4		50.3 ± 12.7	49.7 ± 7.1	45.9 ± 3.4	45.3 ± 1.8	0.18
NO_3		98.3 ± 26.4	70.3 ± 15.4	85.8 ± 34.7	69.5 ± 39.2	0.11
SP		23.0 ± 1.0	23.3 ± 1.1	22.9 ± 0.8	35.8 ± 5.5	6.1
SR		41.7 ± 7.3	33.5 ± 6.4	41.4 ± 3.9	38.7 ± 8.3	0.37
H′		3.5 ± 0.1	3.3 ± 0.2	3.5 ± 0.1	3.4 ± 0.2	0.30

*Differences significant at $p < 0.05$

CS coarse sand, *FS* fine sand, *EC* electric conductivity, *OM* organic matter, *SP* saturation point, *SR* species richness, *H′* Shannon's index characterized the highest contents of SO_4 (88.8 ± 51.4) and magnesium (22.6 ± 13.0) ions. Sites of group (D) were rich in their organic matter, silt (22.6 ± 4.2), and clay (13.8 ± 2.3) contents and lowest contents of many others.

7.4.1.6 Soil–Vegetation Relationships

The relationship between the vegetation and soil variables was studied using redundancy analysis (RDA), and Fig. 7.12 showed the ordination biplot with vegetation groups (A–D) and the examined soil variables. Preliminary analysis revealed high inflation factors for eight soil variables which should be excluded from the analysis. Consequently, this analysis is based on only nine soil parameters: coarse sand, fine sand, clay, pH, saturation point, bicarbonates, sodium, organic matter, and ammonia. It can be noted that sites of group (A) were highly correlated with fine sand, sodium, and ammonia; group (B) was correlated with coarse sand, while sites of group (D) were affected by the organic matter, clay, and soil saturation.

The species–environment correlations were higher for the four axes, explaining 64.1% of the cumulative variance. These results suggested an association between vegetation and the measured soil parameters presented in the biplot. RDA axis 1 was highly positively correlated with SP and highly negatively correlated with Na. So this axis can be interpreted as saturation point-sodium gradient (Table 7.12). RDA axis 2 was highly positively correlated with organic matter and highly negatively

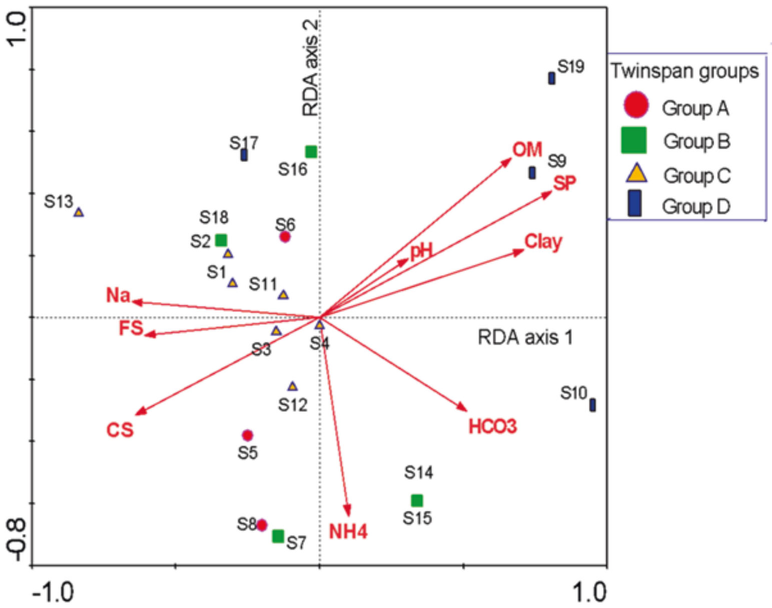

Fig. 7.12 Redundancy analysis (RDA) biplot of axes 1 and 2 showing the distribution of the 19 sites with their TWINSPAN vegetation groups (A–D) and soil variables

Table 7.12 RDA results including the inter-set correlations of the soil variables, together with eigenvalues and species–environment correlation of the 19 studied sites

Axes	Ax1	Ax2	Ax3	Ax4
Eigenvalues	0.128	0.084	0.068	0.057
Species–environment correlations	0.921	0.858	0.949	0.915
Cumulative % variance of species–environment relation	24.4	40.4	53.4	64.1
pH	0.28	0.16	0.057	−0.07
OM	0.61	0.44	0.17	0.002
CS	−0.59	−0.27	−0.36	0.26
FS	−0.56	−0.05	0.22	−0.23
Clay	0.65	0.19	−0.29	0.03
HCO_3	0.47	−0.26	−0.58	−0.24
Na	−0.60	0.043	0.039	0.25
NH_4	0.09	−0.55	0.49	0.11
SP	0.74	0.35	0.18	−0.023

For soil variable abbreviations and units, see Table 6.11

correlated with ammonia. Thus, this axis can be interpreted as organic matter–ammonia gradient. A test for significance with an unrestricted Monte Carlo permutation test (499 permutation) for the eigenvalue of axis 1 is found to be significant ($P = 0.05$).

7.5 General Remarks

1. The importance of spatial variation of weed communities has emerged from analysis of comparisons between geographical regions (Dale et al. 1992; Salonen 1993; Hallgren et al. 1999) and recently from point-referenced data (Hyvönen et al. 2005). In this study, pronounced regional differences and species that were characteristic of this gradient were observed. While comparing the floristic relationships between the weed flora of the reclaimed lands in this study and those in other adjacent areas, as those in Minya Province to the south and Tahrir area to the north, Jaccard's similarity coefficient showed that the floristic composition of the reclaimed lands in the present study was highly correlated (0.430) to those of El-Tahrir area than those of Minya Province (0.355). Altogether 308 species were included, of which 202 species were recorded in the reclaimed lands of El-Tahrir area, 186 in Minya Province, and 150 in the reclaimed lands of this study. It revealed that 72 species were of common occurrence in the three areas, 62 species were confined to Minya Province, 60 species to Tahrir area, and 28 to the reclaimed areas of the present study. The possible reasons for this difference could be attributed to crop management practices, such as continuous use of the same herbicide for a long period of time and the type of irrigation system (floods, sprinkle, or drip), which might have created selective pressure on weeds, and also the introduction of new weed species into the area. Weed

community composition is largely determined by a regional species pool, but, within a region, weeds may specialize on particular soil conditions (Hallgren et al. 1999).

2. The wide distribution of some weeds in this investigation may be interpreted as ubiquitous species. Species with wide amplitude (e.g. *Cynodon dactylon* and *Sonchus oleraceus*) are often caused by phenotypic plasticity and heterogeneity (Shaltout and Sharaf El-Din 1988). The restricted distribution of some weeds such as *Cressa cretica* in salinized or waste lands and *Phyla nodiflora* and *Eclipta prostrata* along canal banks can be attributed to habitat preference phenomenon. In line with this, Abd El-Ghani and Fawzy (2006) discussed this phenomenon in the farmlands of the Egyptian Oases. They concluded that each of the five distinguished habitats (farmlands, canal banks, reclaimed lands, waste lands, and water bodies) has its own preferential species.
3. The land reclamation processes entail an almost complete change of the environmental factors. Thus, weeds find the new conditions favorable for their growth. The weed invasion is affected by ecological conditions prevailing in the reclaimed lands; it has certain characteristics and floristic features. Close to the boundaries of the desert and within the agroecosystems of this study, species of xerophytic nature grow among the weeds of the cultivation. These included *Zygophyllum coccineum*, *Launaea mucronata* subsp. *cassiniana*, *Farsetia aegyptia*, *Ochradenus baccatus*, *Fagonia arabica*, *Stachys aegyptiaca*, *Heliotropium bacciferum*, *Haloxylon salicornicum*, *Zilla spinosa*, *Deverra tortuosa*, and *Capparis spinosa*. This indicated that these species are native to the natural desert vegetation and can remain after the reclamation process. On the other hand, the vegetation of the components of the agroecosystem of the reclaimed lands consisted mainly of the weed species growing in the crops of the old cultivated lands in addition to some desert annuals such as *Senecio glaucus*, *Cotula cinerea*, *Neurada procumbens*, *Zygophyllum simplex*, *Ifloga spicata*, and *Bassia muricata.* This suggests that land reclamation in the study area entails weed species replacing natural plant communities. Therefore, the reclaimed areas of this study can be considered as a transitional phase of the succession process between the habitat of the old cultivated lands and that of the desert. In line with this, several authors reported similar conclusions (Staniforth and Scott 1991; Shaltout and El-Halawany 1992; Bazzaz 1996; Gomaa 2002; Shaheen 2002).
4. The type of crop is the second most important gradient in weed species composition. This is contradictory to the concept of phytosociological classifications from the Central and Northern European point of view (Ŝilc et al. 2008). However, crop is a more important factor in Southern Europe than in the Central and Northern part, as weed species in Southern Europe are in their optimal climatic conditions (Holzner 1978). Fried et al. (2008) also confirmed that crop has the most significant impact on species composition in Western Europe, with Atlantic and Mediterranean climates. In Egypt, usually, two crops are grown in a seasonal sequence: a winter crop and a summer crop. It follows that a crop rotation is accompanied by a weed-flora rotation (El Hadidi and Kosinova 1971). The winter weeds represent the main bulk of the recorded species within each crop, while desert perennials exhibits notable variation.

The higher number of desert perennials (30 species) in olive orchards compared to other crops may be attributed to the ploughing scarcity of this crop. The decline of desert perennials in other crops in the reclaimed lands may confirm decreasing of xerophytic species which are replaced by mesophytic and canal bank species. Similar conclusion was reported by Soliman (1989) in the reclaimed lands of Tahrir area. This large number of weeds in olive orchards can be attributed to its long growth cycle, wider spacing between trees rows, and constant moist conditions due to irrigation, which might have created conducive conditions for the growth of weeds. Similar conclusion was reported by Firehun and Tamado (2006) in sugarcane plantations of Ethiopia. Moreover, the environment of olive orchards exhibited two different microhabitats according to light conditions: (1) the shaded microhabitat below the crowns of olive trees and (2) sunny microhabitat between trees. The environmental microheterogeneity causes the weed species to form isolated patches. The shade-loving species such as *Oxalis corniculata*, *Bidens pilosa*, and *Sisymbrium irio* dominated the shaded areas, whereas the sunny areas support the growth of other species in other croplands. This result is consistent with that in *Citrus* orchards of Beni Suef governorate (Gomaa 2002). Moreover, the shade effect produced by the olive orchards keeps the soil moisten for longer time than in the open sites. Therefore, it allows the growth of certain species characteristic to canal banks and moist areas such as *Cyperus laevigatus*, *C. rotundus*, *Imperata cylindrica*, and *Phragmites australis.*

5. The application of redundancy analysis (RDA) demonstrated the effect of edaphic factors on the spatial distribution of weed communities in the study area. Soil organic matter, coarse sand, fine sand, silt, and soil saturation point were of significant variations ($p < 0.05$) among the four vegetation (site) groups. Karar et al. (2005) reported the influence of irrigation and fertilizer application on flora composition in the Gezira Scheme (Sudan). In line with this, different authors reported that fertilizer application affects the seed production potential, germination rate, and growth of weeds, which in turn affects the frequency and density of weed flora (Jrnsgard et al. 1996; Andersson and Milberg 1998). Similarly, Ampong-Nyarko and De Datta (1993) reported an increased seed production and growth rate of the weed flora with an increased rate of nitrogen fertilization.

7.6 Desert Roads

Roads were reported as one of the most widespread forms of modification of the landscape that occurred during the past century (Trombulak and Frissell 2000). Construction of roads was one of the most destructive impacts. The plant communities of the roadside vegetation were influenced not only by anthropogenic factors but also by geographical differentiation, physiography, and topography (Ullmann et al. 1990). The advantage of roadsides for studies of species and vegetation performance along environmental gradients was widely encouraged (Ullmann and Heindl 1989; Wilson et al. 1992).

The most severe habitat reduction occurs when a natural ecosystem is converted to an artificial system, as it happens for a road construction (Geneltti 2003). Roads are conspicuous artificial structures in the natural landscape that evolved from foot trails to complex highway systems. The pavement plus-managed roadsides and parallel-vegetated strips along the roadside that extend up to the end of the right of way are known as road corridors (Forman and Alexander 1998). Road corridors are becoming a focus of ecological research because of their distinctive structure, function, and impact on surrounding ecosystems (Mallik and Karim 2008).

Seven general ways were reported by Trombulak and Frissell (2000) that affect all kinds of roads in terrestrial and aquatic ecosystems: (1) increased mortality from road construction, (2) increased mortality from collision with vehicles, (3) modification of animal behavior, (4) alteration of the physical environment, (5) alteration of the chemical environment, (6) spread of exotic species, and (7) increased alteration and use of habitats by humans.

7.6.1 Surveyed Areas

7.6.1.1 Desert Roads in the Central Eastern Desert

The Eastern Desert of Egypt is traversed by numerous canyon-like depressions (wadis) running to the Red Sea or to the Nile Valley with the Red Sea coast through the Eastern Desert. Of these Qift–Quseir road connects Qift City on the Nile Valley with Quseir on the Red Sea coast. The region in which this road lies is located in Upper Egypt (latitudes 26° 15′–25° 35′N and longitudes 32° 48′–34° 16′E). It crosses 14 wadis or their tributaries: Wadi Abu Sakranah, Al-Qarn, El-Matuli, Zeidun, Al-Hammamat, Al-Muwayh Al-Atshan, Ummhad, and At-Tella, Abu-Ziran, Abu-Hammad, Al-Harami, Al-Karim Al-Nakhil, and Ambaji, respectively, from west to east (Ismaiel et al. 2012). The first seven wadis debouch their water into the Nile Valley to the west, while the rest debouch their water into the Red Sea to the east. The wadis studied in the present work lack semi-permanent water resources and therefore belong to extremely dry habitats among similar wadis that drain this desert into the Nile Valley on rare occasions when rainfall occurs. Such rain usually occurs in sudden cloud bursts which cause torrents that overflow the wadi course, usually originating in mountainous areas in the middle of this desert and flowing eastwards or westwards to the Red Sea and Nile Valley, respectively. Due to the versatile ecological conditions characterizing such wadis (participating in the highway course), differences in floral characteristics and vegetation composition are something expectable. It was luring to carry out this study with the aim of recognizing the vegetation communities along the road in relation to environmental differences.

Human impact was recognized as the most important influence on the composition of the flora and vegetation. This impact had a dominant environmental factor in the arid environments of the world, particularly in the Middle East for thousands of years (Zohary 1983). The construction of roads was one of these impacts. The construction and use of highways, tracks, railways, and airports involved many changes; some of them were direct and others were indirect. Direct influences include the destruction of the existing habitats and the provision of new ones that have special characteristics. These provided more or less continuous stretches of open habitats extending for hundreds of miles and forming a nationwide network, with opportunities for rapid colonization and spread.

The plant communities of the roadside vegetation were influenced not only by anthropogenic factors but also by geographical differentiation, physiography, and topography (Ullmann et al. 1990). The advantage of roadsides for studies of species and vegetation performance along environmental gradients was widely encouraged (Ullmann and Heindl 1989; Wilson et al. 1992). Such studies were well documented in North America (Lausi and Nimis 1985), in Europe (Stottele and Schmidt 1988; Heindl and Ullmann 1991), in North Africa (Shaltout and Sharaf El Din 1988; Abd El-Ghani 1998, 2000), in Saudi Arabia (Batanouny 1979; Fayed and Zayed 1989; Abd El-Ghani 1996), in the Judean Desert (Holzapfel and Schmidt 1990), and in New Zealand (Ullmann et al. 1995). In Egypt, desert highways, and the agricultural roads that traverse cultivated areas, were adequately interconnected. Altogether, the present road net amounts to 41.300 km, of which 19.6% were in Sinai Peninsula. Ranked second were those of the Nile Delta (18.7%) and the Nile Valley (15.7%), while the least (8%) were in the Western and Eastern Desert of the country (Abd El-Ghani and El-Sawaf 2005).

Floristic Analysis, Biological and Chorological Spectra

The studied road extends for about 180 km from Qift City at the west along the Nile Valley to Quseir city at the east along the Red Sea coast (Fig. 7.13). The road crosses several structural control valleys (wadis) especially fault control wadis including Wadi El-Matuli, tributaries of Wadi Zeidun and Wadi Hammamat. A total of 61 species (28 annuals and 33 perennials) belonging to 50 genera and 27 families were recorded. The largest families were Fabaceae (8); Zygophyllaceae (7); Asteraceae, Brassicaceae, and Poaceae (6 for each); Asclepiadaceae and Resedaceae (3 for each); and Amaranthaceae and Cleomaceae (2 for each). They constituted about 70.5% of the recorded species and represent most of the floristic structure in the Eastern Desert of Egypt (Abd El-Ghani 1998; Salama et al. 2013). Eighteen families were represented by only one species. The largest genus was *Fagonia* with four species (Table 7.13).

Zygophyllum coccineum was the only ubiquitous species (has a wide ecological range of distribution) with the highest presence value of $P = 90.70\%$. Among perennials, *Morettia philaeana*, *Salsola imbricata* subsp. *imbricata*, *Pulicaria undulata*, and *Citrullus colocynthis* had the highest presence values 60.47%, 51.16%, 41.86%, and 41.86%, respectively. Among annuals, *Zygophyllum simplex* and *Forsskaolea tenacissima* showed the highest presence estimate 37.21 and 30.23%. Thirty-three species or about 54.1% of the total recorded species were perennials and demonstrated a certain degree of constancy. The presence of *Juncus rigidus*, *Tamarix nilotica*, and *Salsola imbricata* subsp. *imbricata* refers to salinization.

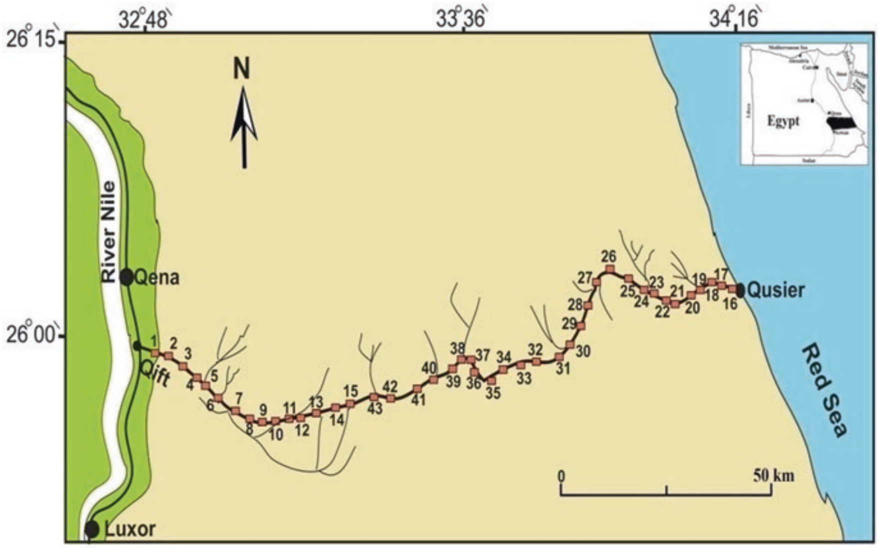

Fig. 7.13 Location map of Qift–Quseir road in Eastern Desert in Egypt, the stands are given by their numbers

Table 7.13 Floristic composition, presence value (*P%*), life forms (LF), and chorology of the recorded species in the studied area

Species	D	Chorology	LF	P%
Amaranthaceae				
Aerva javanica (Burm. F.) Juss. ex Schult.	Per	SA+SZ	Ch	9.30
Amaranthus graecizans L.	Per	ME+IT	Ch	2.33
Asclepiadaceae				
Calotropis procera (Aiton) W.T. Aiton	Per	SA+SZ	Ph	6.98
Leptadenia pyrotechnica (Forssk.) Decne.	Per	SA+SZ	Ph	4.65
Pergularia tomentosa L.	Per	SA+SZ	Ch	4.65
Asteraceae				
Cotula cinerea Delile	Ann	SA	Th	9.30
Ifloga spicata (Forssk.) Sch. Bip.	Ann	SA	Th	2.33
Launaea cassiniana	Ann	SA	Th	9.30
L. nudicaulis (L.) Hook. f.	Per	SA+IT	H	2.33
Pulicaria incisa (Lam.) DC.	Ann	SA	H	16.28
P. undulata (L.) C. A. Mey	Per	SA	H	41.86
Boraginaceae				
Trichodesma africanum (L.) R. Br.	Ann	SA+SZ	Ch	27.91
Brassicaceae				
Diplotaxis acris (Forssk.) Boiss.	Ann	SA	Th	13.95
D. harra (Forssk.) Boiss.	Ann	SA	H	4.65

(continued)

Table 7.13 (continued)

Species	D	Chorology	LF	P%
Eruca sativa Mill.	Ann	ME+IT	H	2.33
Morettia philaeana (Delile) DC.	Ann	SA	H	60.47
Schouwia purpurea (Forssk.) Schweinf.	Ann	SA	Th	25.58
Zilla spinosa (L.) Prantl.	Per	SA	Ch	74.42
Cactaceae				
Opuntia ficus-indica (L.) Mill.	Per	SA	Ph	6.98
Caryophyllaceae				
Polycarpaea robbairea (Kuntze) Greuter & Burdet	Ann	SA	Th	4.65
Casuarinaceae				
Casuarina equisetifolia L.	Per	Cultivated	Ph	2.33
Chenopodiaceae				
Salsola imbricata subsp. *imbricata*	Per	SA	Ch	51.16
Cleomaceae				
Cleome amblyocarpa Barratte &Murb.	Ann	SA+SZ	Th	2.33
C. droserifolia (Forssk.) Delile	Per	SA+IT	H	2.33
Cucurbitaceae				
Citrullus colocynthis (L.) Schrad.	Per	ME+SA+IT	H	41.86
Fabaceae				
Astragalus hamosus L.	Ann	ME+IT	Th	6.98
A. vogelii (Webb) Bornm.	Ann	SA	Th	2.33
Crotalaria aegyptiaca Benth.	Per	SZ	H	9.30
Lotus deserti Tackh. & Boulos	Ann	SA	H	4.65
L. hebranicus Hochst. ex Brand	Ann	SA	H	16.28
Retama raetam (Forssk.) Webb & Berthel	Per	SA+IT	Ph	2.33
Senna italica Mill.	Per	SA	H	6.98
S. occidentalis (L.) Link	Per	SZ	Ch	9.30
Geraniaceae				
Monsonia heliotropoides (Cav.) Boiss.	Per	SA	H	2.33
Juncaceae				
Juncus rigidus Desf.	Per	IT+SA	H	2.33
Mimosaceae				
Acacia tortilis (Forssk.) Hayne subsp. *raddiana* (Savi) Brenan	Per	SA	Ph	20.93
Myrtaceae				
Eucalyptus globulus Labill.	Per	Cultivated	Ph	2.33
Palmae				
Phoenix dactylifera L.	Per	SA+SZ	Ph	9.30
Plantaginaceae				
Plantago ovata Forssk.	Ann	ME+SA+IT	Th	4.65
Poaceae				
Cynodon dactylon (L.) Pers.	Per	PAN	G	2.33

(continued)

Table 7.13 (continued)

Species	D	Chorology	LF	P%
Digitaria ciliaris (Retz.) Koeler	Ann	PAN	Th	2.33
Echinochloa colona (L.) Link	Ann	PAN	G	2.33
Phragmites australis (Cav.) Trin. ex. Steud.	Per	PAL	G	6.98
Polypogon monspeliensis (L.) Desf.	Ann	COSM	Th	2.33
Stipagrostis plumosa (L.) Munro ex T. Anderson	Ann-Per	SA+IT	H	2.33
Polygonaceae				
Rumex vesicarius L.	Ann	ME+SA+IT	Th	2.33
Portulacaceae				
Portulaca oleracea L.	Ann	COSM	Th	2.33
Resedaceae				
Ochradenus baccatus Delile	Per	SA	Ph	2.33
Oligomeris linifolia (Hornem) J. F. Macbr.	Ann	SA+SZ	Th	2.33
Reseda pruinosa Delile	Ann	SA	Th	27.91
Rhamnaceae				
Zizyphus spina-christi (L.) Desf.	Per	ME+ SA+ SZ + IT	Ph	6.98
Solanaceae				
Solanum nigrum L.	Ann	COSM	Th	2.33
Tamaricaceae				
Tamarix nilotica (Ehrenb.) Bunge	Per	ME+SA+SZ	Ph	20.93
Urticaceae				
Forsskaolea tenacissima L.	Per	SA+SZ	H	30.23
Zygophyllaceae				
Fagonia Arabica L.	Per	SA	Ch	9.30
F. bruguieri	Per	SA+IT	H	13.95
F. indica Burm.	Per	SA	Ch	27.91
F. thebaica Bioss.	Per	SA	Ch	18.60
Tribulus pentandrus Forssk.	Ann	SA+SZ	Th	6.98
Zygophyllum coccineum L.	Per	SA	Ch	90.70
Z. simplex L.	Ann	SA+SZ	Th	37.21

D duration, *Per* perennials, *Ann* annuals, *Ph* phanerophytes, *H* hemicryptophyte, *Ch* chorology, *Ch* chamaephytes, *Th* theophytes, *Cr* cryptophytes, *G* geophytes, *SA* Saharo–Arabian, *SZ* Sudano–Zambezian, *IT* Irano–Turanian, *ME* Mediterranean, *PAL* Palaeotropical, *PAN* Pantropical, *COSM* Cosmopolitan

Figure 7.14 showed the life forms of the recorded species according to Raunkiaer system (1937). The recorded 61 species belong to 6 different life forms. Therophytes (31.15%) constituted the main bulk of species (19 species), followed by hemicryptophytes (28%) and chamaephytes and phanerophytes (18% for each). Geophytes were the least represented (4.92%) among the life forms.

Chorological analysis of the surveyed flora (59 species after excluding the two cultivated species) presented in Fig. 7.15 revealed that 27 species (45.8% of the total recorded species) were monoregional, of which 25 species (42.4 %) being native to

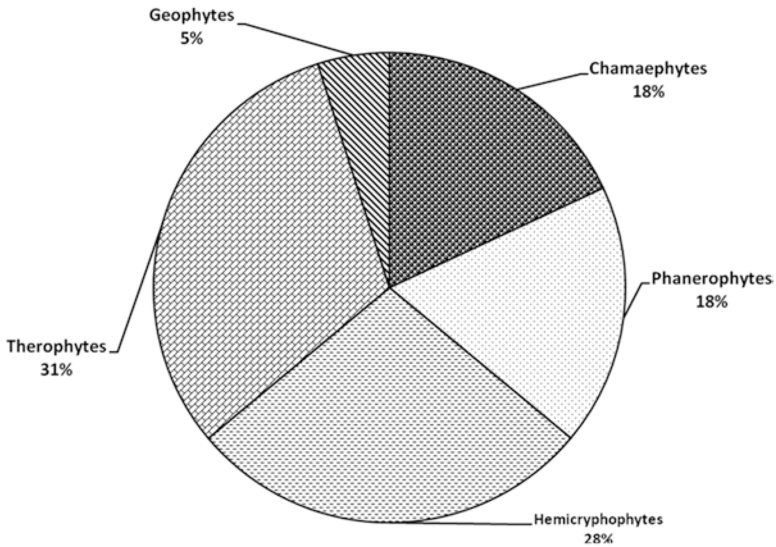

Fig. 7.14 Plant life forms of the recorded species in Qift–Quseir road; the figure presents percentage proportions

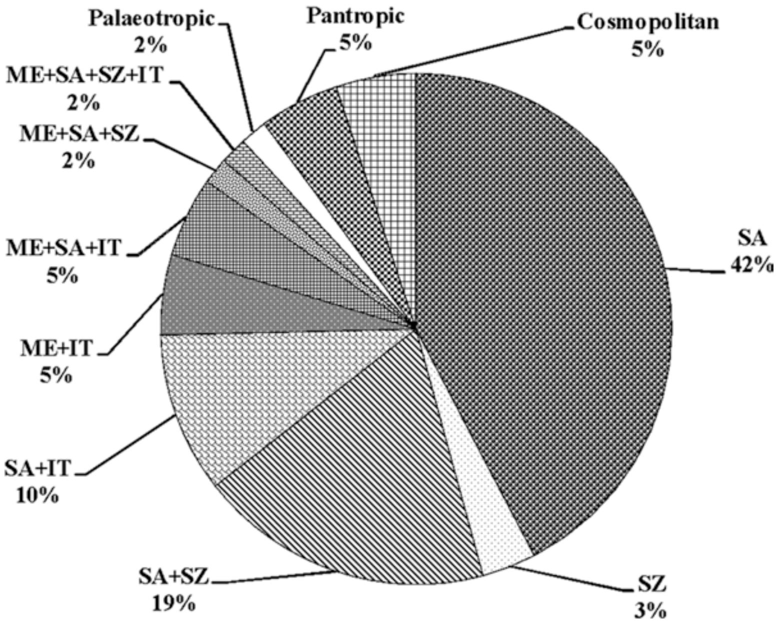

Fig. 7.15 Chorological analysis of the recorded species in Qift–Quseir road; the figure presents percentage proportions

Saharo–Arabian chorotype. Sudano–Zambezian ranked second with 3.4%. About 42.4% of the recorded species were biregional and pluriregional extending their distribution all over the Saharo–Arabian, Sudano–Zambezian, Irano–Turanian, and Mediterranean regions. Being part of Saharo–Arabian region, the Saharo–Arabian chorotype (bi- and pluri-) constituted 33.9% and 8.5% of the recorded species, respectively. *Phragmites australis* is the only Palaeotropical species, meanwhile Pantropical and Cosmopolitan taxa were equally represented (5.1% each).

Multivariate Analysis of Data

Based on their presence values, classification of the 61 species recorded in 43 stands using the cluster analysis yielded 6 vegetation groups at level 63 of the hierarchy (Fig. 7.16, Table 7.14). These groups were named after the first and second dominant species as follows: (1) *Calotropis procera–Opuntia ficus-indica*, (2) *Morettia philaeana–Salsola imbricata* subsp. *imbricate*, (3) *Zygophyllum coccineum–Tamarix nilotica*, (4) *Zilla spinosa–Citrullus colocynthis*, (5) *Lotus hebranicus–Pulicaria undulata*, and (6) *Forsskaolea tenacissima–Reseda pruinosa*. The largest number of species (29) were recorded in group 1 followed by group 5 (27 species) and group 6 (23 species), whereas the lowest number of species were in group 2 (14 species). Data indicated that stands of group 1 located near the Nile Valley at Qift City, while those of group 5 lie near the Red Sea shore at Quseir city. It is noted that group 1 included the highest number of weeds than other groups. According to one-way ANOVA test (Table 7.15), significant differences of the soil variables among the recognized six groups were pH (F-ratio = 7.82, $P = 0.001$) and PO_4 (F-ratio = 3.26, $P = 0.015$).

Detrended Correspondence Analysis (DCA) ordination plot of the 43 stands on axes 1 and 2 was shown in Fig. 7.17, with the six vegetation groups superimposed. The stands were spread out at 4.85 SD units of the first axis (eigenvalue = 0.69), expressing the high floristic variation among the vegetation groups and indicating

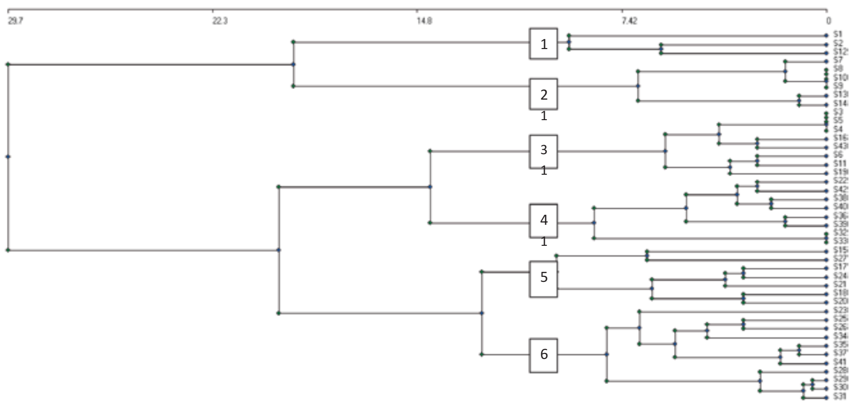

Fig. 7.16 Classification of the studied 43 stands using cluster analysis. 1–6 are the vegetation groups

Table 7.14 Synoptic table of the vegetation groups yielded from the classification

Species	Vegetation groups					
	1	2	3	4	5	6
Number of stands	3	6	8	8	7	11
Number of species	29	14	16	16	27	23
Calotropis procera	**100**					
Opuntia ficus-indica	**100**					
Morettia philaeana		**100**				
Salsola imbricata subsp. *imbricata*		**100**				
Zygophyllum coccineum			**62.5**			
Tamarix nilotica			**37.5**			
Zilla spinosa				**75**		
Citrullus colocynthis				**62.5**		
Lotus hebranicus					**71.43**	
Pulicaria undulata					**71.43**	
Forsskaolea tenacissima						**63.64**
Reseda pruinosa						**63.64**

Figures in **bold** are species with the highest presence values

Table 7.15 Results of ordination for the first three axes of CCA (Canonical Correspondence Analysis) inter-set correlations of the soil variables, together with eigenvalues and species–environment correlation coefficients

			CCA axis		
		F-ratio	1	2	3
Eigenvalues			0.483	0.314	0.227
Species–environment correlation coefficients			0.924	0.939	0.820
pH		7.82**	0.398	−0.523	0.464
Coarse sand (CS)	(%)	0.97	−0.110	−0.037	−0.685
Fine sand (FS)	(%)	2.23	0.347	−0.208	0.197
Silt	(%)	0.56	−0.028	0.202	0.657
Clay	(%)	0.83	−0.085	0.098	0.446
Organic matter	(%)	1.67	0.514	0.408	0.008
Na	(mg/l)	0.84	0.465	0.770	−0.006
K	(mg/l)	0.92	0.570	0.729	−0.058
Ca	(mg/l)	0.71	0.510	0.747	−0.080
Cl	(mg/l)	0.86	0.376	0.747	−0.212
SO4	(mg/l)	1.13	0.366	0.397	−0.172
PO4		3.26*	0.446	−0.390	0.080

$*P < 0.05$, $**P < 0.01$

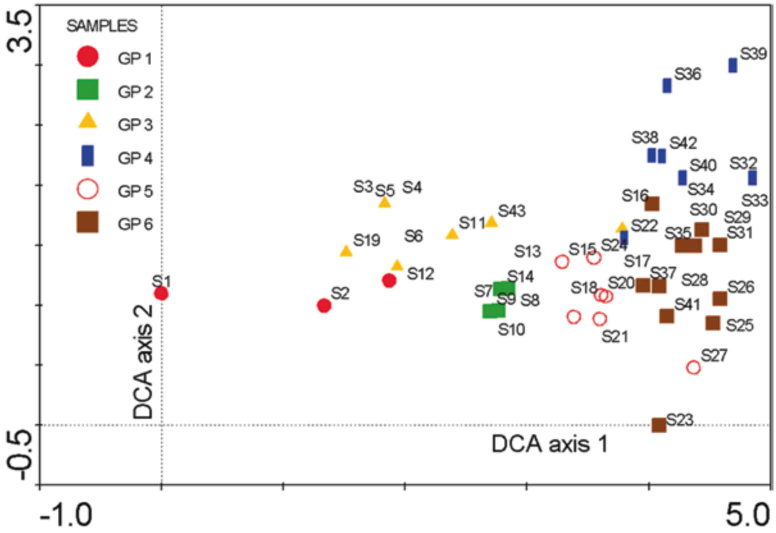

Fig. 7.17 DCA ordination diagram of the 43 stands on axes 1 and 2 as classified by cluster analysis; 1–6 are the six vegetation groups

that complete turnover in species composition took place (Hill 1979). Stands of groups 4, 5, and 6 were separated towards the positive end of DCA axis 1, while those of groups 1 and 3 were separated out along the other end. DCA axis 2 with eigenvalue of 0.32 and a gradient length of 2.99 was less important.

The species–environment correlations were higher for the first three canonical axes, explaining 54.6.4% of the cumulative variance (Table 7.15). 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 organic matter, Na, K, and Ca and negatively with coarse sand. This axis can be defined as K-coarse sand gradient. CCA axis 2 was positively correlated with Na, K, and Ca and negatively correlated with pH. Therefore, CCA axis 2 can be defined as Na–pH gradient. This fact becomes evident in the ordination biplot (Fig. 7.18). 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 (Jongman et al. 1987).

7.7 General Remarks

1. The vegetation in the study area, as in other hyperarid regions, is restricted to wadis, runnels, and depressions with deep fine sediments that receive adequate water supply (Monod 1954; Zohary 1962; Walter 1963). As Parker (1991) suggested, the distribution of the dominant species and variations in distributional patterns over a small geographic area in desert ecosystem may be related to edaphic factors and local topography. Application of classification to floristic data in the

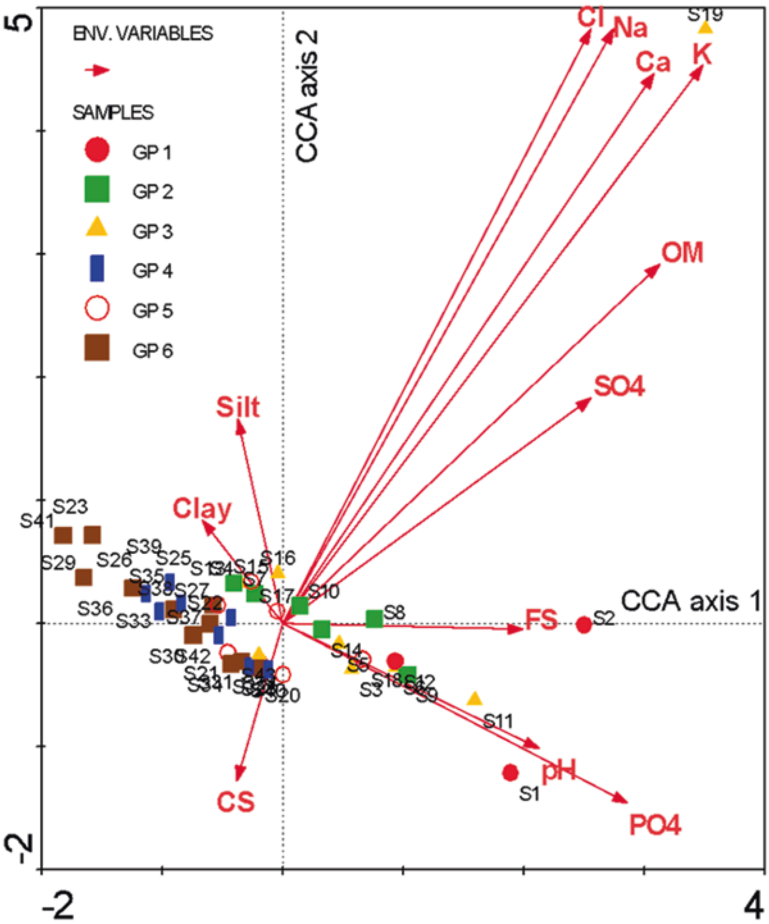

Fig. 7.18 CCA ordination biplot of the studies 43 stands, and soil variables, together with their vegetation groups

present study revealed six vegetation groups: (1) *Calotropis procera–Opuntia ficus-indica*, (2) *Morettia philaeana–Salsola imbricata* subsp. *imbricata*, (3) *Zygophyllum coccineum–Tamarix nilotica*, (4) *Zilla spinosa–Citrullus colocynthis*, (5) *Lotus hebranicus–Pulicaria undulata*, and (6) *Forsskaolea tenacissima–Reseda pruinosa*. Some of the characteristic species of the identified groups were salt-tolerant species, indicating the saline nature of the study area. Detrended Correspondence Analysis (DCA) supports the distinction between these groups. Some of the identified vegetation groups have very much in common with that recorded along the western Mediterranean coastal region (Shaltout and El-Ghareeb 1992), in south Sinai region (El-Ghareeb and Shabana 1990 and; Abd El-Ghani and Amer 2003), in some wadis of the Eastern (Salama and Fayed 1990; Fossati et al. 1998) and Western Desert (Bornkamm and Kehl 1985; Abd El-Ghani 2000; Abd El-Ghani and Marei 2007), and in the Negev Desert of

Israel (Olsvig-Whittaker et al. 1983; Tielbörger 1997). Owing to the specific environment of the study area, many species with nitrophilous (e.g. *Cynodon dactylon* and *Phragmites australis*), psammophilous (e.g. *Acacia tortilis* subsp. *raddiana, Zygophyllum coccineum*, *Schouwia purpurea*, *Launaea cassiniana*, *Zilla spinosa*, and *Pulicaria undulata*), halophilous (e.g. *Juncus rigidus*), and psammohalophilous (e.g. *Salsola imbricata* subsp. *imbricata* and *Tamarix nilotica*) characters occurred in the distinguished vegetation groups.

2. The results of Canonical Correspondence Analysis (CCA) indicated that organic matters, Na, K, Ca, and pH, were the most important factors for the distribution of the vegetation pattern along the road verges in the study area. Similar results were reached by Batanouny (1979) and Abd El-Ghani (1998). The distribution of the vegetation groups reflects these relations, with groups 4, 5, and 6 located near the Red Sea shore, while those of groups 1, 2, and 3 near Nile Valley. The soil characteristics of stands of the latter groups showed relatively high salinity than those near the Red Sea. This may be attributed to the fact that most of these salts were leached by the water of rainfall and torrents towards the sea, which can be detected by the dominance of some salt-tolerant species such as *Salsola imbricata* subsp. *imbricata* and *Tamarix nilotica.* On the other hand, groups 1, 2, and 3 included some weed species (e.g. *Amaranthus graecizans*, *Digitaria ciliaris*, *Echinochloa colona*, *Polypogon monspeliensis*, and *Portulaca oleracea*) of arable lands than the other groups. These weeds were known among the common weeds of Egypt (El Hadidi and Kosinova 1971; Abd El-Ghani and El-Sawaf 2005). That is because the study area close to the boundaries of the agroecosystem of the Nile Valley at Qift City and many lands have been reclaimed and under recent cultivation. Thus, weeds find the new conditions favorable for their growth, and their invasion took place. Therefore, the road verges near the Nile Valley of this study can be considered as a transitional phase of the succession process between the habitat of the old cultivated lands and that of the desert.
3. The prevalence of the Saharo–Arabian element in the studied flora confirms its clear consistency to the Saharo–Arabian region of the Holarctic Kingdom. Whereas the Sudano–Zambezian element is not represented, the Mediterranean taxa are very modestly represented in the therophyte and chamaephyte layers. Accordingly, species of the Saharo–Arabian region are good indicators for harsh desert conditions (Hegazy et al. 1998; Abd El-Ghani and Amer 2003).

7.7.1 Along Six Desert Roads Crossing the Eastern Desert

The study was done along six main desert roads (transects) running from east to west in the Eastern Desert of Egypt (Fig. 7.19). These roads represent, as much as possible, the different geomorphological regions encountered in this area. Three roads are located in the northern part (R1, R2, and R3) of the Eastern Desert, while the remaining three (R4, R5, and R6) are located in the southern part, from north to south: Cairo–Suez road (R1) about 120 km between 30° 05′N and 31° 51′E,

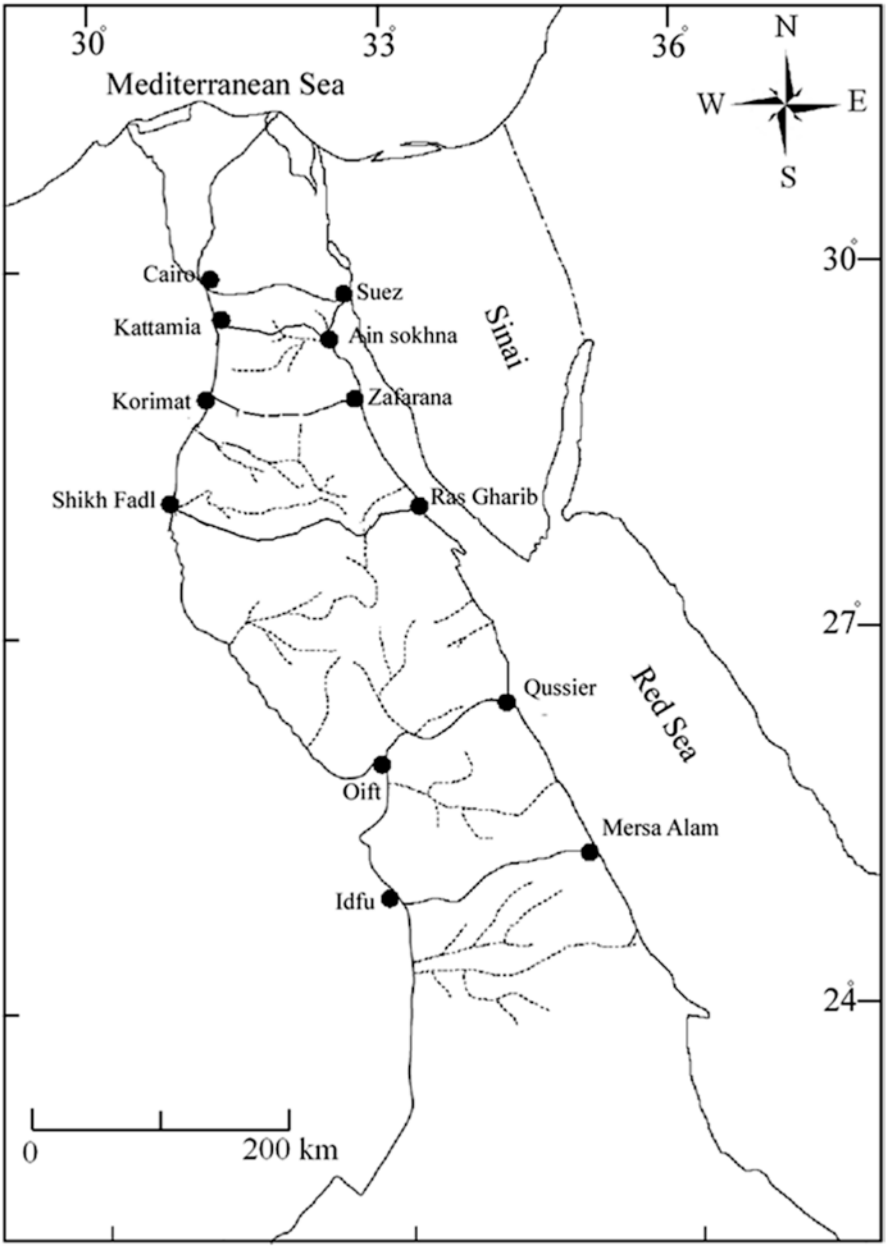

Fig. 7.19 Map showing the location of the studied six roads

Kattamia–Ain Sokhna road (R2) about 117 between 29° 54′ N and 32° 09′E, Korimat–Zaafarana road (R3) about 160 km between 29° 03′N and 31° 04′E, Sheikh fadl–Ras Gharib road (R4) about 240 km between 28° 18′N and 31° 21′E, and Qift–Quseir road (R5) about 165 km between 25° 56′ N and 33° 22′E, and Edfu–Marsa Alam road (R6) about 212 km between 24° 59′N and 33° 20′E.

Taxonomic richness indicates that the northern roads (Cairo–Suez, Kattamia–Ain Sokhna, and Korimat–Zaafarana) are highly rich with species than that of the middle and south parts. The Korimat–Zaafarana road has the highest number of species (114 species) followed by Cairo–Suez road and Kattamia–Ain Sokhna road by 113 and 101 species, respectively. A total of 55 species were common among these three roads. The remaining three roads (Shikh Fadl–Ras Gharib, Qift–Quseir, and Edfu–Marsa Alam road) showed low value of species richness; the recorded species were 54, 52, and 31, respectively, with 15 common species. Along all of the studies roads, only nine species were common, and two species were recorded in more than half of the recorded sites: *Zilla spinosa* (86.2%) and Zygophyllum *coccineum* (62.7%); these two species were indicated as the more constant plants in the study area (Fossati et al. 1998). The variation in the floristic composition between the studied roads can be contributed to the harsh environmental condition that controls the middle and south parts of the Eastern Desert of Egypt.

Based on indicator species, the two-way indicator species analysis (TWINSPAN) of the 145 studies sites versus the 202 recorded species produced 8 vegetation groups named after the first and second dominant species (Fig. 7.20; Table 7.16). The first hierarchical division separated the sites of Qift–Quseir and Edfu–Marsa Alam roads (southern roads) from the others. The allocation of each of the separated vegetation

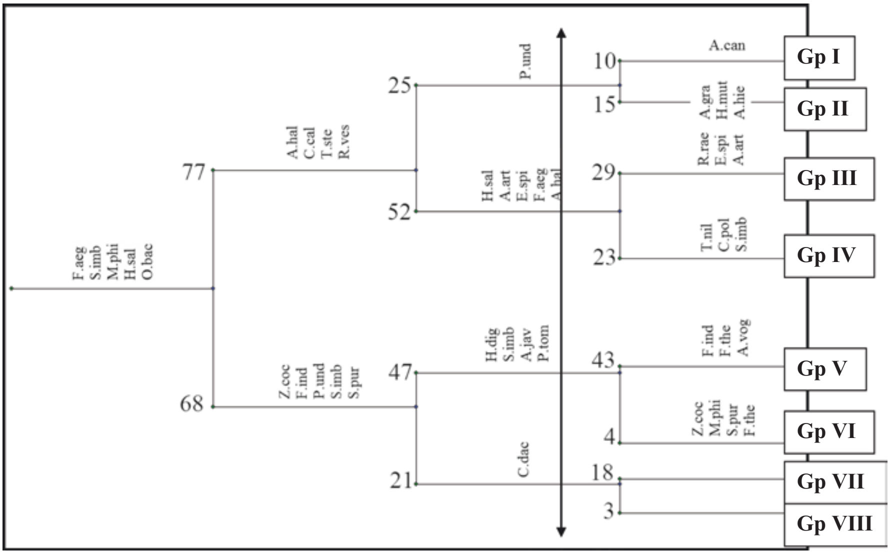

Fig. 7.20 TWINSPAN dendrogram showing the resulted eight vegetation groups (I–VIII)

Table 7.16 Floristic composition of the eight TWINSPAN vegetation groups, together with their life forms (Lf) and chorotypes

Family	Species	Vegetation groups								Lf	Chorotypes
		I	II	III	IV	V	VI	VI I	VIII		
Aizoaceae	*Mesembryanthemum nodiflorum* L.								10	Th	Med, ES, SS
Aizoaceae	*Mesembryanthemum crystallinum* L.								10	Th	Med, ES
Chenopodiaceae	*Atriplex lindleyi* Moq.								20	Th	Med, SS
Chenopodiaceae	*Chenopodium album* L.								10	Th	Cosm
Chenopodiaceae	*Chenopodium ficifolium* Sm.								20	Th	SS, IT
Chenopodiaceae	*Traganum nudatum*								30	Ch	SS
Asteraceae	*Bidens pilosa* L.								10	Th	Med, IT, ES
Brassicaceae	*Savignya parviflora* (Delile) Webb								10	Th	SS
Brassicaceae	*Pseuderucaria clavata* (Boiss & Reut.) O.E. Schulz								60	Th	SS
Frankeniaceae	*Frankenia pulverulenta* L.								10	Th	Med, SS, IT
Poaceae	*Hordeum murinum* L.								10	Th	SS, IT
Poaceae	*Schismus barbatus* (L.) Thell.								10	Th	Med, IT, ES
Fabaceae	*Alhagi graecorum* Boiss.								30	H	SS, IT
Orobanchaceae	*Cistanche tubulosa* (Schenk) Hook. f.								30	P	SS, IT
Orobanchaceae	*Orobanche crenata* Forsk.								10	P	Med, SS, IT
Polygonaceae	*Polygonum equisetiforme* Sm.								20	Ch	Med, SS, IT
Typhaceae	*Typha domingensis* (Pers.) Poir. ex Steud.								10	HH	Pan
Zygophyllaceae	*Peganum harmala* L.								20	H	Med, SS, IT, ES

(continued)

Table 7.16 (continued)

Family	Species	Vegetation groups I	II	III	IV	V	VI	VII	VIII	Lf	Chorotypes
Aizoaceae	*Mesembryanthemum forsskalei* Hochst.							13	50	Th	SS
Caryophyllaceae	*Gymnocarpos decandrum* Forssk.							20	20	Ch	SS
Caryophyllaceae	*Spergularia marina* (L.) Griseb.							20	20	Th	Med, IT, ES
Asteraceae	*Volutaria lippii* (L.) Cass. ex Maire							20	10	Th	Med, SS
Asteraceae	*Atractylis carduus* (Forssk.) Christens.							7	10	H	SS
Asteraceae	*Conyza bonariensis* (L.) Cronquist							13	20	Th	Med
Geraniaceae	*Erodium malacoides* (L.) L'Hér.							13	20	Th	Med, IT
Poaceae	*Avena fatua* L.							7	10	Th	Cosm
Malvaceae	*Malva parviflora* L.							13	30	Th	Med, IT, ES
Boraginaceae	*Lappula spinocarpos* (Forssk.) Asch. ex Kuntze							20		Th	SS, IT
Caryophyllaceae	*Herniaria hemistemon* J. Gay							7		Th	SS, IT
Caryophyllaceae	*Pteranthus dichotomus* Forssk.							40		Th	SS
Chenopodiaceae	*Agathophora alopecuroides* (Delile) Fenzl ex Bunge							20		Ch	SS
Chenopodiaceae	*Suaeda monoica* Forssk. ex J.F. Gmel							20		Ph	SS, SZ
Cistaceae	*Helianthemum kahiricum* Delile							7		Ch	SS
Asteraceae	*Phagnalon barbeyanum* Asch. & Schweinf.							7		Ch	SS
Asteraceae	*Cichorium pumilum* Jacq.							7		Th	Med, IT

Asteraceae	*Filago desertorum* Pomel							13		Th	SS, IT
Asteraceae	*Atractylis mernephthae* Asch.							13		Th	SS
Convolvulaceae	*Convolvulus lanatus* Vahl							7		Ch	SS
Poaceae	*Aeluropus lagopoides* (L.) Trin. ex Thwaites							7		H	Med, IT, ES,SS
Poaceae	*Avena sterilis* L.							7		Th	Med, IT
Poaceae	*Bromus madritensis* L.							7		Th	Med, SS, IT
Poaceae	*Leptochloa fusca* (L.) Kunth							13		H	Pal
Poaceae	*Crypsis aculeata* (L.) Aiton.							7		Th	Med, IT, ES
Poaceae	*Lolium perenne* L.							7		H	Med, IT, ES
Poaceae	*Phalaris paradoxa* L.							7		Th	Med, IT
Fabaceae	*Lotus halophilus* Boiss. & Spruner							13		Th	Med, SS, IT
Fabaceae	*Cullen plicata* (Delile) C. H. Stirt.							7		H	SS
Plantaginaceae	*Plantago ovata* Forssk.							47		Th	Med, SS, IT
Resedaceae	*Caylusea hexagyna* (Forssk.) M.L. Green							7		Th	SS
Resedaceae	*Reseda decursiva* Forssk.							7		Th	SS
Zygophyllaceae	*Fagonia glutinosa* Delile							13		H	SS
Zygophyllaceae	*Fagonia terristris* Sickenb.							33		Ch	SS
Capparidaceae	*Capparis spinosa* L.						3	7		Ph	Med, SS, IT
Caryophyllaceae	*Paronychia arabica* (L.) DC.						7	33		Th	SS, IT
Asteraceae	*Achillea fragrantissima* (Forssk.) Sch. Bip.						14	20		Ch	SS, IT
Asteraceae	*Artemisia monosperma* Delile						14	7		Ch	SS
Asteraceae	*Nauplius graveolens* (Forssk.) Wiklund						7	47		H	SS

(continued)

Table 7.16 (continued)

Family	Species	Vegetation groups								Lf	Chorotypes
		I	II	III	IV	V	VI	VII	VIII		
Astraceae	*Launaea capitata* (Spreng.) Dandy						7	33		Th	SS
Ephedraceae	*Ephedra aphylla* Forssk.						3	7		Ph	SS
Fabaceae	*Astragalus annularis* Forssk.						3	13		Th	SS, IT
Liliaceae	*Asphodelus tenuifolius* Cav.						7	13		Th	Med, SS, IT
Neuradaceae	*Neurada procumbens* L.						7	13		Th	SS
Fabaceae	*Medicago laciniata* (L.) Mill.						3	33		Th	SS
Plantaginaceae	*Plantago ciliata* Desf.						3	20		Th	SS, IT
Polygonaceae	*Emex spinosus* (L.) Campd.						3	7		Th	Med, IT
Resedaceae	*Reseda arabica* Boiss.						7	20		Th	SS
Zygophyllaceae	*Zygophyllum decumbens* Delile						7	7		Ch	SS
Rutaceae	*Haplophyllum tuberculatum* (Forssk.) A. Juss.						14			Ch	SS
Fabaceae	*Senna italica* Mill						10			H	SZ
Poaceae	*Imperata cylindrica* (L.) Raeusch.						10			H	Med, SS, IT
Lamiaceae	*Lavandula stricta* Delile						10			Ch	SS
Zygophyllaceae	*Fagonia arabica* L.						10			Ch	SS
Fabaceae	*Astragalus sieberi* DC.						7			Ch	SS
Cannabaceae	*Cannabis sativa* L.						3			Th	Cosm
Chenopodiaceae	*Cornulaca monacantha* Delile						3			Ch	SS
Cistaceae	*Helianthemum lippii* (L.) Dum. Cours.						3			Ch	SS
Convolvulaceae	*Convolvulus pilosellifolius* Desr.						3			H	SS, IT
Fabaceae	*Astragalus hamosus* L.						3			Th	Med.

Fabaceae	*Astragalus schimperi* Boiss.						3			Th	SS
Fabaceae	*Hippocrepis constricta* Knuze						3			Th	Med
Solanaceae	*Hyoscyamus albus* L.						3			H	Med
Sterculiaceae	*Glossostemon bruguieri* Desf.						3			Th	IT
Zygophyllaceae	*Tribulus megistopterus* Kralik						3			Th	SS
Fabaceae	*Taverniera aegyptiaca* Boiss.					4	3			Ch	SS
Juncaceae	*Juncus rigidus* Desf.					4				Hel	Med, SS, IT
Solanaceae	*Hyoscyamus boveanus* (Dunal) Asch. & Schweinf.					4				H	SS
Chenopodiaceae	*Suaeda altissima* (L.) Pall.				5	4				Th	Med, IT, ES
Fabaceae	*Lotus hebranicus* Brand				33	4				H	SS
Caryophyllaceae	*Polycarpaea robbairea* (Kuntze) Greuter & Burdet				12					Th	SS
Cleomaceae	*Cleome chrysantha* Decne.				2					H	SS
Cleomaceae	*Cleome droserifolia* (Forssk.) Delile				7					H	SS
Geraniaceae	*Monsonia nivea* (Decne.) Webb				2					H	SS
Geraniaceae	*Monsonia heliotropoides* (Cav.) Bioss.				2					H	SS
Fabaceae	*Astragalus eremophilus* Boiss.				2					Th	SS
Fabaceae	*Lotononis platycarpa* (Viv.) Pic. Serm.				7					Th	SZ
Boraginaceae	*Heliotropium digynum* (Forssk.) Asch. ex C.Chr.			50						Ch	SS
Caryophyllaceae	*Polycarpaea repens* (Forssk.) Asch. & Schweinf.			25						Th	SS
Brassicaceae	*Farsetia stylosa* R. Br.		17							Ch	SZ

(continued)

Table 7.16 (continued)

Family	Species	Vegetation groups								Lf	Chorotypes
		I	II	III	IV	V	VI	VII	VIII		
Amaranthaceae	*Amaranthus graecizans* L.	33								Th	Pal
Poaceae	*Echinochloa colona* (L.) link	33								Th	SS, IT
Portulacaceae	*Portulaca oleracea* L.	33								Th	Cosm
Solanaceae	*Solanum nigrum* L.	33								Th	Cosm
Amaranthaceae	*Amaranthus viridis* L.						3		10	Th	Cosm
Caryophyllaceae	*Spergularia diandra* (Guss.) Boiss.						3		10	Th	Med, SS, IT
Chenopodiaceae	*Anabasis articulata* (Forssk.) Moq.						41		40	Ch	SS, IT
Chenopodiaceae	*Arthrocnemum macrostachyum* (Moric.) K. Koch						3		40	Ch	Med, SS
Euphorbiaceae	*Chrozophora oblongifolia* (Delile) Spreng.						3		10	Ch	Med, SS
Poaceae	*Pennisetum divisum* (Forssk. ex J. F. Gmel.) Henrard						3		10	H	SS
Aizoaceae	*Aizoon canariense* L.						14	7	10	Th	SZ
Asclepiadaceae	*Cynanchum acutum* L.						3	20	70	H	SS
Boraginaceae	*Anchusa hispida* Forssk.						3	33	20	Th	SS, IT
Caryophyllaceae	*Gypsophila capillaris* (Forssk.) C.Chr.						10	7	20	H	Med, SS
Asteraceae	*Anthemis melampodina* Delile						3	13	10	Th	SS, IT
Asteraceae	*Centaurea calcitrapa* L.						7	73	40	H	Med, SS, IT
Asteraceae	*Pluchea dioscoridis* (L.) DC.						3	7	20	Ph	SS, KN, SZ
Asteraceae	*Echinops spinosissimus* Turra						41	60	20	Ch	SS, IT
Asteraceae	*Reichardia tingitana* (L.) Roth						7	33	20	Th	Med, SS, IT

Brassicaceae	*Diplotaxis harra* (Forssk.) Boiss.						24	80	30	H	SS
Brassicaceae	*Matthiola livida* (Delile) DC.						14	27	20	Th	SS
Geraniaceae	*Erodium glaucophyllum* (L.) L'Hér.						10	20	50	H	SS
Geraniaceae	*Erodium oxyrrhynchum* M. Bieb						3	33	10	H	SS
Fabaceae	*Astragalus bombycinus* Boiss.						3	7	10	Th	SS, IT
Malvaceae	*Althaea ludwigii* L.						3	40	10	Th	SS
Plantaginaceae	*Plantago cylindrica* Forssk.						3	13	30	Th	SS
Scrophulariaceae	*Kickxia aegyptiaca* (Dum.) Nabelek						20	20	10	Ch	SS
Solanaceae	*Lycium shawii* Roem. et Sch.						3	40	30	Ph	SS
Boraginaceae	*Heliotropium bacciferum* Forssk.					9	14	13	30	Ch	SS
Chenopodiaceae	*Bassia muricata* (L.) Murr.					4	7	40	40	Th	SS, IT
Asteraceae	*Senecio glaucus* L.					4	7	60	20	Th	Med, SS, IT
Brassicaceae	*Anastatica hierochuntica* L.					30	7	47	10	Th	SS
Ephedraceae	*Ephedra alata* Decne.					4	3	7	10	Ph	Med, SS
Euphorbiaceae	*Euphorbia retusa* Forssk.					22	17	40	50	H	SS
Poaceae	*Lasiurus scindicus* Henrad					4	17	13	40	H	SS
Fabaceae	*Trigonella stellata* Forssk.					4	17	80	60	Th	SS, IT
Solanaceae	*Hyoscyamus muticus* L.					17	24	27	40	H	SS, IT
Apiaceae	*Deverra tortuosa* (Desf.) DC.					4	24	7	40	Ch	SS
Zygophyllaceae	*Fagonia mollis* Delile					9	45	27	40	Ch	SS
Chenopodiaceae	*Anabasis setifera* Moq.				2	43	28	60	50	Ch	SS, IT
Chenopodiaceae	*Haloxylon salicornicum* (Moq.) Bung ex Boiss.				5	87	45	60	20	Ch	SS, IT

(continued)

Table 7.16 (continued)

Family	Species	Vegetation groups								Lf	Chorotypes
		I	II	III	IV	V	VI	VII	VIII		
Cleomaceae	*Cleome amblyocarpa* Barratte &Murb.				2	9	24	13	20	Th	SS, SZ
Asteraceae	*Artemisia judaica* L.				2	9	3	13	10	Th	SS
Asteraceae	*Centaurea aegyptiaca* L.				2	13	7	20	10	H	SS
Asteraceae	*Launaea nudicaulis* (L.) Hook. f.				5	4	28	67	20	H	SS, IT
Brassicaceae	*Farsetia aegyptia* Turra				2	13	59	67	40	Ch	SS
Fabaceae	*Retama raetam* (Forssk.) Webb & Berthel.				2	17	41	27	20	Ph	SS
Polygonaceae	*Rumex vesicarius* L.				2	4	10	60	60	Th	SS, IT
Resedaceae	*Ochradenus baccatus* Delile				5	78	48	73	30	Ph	SS
Zygophyllaceae	*Fagonia brugieri* DC.				23	39	38	40	10	H	SS, IT
Asclepiadaceae	*Pergularia tomentosa* L.			75	2	4	21	60	40	Ch	SS
Brassicaceae	*Zilla spinosa* (L.) Prantl		94	75	98	65	93	80	80	Ch	SS
Zygophyllaceae	*Zygophyllum coccineum* L.	33	17	25	65	83	86	47	60	Ch	SS
Tamaricaceae	*Tamarix nilotica* (Ehrenb.) Bge	100	5		9	48	38	67	10	Ph	SS, IT
Zygophyllaceae	*Zygophyllum simplex* L.		28		42	22	41	40	90	Th	SS, Nam
Chenopodiaceae	*Salsola imbricata*	67	100		49	35	10	7	10	Ch	SS
Poaceae	*Phragmites australis* (Cav.) Trin. ex Steud.	33	11			13	7	13	20	Hyd, Hel	Pan
Asclepiadaceae	*Calotropis procera* (Ait.) Ait. f.	100	11		2		14	13	20	Ph	SS
Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.	67	22		51		14	20	20	H	Med, SS, IT

Boraginaceae	*Trichodesma africanum* (L.) R. Br.		22		42		28	53	10	Ch	SS,SZ, GC
Asteraceae	*Sonchus oleraceus* L.	33					14	53	20	Th	Cosm
Poaceae	*Polypogon monspeliensis* (L.) Desf.	33					7	7	20	Th	Cosm
Poaceae	*Panicum turgidum* Forssk.			25			34	47	20	G	Med, SS, IT
Chenopodiaceae	*Atriplex halimus* L.				7	39		67	70	Ph	Med, SS, IT
Chenopodiaceae	*Bassia indica* (Wight) A.J. Scott				2	13		13	40	Th	SS, IT
Tamaricaceae	*Reaumuria hirtella* Jaub. et Sp.					4.3		40	30	Ch	SS
Asteraceae	*Iphiona mucronata* (Forssk.) Asch. et Schweinf.			50			17	47	10	Ch	SS
Zygophyllaceae	*Zygophyllum album* L.f.					4	3		20	Ch	SS, IT
Amaranthaceae	*Aerva javanica* (Burm. f.) Spreng.		22	75	16		3		10	Ch	SS
Poaceae	*Cynodon dactylon* (L.) Pers.	100					7		20	G	Cosm
Resedaceae	*Reseda pruinosa* Delile				28	4	3		10	Th	SS
Chenopodiaceae	*Atriplex leucoclada* Boiss				2	4			20	Ch	SS, IT
Nitrariacea	*Nitraria retusa* (Forssk.) Asch.					4			30	Ph	SS
Tamaricaceae	*Tamarix tetragyna* Ehrenb.					4			20	Ph	Med, SS, IT
Zygophyllaceae	*Tribulus terrestris* L.	33	6						10	Th	Pan
Asteraceae	*Pulicaria undulata* (L.) Kostel		17	75	58	30	55	87		Ch	SS
Fabaceae	*Acacia raddiana* (Savi) Brenan		44	50	26	9	28	27		Ph	SS, SZ
Asteraceae	*Cotula cinerea* Delile		6		7	17	28	7		Th	SS
Resedaceae	*Oligomeris linifolia* (Vahl) Macbr.				9	4	10	27		Th	SS
Asteraceae	*Launaea mucronata* (Forssk.) Muschl.		11		2		28	40		H	SS

(continued)

Table 7.16 (continued)

Family	Species	Vegetation groups								Lf	Chorotypes
		I	II	III	IV	V	VI	VII	VIII		
Brassicaceae	*Diplotaxis acris* (Forssk.) Boiss.				5		7	7		Th	SS
Fabaceae	*Lotus glinoides* Delile				2		7	7		Th	SS
Zygophyllaceae	*Fagonia indica* Burm. f.				44		10	33		Ch	SS
Orobanchaceae	*Cistanche phelypaea* (L.) Cout.					13	31	7		P	Med, SS, IT
Asteraceae	*Ifloga spicata* (Forssk.) Sch. Bip.				5		7	20		Th	Med, SS, IT
Chenopodiaceae	*Chenopodium murale* L.	33						13		Th	Cosm
Brassicaceae	*Eruca sativa* Miller	33						13		Th	SS, IT
Plantaginaceae	*Plantago amplexicaulis* Cav.				2			13		Th	Med, SS, IT
Fabaceae	*Astragalus vogelii* (Webb.) Bornm.		17		23			13		Th	SS
Asteraceae	*Launaea spinosa* (Forssk.) Sch. Bip.				2		24			Ch	SS
Fabaceae	*Crotalaria aegyptiaca* Benth.				7		14			H	SS
Urticaceae	*Forsskaolea tenacissima* L.				35		10			H	SS, SZ
Euphorbiaceae	*Euphorbia granulata* Forssk.				2		7			Th	SS
Brassicaceae	*Eremobium aegyptiacum* (Spreng.) Asch. & Schweinf. ex Bioss				7		3			Th	SS
Poaceae	*Stipagrostis plumosa* (L.) Munro ex T. Anderson				9		3			H	SS, IT
Polygonaceae	*Calligonum polygonoides* L.				2	35	3			Ch	Med, SS
Tamaricaceae	*Tamarix aphylla* (L.) H. Karst.		17			22	3			Ph	SS

Asteraceae	*Pulicaria incisa* (Lam.) DC.				7	4	17			H	SS,GC
Fabaceae	*Astragalus trigonus* DC.					4	7			Ch	SS
Asclepiadaceae	*Leptadenia pyrotechnica* (Forssk.) Decne			25	16		3			Ph	SS
Brassicaceae	*Morettia philaeana* (Delile) DC.		72		46					H	SS
Zygophyllaceae	*Tribulus pentandrus* Forssk.		6		7					Th	SS
Zygophyllaceae	*Fagonia thebaica* Bioss.		50		9					Ch	SS
Brassicaceae	*Schouwia purpurea* (Forssk.) Schweinf.	67	67		2					Th	SS

Figures are the presence percentages (*P%*). For life form abbreviations, see Table 7.13
Chorotype abbreviations: *SS* Saharo-Sindian, *SZ* Suda no-Zambezian, *IT* Irano-Turanian, *ES* Euro-Siberian, *Med* Mediter ranean, *GC* Guinea-Congo, *Cosm* Cpsmopolitan, *Pan* Pantropical, *Pal* Paleotropical

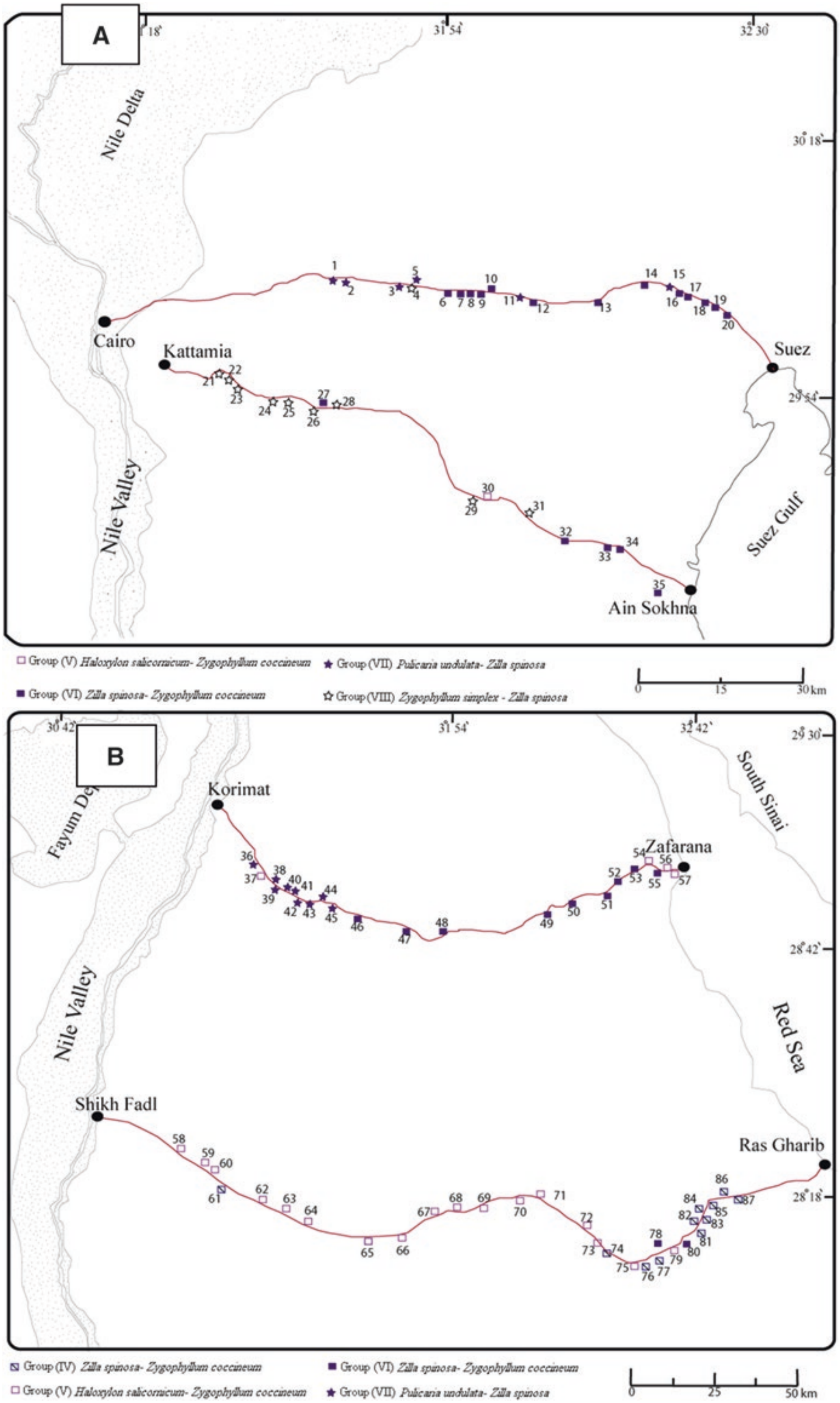

Fig. 7.21 (**A–C**) Allocating each of the eight vegetation groups resulted from TWINSPAN analysis of the studied roads

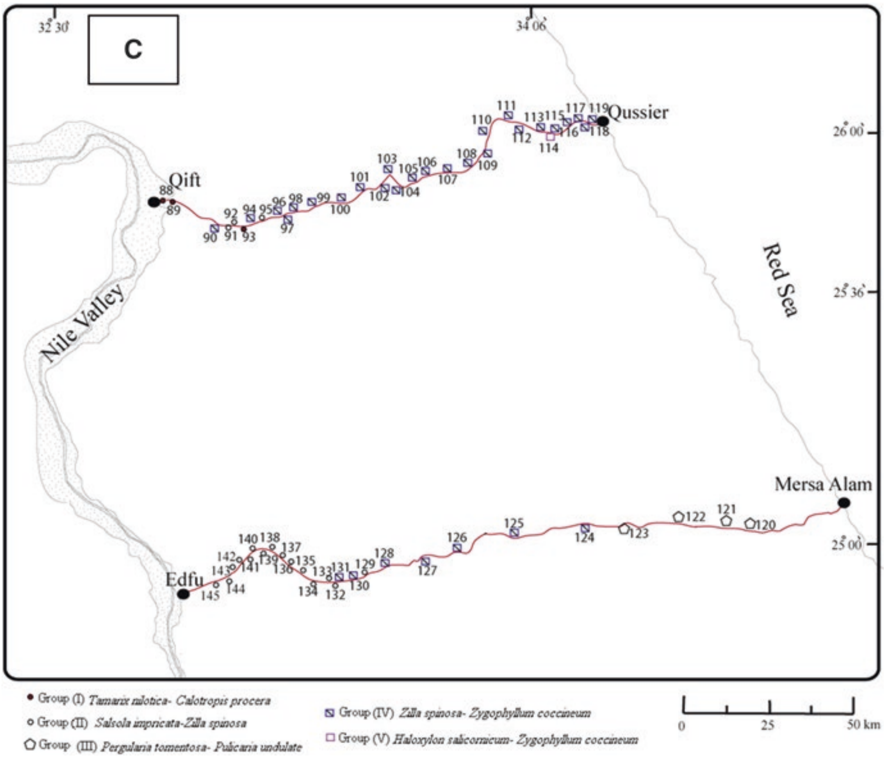

Fig. 7.21 (continued)

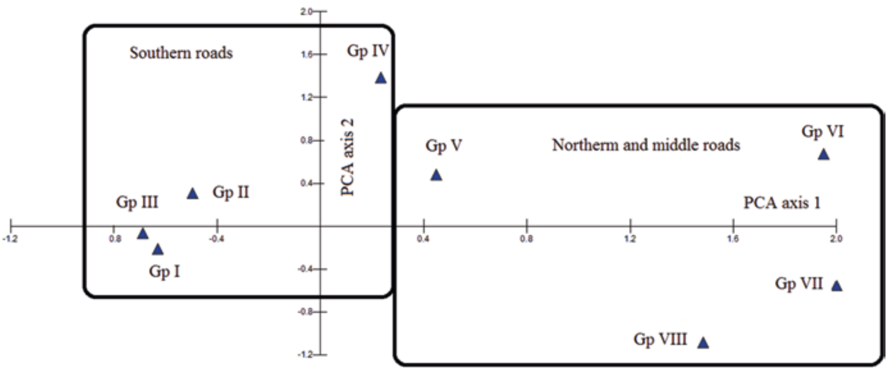

Fig. 7.22 PCA ordination diagram displaying the separation of the eight vegetation groups along the first two axes

groups is displayed on the studied roads (Fig. 7.21a–c) and along the first two axes of PCA (Fig. 7.22). A brief description of these vegetation groups is presented below:

I. *Tamarix nilotica–Calotropis procera* group. It represents plant communities of the newly reclaimed desert lands. It is a less diversified group containing 17 species over 3 sites; the most prominent associates were *Salsola imbricata* subsp. *imbricata*, *Citrullus colocynthis*, and *Schouwia purpurea.* Other associates included ephemerals and weedy species such as *Chenopodium murale*, *Portulaca oleracea*, *Sonchus oleraceus*, and *Tribulus terrestris.*

II. *Salsola imbricata* subsp. *imbricata–Zilla spinosa* vegetation group (22 species; 18 sites). Together with other perennials, both species germinate in the rainy season, but the early stages of their development are much slower than that of the ephemerals. A similar plant community was reported by Zahran and Willis (1992) at 10–20 km east of Idfu and at wadi Abbad of the southern part of the Eastern Desert of Egypt. Perennials included *Acacia raddiana*, *Calotropis procera*, and *Pulicaria undulata*, while annuals were represented by *Astragalus vogelii*, *Morettia philaeana*, *Schouwia purpurea*, and *Zygophyllum simplex*.

III. *Pergularia tomentosa–Pulicaria undulata* group. It is the least diversified (11 species; 4 sites) and representing the plant communities at the late summer in the southern roads of the study area. Eleven perennial species were recorded in this group including *Acacia raddiana*, *Aerva javanica*, *Heliotropium digynum*, *Leptadenia pyrotechnica*, *Zilla spinosa*, and *Zygophyllum coccineum.*

IV. *Zilla spinosa–Zygophyllum coccineum* vegetation group. It is the most diversified (59 species; 43 sites) among the four groups of the southern part, mainly occupying Qift–Quseir road. Other than *Z. coccineum* and *Z. spinosa*, only *Citrullus colocynthis* and *Pulicaria undulata* showed presence value more than 50% and forming the most common species along Qift–Quseir road. Other associates included *Fagonia indica*, *Forsskaolea tenacissima*, *Morettia philaeana*, *Salsola imbricata* subsp. *imbricata*, *Trichodesma africanum*, and *Zygophyllum simplex.* Important sporadic species included *Astragalus eremophilus*, *Cleome amblyocarpa*, *C. crysantha*, *Euphorbia granulata*, *Monsonia heliotropoides*, and *M. nivea.*

The *remaining* sites were then divided into four vegetations groups representing the remaining four roads of the northern and middle roads of the Eastern Desert. The following is a brief description of these groups:

V. *Haloxylon salicornicum–Zygophyllum coccineum* group. *Haloxylon salicornicum* community type is widespread and abundant in several parts of the Egyptian deserts: Cairo–Suez desert (EI-Abyad 1962) and Mediterranean coastal desert (Tadros and Atta 1958). In this work, the vegetation of the *H. salicornicum* group (51 species; 23 sites) showed conspicuous layering. The frutescent layer is of little significance and included the shrubs *Acacia raddiana*, *Calotropis procera*, *Retama raetam*, *Tamarix aphylla*, *T. nilotica*, and *T. tetragyna*. The suffrutescent layer comprised of the dominant and numerous associated perennials such as *Deverra tortuosa*, *Farsetia aegyptia*, *Lotus hebranicus*, and *Taverniera aegyptiaca*. During the rainy season, this group was enriched with the growth of therophytes as *Anastatica hierochuntica*, *Cleome amblyocarpa*, *Reseda pruinosa*, *Rumex vesicarius*, *Trigonella stellata*, and *Zygophyllum simplex*.

VI. *Zilla spinosa–Zygophyllum coccineum* group. It is one of the widespread communities within the limestone country with different floristic compositions. *Z. coccineum* dominates in areas where the ground level is fairly high, but the water table is so close to the surface that available soil water is within the reach of roots of the dominant species and its xerophytic associates (Zahran and Willis 1992). It is plentiful in the affluent of the drainage systems and in the parts of the main channels where the deposits are shallow and coarse. It is less common in the basement complex and is absent from the sandstone country. This group (117 species; 29 sites) is occupying Cairo–Suez road and parts of Kattamia–Ain Sokhna and Korimat–Zaafarana roads. *Pulicaria undulata* and *Farsetia aegyptia* were the common associated species in this group, followed by *Anabasis articulata*, *Echinops spinosissimus*, *Fagonia mollis*, *Ochradenus baccatus*, *Retama raetam*, and *Zygophyllum simplex.* Occasional associates included, among others, *Astragalus schimperi*, *Calligonum polygonoides* and *Cannabis sativa*, and *Convolvulus pilosellifolius.*

VII. *Pulicaria undulata–Zilla spinosa group.*This group (120 species; 15 sites) represented the vegetation structure in the inland part of Korimat–Zaafarana road. About 18 species have presence value of more than 50% and dominated and/or codominated this area and included, among others, *Atriplex halimus*, *Haloxylon salicornicum*, *Ochradenus baccatus*, *Pergularia tomentosa*, *Rumex vesicarius*, *Trichodesma africanum*, and *Trigonella stellata.* Other associates were *Anchusa hispida*, *Artemisia judaica*, *Fagonia mollis*, and *Gymnocarpos decandrum.*

VIII. *Zygophyllum simplex–Zilla spinosa* group. *Z. simplex* vegetation group (98 species; 10 sites) was represented the vegetation structure of the northern Eastern Desert during rainy season, which usually covers a wide area between the perennial trees and shrubs. It is characterized by shallow roots and survives throughout a season longer than other ephemerals. In exceptionally wet years or highly favoured localities, *Z. simplex* may extend its life span for a whole year or more. A total of 40 therophytic plant species were recorded in this group such as *Aizoon canariense*, *Asphodelus tenuifolius*, *Astragalus hamosus*, *Cichorium pumilum*, *Malva parviflora*, *Mesembryanthemum crystalinum*, *M. forsskalei*, *M. nodiflorum*, *Neurada procumbens*, and *Savignya parviflora.* Tree layer was represented by *Acacia raddiana*, *Calotropis procera*, *Leptadenia pyrotechnica*, *Lycium shawii*, *Retama raetam Tamarix aphylla*, and *Tamarix tetragyna.* The shrub layer and other associates included *Achillea fragrantissima*, *Alhagi graecorum*, *Atractylis carduus*, *Cullen plicata*, and *Zygophyllum decumbens*.

Appendix

Floristic composition of the five main habitats in the studies cities

Species	WL	L	HG	PG	D
(I) Cultivated (ornamental, hedges, shade, fodder, vegetables, fruits)					
Acokanthera oblongifolia (Hochst.) Codd.	2	15.4		2.6	
Agave americana L. subsp. *americana*			4.4		
Allium cepa L.		3.8			
Aloe vera L.			4.4		
Anethum graveolens L.	2			2.6	
Arachis hypogaea L.			4.4		
Capsicum frutescens L.			8.7		
Cassia fistula L.				5.1	
Cassia nodosa Roxb.				7.7	
Casuarina cunninghamiana Miq.	4.1			2.6	
Ceratonia siliqua L.	2				
Citrullus vulgaris L.	2				
Clerodendrum acerbianum (Vis.) Benth. & Hook. f.				2.6	
Cupressus sempervirens L.		11.5	8.7		
Daucus carota L.		7.7	4.4	2.6	
Dodonaea viscosa (L.) Jacq.	6.1		21.7	10.3	
Enterolobium contortisiliqum (Vell.) Morong.				5.1	
Eruca sativa Mill.	2	3.8	8.7	2.6	
Eucalyptus camaldulensis Dehnh.	2				3.6
Faba vulgaris L.			4.4		
Ficus carica L.			4.4		
Ficus elastica Roxb.ex Hornem. var. *decora*		3.8		10.3	
Ficus nitida Thunb.	6.1	26.9	39.1	28.2	
Foeniculum vulgare Mill.	2	3.8	13	5.1	
Hibiscus esculentus L.			4.4		
Hibiscus rosa-sinensis L.		7.7	4.4	5.1	
Hibiscus sabdariffa L.			8.7		
Ipomoea batatas L.	2				
Ipomoea carnea Jacq.			4.4		
Jacaranda mimosifolia D. Don				2.6	
Lantana camara L.		3.8		2.6	
Linum usitatissimum L.		3.8			
Lycopersicon lycopersicum (L.) Karst. ex Farw.				2.6	
Mangifera indica L.	2				
Medicago sativa L. subsp. *sativa*		3.8	4.4	5.1	
Mentha piperita L.			4.4		
Morus alba L.	2				

Species	WL	L	HG	PG	D
Musa nana Lour.	2				
Nerium oleander L.		50	21.7	20.5	3.6
Nicotiana glauca R.C. Graham	10.2				
Ocimum basilicum L.	2	3.8	21.7		
Olea europaea L.	6.1		4.4		
Opuntia ficus-indica (L.) Mill	4.1				
Pelargonium zonale (L.) L' Hér. ex Ait		3.8		2.6	
Petroselinum crispum (Mill.) A. W. Hill			4.4		
Phoenix dactylifera L.	8.2	7.7	21.7	18	3.6
Delonix regia (Bojer) Raf.		19.2	13	28.2	
Psidium guajava L.			4.4		
Raphanus sativus L.			4.4		
Ricinus communis L.	4.1		13	12.8	3.6
Rosa sp.			8.7		
Schinus terebinthifolius Raddi		15.4	4.4	12.8	
Sesbania sesban (L.) Merr.	10.2		4.4	2.6	3.6
Solanum melongena L.			4.4		
Tecoma stans (L.) Juss. ex HBK.			4.4	2.6	
Thevetia peruviana (Pers.) K. Schum.		15.4		5.1	
Platycladus orientalis (Lufi) Franco				10.2	
Trifolium alexandrinum L.			4.4		
Triticum aestivum L.		3.8			
Vitex agnus-custus L.		3.8			
Washingtonia robusta H. Wendl.		15.4		10.2	
Zea mays L.			17.4		
(II) Wetlands, canal banks, salinized areas, etc.					
Atriplex leucoclada Boiss.	2				
Atriplex halimus L.	6.1				3.6
Atriplex lindleyi Moq. subsp. *Inflata* (F.Mull.) P.G.Wilson	8.2	3.8		5.1	3.6
Bolboschoenus glaucus (Lam.) S. G. Smith		3.8			
Cyperus alopecuroides Rottb.	6.1	7.7	8.7		3.6
Cyperus articulatus L.		7.7		2.6	
Cyperus difformis L.	2		4.4	2.6	
Cyperus laevigatus L.	2	3.8			
Cyperus rotundus L.	6.1	53.8	21.7	18	3.6
Dichanthium annulatum (Forssk.) Stapf	14.3	26.9	17.4	46.2	3.6
Epilobium hirsutum L.					3.6
Fimbristylis bisumbellata (Forssk.) Bubani	2				
Juncus rigidus Desf.	2	3.8			
Leptochloa fusca (L.) Kunth	2	7.7		5.1	
Ludwigia stolonifera (Guill. & Perr.) P. H. Raven	2				
Panicum repens L.		7.7	4.4	2.6	

Species	WL	L	HG	PG	D
Paspalidium geminatum (Forssk.) Stapf.				2.6	
Paspalum distichum L.		3.8		10.3	
Phragmites australis (Cav.) Trin. ex Steud.	20.4			18	17.9
Pluchea dioscoridis (L.) DC.	32.6	11.5	17.4	18	21.4
Silybum marianum (L.) Gaertn.		3.8			
Spergularia marina (L.)Bessler				2.6	
Tamarix nilotica (Ehrenb.) Bunge	49		4.4	5.1	53.6
Typha domingensis (Pers.) Poir. ex Steud.	8.2			2.6	7.1
Veronica anagallis-aquatica L.	4.1				
(III) Dry lands					
Aerva javanica (Burm.f.) Juss. ex Schult	8.2				7.1
Aizoon canariense L.	6.1				17.9
Alhagi graecorum Boiss.	18.4	3.8		2.6	7.1
Anabasis articulata (Forssk.) Moq.	4.1				25
Arisarum vulgare Targ.Tozz.					7.1
Arnebia decumbens (Vent.) Coss. & Kralik					7.1
Artemisia monosperma Delile	12.2				17.9
Asphodelus aestivus Bort.					17.9
Astragalus caprinus L.					3.6
Astragalus spinosus (Forssk.) Muschl.	4.1				3.6
Atractylis carduus (Forssk.) C. Chr.	4.1				7.1
Bassia indica (Wight) A. J. Scott	57.1	34.6	17.4	33.4	39.3
Bassia muricata (L.) Asch.	6.1		4.4		14.3
Brassica tournefortii Gouan	2				3.6
Calligonum polygonoides L.	14.3				28.6
Centaurea alexandrina Delile	2				10.7
Centaurea glomerata Vahl					7.1
Centropodia forsskaolii (Vahl) Cope	20.4				17.9
Chiliadenus montanus (Vahl) Brullo	2				3.6
Chrozophora oblongifolia (Delile) Spreng.	2				14.3
Chrozophora tinctoria (L.) Raf.	2				
Citrullus colocynthis (L.) Schrd.	2				
Convolvulus hystrix Vahl	2				3.6
Convolvulus lanatus Vahl	14.3				3.6
Cornulaca monacantha Delile					7.1
Cotula cinerea Delile	6.1				7.1
Crepis micrantha Czerep					3.6
Cutandia dichotoma (Forssk.) Batt. & Trab.				2.6	
Cynanchum acutum L. subsp. *acutum*	38.8	19.2	43.5	25.6	21.4
Cynara cornigera Lindl.	2				
Deverra tortuosa (Desf.) DC.	26.5				57.1
Echinops spinosus L.	8.2				7.1

Species	WL	L	HG	PG	D
Echium angustifolium Mill.	2	3.8			10.7
Enarthrocarpus strangatulus Boiss.					3.6
Erodium glaucophyllum (L.) L' Hėr.	6.1		4.4	2.6	7.1
Erodium laciniatum (Cav.) Willd.	2				
Eryngium creticum Lam.	8.2				7.1
Fagonia arabica L.	4.1				21.4
Fagonia cretica L.	4.1				3.6
Farsetia aegyptia Turra	22.5				42.9
Filago desertorum Pomel					3.6
Forsskaolea tenacissima L.	4.1		4.4		7.1
Glebionis coronaria (L.) Tzvelev				2.6	
Globularia arabica Jaub. & Spach.					10.7
Gymnocarpos decanter Forssk.					17.9
Haloxylon salicornicum Bunge ex Boiss.	8.2				17.9
Haplophyllum tuberculatum (Forssk.) Juss.	4.1				7.1
Helianthemum lippii (L.) Dum. Cours.	6.1				7.1
Heliotropium digynum (Forssk.) Asch. ex C. Chr.	2				7.1
Herniaria hemistemon J. Gay.	2				3.6
Hyoscyamus muticus L.	16.3			5.1	35.7
Ifloga spicata (Forssk.) Sch. Bip.	2				
Iphiona scarbra DC.					3.6
Launaea amal-aminae N. Kilian	10.2	15.8	4.4	7.7	3.6
Launaea capitata (Spreng.) Dandy	2			2.6	
Launaea nudicaulis (L.) Hook. f.	55.1	7.7	17.4	18	46.4
Launaea fragilis (Asso) Pau				2.6	3.6
Launaea spinosa (Forssk.) Sch. Bip. ex Kuntze				2.6	
Linaria albifrons (Sm.) Spreng.	8.2				
Lycium europaeum L.					10.7
Marrubium alysson L.	2				
Matthiola longipetala (Vent.) DC.	4.1				10.7
Mesembryanthemum forsskaolii Hochst. ex Boiss.	2				10.7
Mesembryanthemum nodiflorum L.					3.6
Moltkiopsis ciliata (Forssk.) I. M. Johnst.	6.1				10.7
Monsonia nivea (Decne.) Webb	2				10.7
Neurada procumbens L.					3.6
Noaea mucronata (Forssk.) Asch. & Schweinf.	4.1				3.6
Panicum turgidum Forssk.	6.1				10.7
Peganum harmala L.	6.1				
Pergularia tomentosa L.	8.2				7.1
Phagnalon rupestre (L.) DC.					10.7
Picris longirostris Sch. Bip.	2				
Plantago crypsoides Boiss.	2				

Species	WL	L	HG	PG	D
Plantago notata Lag.					3.6
Polycarpaea repens (Forssk.) Asch. & Schweinf.	10.2				25
Polygonum bellardii All.				5.1	
Pulicaria arabica (L.) Cass.	2				
Pulicaria undulata (L.) C. A. Mey. subsp. *undulata*	18.4	3.8			39.3
Reaumuria hirtella Jaub. & Spach					3.6
Reichardia tingitana (L.) Roth				2.6	10.7
Retama raetam (Forssk.) Webb & Berthel.subsp. *raetam*	4.1				7.1
Salsola kali L.	4.1				3.6
Salvia aegyptiaca L.					14.3
Salvia lanigera Poir.	2				3.6
Schismus barbatus (L.) Thell.	2		4.4		3.6
Stipagrostis hirtigluma (Steud. ex Trin. & Rupr.) De Winter	8.2				7.1
Stipagrostis plumosa (L.) Munro ex T. Anderson	14.3				25
Stipagrostis scoparia (Trin. & Rupr.) De Winter					3.6
Suaeda vermiculata Forssk. ex J. F.Gmel	10.2	3.8			14.3
Thymelaea hirsuta (L.) Endl.	8.2				17.8
Thymus capitatus (L.) Link					10.7
Traganum nudatum Delile					3.6
Tribulus terrestris L.	6.1	26.9	13	20.5	
Trigonella stellata Forssk.	4.1	3.8			
Zilla spinosa (L.) Prantl	16.3				25
Zygophyllum aegyptium Hosny					3.6
Zygophyllum coccineum L.	2				
Zygophyllum simplex L.	10.2				14.3
(IV) Weeds of arable lands					
Achillea santolina L.	2				7.1
Adonis dentata Delile	2				3.6
Amaranthus graecizans L.	4.1	3.8	4.4	5.1	3.6
Amaranthus hybridus L.				2.6	
Amaranthus lividus L.	20.4	46.2	34.8	43.6	3.6
Ammi majus L.	4.1	3.8		5.1	
Anagallis arvensis L. subsp. *arvensis* var. *arvensis*	6.1	19.2	8.7	12.8	
Anagallis arvensis L. subsp.*arvensis* var. *caerulea* Gouan	4.1	7.7	13	5.1	
Avena fatua L.	6.1		4.4	2.6	3.6
Avena sativa L.		3.8		10.3	
Beta vulgaris L. subsp. *maritima* (L.) Arcang.	6.1		8.7	5.1	
Bidens pilosa L.	4.1		47.8	41	
Brachiaria reptans (L.) C. A. Gardner & C. E. Hubb.		3.8	4.4		
Brassica nigra (L.) Koch				2.6	
Bromus catharticus Vahl		19.2	17.4	38.5	

Species	WL	L	HG	PG	D
Capsella bursa-pastoris (L.) Medik.				5.1	
Carthamus tenuis (Boiss. & Blanche) Bornm. subsp. *Foliosus* Hanelt	2				7.1
Caylusea hexagyna (Forssk.) M. L. Green					3.6
Cenchrus ciliaris L.	38.8	50	60.9	53.9	10.7
Chenopodium album L.	2	3.8	4.4	7.7	3.6
Chenopodium glaucum L.				2.6	
Chenopodium murale L.	22.5	19.2	26.1	38.5	
Chloris virgata Sw.	2		4.4	2.6	7.1
Cichorium endivia L. subsp. *divaricatum* (Schousb.) P. D. Sell	4.1	11.5	4.4	2.6	
Cleome amblyocarpa Barratte & Murb.	2				3.6
Convolvulus althaeoides L. var. *pedatus* Choisy	2				
Convolvulus arvensis L.	10.2	50	30.4	46.2	3.6
Conyza bonariensis (L.) Cronquist	26.5	53.8	65.2	51.3	10.7
Corchorus olitorius L.	2		8.7		
Coronopus didymus (L.) Sm.	2		4.4	2.6	
Coronopus squamatus (Forssk.) Asch.			4.4		
Cynodon dactylon (L.) Pers.	40.8	100	87	82.1	3.6
Dactyloctenium aegyptium (L.) Willd.	2	7.7	13	7.7	
Digitaria sanguinalis (L.) Scop.	12.2	26.9	26.1	25.6	3.6
Dinebra retroflexa (Vahl) Panz.	2		4.4		
Echinochloa colona (L.) Link	6.1	30.8	21.7	28.2	3.6
Eleusine indica (L.) Gaertn.			4.4	2.6	
Emex spinosa (L.) Campd.		3.8			
Eragrostis pilosa (L.) P. Beauv.	14.3	23.1	73.9	64.1	3.6
Eragrostis tef (Zucc.) Trott.				5.1	
Euphorbia forsskaolii J. Gay				2.6	
Euphorbia granulata Forssk.	4.1	3.8	4.4	2.6	
Euphorbia heterophylla L.			4.4	2.6	
Euphorbia hirta L.		3.8	17.4	7.7	
Euphorbia indica Lam.		3.8			
Euphorbia peplus L.	6.1	7.7	13	15.4	
Euphorbia prostrata Aiton	12.2	11.5	26.1	5.1	
Euphorbia retusa Forssk.	6.1		4.4	7.7	
Hibiscus trionum L.		3.8			
Hordeum murinum L.	6.1	15.4		7.7	3.6
Imperata cylindrica (L.) Raeusch.	40.8	26.9	17.4	41	10.7
Lactuca serriola L.	12.2		4.4	2.6	
Lolium perenne L.		11.5	8.7	10.3	3.6
Lolium rigidum Gaudin		3.8	4.4	10.3	
Lotus glaber Mill.	6.1	38.5	8.7	20.5	

Species	WL	L	HG	PG	D
Lotus hebranicus Hochst. ex Brand	2				
Malva parviflora L.	24.5	50	52.2	48.7	3.6
Malva sylvestris L.				2.6	
Matricaria recutita L.		3.8	4.4		
Medicago intertexta (L.) Mill. var. *ciliaris* (L.) Heyn	2	3.8		7.7	
Medicago laciniata (L.) Mill.					3.6
Medicago lupulina L.		3.8	4.4	7.7	
Medicago polymorpha L.	6.1	11.5	17.4	20.5	
Melilotus indicus (L.) All.	4.1	15.4	13	18	
Oryzopsis miliacea (L.) Asch. & Schweinf.		7.7			
Oxalis corniculata L.		15.4	26.1	25.6	
Panicum coloratum L.	4.1	34.6	17.4	35.9	
Paspalum dilatatum Poir.		23.1	21.7	23.1	
Pennisetum glaucum (L.) R. Br.				2.6	
Phalaris paradoxa L.	2	3.8	8.7		
Plantago lagopus L.	2	46.1	13	46.2	
Plantago major L.		30.8	47.8	46.2	
Poa annua L.	2	11.5	17.4	10.3	
Polypogon monspeliensis (L.) Desf.	12.2	11.5	13	7.7	3.6
Portulaca oleracea L.	8.2	53.8	39.1	38.5	7.1
Ranunculus marginatus d'Urv.		3.8			
Rostraria cristata (L.) Tzvelev	2				
Rumex dentatus L.	2		4.4	2.6	
Senecio glaucus L.	14.3	15.4	21.7	12.8	14.3
Setaria pumila (Poir.) Roem. & Schult.	2	15.4	8.7	7.7	
Setaria verticillata (L.) P. Beauv.	4.1	7.7	17.4	15.4	
Setaria viridis (L.) P. Beauv.		3.8			
Sida alba L.				2.6	
Silene rubella L. var. *rubella*				2.6	
Sinapis arvensis L.	2			2.6	
Sisymbrium irio L.	6.1	15.4	17.4	28.2	
Solanum nigrum L.	6.1		21.7	7.7	7.1
Sonchus oleraceus L.	28.6	42.3	52.2	43.6	7.1
Sorghum halepense (L.) Pers.	6.1				
Sorghum virgatum (Hack.) Stapf	2	3.8	8.7	7.7	
Stellaria media (L.) Vill.			4.4	2.6	
Symphyotrichum squamatum (Spreng.) Nesom	2		13	12.8	10.7
Trianthema portulacastrum L.				2.6	
Trianthema triquetra Willd.	2			2.6	
Trifolium repens L.				7.7	
Trifolium resupinatum L.	6.1	30.8	34.8	31	
Urospermum picroides (L.) F. W. Schmidt	8.2	7.7	4.4	5.1	
Urtica urens L.		3.8			
Xanthium spinosum L.	6.1	3.8			
Xanthium strumarium L.	4.1				

Photo Gallery

Photo 7.1 Part of the desert-reclaimed lands along the northern sector of the Nile Valley. Note the sprinkle irrigation method used in wheat cultivation

Photo 7.2 Wheat cultivations in the reclaimed desert lands, with part of the natural desert vegetation appearing in the background (*left*)

Photo 7.3 A recently reclaimed land cultivated with olive saplings. Note the growth of desert plants (*Zygophyllum coccineum*, *Bassia indica*, and *Launaea nudicaulis*) in between

Photo 7.4 An old vineyard and date palms growing in the orchard habitat of the reclaimed desert lands

Photo 7.5 The vegetation in the bounding desert surrounds the newly industrial 6th October City

Photo 7.6 Part of the desert vegetation surrounds the industrial 10th Ramadan City. Note the growth *of Zygophyllum coccineum*, *Pulicaria undulata*, and *Tamarix nilotica*

Photo 7.7 A home garden at the industrial 6th October City

Photo 7.8 A public garden at 6th October City

Photo 7.9 A waste land habitat at Sadat City, with dense growth of *Phragmites australis* and *Bassia indica*

Photo 7.10 Lawn at 10th Ramadan City, with *Delonix regia* and *Ficus nitida* trees

Photo 7.11 Two clear zones: the foreground (salinized area with *Suaeda vermiculata*) and the midzone (cultivated area with Egyptian clover). The city zone of Burg El-Arab (along the Mediterranean western coast) can be seen in the background

Photo 7.12 Lawn habitat in El-Sadat City

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Chapter 8
Plant Responses to Desert Environment

Abstract In this chapter, three main plant groups (climbing, succulent, and parasitic plants) that occur as a direct response to desert environments in Egypt were investigated. There are both herbaceous and woody climbing plants, the woody known as lianas while the herbaceous are vines. *Citrullus colocynthis*, *Cocculus pendulus*, *Cucumis prophetarum*, *Pergularia tomentosa*, and *Periploca angustifolia* were the selected vines for study. The distribution patterns of the five selected plant species revealed that *Citrullus colocynthis* indicated a wide geographical range of distribution in Egypt. *Cucumis prophetarum* and *Cocculus pendulus* were confined to the eastern part of Egypt (Eastern Desert, Red Sea region, and Sinai Peninsula) between latitudes 22–30.5° and longitudes 31–36.2°. The vine–insect relationships indicated the record of 31 insect species belonging to 5 orders and 18 families in association with the studied plant species. The most associated insects were belonging to orders Hymenoptera (ants, bees, and wasps) and Coleoptera (beetles). The distribution patterns of succulents in Egypt in Sinai Peninsula and the Mediterranean regions included most of the succulent species (59 species in 11 families in Sinai and 44 species in 14 families in the Mediterranean region). Three xerophytic succulents (*Anabasis articulata*, *Zygophyllum coccineum*, and *Haloxylon salicornicum*), a halophytic succulent (*Arthrocnemum macrostachyum*), and a halophytic xerophytic succulent (*Zygophyllum album*) were selected for this study. The occurrence of parasite–host associations in southern Sinai, in the Galala and Arabian Deserts, and in Gebel Elba regions was restricted to the silt terraces and to channels and runnels of the main *wadis* which receive soft materials. Patterns of host specialization occur in the two species of *Cistanche* while *Orobanche cernua* parasitized members of this Zygophyllaceae.

8.1 Climbing Plants

Climbing plants are one of the most interesting but also a much neglected group of plants. They consist of plants which are rooted in the ground but need support for their weak stems. There are both herbaceous and woody climbing plants, the woody

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known as *lianas* while the herbaceous are *vines*. Climbers are a conspicuous feature of all forests and compete actively with trees for light and space (Richards 1952). Their high abundance is an important physiognomic feature differentiating tropical from temperate forest (Gentry 1991).

In desert areas, the incidence, ecology, phytogeography, and floristics of both woody and herbaceous vines are particularly poorly known, the only detailed study being the account by Krings (2000) for the Sonoran and Chihuahuan Deserts (Parsons 2005). Vines compose up to 19 % of the species in tropical forests, but only 6 % in temperate forests (Molina-Freaner et al. 2004) and in the range of 1–3 % for Mediterranean climate and arid zone floras (Rundel and Franklin 1991). In desert floras of the world and Mediterranean climate, vines represent a small but morphologically and ecologically diverse component. This grouping under the designation of "vines" covers a range of growth forms, from annual to herbaceous perennials with succulent storage organs, to woody vines, and even to herbaceous parasites.

As vines are not treated as an unambiguous growth form in most floristic studies in arid ecosystems, thus our knowledge about the abundance of vines is rather poor and difficult to obtain (Rundel and Franklin 1991). Egypt, as well as the great Sahara regions, has no previous studies on vines, so the present study encompasses the selection of the most common woody and herbaceous vine species, of frequent distribution in Egypt, to be a preliminary study on the climbing plants.

Insects are interacting with climbing plants through many different ways. The fleshy tissues of climbers would seem to present an attractive resource for herbivorous insects that cause damage to them (Arnett 1985). A number of pests can attack climbers developing buds, leaves, shoots, roots, flowers, and fruits. A heavy infestation of any pest, however, can damage the health of the vine. On the other hand, some insects may pollinate the climbing plants, while others use vines for protection, mating, or searching for their prey. Insects that associated with climbing plants are numerous, belonging to different orders including beetles and weevils (Coleoptera); butterflies and moths (Lepidoptera); flies (Diptera); scale insects and aphids (Homoptera); true bugs (Heteroptera); wasps, bees, and ants (Hymenoptera); and grasshoppers and locusts (Orthoptera) (Strong et al. 1984).

8.1.1 The Selected Plants

An extensive detailed survey was carried out at many sites (Fig. 8.1) covering different types of habitats in Egypt for collecting the selected climbing plants and the associated plant species. The studied plants were *Citrullus colocynthis* (L.) Schrad, *Cocculus pendulus* (J.R. & G.Forst.) Delile, *Cucumis prophetarum* L., *Pergularia tomentosa* L., and *Periploca angustifolia* Labill.

A floristic-count list was taken from the 41 sites (Fig. 8.1) to represent the five climbing plants in different phytogeographic regions of Egypt and distributed as follows: 14 from the Red Sea, 13 from the Mediterranean, 10 from Sinai, and 4 from the Eastern Desert. *Citrullus colocynthis* was represented by 18 sites in the Red Sea, Mediterranean, and Sinai regions; eight sites for *Cocculus pendulus* from the

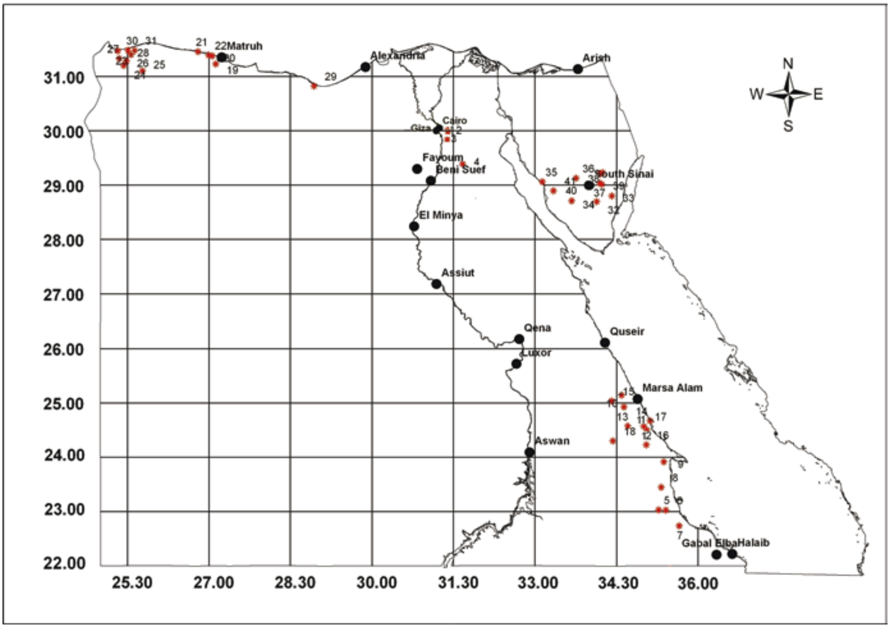

Fig. 8.1 A map showing the distribution of collecting sites

Eastern Desert, Red Sea, and Sinai Peninsula; six sites for *Cucumis prophetarum* from Red Sea region and Sinai Peninsula; nine sites for *Pergularia tomentosa* from the Eastern Desert, Red Sea region, and Sinai Peninsula; and nine sites for *Periploca angustifolia* from the western Mediterranean coastal strip.

8.1.1.1 Diversity of Climbing Plants

Reviewing the Egyptian flora, a total of 93 climbing species (76 vines and 17 lianas) belonging to 15 family and 41 genera were listed (Appendix) and representing 4.4 % of the total vascular flora of Egypt. This figure was slightly higher than the normal range of 1–3 % found for Mediterranean climate and arid zone floras that was proposed by Rundel and Franklin (1991) and clearly much lower than that recorded in the tropical forests (19 %) and 6 % in temperate forests (Molina-Freaner et al. 2004). Markedly, the herbaceous species (vines) dominated the recorded climbers (81.7 %, 76 species), most abundant in Leguminosae (29 species, 31.2 %), Convolvulaceae (17 species, 18.3 %), Cucurbitaceae (13 species, 14.0 %), and Asclepiadaceae (8 species, 8.6 %). The remaining families constituted together 26 species (27.9%) including Cuscutaceae, Rubiaceae, Capparaceae, Ephedraceae, Loranthaceae, Oleaceae, Vitaceae, Labiatae, Menispermaceae, and Polygonaceae. This result is in consistent with the conclusion of Rundel and Franklin (1991) in their study on vines of arid and semiarid environments as they reported that the great majority of arid zone climbers are herbaceous (vines), while woody climbers (lianas) are rare.

Contrary to those of tropical forests (Balfour and Bond 1993; Parthasarathy et al. 2004; Dewalt et al. 2006), trees were not represented among the 93 climbing plants of Egypt. Herbs were the dominant growth form (76 species; 81.7 %) of which 46 were annuals such as *Convolvulus siculus*, *Lathyrus annuus*, and *Cucumis dipsaceus* and 30 were perennials like *Citrullus colocynthis*, *Cynanchum acutum*, and *Rhynchosia minima*. Shrubs were represented by 15 species (16.1 %) such as *Cissus quadrangularis*, *Pergularia tomentosa*, and *Cocculus pendulus*, and two semiparasites (2.1 %) such as *Plicosepalus acaciae* and *P. curviflorus* were reported. Twenty of the known climbing species in the flora of Egypt were confined to Gebel Elba region (SE corner of Egypt; on the Egyptian–Sudanese border) and do not penetrate to the other regions, e.g. *Podostelma schimperi*, *Maerua oblongifolia*, and *Kedrostis gijef*. On the other hand, nine species were consistent in their geographical distribution to the Nile region such as *Ipomoea eriocarpa* and *Vigna luteola*; nine in the Mediterranean region such as *Bryonia cretica*, and *Lathyrus setifolius*; seven in Sinai Peninsula such as *Convolvulus palaestinus* and *Ephedra foeminea*; and *Vicia hirsuta* in the Eastern Desert (see Appendix). According to (El-Hadidi et al. 1992), six climbing plants were considered endangered such as *Cadaba farinosa*, *Maerua oblongifolia*, *Ephedra foeminea*, and *Plicosepalus curviflorus*, whereas Täckholm (1974) considered another 17 very rare climbing plants (e.g. *Podostelma schimperi*, *Merremia semisagittata*, *Corallocarpus schimperi*, *Kedrostis foetidissima*, *Cissus quadrangularis*, *Pentatropis nivalis*, and *Pergularia daemia*).

Considering the total number of species, the much lower total number of vines in Australian deserts compared with North American and Egyptian ones (Table 8.1) may partly reflect rainfall differences, as parts of the Sonoran and Chihuahuan Deserts receive up to 470 and 500 mm mean annual rainfall, respectively (Shreve and Wiggins 1964). In contrast, in the Western Australian Deserts, mean annual rainfall reaches 300 mm in a small area in the northwest and is more usually 180–200 mm (Beard 1969). Yet, in the Egyptian deserts, it differs substantially from the western

Table 8.1 The most species-rich families of climbing plants in Egypt compared with the Australian and two North American deserts

Egypt[a]		Australian desert[b]		Sonoran Desert[c]		Chihuahuan Desert[c]	
Family	*N*	Family	*N*	Family	*N*	Family	*N*
Fabaceae	29	Convolvulaceae	10	Convolvulaceae	53	Convolvulaceae	35
Convolvulaceae	17	Fabaceae	6	Fabaceae	34	Fabaceae	31
Cucurbitaceae	13	Asclepiadaceae	5	Cucurbitaceae	30	Cucurbitaceae	19
Asclepiadaceae	8	Lauraceae	3	Asclepiadaceae	27	Asclepiadaceae	14
Cuscutaceae	8	Cucurbitaceae	2	Vitaceae	7	Vitaceae	6
Others	18	Others	11	Others	47	Others	28
Total	93		37		198		133

N Number of species
[a]Present study
[b]Parson (2005)
[c]Krings (2000)

(where mean annual rainfall decreases from 150 mm at the coast to practically zero in the south) to the eastern (where mean annual rainfall decreases from 30 mm in the north to almost zero in the south). Therefore, the gradient in the annual rainfall is obvious, which is also associated with an inverse evaporation gradient, indicating the increase of aridity from west to east and from north to south (Ayyad and Ghabbour 1986; Abd El-Ghani 1998, 2000; Abd El-Ghani and El-Sawaf 2004, 2005). The highest desert value, 198 species or 7.5 % in the Sonoran Desert (Krings 2000), is positively related to the migration of taxa from wetter, more tropical areas nearby (Rundel and Franklin 1991; Krings 2000). There is no sign of a similar effect in the Australian data, although the Great Sandy Desert directly adjoins wetter, more tropical country to its north, unlike the other deserts (Parsons 2005).

The comparison between the members of desert climbing plants in Egypt and those of deserts in other continents (Australian, Sonoran, and Chihuahuan Deserts) revealed that Convolvulaceae, Leguminosae, Cucurbitaceae, and Asclepiadaceae were the dominant plant families. These four families comprised 74.4, 72.7, 72.1, and 62.1 % in Chihuahuan, Sonoran, Egypt, and Australian Deserts, respectively. This may reflect the large proportion of Pantropical and Cosmopolitan families shared between all of these data sets (Table 8.1). Although Rundel and Franklin (1991) thought that Convolvulaceae was especially important in Australian deserts, that view was not supported in the vines of Egyptian deserts. In fact, of the total vine species, the percentage in that family is 18 % and 26–27 % in the Australian, Sonoran, and Chihuahuan Deserts (Parsons 2005). Speciation in the family Convolvulaceae has been more prolific in the Thar Desert of India, where it is the fourth largest family in the vascular flora (Shmida 1985). Values for Cucurbitaceae in Egypt (Table 8.1) were similar to those of the North American areas (14–15 %) compared with Australia (5 % of all vines). Again, the values in the Thar Desert were likely to be higher still (Shmida 1985). The Vitaceae, the fifth largest vine family in the two North American deserts, were poorly represented in the Egyptian deserts (two species) but not known in Australian deserts. Australia has only about 34 species of the ca. 700 species of Vitaceae worldwide (Morley and Toelken 1983), the family being considered Laurasian (Krings 2000). When comparing the climbing plant species of Egypt and those of the surrounding countries of arid environment, the Egyptian flora was more rich (93 species) than the others. For more information, see Table (8.1).

8.1.1.2 General Distribution Patterns of the Five Climbing Plants

In the last decades, most of the phytogeographic regions of Egypt were affected by human activities including the intensive collection of plant species for its values (medicinal, fuel, fibre, etc.) which influenced the natural vegetation and distribution of plants in these areas. In their study of the diversity and distribution of medicinal plants in North Sinai (Egypt), Abd El- Wahab et al. (2008) stated that "about 60 % of medicinal plants are threatened due to intensive collection and human activities". Moreover, due to the currently increased Egyptian population, the Red Sea coast was also severely subjected to human activities as many new settlements were established in the vicinity of the old cities like Hurgada, Safaga, and Quseir (Zohary 1983; Abd El-Ghani 1998). Constriction of roads is one of man's impacts on the desert vegetation.

The distribution patterns of the five selected plant species of this study were shown in Fig. 8.2. *Citrullus colocynthis* indicated a wide geographical range of distribution in Egypt. During the last decades, *Citrullus colocynthis* was collected, nearly, from all of the phytogeographic regions of Egypt. Kassas and Imam (1954) reported that the fruits of *Citrullus colocynthis* are extensively collected for their medicinal values which reduce the reproductive capacity of the plant and consequently its abundance. Recently, it was considered as a very rare species in the North Sinai by Abd El-Wahab et al. (2008). In the present study, the plant was collected from three phytogeographic regions (Sinai Peninsula, Mediterranean, and Red Sea regions).

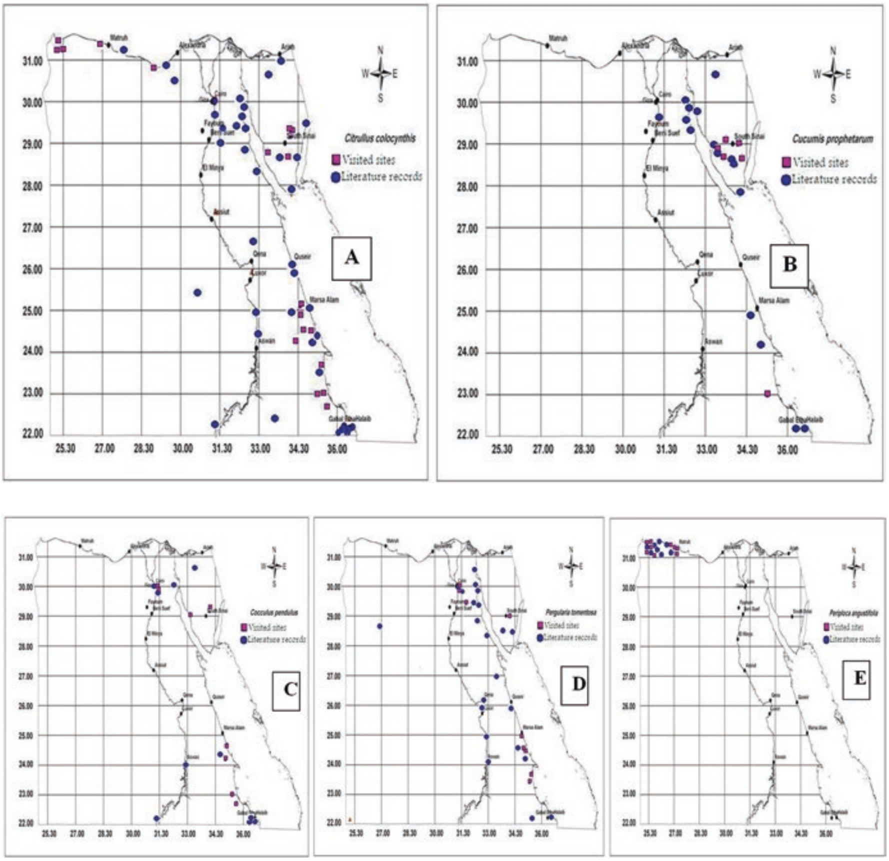

Fig. 8.2 Distributional patterns of **a** *Citrullus colocynthis*, **b** *Cucumis prophetarum*, **c** *Cocculus pendulus*, **d** *Pergularia tomentosa*, and **e** *Periploca angustifolia*, showing visited sites and literature records

Practically, we did not succeed to collect it from wadies of the Eastern Desert. *Citrullus colocynthis* has been considered by Kassas and Imam (1954) as rare species in Wadi Hof area (located in the Eastern Desert). Markedly, from that time the plant was neither collected from that location nor in the present study.

Cucumis prophetarum and *Cocculus pendulus* were confined to the eastern part of Egypt (Eastern Desert, Red Sea region, and Sinai Peninsula) between latitudes 22–30.5° and longitudes 31–36.2°. The River Nile may act as a natural barrier for the spreading of the two species westwards, so it could not penetrate to the western part of the country. Herbarium records of *Cocculus pendulus* showed that it was recorded in 1910 from Mokattam and in 1926 and from Dwaiqa area (near Cairo). In this investigation, the general physiographic features of these two areas were substantially changed, resulting in the vanishing of many species that were recorded earlier. *Pergularia tomentosa* is mainly restricted in its distribution to the eastern part of Egypt (Zahran and Willis 1992). According to the literature and the present records, *Pergularia tomentosa* was nearly collected from all parts of Eastern Desert of Egypt and Sinai Peninsula. It was recorded once from few sites of the western part of Egypt. *Periploca angustifolia* is restricted to the northern western part of Egypt and was not recorded from any other part. Täckholm (1974) considered it as rare species in the Egyptian flora, but recently it was recorded in the many regions of the Western Desert (Salama et al. 2005). In its habitat, *Periploca angustifolia* is usually exposed to heavy grazing by goats and camels. In the Sallum area (at Libyan frontier), its occurrence represents the westernmost geographical distribution in Egypt. More future investigation should be conducted on the biology and ecological correlates determining its distribution limits.

8.1.1.3 Biological Spectrum and Chorological Affinities of the Associated Vegetation

Ninety-seven species from 33 and 1 gymnosperm family belonging to 85 genera were recorded in this study associated with the selected 5 climbing plants (Table 8.2). The most species-rich families were Chenopodiaceae (12.4 % of the total flora), followed by Fabaceae (11.3 %), Zygophyllaceae (9.2 %), Asteraceae (8.3 %), Brassicaceae (6.2 %), and Asclepiadaceae (5.1%). They constituted 23 annuals and 74 perennials. Shrubs (50 species) and perennial herbs (17 species) were the dominant growth form where they form 69 % of the total flora. Five trees (*Calotropis procera*, *Acacia tortilis* subsp. *raddiana*, *A. tortilis* subsp. *tortilis*, *Tamarix aphylla*, and *T. nilotica*) were also enumerated. The distribution of chorotypes with different growth form categories are shown in Fig. 8.3. Preponderance of annuals and shrubs reflects a typical desert flora where it is closely related with topography (Zohary 1973; Orshan 1986). On the other hand, they may be a response to the hot dry climate and human and animal interferences. As presented in this study, the dominance of shrubby plant species over the grasses was evident.

Phytogeographically, Egypt is the meeting point of floristic elements belonging to at least four phytogeographic regions, the African Sudano–Zambazian, the Asiatic

Table 8.2 Distribution of the species recorded in the four vegetation groups resulting from cluster analysis, together with their presence percentages (*P*%), families, growth forms (GF), and chorotypes (CT)

Species	GF	CT	Family	Vegetation groups			
				A	B	C	D
Total number of sites				**13**	**15**	**9**	**4**
Total number of species				**34**	**61**	**40**	**32**
Species present in all groups							
Echinops spinosissimus Turra	S	SA + IT	Asteraceae	23	7	11	75
Retama raetam (Forssk.) Webb. & Berthel.	S	SA + IT	Fabaceae	38	27	33	75
Zilla spinosa (L.) Prantl	S	SA	Brassicaceae	31	**80**	55	**100**
Species present in three groups							
Anabasis articulata (Forss.) Moq.	S	SA + IT	Chenopodiaceae	**85**	7	55	0
Citrullus colocynthis (L.) Schrad.	Ph	SA	Cucurbitaceae	38	60	44	0
Euphorbia retusa Forssk.	Ph	SA	Euphorbiaceae	15	7	33	0
Deverra tortuosa (Desf.) DC.	S	SA + SZ	Apiaceae	77	2	0	75
Farsetia aegyptia Turra	S	SA + SZ	Brassicaceae	8	27	0	5
Gymnocarpos decander Forssk.	S	ME + SA	Caryophyllaceae	31	13	0	75
Lycium shawii Roem. & Schult.	S	SA + SZ	Solanaceae	61	27	0	75
Rumex vesicarius L.	A	SA + IT	Polygonaceae	8	4	0	25
Achillea fragrantissima (Forssk.) Sch. Bip.	Ph	SA + IT	Asteraceae	0	4	33	5
Artemisia judaica L.	Ph	SA	Asteraceae	0	13	22	75
Cocculus pendulus (J.R. & G.Forst.) Diels	S	PAL	Menispermaceae	0	27	22	5
Ochradenus baccatus Delile	S	SA + SZ	Resedaceae	0	4	33	**100**
Trichodesma africanum (L.) R. Br.	S	SA + SZ	Boraginaceae	0	33	11	5
Zygophyllum simplex L.	A	SA + SZ	Zygophyllaceae	0	13	11	25
Species present in two groups							
Asphodelus ramosus L.	A	ME + SA	Liliaceae	61	7	0	0
Convolvulus arvensis L.	Ph	PAL	Convolvulaceae	23	7	0	0
Leptadenia pyrotechnica (Forssk.) Decne.	S	SA + SZ	Asclepiadaceae	8	53	0	0
Nitraria retusa (Forssk.) Asch.	S	SA + IT	Zygophyllaceae	8	33	0	0
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	S	SZ	Chenopodiaceae	77	0	22	0

(continued)

Table 8.2 (continued)

Species	GF	CT	Family	Vegetation groups			
				A	B	C	D
Peganum harmala L.	Ph	ME + IT	Zygophyllaceae	23	0	11	0
Solenostemma argel (Delile) Hayne	S	SA + SZ	Asclepiadaceae	8	0	55	0
Aerva javanica (Burm.f.) Juss. ex Schult.	S	SA + SZ	Amaranthaceae	0	53	55	0
Aristida adscensionis L.	A	PAL	Poaceae	0	2	44	0
Bassia muricata (L.) Asch.	A	SA + IT	Chenopodiaceae	0	2	33	0
Calotropis procera (Aiton.) W.T. Aiton	T	SA + SZ	Asclepiadaceae	0	7	55	0
Caylusea hexagyna (Forssk.) M.L. Green	A	SA + IT	Resedaceae	0	7	44	0
Chrozophora plicata (Vahl) Spreng.	A	SA + SZ	Euphorbiaceae	0	2	55	0
Cleome droserifolia (Forssk.) Delile	S	SA + IT	Capparaceae	0	53	**67**	0
Cucumis prophetarum L.	Ph	SA + SZ	Cucurbitaceae	0	7	55	0
Erodium laciniatum (Cav.) Willd.	Ph	ME + IT	Geraniaceae	0	7	11	0
Fagonia arabica L.	S	SA	Zygophyllaceae	0	4	22	0
Forsskaolea tenacissima L.	Ph	SA + SZ	Urticaceae	0	33	44	0
Oligomeris linifolia (Hornem) J.F. Macbr.	A	ME + SA + SZ	Resedaceae	0	2	33	0
Tephrosia purpurea (L.) Pers.	Ph	SZ + SA	Fabaceae	0	33	11	0
Tribulus terrestris L.	A	SA + SZ	Zygophyllaceae	0	7	11	0
Trigonella stellata Forssk.	A	SA + SZ	Fabaceae	0	7	44	0
Atriplex halimus L.	S	ME + SA	Chenopodiaceae	0	7	0	75
Capparis sinaica Veill.	S	SA	Capparaceae	0	7	0	75
Iphiona mucronata (Forssk.) Asch. & Schweinf.	S	SA + SZ	Asteraceae	0	4	0	5
Pergularia tomentosa L.	S	SZ + SA	Asclepiadaceae	0	4	0	75
Pulicaria undulata (L.) Kostel	S	S-Z + SA-SI	Asteraceae	0	**73**	55	0
Zygophyllum coccineum L.	S	SA + SZ	Zygophyllaceae	0	53	0	75
Zygophyllum decumbens Delile	S	SA + SZ	Zygophyllaceae	0	13	0	25
Fagonia mollis Delile	S	SA + IT	Zygophyllaceae	0	0	55	75
Heliotropium digynum (Forssk.) C. Chr.	S	SA + IT	Boraginaceae	0	0	44	5
Launaea nudicaulis (L.) Hook.f.	Ph	SA + IT	Asteraceae	0	0	**67**	75

(continued)

Table 8.2 (continued)

Species	GF	CT	Family	Vegetation groups			
				A	B	C	D
Species present in one group							
Anagallis arvensis L.	A	ME + IT	Primulaceae	8	0	0	0
Astragalus sieberi DC.	S	SA + IT	Fabaceae	31	0	0	0
Atriplex portulacoides L.	S	SA	Chenopodiaceae	23	0	0	0
Convolvulus lanatus Vahl	S	ME + SA	Convolvulaceae	8	0	0	0
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. ex Boiss.	Ph	SA + SZ	Brassicaceae	8	0	0	0
Globularia arabica Jaub. & Spach.	S	ME + IT	Globulariaceae	15	0	0	0
Halocnemum strobilaceum (Pall.) M. Bieb.	S	SA + IT	Chenopodiaceae	15	0	0	0
Limoniastrum monopetalum (L.) Boiss.	S	ME + SA + IT	Plumbaginaceae	31	0	0	0
Lygeum spartum Loefl. ex L.	Pg	SA	Poaceae	8	0	0	0
Noaea mucronata (Forssk.) Asch. & Schweinf.	S	ME + IT	Chenopodiaceae	23	0	0	0
Periploca angustifolia Labill.	S	ME	Asclepiadaceae	69	0	0	0
Salsola tetrandra Forssk.	S	SA + IT	Chenopodiaceae	15	0	0	0
Suaeda pruinosa Lange	S	SA + IT	Chenopodiaceae	46	0	0	0
Thymelaea hirsuta (L.) Endl.	S	ME + SA	Thymelaeaceae	**100**	0	0	0
Zygophyllum album L. f.	S	ME + SA	Zygophyllaceae	8	0	0	0
Acacia tortilis (Forssk.) Hayne subsp. *raddiana* (Savi)	T	SA + SZ	Fabaceae	0	33	0	0
Acacia tortilis (Forssk.) Hayne subsp. *tortilis*	T	SA + SZ	Fabaceae	0	**73**	0	0
Aizoon canariense L.	A	SA + SZ	Mesembryanthemaceae	0	33	0	0
Arnebia hispidissima (Lehm.) DC.	A	SA + IT	Boraginaceae	0	33	0	0
Atriplex farinosa Forssk.	S	SA	Chenopodiaceae	0	53	0	0
Cotula cinerea Delile	A	SA	Asteraceae	0	6	0	0
Crotalaria aegyptiaca Benth.	S	SA + SZ	Fabaceae	0	6	0	0
Euphorbia granulata Forssk.	A	SA	Euphorbiaceae	0	47	0	0
Launaea spinosa (Forssk.) Sch. Bip. ex Kuntze	S	SA + SZ	Asteraceae	0	47	0	0
Morettia philaeana (Delile) DC.	Ph	SA + IT	Brassicaceae	0	33	0	0

(continued)

Table 8.2 (continued)

Species	GF	CT	Family	Vegetation groups			
				A	B	C	D
Neurada procumbens L.	A	ME + SA	Neuradaceae	0	33	0	0
Panicum turgidum Forssk.	Pg	SA + IT	Poaceae	0	6	0	0
Salvia aegyptiaca L.	S	SZ + IT	Lamiaceae	0	53	0	0
Schouwia purpurea (Forssk.) Schweinf.	A	SA + IT	Brassicaceae	0	4	0	0
Solanum nigrum L.	A	COSM	Solanaceae	0	7	0	0
Tamarix aphylla (L.) H. Karst.	T	SA + IT	Tamaricaceae	0	7	0	0
Tamarix nilotica (Ehrenb.) Bunge	T	SA + IT	Tamaricaceae	0	7	0	0
Taverniera aegyptiaca Boiss.	S	SA + IT	Fabaceae	0	4	0	0
Alkanna orientalis (L.) Boiss.	Ph	SA + SZ	Boraginaceae	0	0	11	0
Astragalus eremophilus Boiss.	A	SA + IT	Fabaceae	0	0	33	0
Hyoscyamus muticus L.	Ph	SA + IT	Solanaceae	0	0	55	0
Lotus arabicus L.	A	SA + SZ	Leguminosae	0	0	11	0
Reseda alba L.	A	SA	Resedaceae	0	0	11	0
Senna italica Mill.	S	SA + SZ	Fabaceae	0	0	11	0
Agathophora alopecuroides (Del.) Fenzl ex Bunge	S	SA	Chenopodiaceae	0	0	0	5
Anabasis setifera Moq.	S	SA + IT	Chenopodiaceae	0	0	0	75
Cistanche phelypaea (L.) Cout.	Ph	SA + IT	Orobanchaceae	0	0	0	25
Deverra triradiata Hochst. ex Boiss.	S	SA + SZ	Apiaceae	0	0	0	5
Diplotaxis harra (Forssk.) Boiss.	A	SA + IT	Brassicaceae	0	0	0	25
Ephedra alata Decne.	S	SA	Ephedraceae	0	0	0	5
Gypsophila capillaris (Forssk.) C. Chr.	A	SA	Caryophyllaceae	0	0	0	5
Limonium pruinosum (L.) Chaz.	S	SA	Plumbaginaceae	0	0	0	5
Scrophularia deserti Delile	Ph	SA	Scrophulariaceae	0	0	0	25

Species in *bold* are the climbing plants; figures in *bold* are the indicator and preferential species of the four vegetation groups

Growth forms: *T* Tree, *S* Shrub, *Ph* Perennial herb, *Pg* Perennial grass, *A* Annual, *Chorotypes: COSM* Cosmopolitan, *PAL* Palaeotropical *SA* Saharo–Arabian, *SZ* Sudano–Zambezian, *ME* Mediterranean, *IT* Irano–Turanian

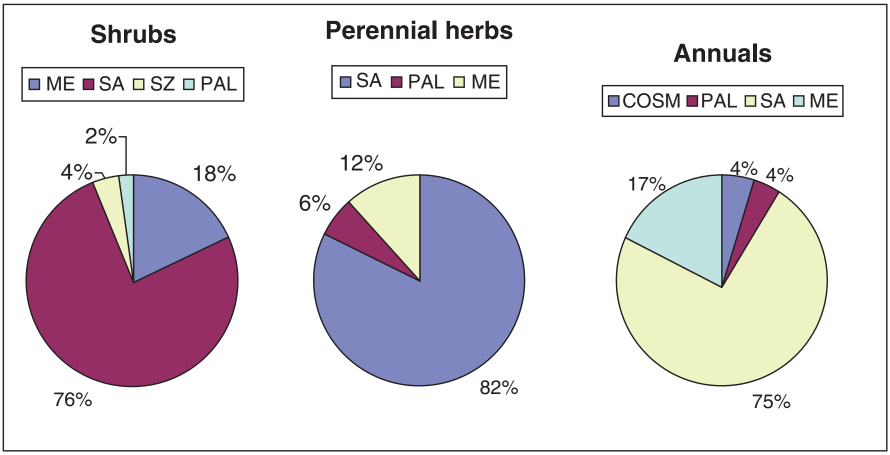

Fig. 8.3 Distribution of the chorotypes in the major growth form categories

Irano–Turanian, the Afro–Asiatic Saharo–Arabian, and the Euro–Afro–Asiatic Mediterranean (El-Hadidi 1993). As the whole country lies within the Saharo–Arabian belt of the Holarctic floristic realm, the chorological analysis of the floristic data indicated the abundance of the Saharo–Arabian chorotype (mono-, bi-, and pluriregional) within the major growth forms (shrubs, perennial herbs, and annuals; Fig. 8.3). Altogether, they comprised 69 species or 71 % of the total recorded flora. On the contrary, the different elements of the Mediterranean chorotype contributed with 15 species (15.5 %) of the total flora. This may be attributed to the fact that plants of the Saharo–Arabian species are good indicators for desert harsh environmental conditions, while Mediterranean species stand for more mesic environment (El-Demerdash et al. 1994; Sheded 2002; Abd El-Ghani and Abdel-Khalik 2006; El-Husseini et al. 2008).

8.1.1.4 Vegetation Characteristics of the Five Climbing Plants

The application of cluster analysis (Fig. 8.4) and DCA ordination (Fig. 8.5) techniques produced four major vegetation groups similar in terms of their species composition (Table 8.2). Each was linked to one or more of the studied climbing plants and named after the dominant species as follows: group (A) *Thymelaea hirsuta–Anabasis articulata*, group (B) *Zilla spinosa–Acacia tortilis* subsp. *tortilis–Pulicaria crispa*, group (C) *Cleome droserifolia-Launaea nudicaulis*, and group (D) *Zilla spinosa–Ochradenus baccatus*. Three species (*Echinops spinosissimus*, *Retama raetam*, and *Zilla spinosa*) have wide ecological range of distribution and occurred in the four identified vegetation groups.

Group (A) was dominated by *Thymelaea hirsuta* and *Anabasis articulata* from 13 sites in the inland western Mediterranean desert with the highest soil pH (7.9, Table 8.3). This group was linked to *Periploca angustifolia*. The vegetation of

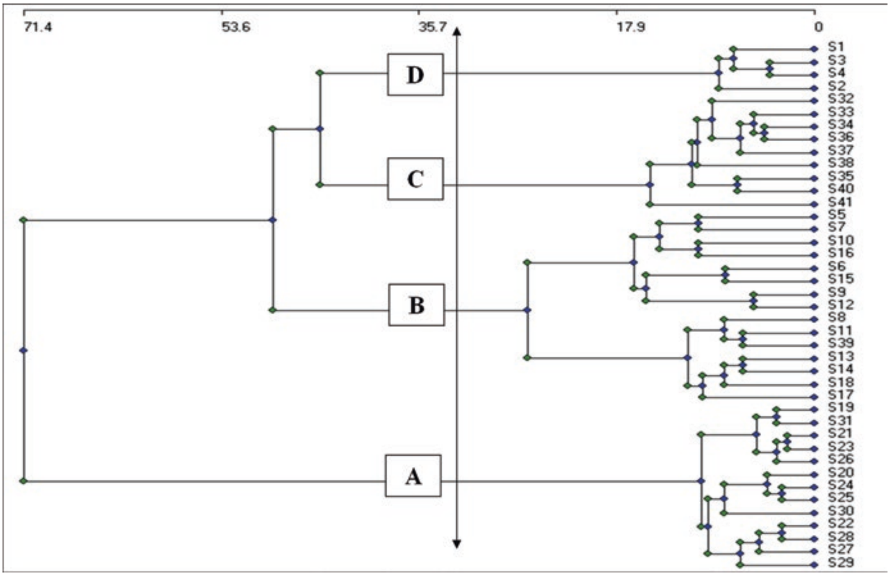

Fig. 8.4 Dendrogram indicating the four vegetation groups (A–D) resulting from the cluster analysis of the 41 sampled sites

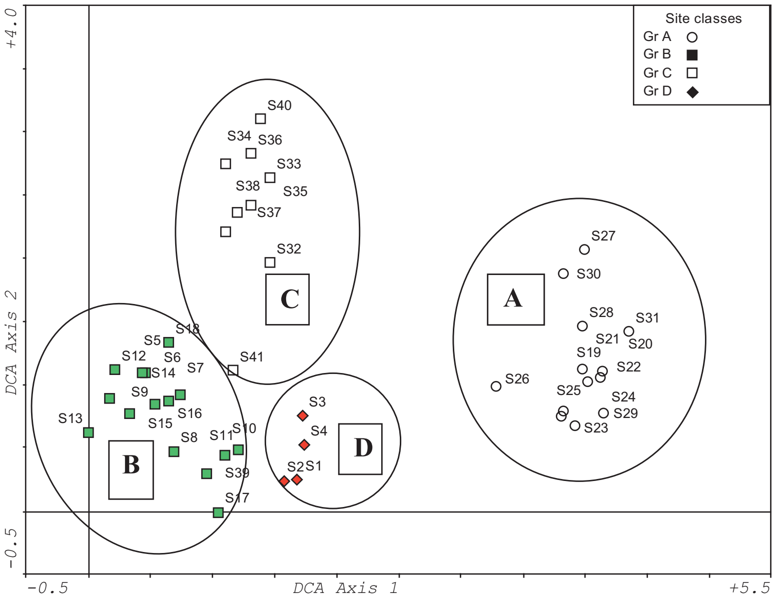

Fig. 8.5 DCA ordination diagram of the 41 sites on axes 1 and 2 as classified by cluster analysis; A–D are the four vegetation groups

Table 8.3 Mean values, standard errors (±SE), ANOVA F-values of the soil variables, and species richness in the 41 sites representing the four vegetation groups (A–D) obtained by cluster analysis

Soil variables		Mean	Vegetation groups				F-ratio
			A	B	C	D	
pH		7.8 ± 0.3	7.9 ± 0.3	7.6 ± 0.4	7.8 ± 0.03	7.8 ± 0.3	1.16
EC	(mS cm^{-1})	1.7 ± 1.1	1.6 ± 0.6	1.4 ± 0.9	1.8 ± 1.3	5.2 ± 0.9	0.56
Gravel	(%)	4.9 ± 3.3	1.9 ± 0.7	7.6 ± 3.8	4.4 ± 1.3	5.2 ± 0.9	11.96**
Coarse sand	(%)	13.6 ± 3.4	15.3 ± 1.8	12.2 ± 3.9	15.6 ± 1.9	9.3 ± 0.6	7.64**
Silt	(%)	8.2 2.1	8.7 ± 2.1	7.8 ± 1.9	7.2 ± 2.0	10.6 ± 1.7	3.15*
Clay	(%)	6.7 ± 3.7	5.4 ± 1.2	9.2 ± 4.9	4.6 ± 2.5	6.4 ± 1.1	4.8**
Ca^{+2}	mg (100 g)$^{-1}$	6.5 ± 5.2	4.8 ± 3.0	9.2 ± 5.8	1.9 ± 1.2	12.1 ± 4.4	8.70**
Mg^{+2}	mg (100 g)$^{-1}$	2.2 ± 1.6	2.7 ± 1.7	2.2 ± 1.7	1.3 ± 0.7	3.0 ± 2.0	1.72
Na^{+}	mg (100 g)$^{-1}$	3.7 ± 2.2	3.2 ± 1.6	4.8 ± 2.2	1.7 ± 0.7	5.6 ± 2.5	7.26**
K^{+} mg	mg (100 g)$^{-1}$	0.9 ± 0.4	0.9 ± 0.3	1.1 ± 0.4	0.5 ± 0.3	1.3 ± 0.5	7.41**
HCO_3^{-}	mg (100 g)$^{-1}$	0.2 ± 1.2	2.1 ± 0.8	3.2 ± 1.3	1.3 ± 0.5	2.1 ± 0.8	7.26**
SO_4^{-2}	mg (100 g)$^{-1}$	3.5 ± 3.3	2.7 ± 2.5	5.0 ± 3.8	0.9 ± 0.5	6.7 ± 1.5	6.11**
Cl^{-}	mg (100 g)$^{-1}$	6.5 ± 4.6	4.9 ± 1.6	8.7 ± 4.0	2.0 ± 0.7	14.1 ± 5.0	18.82**
NH_4^{+}	mg (100 g)$^{-1}$	34.2 ± 12.6	30.5 ± 11.0	32.9 ± 10.9	35.5 ± 10.9	47.8 ± 20.4	2.21
NO_3^{-}	mg (100 g)$^{-1}$	27.5 ± 16.2	31.1 ± 13.4	28.4 ± 12.8	12.9 ± 6.6	45.9 ± 28.0	5.98**
Species richness		15.5 ± 5.9	10.5 ± 2.0	18.7 ± 6.6	14.0 ± 3.4	9.0 ± 2.2	9.79**

*$p < 0.05$, **$p < 0.01$

this site group can be further divided into three subgroups, each included *P. angustifolia*: *Periploca angustifolia–Thymelaea hirsuta*, *Periploca angustifolia–Deverra tortuosa*, and *Periploca angustifolia–Haloxylon salicornicum*. Among the common associates, *Asphodelus ramosus*, *Haloxylon salicornicum*, and *Suaeda pruinosa* occurred. In the Sallum area, Salama et al. (2005) reported a similar floristic composition to the three vegetation subgroups of *Periploca angustifolia*, with 12 species of common occurrence such as *Asphodelus ramosus*, *Citrullus colocynthis*, *Haloxylon salicornicum*, and *Zilla spinosa. Periploca angustifolia* is highly grazed, and conservation measures should be taken for the preservation of the populations of this species in its habitat. It has the lowest share of annuals, where *Asphodelus ramosus*, *Anagallis arvensis*, and *Rumex vesicarius* were only recorded.

Group (B) was characterized by *Zilla spinosa*, *Acacia tortilis* subsp. *tortilis*, and *Pulicaria crispa* that inhabited 15 sandy gravel sites with the highest contents of bicarbonates and the lowest salinity (Table 8.3) from the Mediterranean, Red Sea, and Sinai regions. This is the most diversified among the identified vegetation groups, with the highest total number of recorded species (61; 18.7 ± 6.6 species per site). *Citrullus colocynthis* was linked to this group, with the presence value of 60 %. Apart from the dominant tree species, other four trees were found: *Calotropis procera*, *Acacia tortilis* subsp. *raddiana*, *Tamarix aphylla*, and *T. nilotica*. Common desert perennials were *Crotalaria aegyptiaca*, *Panicum turgidum*, *Aerva javanica*, *Launaea spinosa*, and *Leptadenia pyrotechnica.* Several associated species with this group were repeatedly recorded in the Wadies of the Eastern Desert (Kassas and El-Abyad 1962; Kassas and Girgis 1972; Abd El-Ghani 1998; Sheded 1998), along the Red Sea coast (Salama and Fayed 1989) and along the western Mediterranean coast (Salama et al. 2005). This group had the highest share of annuals (17), of which *Euphorbia granulata*, *Arnebia hispidissima*, *Aizoon canariense*, *Neurada procumbens*, and *Zygophyllum simplex* were of the highest presence values. The agricultural processes, farming practices, and other excessive human disturbances in the studied sites, where many land reclamation projects are still running in the Mediterranean, Red Sea, and Sinai regions, may contribute to the high share of annuals recorded. The relationship between salinity and species diversity was documented by several authors (Danin et al. 1975; Ayyad and El-Ghareeb 1982; Shaltout and El-Ghareeb 1992; Abd El-Ghani and Amer 2003).

Group (C) was dominated by *Cleome droserifolia* and *Launaea nudicaulis* that inhabit nine sites, with the lowest values of the majority (except electric conductivity, gravel, coarse sand, and NH_4^+) of the measured soil variables (Table 8.3). This group was linked to *Cucumis prophetarum*, with the presence value of 55 %. Three vegetation subgroups can be identified including *C. prophetarum*: *Cucumis prophetarum–Launaea nudicaulis* and *Cucumis prophetarum–Cleome droserifolia* from the sites of south Sinai and *Cucumis prophetarum–Achillea fragrantissima* from those of the Red Sea region. As described by Zahran and Willis (1992), the community dominated by *Cleome droserifolia* in association with *Cucumis prophetarum* occupied the limestone country of the Red Sea coastal land and was indicated by the presence of *Fagonia mollis* and *Zilla spinosa.* Despite their pedological and phytogeographical differences, the floristic composition of our *Cucumis prophetarum–Cleome droserifolia* group that was recorded from Sinai seems to be similar to that described above.

Group (D) was dominated by *Zilla spinosa* and *Ochradenus baccatus* inhabiting the four sites studied in the wadies of Digla, Hof, and Araba of the Eastern Desert that linked to *Pergularia tomentosa* and *Cocculus pendulus*. Apart from pH, coarse sand, clay, and bicarbonates, the soil of the studied sites is characterized by the highest values of other examined variables and the lowest mean species richness (9.0 ± 2.2). *Cocculus pendulus* associates can be further classified into three subgroups: *Cocculus pendulus–Aerva javanica*, *Cocculus pendulus–Euphorbia granulata*, and *Cocculus pendulus–Achillea fragrantissima*. *Achillea fragrantissima* and *Retama raetam* shared these groups. Springuel et al. (1997) recorded 50 species in association with *Cocculus pendulus*, of which 21 were recorded in common such as *Acacia tortilis* subsp. *tortilis*, *Aerva javanica*, *Citrullus colocynthis*, *Euphorbia granulata*, *Forsskaolea tenacissima*, *Ochradenus baccatus*, *Zilla spinosa*, and *Zygophyllum coccineum*. A similar floristic composition was also reported by Abd El-Ghani and Abd El-Khalik (2006) in Gebel Elba National Park; among these species, *Acacia tortilis* subsp. *tortilis*, *Aerva javanica*, *Citrullus colocynthis*, *Lycium shawii*, and *Salvia aegyptiaca* were reported.

8.1.1.5 Soil Factors Affecting the Distribution of the Five Climbing Plants

The four vegetation groups with their sites were differentiated along the first (eigenvalue = 0.680) and the second (eigenvalue = 0.311) axes of the Detrended Correspondence Analysis (DCA; Fig. 8.5). The four DCA axes explained 12.7 %, 5.8 %, 3.4 %, and 2.5 % of the total variation in the species data, respectively. This low percentage of variance explained by the axes is attributed to the many zero values in the vegetation data set. Group (A) occupied the extreme positive end of DCA axis 1, while group (B) occupied the negative end. The species–environment correlations were higher for the first three canonical axes, explaining 52 % of the cumulative variance. These results suggested an association between vegetation and the measured soil parameters presented in the biplot (Jongman et al. 1987). Contributions of chlorides, gravel, bicarbonates, clay, coarse sand, and NH_4^+, which were selected by the automatic forward selection option of environmental variables in the program CANOCO, to the variation in species data, were 15.0 %, 12.8 %, 7.5 %, 6.6 %, 7.5 %, and 6.2 %, respectively. They exhibited the most important factors that affected the distribution of the five studied climbing plants. 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 statistic to be significant ($P < 0.005$).

From the inter-set correlations of the soil factors with the first three axes of CCA (Table 8.4), it can be noted that CCA axis 1 was positively correlated with gravel,

Table 8.4 Comparison of the results of ordination for the first three axes of DCA and CCA

	DCA axis			CCA axis		
	1	2	3	1	2	3
Eigenvalues	0.68	0.31	0.19	0.56	0.27	0.15
Species–environment correlation coefficients	0.89	0.79	0.69	0.93	0.94	0.81
pH	0.16	0.16	–0.12	–0.16	0.08	0.17
EC	–0.37	–0.30	–0.22	0.006	0.01	0.23
Gravel	–0.62	–0.20	0.20	0.51	–0.03	0.02
Coarse sand	0.26	0.48	0.18	–0.43	–0.20	0.04
Silt	0.17	–0.30	0.15	0.07	0.11	0.08
Clay	–0.28	–0.35	–0.14	0.20	0.002	–0.09
Ca^{+2}	–0.26	–0.48	–0.25	0.27	0.24	–0.03
Mg^{+2}	0.16	–0.25	–0.12	0.14	0.06	–0.25
Na^+	–0.20	–0.56	–0.39	0.40	0.29	-0.11
K^+	–0.11	–0.44	–0.14	0.19	0.25	–0.09
HCO_3^-	–0.30	–0.38	–0.34	0.23	0.01	–0.002
SO_4^{-2}	–0.15	–0.51	–0.18	0.32	0.35	–0.07
Cl^-	–0.21	–0.630	–0.23	0.40	0.37	–0.06
NH_4^+	–0.02	–0.20	0.17	0.07	0.22	0.31
NO_3^-	0.11	–0.47	–0.20	–0.09	0.34	–0.04

Inter-set correlations of the soil variables, together with eigenvalues and species–environment correlation coefficients. For units, see Table 8.3

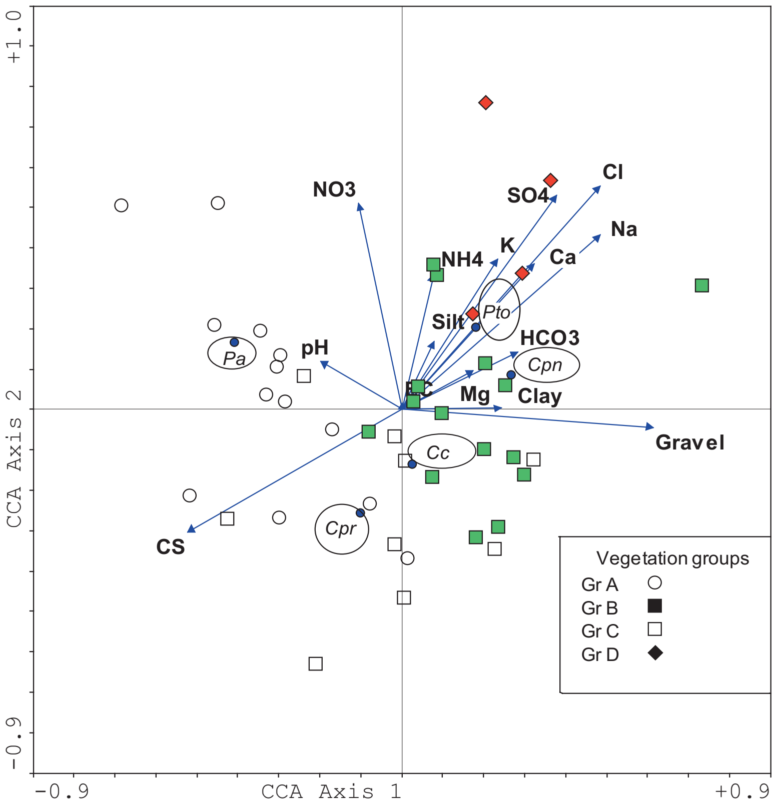

Fig. 8.6 Canonical correspondence analysis (CCA) ordination triplot of the studies of five climbing plants (*encircled*), sites, and soil variables, reflecting distributions of the five climbing plants along gradients of soil variables. *Cc Citrullus colocynthis*, *Cpn Cocculus pendulus*, *Cpr Cucumis prophetarum*, *Pa Periploca angustifolia*, *Pto Pergularia tomentosa* sampling. CCA axis 2 was clearly positively correlated with SO_4^{-2}, Cl^-, and NO_3^- and negatively correlated with coarse sand. This axis can be defined as coarse sand–Cl^- gradient. The pattern of ordination is similar to that of the floristic DCA, with most of the sites remaining in their respective vegetation groups

Na^+, SO_4^{-2}, and Cl^- and negatively correlated with coarse sand. This act becomes more clear in the ordination triplot (Fig. 8.6). This axis can be defined as gravel–coarse sand gradient. 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.

Inspection of Fig. 8.6 indicated also that the distribution of *Cocculus pendulus* (Cpn) can be affected by gravel, clay, bicarbonates, and Mg^{+2}, while *Pergularia tomentosa* (Pto) was affected by SO_4^{-2}, K^+, Na^+, and Cl^-. These two species were assigned to group (D). The distribution of *Periploca angustifolia* (Pa) of group (A) is affected by soil reaction (pH) as it reached its highest value in its group. This can be attributed to its limestone substrate and closure from the Mediterranean Sea coast. A similar conclusion has been reached by Abd El-Ghani and El-Sawaf (2005) on the coastal vegetation along the Eastern Mediterranean coast of Egypt between El-Arish and Rafah of the vegetation type dominated by *Panicum turgidum* and *Thymelaea hirsuta*. *Cucumis prophetarum* (Cpr) was shown to be affected by coarse sand, while *Citrullus colocynthis* (Cc), which is assigned to group (B), showed weak relation to gravel, clay, and bicarbonates. These results were also in line with those obtained from DCA and soil analysis. The role of the percentage of surface sediments of different size classes in the distribution of vegetation in the arid regions is documented as it determines the spatial distribution of soil moisture (Yair et al. 1980; El-Ghareeb and Shabana 1990; Abd El-Ghani 1998).

8.1.1.6 Vine–Insect Relationship

A total of 31 insect species belonging to 5 orders and 18 families were recorded in association with the studied plant species (Table 8.5). The most associated insects were belonging to orders Hymenoptera (ants, bees, and wasps) and Coleoptera (beetles) that counted 45.16 % and 38.7 %, respectively. Among the 18 families of the recorded insects, Tenebrionidae (darkling beetles) was the most dominant family (8 species; 25.8 %) including *Adesmia antigua* and *Pimelia bicarinata*, followed by Formicidae (ants; 6 species) by (ants; 6 species;19.3%), including *Camponotus sericeus* and *Monomorium salomonis*. Moreover, the family Coccinellidae (ladybird beetles) was recorded with two species (6.4 %) and one species (3.2 %) For each of the remaining families.

Based on the similarity between the insect associates, cluster analysis (Fig. 8.7) was demonstrated. The cluster analysis divided the studied plant species into three groups (A–C). It can be noted that *C. colocynthis* (group C) was markedly dissimilar from the other two groups (dissimilarity index 21). At dissimilarity index 19, the two other groups (A and B) were segregated. Group A included *P. angustifolia*. Group B included *C. pendulus*, *P. tomentosa*, and *C. prophetarum*. At dissimilarity index 7, *P. tomentosa* and. *C. prophetarum* were the closely related.

According to feeding habits (Table 8.6), herbivorous were represented by 17 species of high occurrence on *C. colocynthis*; the majority of the recorded herbivores were nectar feeders (7 species) such as *Apis mellifica*, *Lapidus catenulate*, and *Xylocopa hottentotta* and generalized foragers (6 species), including *Camponotus* sp., *Monomorium salomonis*, and *Plagiolepis schmitzii*. Detritivores are represented in this study by eight species; it was found to be in high association with *P. angustifolia* by five species such as *Pimelia bicarinata* and *Strongylium dubium*. The remaining six species were carnivores including four predators and two parasitoids.

The 31 insect species that were found in association with the studied climbers were belonging to the orders Hymenoptera, Coleoptera, Hemiptera, Diptera, and Neuroptera; according to the relation with plant and their feeding habit, they can be classified into three main groups; the first were the herbivores (17 species) which feed on plant material, the second were the detritivores (eight species) that were feeding on the fallen plant parts, and the third were carnivores (six species) which

Table 8.5 Order, family, species, and feeding habits of the associated insect species

Order	Family	Species	Code	*C. co*	*C. pe*	*C. pr*	*P. to*	*P. an*	FH
Coleoptera	Tenebrionidae	*Adesmia antique* (Klug)	Sp1	–	+	–	–	–	Detritivores
Coleoptera	Tenebrionidae	*Pimelia bicarinata* (Klug)	Sp2	–	+	–	–	+	Detritivores
Coleoptera	Tenebrionidae	*Pterolasia squalid* (Solier)	Sp3	–	–	–	–	+	Detritivores
Coleoptera	Tenebrionidae	*Scleron dubium* (Gridelli)	Sp4	–	–	–	–	+	Detritivores
Coleoptera	Tenebrionidae	*Machlopsis crenatocostata* (Redtenbacher)	Sp5	–	–	–	–	+	Detritivores
Coleoptera	Coccinellidae	*Coccinella undecimpunctata* (Linnaeus)	Sp6	–	+	–	+	–	Predator
Coleoptera	Coccinellidae	*Epilachna chrysomelina* (Fabricius)	Sp7	+	–	+	–	–	Herbivores, leaf feeder
Coleoptera	Carabidae	*Cymindis setifensis* (Lucas)	Sp8	–	–	–	–	+	Predator
Coleoptera	Tenebrionidae	*Omophlus* sp.	Sp9	–	–	–	–	+	Herbivores, flower feeder
Coleoptera	Curculionidae	*Ocladius aegyptiacus* (Tournier)	Sp10	+	–	–	–	–	Seed feeder
Coleoptera	Buprestidae	*Lampidus catenulate* (Klug)	Sp11	+	–	–	–	–	Herbivores, pollen and nectar feeder
Hemiptera	Lygaeidae	*Spilostethus pandurus* (Scopoli)	Sp12	+	+	+	–	–	Herbivores, flower, and seed feeder
Hymenoptera	Chrysididae	*Stilbum cyanurum* (Forster)	Sp13	–	+	–	–	–	Predator
Hymenoptera	Sphecidae	*Calosphex niveatus* (Dufour)	Sp14	–	+	–	–	–	Parasitoid- Carnivorous
Hymenoptera	Scelionidae	*Telenomus* sp. (Haliday)	Sp15	–	+	–	–	–	Parasitoid–Carnivorous
Hymenoptera	Halictidae	*Halictus* sp.	Sp16	–	+	–	–	–	Herbivores, pollen and nectar feeder
Hymenoptera	Anthophoridae	*Anthophora byssina* (Klug)	Sp17	+	+	–	–	–	Herbivores, pollen and nectar feeder
Hymenoptera	Apidae	*Apis mellifica* (Linnaeus)	Sp18	+	–	–	–	–	Herbivores, pollen and nectar feeder
Diptera	Muscidae	*Musca sorbens* (Wiedemann)	Sp19	+	–	–	–	–	Detritivores

(continued)

Table 8.5 (continued)

Order	Family	Species	Code	*C. co*	*C. pe*	*C. pr*	*P. to*	*P. an*	FH
Hymenoptera	Formicidae	*Plagiolepis schmitzii* (Forel)	Sp20	–	–	–	–	+	Herbivores, generalized foragers
Hymenoptera	Formicidae	*Camponotus* sp.	Sp21	–	–	–	+	–	Herbivores, generalized foragers
Hymenoptera	Colletidae	*Prosopis* sp.	Sp22	–	–	–	–	+	Herbivores, pollen and nectar feeder
Neuroptera	Chrysopidae	*Chrysoperla carnea* (Stephens)	Sp23	–	–	–	–	+	Predator
Hymenoptera	Formicidae	*Camponotus sericeus* (Fabricius)	Sp24	+	–	–	–	–	Herbivores, generalized foragers
Hymenoptera	Xylocopidae	*Xylocopa hottentota* (Smith)	Sp25	+	–	–	–	–	Herbivores, pollen and nectar feeder
Hymenoptera	Formicidae	*Monomorium salomonis* (Linnaeus)	Sp26	+	–	–	–	–	Herbivores, generalized foragers, and seed feeder
Hymenoptera	Formicidae	*Monomorium bodenheimeri* (Menozzi)	Sp27	–	–	–	+	–	Herbivores, generalized foragers, and seed feeder
Diptera	Syrphidea	*Syrphus crollae*(Linnaeus)	Sp28	–	+	–	+	–	Herbivores, nectar feeder
Coleoptera	Tenebrionidae	*Adesmia bicarinata* (Klug)	Sp29	–	+	–	+	–	Detritivores
Hymenoptera	Formicidae	*Monomorium* sp.	Sp30	–	+	–	+	–	Herbivores, generalized foragers, and seed feeder
Coleoptera	Tenebrionidae	*Gonocephalum setulosum* (Faldermann)	Sp31	–	–	–	–	+	Detritivores

C.co Citrullus colocynthis, *C.pe Cocculus pendulus*, *C.pr Cucumis prophetarum*, *P.to Pergularia tomentosa*, *P.an Periploca angustifolia*, *FH* Feeding habit
– = absent, + = present

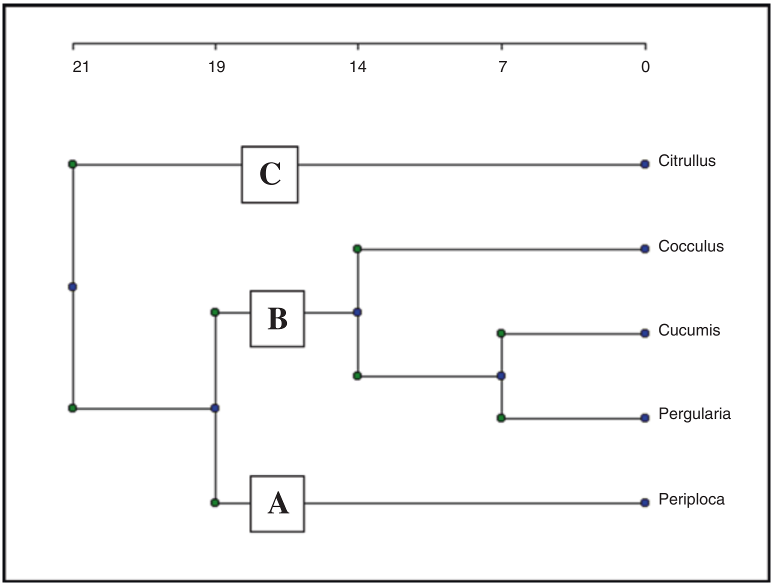

Fig. 8.7 Cluster analysis of the five studied plant species based upon the similarity of associated insects

Table 8.6 Associated insect species of the five studied climbing plants

Insect species	*C.co*	*C.pe*	*C.pr*	*P.to*	*P.an*
Sp1	0	1	0	0	0
Sp2	0	1	0	0	1
Sp3	0	0	0	0	1
Sp4	0	0	0	0	1
Sp5	0	0	0	0	1
Sp6	0	1	0	1	0
Sp7	1	0	1	0	0
Sp8	0	0	0	0	1
Sp9	0	0	0	0	1
Sp10	1	0	0	0	0
Sp11	1	0	0	0	0
Sp12	1	1	1	0	0
Sp13	0	1	0	0	0
Sp14	0	1	0	0	0
Sp15	0	1	0	0	0
Sp16	0	1	0	0	0
Sp17	1	1	0	0	0
Sp18	1	0	0	0	0
Sp19	1	0	0	0	0

(continued)

Table 8.6 (continued)

Insect species	*C.co*	*C.pe*	*C.pr*	*P.to*	*P.an*
Sp20	0	0	0	0	1
Sp21	0	0	0	0	1
Sp22	0	0	0	0	1
Sp23	0	0	0	0	1
Sp24	1	0	0	0	0
Sp25	1	0	0	0	0
Sp26	1	0	0	0	0
Sp27	0	0	0	1	0
Sp28	0	1	0	1	0
Sp29	0	1	0	1	0
Sp30	0	1	0	1	0
Sp31	0	0	0	0	1

For nomenclature of the insect species, see Table 8.5
C.co Citrullus colocynthis, *C.pe Cocculus pendulus*, *C.pr Cucumis prophetarum*, *P.to Pergularia tomentosa*, *P.an Periploca angustifolia*. *0* absent, *1* present

visit plants searching for their prey or host. Darkling beetles showed the highest species richness (11 species), and this is related to the arid habitat of the studied plant group, where darkling beetles are a conspicuous element of most arid and semiarid environments (Doyen and Tschinkel 1974).

The 12 insect species that recorded with *Cocculus pendulus* show high variation in their feeding habits. The herbivores were counted as five species; three of them are pollen and nectar feeders; this indicates the insect *C. pendulus* interaction through pollination. Another four species visit *C. pendulus* to search for preys (predators and parasitoid); the remaining three species were detritivores. Markedly, the rarity of *Cucumis prophetarum* and its limited distribution may explain the lowest number of insect species found with it, as only two species were recorded in association with it.

Notably, *Citrullus colocynthis* was recorded with the highest number of herbivore species (nine species); four of these herbivores were pollinators. *Citrullus colocynthis* was reported as mainly insect pollinated without much inbreeding depression (Robinson and Decker-Walters 1997) The intensive grazing of *Periploca angustifolia* by camels, goats, and sheeps causing high presence of the fallen plant material which attracts detritivore insects may be the explanation of the high abundance of detritivores (six species) that were represented in association with *P. angustifolia*. On the other hand, most of the recorded insects with *Pergularia tomentosa* were herbivores that are feeding on it.

8.1.2 Succulent Plants

Succulents are plants that are able to withstand drought because of the water stored in some of their organs. They constitute a widespread group, being represented in several families of flowering plants and, to some extent, in the gymnosperms as well

(Sajeva and Costanzo 1994). Succulents are native to many regions from northern Europe to the Far East, although most are concentrated in southern and eastern Africa. Exploration and trading over the last four centuries and natural distribution enabled cacti and succulents to establish in new habitats across the world (Hewitt 1993). Cactaceae is the largest family of succulent plants, nearly endemic to North and South America, followed by Aizoaceae in South Africa. Euphorbiaceae is considered the sixth largest family among flowering plants, with over 300 genera and 5,000 species of worldwide distribution.

Succulents vary in shape and size, from more than a few millimetres high to massive trees such as the African baobab (*Adansonia digitata* L.). Hewitt (1993) recognized three different habitats for succulents: (1) desert plains including harsh dry habitats; (2) mountainous terrain, including high plateau, screes, and rocky slopes—the soil is often very thin, does not retain much water, and has a high mineral content that can be toxic to non-succulent plants; and (3) forests, where species inhabit subtropical and tropical rainforests such as those in Central and South America, Africa, Sri Lanka, and the West Indies as the climate is constantly hot and humid, and sunlight is filtered through a thick tree canopy. Economically, they can be used as medicinal (e.g. *Aloe ferox*) and mystical (e.g. *Haworthia limifolia*) purposes or as food (e.g. *Fockea edulis*) and cordage (e.g. *Sansevieria aethiopica*).

In harsh dry habitats, cacti and succulents are dominating, enduring great temperature and extremes of scorching days and freezing nights. Although a few can survive without water for years at a stretch and live in true deserts, which have less than 25 mm of rainfall a year, most grow in semideserts, which receive sporadic rainfalls between droughts. Semideserts have very poor soil with sparse vegetation and rocky outcrops, rather than pure sand. The rainfall is sometimes augmented by heavy dews or coastal mists. Desert cacti and succulents have the capacity to conserve moisture and withstand drought, by becoming dormant, and to produce new growth in favourable conditions. This growth pattern can be copied by keeping the plants dry in their dormant period and watering them in the growing season.

8.1.2.1 Distribution Patterns of Succulents in Egypt

Table 8.7 shows the distribution of the succulent flora in the different phytogeographic regions of Egypt. The Sinai Peninsula and the Mediterranean regions included most of the succulent species (59 species in 11 families in Sinai and 44 species in 14 families in the Mediterranean region. The best represented succulent genera are *Suaeda* (nine species), *Zygophyllum* (five species), *Salsola* and *Caralluma* (four species for each), *Mesembryanthemum*, and *Euphorbia* (three species for each). The most species-rich succulent families are Chenopodiaceae (28 species) followed by Aizoaceae (ten species), then Zygophyllaceae (six species), Crassulaceae, Orobanchaceae, and Tamaricaceae (five species for each). The most species-poor succulent families are Compositae, Elatinaceae, Peganaceae, Sphenocleaceae, and Vitaceae (one species for each). The species varied according to their affinities in the different phytogeographic regions. *Hyoscyamus muticus* and

Arthrocnemum macrostachyum were represented in all phytogeographic regions (seven regions). *Suaeda vera*, *S. vermiculata*, and *Cistanche phelypaea* were represented in six regions for each, exhibiting a wide geographical and ecological range of distribution. Some species showed a certain degree of consistency, i.e. confined to a certain phytogeographic region. Ten species were confined to Gebel Elba, such as the perennial herb *Caralluma acutangula, Haloxylon negevensis* in the Sinai, and the annual *Suaeda altissima* in the Mediterranean region.

In a trial to compare the floristic composition of succulent plants of the arid region in countries neighbouring Egypt, Tables 8.7 and 8.8 showed that the succulent species-rich families were Chenopodiaceae, Aizoaceae, and then Zygophyllaceae, respectively. In Sudan, Euphorbiaceae (six species) ranked second to Chenopodiaceae

Table 8.7 Distribution of succulent flora in the different phytogeographic regions of Egypt

Families	Species	Habit	N	O	M	D	R	GE	S
(1) Succulent leaf									
Aizoaceae	*Aizoon canariense*	AH			☼ ▲■	☼ ▲■		☼ ▲	☼ ▲■
Aizoaceae	*A. hispanicum*	AH	☼ ▲		☼ ▲■	☼ ▲■			☼ ▲■
Aizoaceae	*Mesembryanthemum crystallinum*	AH	☼ ▲		☼ ▲■	☼ ▲■			☼
Aizoaceae	*M. forsskaolii*	AH		☼ ▲■	☼ ▲■	☼ ▲■			☼ ▲■
Aizoaceae	*M. nodiflorum*	AH	☼ ▲		☼ ▲■				☼
Aizoaceae	*Sesuvium sesuvioides*	AH						☼ ▲■	
Aizoaceae	*Trianthema portulacastrum*	AH						☼ ▲■	
Aizoaceae	*Trianthema triquetra*	AH				☼ ▲■	☼ ▲■	☼ ▲■	
Aizoaceae	*Zaleya decandra*	AH						☼ ▲■	
Aizoaceae	*Z. pentandra*	AH	☼ ▲■			☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲■
Caryophyllaceae	*Polycarpon succulentum*	AH	☼ ▲		☼ ▲■	☼ ▲■			☼ ▲■
Caryophyllaceae	*Sclerocephalus arabicus*	AH				☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲■
Chenopodiaceae	*Halopeplis amplexicaulis*	S	☼ ▲	☼ ▲■	☼ ▲■				☼
Chenopodiaceae	*H. perfoliata*	S			☼ ▲■		☼ ▲■		☼

(continued)

Table 8.7 (continued)

Families	Species	Habit	N	O	M	D	R	GE	S
Chenopodiaceae	*Salsola imbricata* subsp. *gaetula*	S		☼ ■	☼ ■	☼ ■			☼
Chenopodiaceae	*S. imbricata* subsp. *imbricata*	S	☼	☼ ▲■		☼ ▲■		☼ ▲■	☼ ▲
Chenopodiaceae	*S. kali*	AH	☼ ▲		☼ ▲■	▲			☼ ▲
Chenopodiaceae	*S. tetrandra*	S		☼ ▲	☼ ▲■	☼ ▲■			☼ ▲■
Chenopodiaceae	*S. volkensii*	AH	☼ ▲		☼ ▲■	☼ ▲■			☼ ■
Chenopodiaceae	*Seidlitzia Rosmarinus*	S				☼ ▲■			☼ ▲■
Chenopodiaceae	*Sevada schimperi*	S				☼ ▲■	☼ ▲■	☼ ▲■	
Chenopodiaceae	*S. aegyptiaca*	AH	☼ ▲	☼ ▲■	☼ ▲■	☼ ▲■			☼
Chenopodiaceae	*S. altissima*	AH			☼ ▲■				
Chenopodiaceae	*Suaeda maritima*	AH	☼ ▲	☼ ■	☼ ▲■	☼ ▲■			
Chenopodiaceae	*S. monoica*	S		☼ ▲■		☼ ▲	☼ ▲■	☼ ▲	☼ ▲
Chenopodiaceae	*S. palaestina*	S			☼ ■				☼
Chenopodiaceae	*S. pruinosa*	S			☼ ▲■	▲■			☼
Chenopodiaceae	*S. splendens*	AH	☼ ▲		☼ ▲■	■			☼
Chenopodiaceae	*S. vera*	S	☼ ▲		☼ ▲■	☼ ▲	▲	▲	☼ ▲
Chenopodiaceae	*S. vermiculata*	S	☼ ▲	☼ ▲	☼ ▲■	☼ ▲■	☼ ▲■		☼ ▲■
Chenopodiaceae	*Traganum nudatum*	S		☼ ▲	☼ ■	☼ ▲■			☼ ▲
Commelinaceae	*Commelina forskaolii*	PH						☼	
Commelinaceae	*Cyanotis barbata*	PH						☼ ▲■	
Compositae	*Limbarda crithmoides*	S	☼ ▲■	☼ ▲■	☼ ▲■				
Crassulaceae	*Crassula alata*	AH	▲		☼ ▲■				

(continued)

Table 8.7 (continued)

Families	Species	Habit	N	O	M	D	R	GE	S
Crassulaceae	*Rosularia lineata*	PH				▲■			☼
Crassulaceae	*Umbilicus botryoides*	PH						☼ ▲■	
Crassulaceae	*U. horizontalis* var. *horizontalis*	PH			☼ ▲■				☼
Crassulaceae	*U. rupestris*	PH							☼ ▲■
Cruciferae	*Cakile maritima* subsp. *aegyptiaca*	AH	☼ ▲		☼ ▲■	▲			☼
Cruciferae	*Moricandia sinaica*	PH				☼ ▲			☼ ▲■
Peganaceae	*Tetradiclis tenella*	AH			☼ ▲■				
Portulacaceae	*Portulaca oleracea* subsp. *stellata*	AH	▲■	▲	▲	■			☼ ▲
Portulacaceae	*P. oleracea* subsp. *nitida*	AH	☼ ▲■	☼ ▲■	☼ ▲■	☼ ■			☼ ▲
Portulacaceae	*P. oleracea* subsp. *oleracea*	AH	☼ ▲■	▲	▲■			☼ ■	▲
Solanaceae	*Hyoscyamus boveanus*	PH	☼	☼ ▲■		☼ ▲■	☼ ▲■		☼ ▲■
Solanaceae	*H. muticus*	PH	☼ ▲	☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲■	☼ ■	☼ ▲■
Tamaricaceae	*Reaumuria hirtella* var. *brachylepis*	S			▲■	▲■			☼ ■
Tamaricaceae	*R. hirtella* var. *hirtella*	S			☼ ▲■	☼ ▲■			☼ ▲■
Tamaricaceae	*Reaumuria hirtella* var. *palaestina*	S			■	▲■			☼ ▲■
Tamaricaceae	*R. negevensis*	S				▲■			☼
Tamaricaceae	*R. vermiculata*	S		☼ ▲■	☼ ▲■	☼ ▲■			☼
Zygophyllaceae	*Fagonia arabica* var. *viscidissima*	S		☼ ▲■	■	☼ ▲■	■		
Zygophyllaceae	*Zygophyllum aegyptium*	S	☼		☼ ■	■			☼ ■
Zygophyllaceae	*Z. album*	S		☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲■		☼ ▲■
Zygophyllaceae	*Z. coccineum*	S		☼ ▲■		☼ ▲■	☼ ▲■		☼ ■

(continued)

Table 8.7 (continued)

Families	Species	Habit	N	O	M	D	R	GE	S
Zygophyllaceae	*Z. dumosum*	S				☼ ▲■			☼ ▲■
Zygophyllaceae	*Z. simplex*	AH				☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲
Chenopodiaceae	*Halocnemum strobilaceum*	S	☼ ▲■		☼ ▲■	☼ ▲■	☼ ▲■		☼ ▲■
(2) Succulent stem									
Asclepiadaceae	*Caralluma acutangula*	PH						☼ ▲	
Asclepiadaceae	*C. edulis*	PH						☼ ▲	
Asclepiadaceae	*C. europaea*	PH			☼ ▲■				☼
Asclepiadaceae	*C. sinaica*	PH				▲■			☼ ▲■
Chenopodiaceae	*Anabasis articulata*	S		☼ ▲■	☼ ▲■	☼ ▲■	■		☼ ▲■
Chenopodiaceae	*A. setifera*	S				☼ ▲■	☼ ▲	☼ ▲	☼ ▲■
Chenopodiaceae	*Arthrocnemum macrostachyum*	S	☼ ▲	☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲■	■	☼ ▲
Chenopodiaceae	*Haloxylon negevensis*	S							☼
Chenopodiaceae	*H. salicornicum*	S		☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲■		☼ ▲■
Chenopodiaceae	*Salicornia europaea*	AH	☼ ▲■	☼ ▲	☼ ▲■				☼
Chenopodiaceae	*Sarcocornia fruticosa*	S	☼ ▲	☼ ▲■	☼ ▲■	☼ ▲■			☼
Chenopodiaceae	*S. perennis*	S	■		☼ ▲■	▲			☼
Elatinaceae	*Bergia capensis*	AH	☼ ▲■	☼ ▲■					
Euphorbiaceae	*Euphorbia consobrina*	S					☼ ▲	☼ ▲	
Euphorbiaceae	*E. mauritanica*	S	☼ ▲		☼ ▲				
Euphorbiaceae	*E. polyacantha*	S						☼ ▲	
Orobanchaceae	*Cistanche phelypaea*	PH	☼ ▲	☼ ▲■	☼ ▲■	☼ ▲■	☼ ▲■		☼ ▲■

(continued)

Table 8.7 (continued)

Families	Species	Habit	N	O	M	D	R	GE	S
Orobanchaceae	*C. sala*	PH				■			☼
Orobanchaceae	*Cistanche tubulosa* var. *albiflora*	PH							☼ ▲
Orobanchaceae	*C. tubulosa* var. *tubulosa*	PH	▲■		☼ ▲	☼ ▲■		☼ ▲■	☼ ▲■
Orobanchaceae	*Orobanche crenata*	AH	☼ ▲■	▲■	☼ ▲■	☼ ▲■			☼ ▲■
Sphenocleaceae	*Sphenoclea zeylanica*	AH	▲■	☼ ▲■	▲				
Vitaceae	*Cissus quadrangularis*	PH						☼ ▲■	

Symbols: ☼ = Boulos (1999, 2000, 2002, 2005), ▲ = Täckholm (1974), and ■ = El Hadidi and Fayed (1994/1995)
S Shrub, *AH* Annual herb, *PH* Perennial herb
Phytogeographic region abbreviations: *N* Nile region, *M* Mediterranean region, *O* Oases, *D* All deserts except Sinai, *R* Red Sea, *GE* Gebel Elba, *S* Sinai Peninsula

Table 8.8 Numbers of succulent species in different families in the flora of Egypt as well as other adjacent countries for comparison

Families	Egypt[1]	Palestine[2]	Saudi Arabia[3]	Libya[4]	Sudan[5]
Chenopodiaceae	28	20	18	16	7
Aizoaceae	10	6	7	8	4
Zygophyllaceae	6	4	3	3	3
Crassulaceae	5	3	2	3	3
Orobanchaceae	5	3	2	3	1
Tamaricaceae	5	4	1	2	0
Asclepiadaceae	4	2	3	1	4
Euphorbiaceae	3	0	2	0	6
Portulacaceae	3	3	2	2	3
Commelinaceae	2	0	3	3	1
Other families	11	6	8	7	15
All species	82	51	51	48	47

1 Boulos (1999- 2005); 2 Zohary (1966, 1972) and Feinbrun-Dothan (1978, 1986); 3 Migahid (1996); 4 Flora of Libya (different families); 5 Andrews (1950, 1952, 1956)

(seven species). It was also obvious that Egypt had the highest number of succulents (82 species) followed by Palestine and Saudi Arabia (51 species for each), Libya (48 species), and Sudan (47 species).

Generally, the biological spectrum of the succulent species in Egypt included 35 shrubs, 18 perennial herbs, and 29 annuals (Zohary 1966, 1972; Feinbrun-Dothan 1978, 1986; Gibson 1996). The 82 known succulent species can be classified into 59 leafy succulents (e.g. *Zygophyllum coccineum*, *Suaeda monoica*, *Mesembryanthemum* *crystallinum*, and *Portulaca oleracea*) and 23 stem succulents (e.g. *Arthrocnemum macrostachyum*, *Anabasis articulata*, *Euphorbia polyacantha*, and *Cistanche tubulosa* var. *albiflora*). The most species-rich succulent families are Chenopodiaceae (28 species) followed by Aizoaceae (ten species), then Zygophyllaceae (six species), Crassulaceae, Orobanchaceae, and Tamaricaceae (five species for each). The most species-poor succulent families are Compositae, Elatinaceae, Peganaceae, Sphenocleaceae, and Vitaceae (one species for each).

Species varied according to their affinities in the different phytogeographic regions. *Hyoscyamus muticus* and *Arthrocnemum macrostachyum* were represented in all the phytogeographic regions (seven regions). *Suaeda vera*, *S. vermiculata*, and *Cistanche phelypaea* were represented in six regions for each, exhibiting a wide geographical and ecological range of distribution. Some species showed a certain degree of consistency, i.e. confined to a certain phytogeographic region. Ten species were confined to Gebel Elba, such as the perennial herbs *Caralluma acutangula* and *Cissus quadrangularis*; *Umbilicus rupestris*, *Cistanche tubulosa* var. *albiflora*, and *Haloxylon negevensis* in the Sinai; and the annual *Suaeda altissima* and *Tetradiclis tenella* in the Mediterranean.

8.1.3 The Selected Plants

Five succulent plant species were found to be of high significance (performance) during the course of this study: three xerophytic succulents *Anabasis articulata* (Forssk.) Moq., *Zygophyllum coccineum* L., and *Haloxylon salicornicum* (Moq.) Bunge ex Boiss., a halophytic succulent *Arthrocnemum macrostachyum* (Moric.) K. Koch, and a halophytic xerophytic succulent *Zygophyllum album* L. Field surveys were carried out between many localities covering different types of habitats in Egypt for collecting the selected succulent plants and the associated plants species (Fig. 8.8).

8.1.3.1 Spatial Distribution Patterns of the Studied Succulents

In this study, a total of 137 species of the vascular plants were recorded belonging to 37 families. They consisted of one tree (*Tamarix nilotica*), 57 shrubs, 30 perennial herbs, 2 biennials, and 47 annuals. The most species-rich families were Chenopodiaceae (24) and Asteraceae (23), representing 17.5 % and 16.8 % of the total collected flora, respectively, followed by Zygophyllaceae and Poaceae (ten for each), Brassicaceae and Fabaceae (seven for each), Polygonaceae (five), and Aizoaceae and Boraginaceae (four for each). Shrubs and subshrubs constituted the largest number of the collected flora (41.6 %). Herbaceous perennials represented 21.9 % of the recorded species, whereas annuals were represented by 34.3 % of the recorded species.

Anabasis articulata was collected from 13 out of the studied 59 stands (Fig. 8.9) in four of the six selected regions as follows: three from the Red Sea region, three

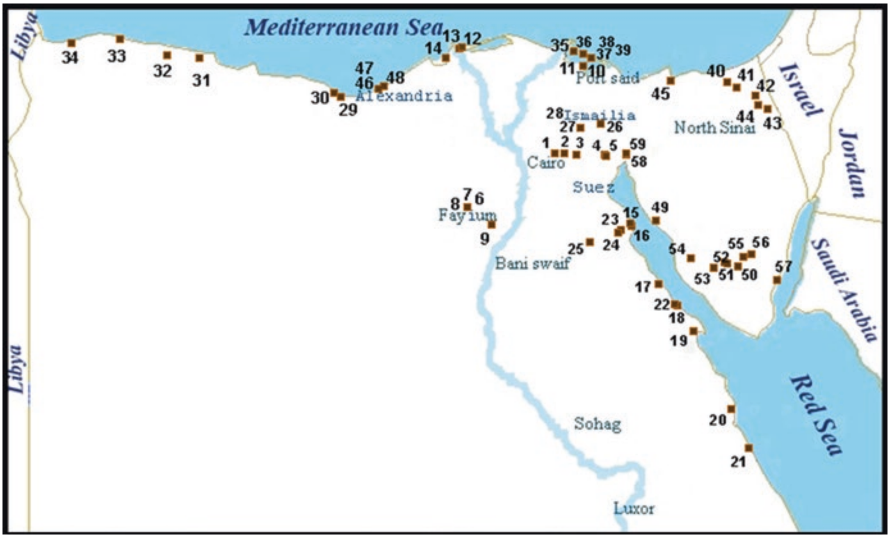

Fig. 8.8 A map of Egypt showing the distribution of the studied 59 stands

from the west Mediterranean region, four from the North Sinai region, and another three from the south Sinai region. *Zygophyllum album* was collected from 15 stands as follows: four from the Nile region, five from the Red Sea coastal region, two from the Eastern Desert region, one from the West Mediterranean coastal region, and three from the North Sinai region. The records showed that *Haloxylon salicornicum* was collected from 14 stands in four of the six selected phytogeographic regions: four from the Eastern Desert region, four from the west Mediterranean coastal region, two from the North Sinai region, and four from the south Sinai region. Monospecific stands were detected in stand 31 along the west Mediterranen coast and in stand 52 in south Sinai. *Zygophyllum coccineum* was collected from 16 stands (Fig. 8.9) in three phytogeographic regions: eight from the Eastern Desert region, four from the Red Sea coastal region, and another four from the south Sinai region. *Arthrocnemum macrostachyum* was collected from 12 stands in two phytogeographic regions: 11 from the Nile region and one from the North Sinai region. Monospecific stands were detected in stands 7 and 8, both in the Nile region.

8.1.3.2 Classification of the Associated Vegetation

The TWINSPAN classification of 59 stands resulted in eight vegetation groups (A–H; Table 8.9) at the third level of hierarchical classification. A dendrogram was depicted in Fig. 8.10, along with the indicator species which characterize the stand groups. The eight vegetation groups were named after their characteristic species (have the highest presence values) as follows: group A, *Mesembryanthemum crystallinum–Mesembryanthemum nodiflorum*; group B, *Haloxylon salicornicum–Polygonum*

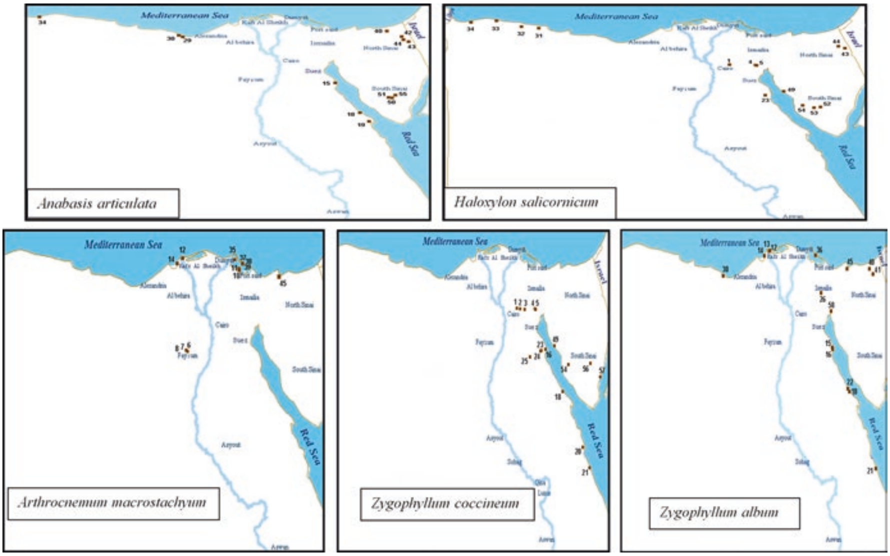

Fig. 8.9 Distributional patterns of the five studied succulents showing their visited stands

Table 8.9 Characteristic species of the eight TWINSPAN groups (A–H), with their presence values (*P%*)

TWISPAN groups	A	B	C	D	E	F	G	H
Total number of stands	**3**	**3**	**18**	**15**	**6**	**3**	**8**	**3**
Total number of species	**22**	**21**	**52**	**48**	**17**	**17**	**14**	**17**
Mesembryanthemum crystallinum L.	**100**					66.7		
Mesembryanthemum nodiflorum L.	**100**							
Bassia muricata (L.) Asch.	66.7			20		33.3	12.5	
Schismus barbatus (L.) Thell.	66.7			13.3				
Asphodelus aestivus Brot.	66.7	33.3						
Polygonum equisetiforme Sm.	66.7	**100**						
Deverra tortuosa (Desf.) DC.	33.3	**100**	5.6	6.7				
Haloxylon salicornicum (Moq.) Bunge ex Boiss.		**100**	33.3	33.3				
Carduncellus mareoticus (Delile) Hanelt		**100**	16.7	13.3				
Thymelaea hirsuta (L.) Endl.	66.7	66.7	16.7					
Echinops spinosus L.		66.7		6.7				
Anabasis articulata (Forssk.) Moq.			**66.7**		16.7			
Fagonia mollis Delile			33.3	6.7				
Zygophyllum coccineum L.			16.7	**86.7**				
Zilla spinosa (L.) Prantl			27.8	**66.7**				
Zygophyllum simplex L.				53.3				

(continued)

Table 8.9 (continued)

TWISPAN groups	A	B	C	D	E	F	G	H
Pulicaria undulata (L.) C. A. Mey. subsp. *undulata*			11.1	46.7				
Fagonia arabica L.			22.2	33.3				
Zygophyllum album L.			27.8	6.7	**100**	**100**		
Tamarix nilotica (Ehrenb.) Bunge				6.7	50	33.3	12.5	**100**
Halocnemum strobilaceum (Pall.) M. Bieb.					50	33.3	37.5	
Cistanche phelypaea (L.) Cout.					33.3			
Senecio glaucus L.			5.6		33.3	**100**	12.5	
Limbarda crithmoides (L.) Dumort.					16.7	66.7	12.5	33.3
Bromus rubens L.						66.7		
Hordeum murinum L. subsp. *glaucum* (Steud.) Tzvelev						66.7		
Arthrocnemum macrostachyum (Moric.) K. Koch					33.3	33.3	**100**	33.3
Phragmites australis (Cav.) Trin. ex Steud.					16.7	66.7	75	33.3
Suaeda aegyptiaca (Hasselq.) Zohary							37.5	
Juncus rigidus Desf.						66.7	12.5	66.7
Alhagi graecorum Boiss.			5.6				12.5	33.3
Symphyotrichum squamatum (Spreng.) G.L. Nesom			5.6					33.3
Zygophyllum aegyptium Hosny			5.6					33.3

Figures in *bold* are the dominant species with the highest values

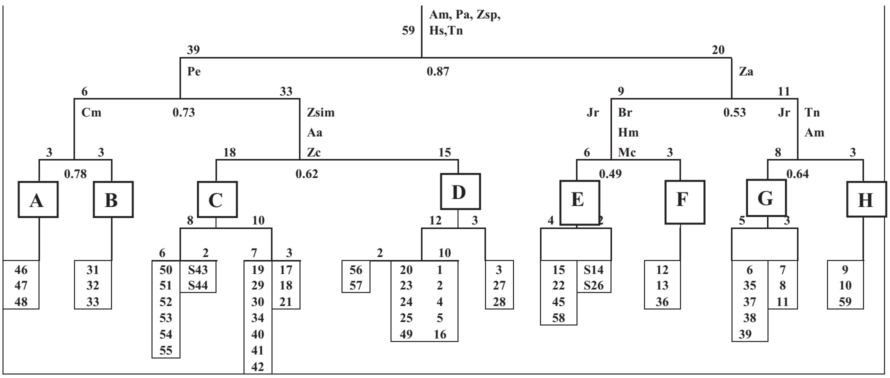

Fig. 8.10 TWINSPAN classification of the 59 stands in the study areas, showing the eight vegetation groups (A–H) at the third hierarchical level of classification. Indicator species: *Am Arthrocnemum macrostachyum*, *Pa Phragmites australis*, *Zsp Zilla spinosa*, *Hs Haloxylon salicornicum*, *Tn Tamarix nilotica*, *Pe Polygonum equisetiforme*, *Za Zygophyllum album*, *Cm Carduncellus mareoticus*, *Aa Anabasis articulata*, *Zsim Zygophyllum simplex*, *Zc Zygophyllum coccineum*, *Mc Mesembryanthemum crystallinum*, *Br Bromus rubens*, *Hm Hordeum murinum* subsp. *glaucum*, *Jr Juncus rigidus*

equisetiforme–Deverra tortuosa–Carduncellus mareoticus; group C, *Anabasis articulata*; group D, *Zygophyllum coccineum–Zilla spinosa*; group E, *Zygophyllum album*; group F, *Zygophyllum album–Senecio glaucus*; group G, *Arthrocnemum macrostachyum*; and group H, *Tamarix nilotica.* Table 8.10 displayed the variations in soil characteristics among the identified TWINSPAN vegetation groups. Clearly, eight soil parameters were highly significant ($P \leq 0.01$), and four showed significant differences ($P \leq 0.05$). Besides, species richness (SR) was highly significant among the groups.

Group A. Mesembryanthemum crystallinum–Mesembryanthemum nodiflorum Group

This group comprised 22 species in three stands located in Burj Al-Arab, of loamy sand soil with high content of calcium carbonates (Table 8.10), soil reaction (pH), and potassium and low values of salinity, chlorides, and sulphates. Twelve common associated species (P = 66.7 %) were recognized such as *Atriplex leucoclada*, *Globularia arabica*, and *Thymelaea hirsuta.*

Group B. Haloxylon salicornicum–Polygonum equisetiforme–Deverra tortuosa–Carduncellus mareoticus Group

This group comprised 21 species in three stands located in the western Mediterranean coastal region. The soil is characterized with high contents of calcium carbonate and sand and low contents of salinity, chlorides, and sulphates. *Haloxylon salicornicum*, *Polygonum equisetiforme*, *Deverra tortuosa*, and *Carduncellus mareoticus* were the dominant species (P = 100 %). Four associated species with P = 66.7 % were recognized such as *Thymelaea hirsuta* and *Verbascum letourneuxii.*

Group C. Anabasis articulata Group

This group comprised 52 species in 18 stands located in different regions: the Red Sea coast, the western Mediterranean coast, and North and south Sinai. The soil was characterized by high content of sand, calcium carbonates, and potassium and low values of salinity, chlorides, and sulphates. The species that showed moderate presence (P = 33.3 %) were the shrubs of *Haloxylon salicornicum* and *Fagonia mollis*.

Group D. Zygophyllum coccineum–Zilla spinosa Group

This group comprised 48 species in 15 stands located in different regions: the Red Sea coast, the Eastern Desert, and south Sinai. The soil was characterized by high contents of sand and calcium carbonates and low values of salinity, chlorides, and sulphates. The common associated species were *Zygophyllum simplex* (P = 53.3 %, recorded in eight stands) and *Pulicaria undulata* subsp. *undulata* (P = 46.7 %, recorded in seven stands).

Group E. Zygophyllum album Group

This group comprised 17 species in six stands located in the salt marshes of the Nile region (Lake Idku), Red Sea coastal region, Eastern Desert region, and North Sinai region. The soil was characterized by high contents of sand, salinity, chlorides, sodium, and sulphates. The high salinity content of the soil favours the growth of some halophytic species such as *Zygophyllum album*, *Tamarix nilotica*, *Nitraria*

Table 8.10 Mean values, standard deviations (±), and ANOVA F values of the soil variables, species richness (SR), and Shannon's index (H′) in the stands representing the eight vegetation groups obtained by TWINSPAN in the study areas

Soil variables		Total mean	TWINSPAN groups								*P*
			A	B	C	D	E	F	G	H	
pH		8.36 ± 0.5	9.03 ± 0.7	7.9 ± 0.26	8.44 ± 0.64	8.27 ± 0.37	8.12 ± 0.29	8.33 ± 0.25	8.68 ± 0.33	7.9 ± 0.52	0.03*
EC		3.98 ± 8.0	0.79 ± 0.4	1.31 ± 0.86	1.2 ± 1.68	0.7 ± 0.45	11.02 ± 16.23	3.8 ± 3.4	10.45 ± 11.25	11.81 ± 12.4	0.006**
$CaCO_3$	(%)	20.21 ± 20.9	45.73 ± 30.0	38.8 ± 23.59	23.61 ± 23.56	21.7 ± 17.1	12.47 ± 19.02	2.23 ± 1.54	9.68 ± 13.22	9.8 ± 2.31	0.054
Ca^{+2}	(ml eq/l)	7.38 ± 10.1	1.1 ± 0.6	2.07 ± 1.7	3.75 ± 5.37	3.49 ± 4.27	18.62 ± 16.82	13.2 ± 10.5	10.64 ± 11.47	23.2 ± 12.1	0.000**
Mg^{+2}	(ml eq/l)	5.55 ± 8.8	1.43 ± 1.4	4.53 ± 3.23	3.14 ± 3.96	1.27 ± 0.86	13.48 ± 15.84	6.2 ± 4.39	10.38 ± 11.37	17.267 ± 17.3	0.005**
Na^{+}	(ml eq/l)	28 ± 73.3	4.07 ± 2.9	6.28 ± 3.73	4.2 ± 8.19	1.85 ± 1.37	91.55 ± 170.9	20.39 ± 22.29	83.7 ± 93.12	79.1 ± 105.9	0.025*
K^{+}	(ml eq/l)	0.71 ± 0.9	0.86 ± 0.4	0.49 ± 0.10	0.31 ± 0.19	0.33 ± 0.21	1.04 ± 1.38	0.8 ± 0.6	1.94 ± 1.86	1.11 ± 0.79	0.003**
HCO_3^{-}	(ml eq/l)	1.21 ± 0.5	1.53 ± 0.8	2.6 ± 0.78	1.24 ± 0.49	1 ± 0.25	1.05 ± 0.28	0.87 ± 0.15	1.09 ± 0.35	1.43 ± 0.71	0.001**
Cl^{-}		26.5 ± 6.6	2.65 ± 2.3	8.5 ± 6.06	6.82 ± 10.21	1.92 ± 1.32	73.9 ± 135.8	12.58 ± 13.37	77.81 ± 90.45	90.7 ± 132.1	0.023*
SO_4^{-2}	(ppm)	14.1 ± 28.6	3.38 ± 2.5	2.27 ± 2.54	3.62 ± 6.66	3.99 ± 5.40	49.8 ± 66.9	27.1 ± 39.2	27.89 ± 29.59	28.8 ± 6.2	0.006**
N	(ppm)	21.5 ± 15.1	15.7 ± 0.58	30.7 ± 34.1	23.7 ± 16.9	18.1 ± 12.3	21.8 ± 11.1	13.3 ± 7.6	22.3 ± 17.6	28.3 ± 7.6	0.780
P	(ppm)	18.7 ± 9.4	28.7 ± 7.0	17.7 ± 10.1	14.1 ± 7	20.7 ± 12.3	21.2 ± 11.4	20.3 ± 0.58	19.6 ± 4.6	18.7 ± 11.4	0.252
aK	(ppm)	260.4 ± 243.2	328 ± 160.6	325.3 ± 120.4	166.7 ± 101.2	148.9 ± 43.2	248 ± 238	269.3 ± 233.1	555 ± 430.9	477.3 ± 354.3	0.002**
Sand	(%)	86.3 ± 9.8	85.8 ± 0.6	80.6 ± 11.02	88 ± 7.8	89.3 ± 3.7	92.9 ± 3.2	87.3 ± 6.1	78.8 ± 17.4	73.3 ± 13.5	0.019*
Silt	(%)	6.31 ± 8.5	6.3 ± 0.58	13.3 ± 9.2	5.1 ± 4.1	2.6 ± 1.35	1.17 ± 1.33	4 ± 3.46	14.04 ± 16.55	17.3 ± 14.01	0.003**
Clay	(%)	7.37 ± 3.3	7.9 ± 0.00	6.1 ± 2.0	6.95 ± ± 4.03	8.05 ± 3.25	5.95 ± 3.22	8.68 ± 4.08	7.13 ± 3.11	9.34 ± 0.59	0.782
SR		15.92 ± 0.3	15.67 ± 0.58	16 ± 0	15.94 ± 0.24	16 ± 0	15.5 ± 0.55	16 ± 0	16 ± 0	16 ± 0	0.004**
H′		1.6 ± 0.2	1.4 ± 0.28	1.46 ± 0.13	1.59 ± 0.3	1.6 ± 0.12	1.83 ± 0.29	1.63 ± 0.18	1.53 ± 0.23	1.7 ± 0.44	0.262

pH soil reaction, *EC* electric conductivity, $CaCO_3$ calcium carbonate, Ca^{+2} calcium, Mg^{+2} magnesium, Na^{+} sodium, K^{+} potassium, HCO_3^{-} bicarbonates, Cl^{-} chloride, SO_4^{-2} sulphates, *N* soluble nitrogen, *P* phosphorus, *aK* available potassium

$* = P \leq 0.05$ and $** = P \leq 0.01$

retusa, and *Limbarda crithmoides*. *Zygophyllum album* was the dominant species of this group.

Group F. *Zygophyllum album–Senecio glaucus* Group

This group comprised 17 species in three stands located in the salt marshes of the Nile region (Lake Burullus and Dumyat). The soil was characterized by high content of sand and potassium. The associated vegetation encompassed high presence values ($P = 66.7$ %) of *Limbarda crithmoides*, *Phragmites australis*, and *Mesembryanthemum crystallinum*.

Group G. *Arthrocnemum macrostachyum* Group

This group comprised 14 species in eight stands located in the salt marshes of the Nile region (El Faiyum, Lake Manzala, and Dumyat). The soil was characterized by the highest values of potassium and high contents of salinity, sodium, and chloride. *Phragmites australis* was the most characteristic species of this group ($P = 75$ %).

Group H. *Tamarix nilotica* Group

This group comprised 17 species in three stands located in the salt marshes of the Nile and Eastern Desert regions. The soil was characterized by the highest values of salinity, magnesium, and chlorides and high contents of sodium, potassium, and sulphates. *Juncus rigidus* was the most characteristic species of this group ($P = 66.7$ %).

8.1.3.3 Species–Soil Relationships of the Studied Succulents

The species–environment correlations are higher for the first three canonical axes, however, explaining 94.8 % of the cumulative variance. These results suggest an association between vegetation and the measured soil parameters presented in the triplot (Jongman et al. 1987). A test for significance with an unrestricted Monte Carlo permutation test (499 permutations) found the F-ratio for the eigenvalue of axis 1 and the trace statistic to be significant ($P < 0.002$). From the inter-set correlations of the soil factors with the first three axes of CCA (Table 8.11), it can be noted that CCA axis 1 is highly positively correlated with K^+ and highly negatively correlated with $CaCO_3$. This can be seen more clearly in the ordination triplot (Fig. 8.11). This axis can be defined as a K^+–$CaCO_3$ gradient. CCA axis 2 is highly positively correlated with sand and highly negatively correlated with silt. This axis can be defined as a sand–clay gradient.

The information shown in Fig. 8.11 also indicates that the distribution of *Arthrocnemum macrostachyum* (*Art mac*) was affected by Mg and the electric conductivity (EC), which is assigned to the vegetation group (G). The distribution of *Zygophyllum album* (*Zyg alb*) which is assigned to groups (E) and (F) was affected by SO_4, electric conductivity (EC), and Ca^+. *Anabasis articulata*, *Haloxylon salicornicum*, and *Zygophyllum coccineum* were assigned to groups (C), (B), and (D), respectively. These species were highly affected by percentages of sand, clay, $CaCO_3$ content, pH, and N.

Table 8.11 Inter-set correlations of the soil variables along the first three axes of CCA, together with their eigenvalues, species–environment correlations, and cumulative % variance of species–environment relations

Axes	Ax1	Ax2	Ax3
Eigenvalues	0.48	0.26	0.16
Species–environment correlation	0.74	0.64	0.48
Cumulative % variance of species–environment relation	51.00	78.50	94.80
pH	0.17	–0.26	0.06
EC	0.33	0.14	0.10
$CaCO_3$	–0.38	–0.05	–0.10
Ca^{+2}	0.25	0.31	0.01
Mg^{+2}	0.31	0.22	0.12
HCO_3	–0.02	–0.22	0.28
SO_4^{-2}	0.28	0.21	0.09
N	–0.03	–0.20	0.21
P	0.10	0.07	–0.04
K^+	0.57	–0.12	0.04
Sand	–0.31	0.34	–0.01
Silt	0.39	–0.32	0.04
Clay	–0.06	–0.20	–0.04

For units and abbreviations, see Table 8.10

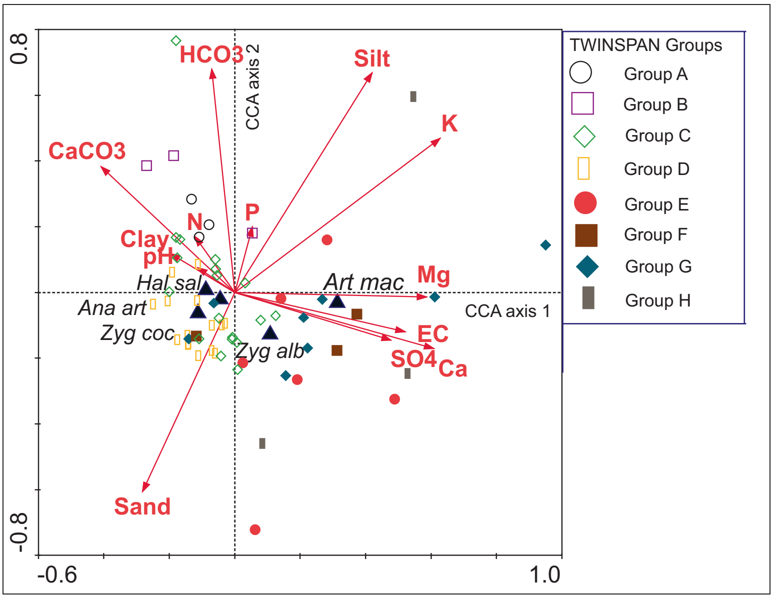

Fig. 8.11 CCA ordination triplot of the five studied succulent plants (solid triangles), stands, and soil variables, reflecting distributions of the five succulent plants along gradients of soil variables. *Art mac Arthrocnemum macrostachyum*, *Hal sal Haloxylon salicornicum*, *Ana art Anabasis articulata*, *Zyg alb Zygophyllum album*, and *Zyg coc Zygophyllum coccineum*

8.1.4 General Remarks

1. Application of multivariate analysis techniques helped to classify the vegetation associated with the studied succulent plants into eight vegetation groups: (A) *Mesembryanthemum crystallinum–Mesembryanthemum nodiflorum* group, (B) *Haloxylon salicornicum–Polygonum equisetiforme–Deverra tortuosa–Carduncellus mareoticus* group, (C) *Anabasis articulata* group, (D) *Zygophyllum coccineum–Zilla spinosa* group, (E) *Zygophyllum album* group, (F) *Zygophyllum album–Senecio glaucus* group, (G) *Arthrocnemum macrostachyum* group, and (H) *Tamarix nilotica* group. Out of these vegetation groups, *Zygophyllum album* (group E) is widely distributed among four phytogeographic regions, viz. the Nile, the Red Sea, the Sinai, and the Eastern Desert regions. It can also be noted that certain vegetation groups are linked to a definite phytogeographic region: *Mesembryanthemum crystallinum–Mesembryanthemum nodiflorum* group (group A) and *Haloxylon salicornicum–Polygonum equisetiforme–Deverra tortuosa–Carduncellus mareoticus* group (group B) are recorded from the Mediterranean region, while *Zygophyllum album–Senecio glaucus* (group F) and *Arthrocnemum macrostachyum* (group G) are recorded from the Nile region only. This investigation demonstrated the role of a dozen soil factors affecting the distribution of the five studied succulent plants: electric conductivity, bicarbonates, available potassium, silt, sulphates, Ca^{++}, Mg^{++}, K^{-}, pH, Na^{+}, Cl^{-}, and sand.
2. The soil reaction in the Egyptian desert is alkaline. The recorded pH value in the different stands of this investigation was in the range of 7.3–9.8. This is inconsistent with the results of Abd El-Wahab et al. (2006) in south Sinai, Mahmoud (2006) in North Sinai, Baayo (2005) in the Sallum area on the Western Mediterranean coast of Egypt, Hassan (2003) along the Red Sea coast, and El-Adawy (2001) for the Eastern Desert.
3. Earlier studies recognized the *Arthrocnemum macrostachyum* group, e.g. Kassas and Zahran (1967) in the littoral salt marshes of the Red Sea coast; Abd El-Ghani (2000) in the Siwa Oasis; Mashaly (2001) in the western sector of the deltaic Mediterranean coast of Egypt; Ramadan (2002) in Lake Manzala, Egypt; and Abd El-Ghani and El-Sawaf (2005) in the saline depressions along El Arish and Rafah road verges (North Sinai).
4. Galal and Fawzy (2007) recognized the *Chenopodium murale–Mesembryanthemum crystallinum* group in the interdune areas of black sand dune in north Nile Delta. The present study showed that this group inhabited soil with high contents of sand, carbonates, pH, and K and low contents of salinity, chlorides, and sulphates. This partly agrees with the results obtained by El Shayeb et al. (2002) who indicated the sandy halophytic nature of this group and Galal and Fawzy (2007) who distinguished this group by its high soil contents of sulphates, calcium, magnesium, sodium, and potassium.
5. *Anabasis articulata* is one of the common desert succulent chenopods that is capable of building phytogenic mounds in various phytogeographic territories of Egypt, demonstrating its wide ecological amplitude. This study revealed that the

Anabasis articulata group is the most diversified (52 species) among the other recognized vegetation groups. This vegetation group inhabited the limestone formations of the Eastern Desert (Kassas and Girgis 1965; El-Adawy 2001) and the salt marshes of the western Mediterranean desert (Ayyad and El-Ghareeb 1982). This study also showed that soil with higher contents of calcium carbonate, K, and sand is the characteristic edaphic condition associated with *Anabasis articulata* group. This result is almost similar to all other relevant studies (Baayo 2005). It is repeatedly recorded in many parts of the country, e.g. Cairo–Suez Desert (Kassas and El-Abyad 1962), Helwan Desert (Girgis 1962), the coastal plain of the Gulf of Suez and in Wadi El-Tor of south Sinai (Zahran and Willis 1992), Wadi Qena of the Eastern Desert (Zahran et al. 1995), and on the gravel plains at the foot of Diffa plateau in Sallum and in Sidi Barani areas of the western Mediterranean coast of Egypt (Salama et al. 2005). Outside Egypt, it was also found in Wadi AI-Ammaria in Saudi Arabia (Alyemeni 2001) and in the Cholistan Desert in Pakistan (Arshad et al. 2008). The results of this study identified the vegetation group of *Haloxylon salicornicum–Deverra tortuosa–Polygonum equisetiforme–Carduncellus mareoticus* which was not recorded earlier. It inhabited soil with high contents of calcium carbonate and sand and low contents of salinity. This result is in line with other relevant studies (Arshad et al. 2008; Alyemeni 2001; Shaltout et al. 2008).

6. On the other hand, *Zygophyllum coccineum* is a widespread xero-succulent inhabiting the drainage channels of the limestone desert, which is formed in this investigation with a distinct vegetation group, viz. *Zygophyllum coccineum–Zilla spinosa* along the Red Sea coastal lands, Eastern Desert, and south Sinai. Shaltout et al. (2004) identified *Zygophyllum coccineum–Zilla spinosa* communities along the Egyptian Red Sea coastal land. Several studies recognized *Zygophyllum coccineum* as a community associated with *Zilla spinosa* (Kassas and El-Abyad 1962; Kassas and Girgis 1965; Abd El-Ghani 1998). Monotypic communities of the dominant species were recorded (Fossati et al. 1998). This study demonstrated that the *Zygophyllum coccineum–Zilla spinosa* vegetation group is mainly characterized by soil rich in its sand contents and calcium carbonates and low values of salinity. The results of this work are inconsistent with other similar studies (Shaltout and El-Sheikh 2002; Hegazy et al. 2004).
7. In Egypt, *Zygophyllum album* is an omnipresent species which has a wider ecological range than *Zygophyllum coccineum* (Kassas and Girgis 1965). It was recognized by several habitats of the country, such as in the littoral salt marshes (Kassas and Zahran 1967), in the inland deserts, in the wadis of the limestone country (Kassas and Girgis 1964), in the sand dunes of the oases of the Western Desert of Egypt (Zahran 1972), and in the inland salt marshes of Wadi El Natrun (Zahran and Girgis 1970). The soil supporting its growth was characterized by high contents of sand, salinity, chlorides, sodium, and sulphates. This result is almost similar to all other relevant studies (Migahid 1996; Hussein 2005). Several authors recognized this group, among others Girgis (1962) in certain wadis (e.g. Wadi El-Warag) of the Helwan Desert; Kassas and Girgis (1965) in some wadis of the limestone desert extending to the east of the Nile Valley;

Ayyad and E1-Ghareeb (Ayyad and El-Ghareeb 1982) in the salt marshes of the west Mediterranean desert of Egypt; Shaltout and El-Sheikh (2002) in the demolished houses, abandoned fields, and along the terraces of railways at the borders of the Nile Delta; Abd El-Ghani and El-Sawaf (2005) in the saline depressions between El Arish and Rafah, the northeastern Mediterranean coast of Sinai; and Hussein (2005) in Lake Bardawil. In the salt marsh stands of the Nile land (N), the soluble chlorides in the soil of *Z. album* were higher than the sulphates. That result was also reached by Kassas and Zahran(Kassas and Zahran 1967) who concluded that in the soil of *Z. album*, the chlorides are nearly equal or higher than the sulphates.

– In conclusion, the Sinai Peninsula and the Mediterranean regions included most of the succulent species. Altogether, 137 species that belonged to 37 families characterized the associated flora. Chenopodiaceae, Asteraceae, Zygophyllaceae, and Poaceae were the most species-rich families. The TWINSPAN classification technique revealed eight vegetation groups; most of the studied succulent plants were assigned to a certain group. The soil factors that characterized the vegetation associated with *Arthrocnemum macrostachyum* were affected by Mg and elerctric conductivity (EC); *Zygophyllum album* was affected by SO_4, electric conductivity (EC), and Ca+; *Anabasis articulata*, *Haloxylon salicornicum*, and *Zygophyllum coccineum* were highly affected by percentages of sand, clay, $CaCO_3$ content, pH, and N.

8.2 Parasitic Plants

The biological group of parasitic angiosperms in Egypt deserves attention, particularly to strengthen interest and to stimulate further research and awareness. Parasitic plants live at the expense of other plants on which they depend for growth and development. Among the parasitic angiosperms, a distinction must be made between root parasites which infect the root system of their hosts and stem parasites which attack the above-ground shoots. This contact occurs, in both, via haustoria which are unique multicellular structures specialized for attachment to and penetration of host tissue (Kuijt 1977).

Despite extensive studies on the flora, vegetation, and ecology of desert plants in Egypt (Zahran and Willis 1992), there have been little works published dealing with the angiosperm parasites as a definite group (Mubarek 1985; El-Hussieni 1988; Fahmy 1992, 1993). Most other studies pertain to their general distribution among other life forms in Egypt (Hassib 1951) or as members in the Egyptian flora (Täckholm 1974). This group of plants has received little attention since it represents a low percentage of the life forms of the arid regions of the Middle East and North Africa (Täckholm 1974; Migahid 1978; Boulos 1983; Daoud 1985). In Egypt, this percentage reaches 0.9 % (Hassib 1951).

The root parasites of this study are all obligate parasitic members of the family Orobanchaceae, attaching themselves to the roots of their hosts; they are best represented in the north temperate regions of the Old World (Daoud 1985). In Egypt, the two genera Cistanche and Orobanche contain about 13 species (Täckholm 1974), their annual flowering stalks appearing above-ground during the spring.

This study was carried out to investigate the distribution of *Cistanche phelypaea* (L.) Cout., *C. tubulosa* (Schenk) Hook. f., and *Orobanche cernua* Loefl., their host ranges, and the environmental conditions in the habitats of these root parasites. It also reports on the biomass of the parasites, hosts, and noninfected species together with their water content and succulence.

8.2.1 Distribution of the Selected Species

The three taxa and their hosts may grow together in the same region (Fig. 8.12), but some phytogeographic regions may harbour two or even one species. The three species were found in three distinct areas: (1) along the Mediterranean coastal belt (M) from El-Arish (east) to El-Sallum (west), (2) southern Sinai (S), and (3) the south-eastern corner of Egypt in Gebel Elba region (Sa). Both *Cistanche phelypaea* and *Orobanche cernua* may be confined to the northern part of the Arabian Desert known as Galala Desert (Dg). *Cistanche tubulosa* and *C. phelypaea* have been recorded in the Arabian Desert (Da) near Qena, and *C. phelypaea* was found in the wadis of the southern part of the Arabian Desert until latitude 23°N.

8.2.2 Edaphic Conditions

The soils are generally low in organic matter content and slightly alkaline, ranging from pH 7·5 to 8·5 (Table 8.12). In the Mediterranean coastal belt, the root parasites and their hosts grow in deep oolitic limestone sand dunes and in loamy, salt-affected ground between the coastal sand dunes. In such regions the total carbonate ranges from 3.5 % of oven-dry soil near El-Arish coastal salt marshes to 34.2 % or more in El-Sallum. The total soluble salts vary between 0.20 % and 6 % oven-dry soil. In the northern part of the Galala Desert, both *C. phelypaea* and *O. cernua* infect hosts growing in the limestone wadis, where the deep soils of the wadi terraces receive runoff water. In such regions, the soluble salts are low, while the total carbonate content of the soil is high, reaching 45.8 % oven-dry soil. In southern Sinai and in that part of the Arabian Desert near Qena, both the hosts and parasites grow in deep fine soil where the total soluble salts and total carbonate are lower than in the Galala Desert. The soil of the southern part of the Arabian Desert, where *C. phelypaea* is found, is usually nonsaline, but climate and soil aridity are important environmental features. In the Gebel Elba region, the soil salinity is low (0.87 % oven-dry soil), while the carbonate content is higher than in the Arabian Desert (Table 8.12).

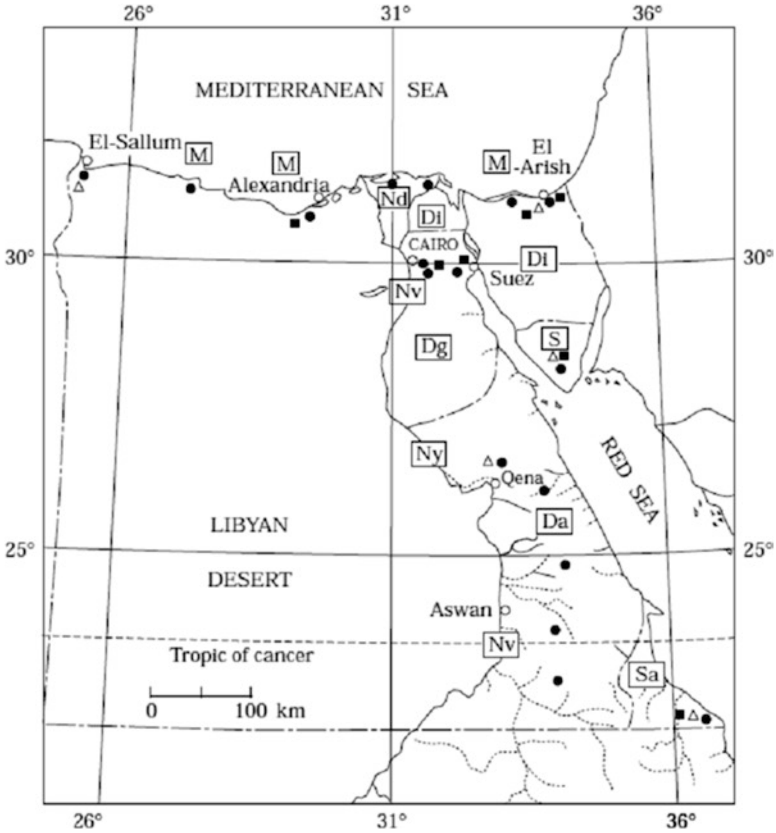

Fig. 8.12 Distribution of the three species of the angiosperm root parasites in different phytogeographic regions in Egypt: *Da* Arabian Desert; *Dg* Galala Desert, *Di* Isthmic Desert, *M* Mediterranean region, *Nd* Nile Delta, *Nv* Nile Valley, *S* southern Sinai, Sa Gebel Elba region. ● = *Cistanche phelypaea*; Δ = *C. tubulosa*; ▲ = *Orobanche cernua*

8.2.3 Climatic Conditions

The examination of Fig. 8.12 and Table 8.13 reveals that the three species of root parasites and their hosts grow under a wide range of rainfall. The highest rainfall occurs in the Mediterranean region, while the lowest annual rainfall is 4 mm at Qena. The source of surface water throughout the Eastern Desert is from rainfall on the chains of mountains bordering the Red Sea. These mountain rains may feed the wadis of the desert with considerable torrential flow (Hassib 1951). At Gebel Elba, the annual rainfall reaches 400 mm at high elevations. Regrettably, there are no available data concerning the amount of rainfall reaching the ground level where the root parasites and their hosts grow in the wadis near the Red Sea coast. The temperature regime in Egypt is governed mainly by the latitudinal location and the maritime effect of the Mediterranean Sea. Ranges of temperature and evaporation variations become greater further inland to the southern part of the country.

Table 8.12 Mean results of soil analysis (% oven-dried matter) in the root zone supporting the angiosperm root parasites *Cistanche* and *Orobanche* species and their hosts

Region	pH	Total soluble salts (%)	Total carbonate (%)
Mediterranean (M)			
El-Arish	7.5	6.00	3.5
El-Sallum	8.5	0.21	34.2
Southern Sinai (S)	8.2	0.20	6.5
Deserts			
Isthmic Desert (Di)			
North Sinai	8.0	0.32	4.3
Galala Desert (Dg)			
Cairo–Suez road	8.5	0.35	45.8
Wadi Hof	8.1	0.42	40.2
Arabian Desert (Da)			
Wadi Qena	7.7	0.15	6.1
*Sahelian Scrub (Sa)			
Coastal plains of Gebel Elba mountainous blocks	7.5	0.87	18.2

Abbreviations of the phytogeographic regions: *M* Mediterranean region, *Dg* Galala Desert, *Da* Arabian Desert, *S* Southern Sinai, *Di* Isthmic Desert, *Sa* Gebel Elba region, * Batanouny and Ezzat 1971

Table 8.13 Some meteorological data obtained from different stations distributed in the phytogeographic regions of Egypt where the three root parasites and their hosts grow

Factor	El-Arish (M)	El-Sallum (M)	Helwan (Dg)	Suez (Dg)	Qena (Da)	Tor (S)
Rainfall (mm)						
Annual	107.0	105.0	22.3	16.3	4.0	13.0
Temperature (°C)						
January	13.6	13.5	13.1	14.7	11.7	14.2
March	16.0	15.5	17.3	18.0	173	*
July	26.2	26.0	26.1	29.0	33.4	28.3
Annual mean	20.4	20.5	21.2	22.4	26.0	22.2
Evaporation (mm.day^{-1})						
January	3.6	7.1	6.0	7.4	10.4	7.1
March	4.5	8.2	10.2	10.7	17.3	*
July	4.8	9.1	14.0	14.5	26.0	12.6
Annual mean	4.5	8.2	11.0	11.5	19.5	9.4

Each value is a mean of 20 years at least. Letters in parentheses denote abbreviations of the phytogeographic region to which the station belongs
*= No available

8.2.4 Host Ranges

Table 8.14 (Fig. 8.13) shows a list of host plants of the studied root parasites. It is to be noted that all host species are perennial dicots belonging to diverse families. Members of Chenopodiaceae represent 57 and 50 % of the total hosts of *C. phelypaea* and *C.tubulosa*, respectively, and the chenopod hosts of *O. cernua* represent about 16 %

Table 8.14 List of host plants of the studied root parasites. Asterisks indicate not previously reported species, and distributions are indicated, followed by the phytogeographic regions

	Hosts		
Root parasites	Family	Host species found in the present study	Host species reported by other botanists and deposited in CAI and CAIM
Cistanche phelypaea	Chenopodiaceae	*Atriplex leucoclada* Boiss.*	*Atriplex* sp.
		Wadi Hof and Suez (Dg)	Matruh and El-Sallum (M), Wadi Digla (Dg)
		Hammada elegans (Bunge) Botsch	*Hammada elegans*
		Suez road (Dg)	Wadi Arabah (Dg)
			Salsola imbricata Forssk.
			Gebel Elba (Sa)
	Nitrariaceae		*Nitraria retusa* (Forssk.) Asch.
			Gebel Elba (Sa)
	Solanaceae		*Lycium* sp.
			Wadi Digla (Dg)
	Zygophyllaceae	*Zygophyllum album* L.*	
		Coastal desert plains at El-Arish (M) and Wadis of Da	
		Zygophyllum coccineum L.	
		Suez (Dg)	
Cistanche tubulosa	Chenopodiaceae	*Anabasis articulata* (Forssk.) Moq*	*Hammada elegans*
		El-Arish and El-Sallum (M)	Wadi Mitla (Di), Wadi Feiran (S)
			Salsola imbricata
	Fabaceae		[b]*Retama* sp.
	Salvadoraceae		*Salvadora persica* L.
			Wadi Allaqi (Da), Gebel Elba (Sa)
	Solanaceae		[b]*Lycium* sp.
	Tamaricaceae	*Tamarix aphylla* (L.) Karst.	[b]*Tamarix* sp.
		Wadi Feiran (S)	[a]*Tamarix* sp.

See Table 8.13 for abbreviations
Asterisks indicate hosts not previously reported
CAI=Cairo University herbarium; *CAIM*=Agriculture Museum herbarium.
a Hassib (1951), *b* Täckholm (1974), *c* Mubarek (1985)

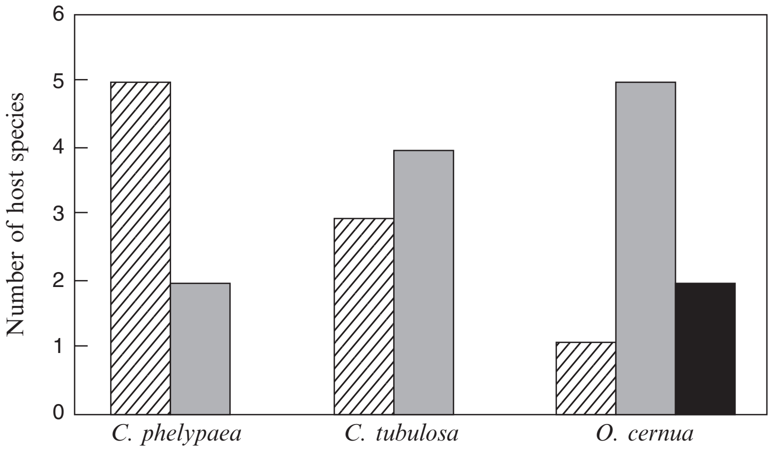

Fig. 8.13 Number of host species of the three root parasitic taxa. C = succulents; H = non-succulents; G = non-succulent mesophytic hosts (crop plants). This figure is based on the information given in Table 8.15

of the total. It is interesting to note that two root parasitic species may separately infect the same host species in one or in several habitats.

Since the succulent desert plants have low transpiration rates and high water content (Abd El-Rahman and Batanouny 1965), it is suggested that the predictable meeting and subsequent possible infection of these hosts by the robust *Cistanche* species are to the advantage of the parasites. This partial specificity to succulent perennials appears to be an ecological adaptation of such parasites to their particular hosts. The occurrence of *O. cernua* on a variety of non-succulent hosts may reflect its low water requirements. This is possibly attributed to its small biomass compared to the robust *Cistanche*.

8.2.5 Biomass

The robust nature of both *Cistanche* species was manifested by comparing their fresh and dry masses with those of *O. cernua* infecting different hosts (Tables 8.15 and 8.16). The high fresh masses of both *Cistanche* species per individual host were accompanied by the presence of two to seven spikes, depending on the host species. The fresh mass of the individual spike ranged from 160 to 980 g. Despite the high number of inflorescences of *O. cernua* infecting *Atriplex* and *Achillea* hosts, their fresh masses were considerably lower than those of the *Cistanche* species. There were no significant differences between the fresh masses or between the dry masses of the noninfected and host species of *O. cernua* (except in *Achillea fragrantissima*). Statistically significant differences existed between the root biomasses of the

Table 8.15 Number of inflorescences, biomass, water content, and succulence ratio of *Cistanche phelypaea* and *C. tubulosa*, the hosts, and the noninfected species growing under natural conditions in different phytogeographic regions

Root parasite	Site and region	Number of species inflorescences of parasite		Plant part examined	Fresh mass (g)	Dry mass (g)	Water content (% FM)	Succulence ratio
C. phelypaea	Wadi Hof (Dg)	*Atriplex leucoclada*	3	P	480	60.6	87.5	7.9
				NIS	1983.4	402.6	79.7	1.9
				HS	1250.5	352.6	71.8	36
				NR	*	*	56.3	2.1
				HR	*	*	54.6	1.5
		A. leucoclada	7	P	6860	875.5	87.2	7.8
				NIS	1800.3	371.0	79.4	4.9
				HS	1133.5	323.1	71.5	3.5
				NIR	184.0	92.0	50.0	2.0
				HR	102.3	55.6	45.7	1.8
	Suez (Gg)	*Hammada elegans*	2	P	263.5	39.5	85.0	6.7
				NIS	1866.0	395.6	78.8	4.7
				HS	1120.0	276.6	75.3	4.1
				NIR	51 1.6	280.4	45.2	1.8
				HR	318.5	187.3	41.2	1.7
	El-Arish (M)	*Zygophyllum album*	4	P	2565.0	313.0	87.8	8.2
				NIS	580.0	80.5	86.1	7.2
				HS	370.0	67.3	81.8	5.5
				NIR	140.0	79.5	43.2	1 8
				HR	150.0	93.0	38.0	1.6
C. tubulosa	El-Arish (M)	*Anabasis articulata*	7	P	3450.0	510.0	85.2	6.7
				NIS	3350.0	686.8	79.5	4.9
				HS	1670.0	479.3	71.3	3.5
				NIR	897.5	555.6	38.1	1.6
				HR	582.2	393.0	32.5	1.5
LSD			3.4		191.2	52.4	3.6	1.0

P parasite; NIR and HR, roots of noninfected and host species; NIS and HS, shoots of noninfected and host species; *LSD* least significant difference between the means at 0·05 level of probability
* = value not determined

noninfected and host plants of *Hammada elegans* infected by *C. phelypaea*. The ratio of fresh mass of the parasite/fresh mass of the host was high and ranged from 5 to 5.6 in the case of *C. phelypaea* infecting *Zygophyllum album* and *Atriplex leucoclada*, respectively (Table 8.15). This ratio was much lower in the case of *C. tubulosa* infecting *Anabasis articulata*. The lowest ratio was exhibited by *O. cernua* and its hosts. On a dry mass basis, the ratio of parasite/host followed the same trend but with much lower values than a fresh mass basis, especially in the case of *O. cernua* and its hosts.

Table 8.16 Number of inflorescences, biomass, water content, and succulence ratio of *Orobanche cernua*, the hosts, and the noninfected species growing under natural conditions in Wadi Hof (Dg)

Root parasite	Species	Number of inflorescences of parasite	Plant part examined	Fresh mass (g)	Dry mass (g)	Water content (% FM)	Succulence ratio
O. cernua	*Atriplex leucoclada*	8	P	140.0	28.0	80.0	5.0
			NIS	625.0	142.0	77.3	4.4
			HS	603.0	156.0	74.0	3.9
			NIR	175.0	71.6	59.1	2.4
			HR	152.0	63.0	58.6	2.4
	Achillea fragrantissima	8	P	300.0	52.0	82.7	5.8
			NIS	3,500.0	1,155.0	67.0	3.0
			HS	3,650.0	1,113.0	69.5	3.3
			NIR	*	*	45.0	2.4
			HR	*	*	40.1	2.1
	Lycium shawii	4	P	42.3	7.6	82.1	5.6
			NIS	5,384.7	1,435.4	73.2	3.8
			HS	5,637.2	1,460.0	74.1	3.9
			NIR	*	*	54.2	1.8
			HR	*	*	49.0	1.3
	Nitraria retusa	1	P	611	12.0	80.5	5.1
			NIS	2,450.0	497.4	79.7	4.9
			HS	2,262.0	520.3	77.0	4.4
			NIR	*	*	58.5	1.8
			HR	*	*	52.5	1.5
LSD		4.5		92.2	40.3	7.5	0.6

Each value is an average of three measurements
*=value not determined

8.2.6 Water Content and Succulence Ratio

Both the water content and the succulence ratios of the root parasites *C. phelypaea* and *C. tubulosa* were significantly higher than their hosts as well as the noninfected species (Table 8.16). The water content and succulence ratio of *O. cernua* were lower than for *Cistanche* species but were still higher than their hosts and the noninfected species of *Achillea fragrantissima* and *Lycium shawii* (Table DCA axis CCA axis 1 2 3 1 2 3 Eigenvalues 0.68 0.31 0.19 0.56 0.27 0.15 Species–environment correlation coefficients 0.89 0.79 0.69 0.93 0.94 0.81 pH 0.16 0.16 −0.12 −0.16 0.08 0.17 EC -0.37 −0.30 −0.22 0.006 0.01 0.23 Gravel −0.62 −0.20 0.20 0.51 −0.03 0.02 Coarse sand 0.26 0.48 0.18 −0.43 −0.20 0.04 Silt 0.17 −0.30 0.15 0.07 0.11 0.08 Clay −0.28 −0.35 −0.14 0.20 0.002 −0.09 Ca^{+2} −0.26 −0.48 −0.25 0.27 0.24 −0.03 Mg^{+2} 0.16 −0.25 −0.12 0.14 0.06 −0.25 Na^{+} −0.20 −0.56 −0.39 0.40 0.29 -0.11 K^{+} -0.11 −0.44 −0.14 0.19 0.25 -0.09 HCO_3^{-} -0.30 −0.38 −0.34 0.23 0.01 -0.002 SO_4^{-2} -0.15 −0.51 −0.18 0.32 0.35 −0.07 Cl^{-} −0.21 −0.630 −0.23 0.40 0.37 -0.06 NH_4^{+} -0.02 −0.20 0.17 0.07 0.22 0.31 NO_3^{-} 0.11 −0.47 −0.20 −0.09 0.34 −0.04). In general, the shoots showed significantly higher values than the roots. The differences between the water contents and between the succulence ratios of shoots of the noninfected plants and those of the hosts of both *Cistanche* species were statistically significant. However such differences were not significant in the case of *O. cernua*.

8.2.6.1 General Remarks

1. Ecologically, the distribution of hosts is the main factor which determines the occurrence of their possible parasitic species. The occurrence of parasite–host associations in southern Sinai, in the Galala and Arabian Deserts, and in Gebel Elba regions was restricted to the silt terraces and to the channels and runnels of the main wadis which receive soft materials. Such habitats constitute a substrate suitable for moisture storage in the deep soil layers which provide the deep roots of perennials with a continuous water supply (Migahid and Abd El-Rahman 1953). The notable wide ecological range of *Zygophyllum album*, together with the wide geographical range of *Z. coccineum* (Kassas and Girgis 1965), which are among the hosts of *C. phelypaea*, appear to be the main reasons for the distribution of this parasite in the phytogeographic regions of this study. The shallow roots of *Zygophyllum coccineum* may increase the possibility of infection by the germinating seeds of the parasite.
2. With regard to their distribution, *C. tubulosa* and *O. cernua* have been considered by Täckholm (1974) as rare species. The occurrence of *C. tubulosa* in isolated areas of southern Sinai and Gebel Elba regions can be considered as enclaves.
3. The three root parasitic species were recorded to infect 16 different host species belonging to eight families. Our field observations indicated that 12 host species are able to form phytogenic hillocks. These hillocks or mounds develop as a result of sand accumulation around plants rooting in the sandy soil (Batanouny and Batanouny 1969). Since the seeds of these root parasites are minute and have small mass (especially those of *O. cernua*), they are possibly brought to the locality, where their hosts grow, by either wind or running water, or by both. The grazing of the host or noninfected species (e.g. *Atriplex leucoclada*, *Hammada elegans*, *Anabasis articulata*, etc.) by desert mammals aids in the long-distance dispersal of parasite seeds, which may either contaminate the grazed shoots or adhere to their fruits. Adherence of *O. cernua* seeds to sunflower before harvest has been claimed by Casteĵon et al. (1991). Long-distance dispersal of *O. cernua* seeds may occur when they adhere to the fruits of *Nitraria retusa* which, according to Kassas and Girgis (1965), are sought by birds and Bedouins. Cutting branches of *Nitraria retusa* and *Anabasis articulata* for domestic purposes and cutting young branches of *Salvadora persica* by desert Bedouins, for making toothbrushes, also facilitate the dispersal of the parasite seeds, which may be mixed with the cut parts.
4. In sandy areas, wind-scattered seeds of desert plants accumulate in sites where the velocity of winds or running water in the runnels and wadis is low, such as the sheltered side of the phytogenic hillock (Kassas and Imam 1954; Danin 1991).

The hillock-forming plants often produce adventitious roots which grow into the accumulated sand (Batanouny and Batanouny 1969). The intricate growth of the plant shoots may locally create a shaded and wind-protected microhabitat. Therefore, it is suggested that such conditions may favour germination of the seeds of root parasites in the close neighbourhood of their specific hosts which trap them in their shoots.

5. Patterns of host specialization occur in the two species of *Cistanche* where more than 50 % of their hosts belonged to the family Chenopodiaceae. While *C. phelypaea* infected two members of the Zygophyllaceae, neither *C. tubulosa* nor *O. cernua* parasitized members of this family. The majority of *Cistanche* hosts are desert perennials, while *O. cernua* seems to have a wider host range since it infects desert perennials and crop plants growing under mesic conditions. Parker (1986) indicates that there is evidence of "races" of *O. cernua* varying in their ability to attack different hosts. This is partly attributable to the autogamous behaviour of the species (Musselman et al. 1982). It is concluded that these races may contain some populations which are clearly adapted to hosts growing in the desert, and others growing under mesic monoculture conditions are able to attack sunflower, tomato, and tobacco.
6. It is apparent that the hosts of both *Cistanche* species were more sensitive to infection than those of *O. cernua*. The percentage change in the dry mass of noninfected plants compared to host plants is proposed as an expression of the degree of sensitivity, a low percentage indicating low sensitivity. Among the hosts of *C. phelypaea*, *Hammada elegans* was more sensitive to infection than *Atriplex leucoclada* and *Zygophyllum album* since the dry mass of *H. elegans* hosts was 30.1 % lower than that of the noninfected plants. Likewise, the host *Anabasis articulata* attacked by *C. tubulosa* showed a similar sensitivity to that of *H. elegans*. Fahmy (1993) recorded 60 % lower dry mass in the hosts of the halophytic herb *Limonium delicatulum* (Gir.) Kuntze due to the infection by the angiosperm root parasite *Cynomorium coccineum* L. (Cynomoriaceae). The occurrence of non-significant differences between the dry masses of the noninfected and host species of *O. cernua* (except in the case of *Achillea fragrantissima*) indicates that such species were not sensitive to infection. This could be due to the low biomass of the parasite compared to the host species. It seems that the metabolic requirements of the parasite are low to a degree which may not affect the perennial hosts.
7. The widely distributed *C. phelypaea* was recorded infecting seven species. Four of these species, namely, *Zygophyllum album*, *Z. coccineum*, *Nitraria retusa*, and *Salsola imbricate* subsp. *imbricata*, are characterized by their succulent leaves. In addition, *Hammada elegans* hosts have succulent stems. Moreover, *C. tubulosa* was recorded infecting one leaf succulent chenopod (*Salsola imbricata*), two stem succulent hosts (*Hammada elegans* and *Anabasis articulata*), and four non-succulent host species (*Retama* sp., *Salvadora persica*, *Lycium* sp., and *Tamarix aphylla*).

Appendix

Climbing-plant families, species, chorotype, status, and their growth forms in different phytogeographic regions of Egypt

Family	Species	N	M	O	S	R	GE	De	Dw	GF	CH	ST
Asclepiadaceae	*Cynanchum acutum* L.	+	+	+	–	–	–	–	–	Ph	ME + IR	X
Asclepiadaceae	*Leptadenia arborea* (Forssk.) Schweinf.	+	–	–	–	–	–	–	–	S	SA	X
Asclepiadaceae	*Oxystelma alpini* Decne.	+	–	–	+	–	–	+	–	Ph	SA + SU	X
Asclepiadaceae	*Pentatropis nivalis* (J.F. Gmel.) D.V. Field & J.R.I. Wood	–	–	–	+	+	+	+	–	S	SA + SU	X
Asclepiadaceae	*Pergularia daemia* (Forssk.) Chiov.	–	–	–	+	+	+	–	–	Ph	SA + SZ	X
Asclepiadaceae	*P. tomentosa L.*	–	–	–	+	–	+	+	–	S	SA + SZ	X
Asclepiadaceae	*Periploca angustifolia* Labill.	–	+	–	–	–	–	–	–	S	ME	X
Asclepiadaceae	*Podostelma schimperi* (Vatke) K.Schum.	–	–	–	–	–	+	–	–	S	SZ + SU	X
Capparaceae	*Cadaba farinosa* Forssk.	–	–	–	–	+	+	+	–	S	Pal	X
Capparaceae	*Maerua oblongifolia* (Forssk.) A. Rich.	–	–	–	–	–	+	–	–	S	SU	X
Convolvulaceae	*Calystegia silvatica* (Kit.) Griseb.	–	+	–	–	–	–	–	–	Ph	ME + IR	W
Convolvulaceae	*Convolvulus althaeoides* L.	–	+	–	+	–	–	+	–	Ph	ME	W
Convolvulaceae	*C. arvensis* L.	+	+	+	+	–	–	+	–	Ph	Pal	W
Convolvulaceae	*C. glomeratus* Choisy	–	–	–	+	–	+	+	–	Ph	SZ	W
Convolvulaceae	*C. palaestinus* Boiss.	–	–	–	+	–	–	–	–	Ph	ME	W
Convolvulaceae	*C. scammonia* L.	–	–	–	+	–	–	–	–	Ph	ME	W
Convolvulaceae	*C. siculus* L.	–	+	+	–	+	+	–	–	Ah	ME + IR	W
Convolvulaceae	*C. stachydifolius* Choisy	–	+	–	–	–	–	–	–	Ph	ME + IR	W
Convolvulaceae	*Ipomoea cairica* (L.) Sweet	+	+	–	–	–	–	–	+	Ph	Pal	W
Convolvulaceae	*I. eriocarpa* R. Br.	+	–	–	–	–	–	–	–	Ah	Pal	W
Convolvulaceae	*I. hederacea* Jacq.	+	–	–	–	–	–	–	–	Ph	Pal	W
Convolvulaceae	*I. obscura* (L.)Ker Gawl.	–	–	–	–	–	+	–	–	Ph	Pal	W
Convolvulaceae	*I. purpurea* (L.) Roth	+	–	–	–	–	–	–	–	Ah	Pal	W

Family	Species	N	M	O	S	R	GE	De	Dw	GF	CH	ST
Convolvulaceae	*I. sinensis* (Desr.) Choisy	–	–	–	–	–	+	+	–	Ah	SZ	W
Convolvulaceae	*Jacquemontia tamnifolia* (L.) Griseb.	–	–	–	–	–	+	–	–	Ah	Pan	W
Convolvulaceae	*Merremia aegyptia* (L.) Urb.	–	–	–	–	–	+	–	–	Ah	Pan	W
Convolvulaceae	*M. semisagittata* (Peter) Dandy	–	–	–	–	–	+	–	–	Ph	Pan	X
Cucurbitaceae	*Bryonia cretica* L.	–	+	–	–	–	–	–	–	Ph	ME	W
Cucurbitaceae	*B. syriaca* Boiss.	–	–	–	+	–	–	–	–	Ph	ME	W
Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.	+	+	+	+	+	+	+	+	Ph	ME + SA	X
Cucurbitaceae	*Coccinia abyssinica* (Lam.) Cogn.	–	–	–	–	–	+	–	–	Ph	Pal	X
Cucurbitaceae	*C. grandis* (L.) Voigt	–	–	–	–	–	+	–	–	Ph	Pal	X
Cucurbitaceae	*Corallocarpus schimperi* (Naudin) Hook. f.	–	–	–	–	–	+	–	–	Ph	IR + SZ	X
Cucurbitaceae	*Cucumis dipsaceus* Ehrenb.	–	–	–	–	–	+	–	–	Ah	IR	W
Cucurbitaceae	*C. prophetarum* L.	–	–	–	+	+	+	+	–	Ph	SA + SZ	X
Cucurbitaceae	*C. pustulatus* Hook. f.	–	–	–	–	–	+	–	–	Ph	SA	X
Cucurbitaceae	*Diplocyclos palmatus* (L.) C. Jeffrey	–	–	–	–	–	+	–	–	Ph	Pal	X
Cucurbitaceae	*Kedrostis foetidissima* (Jacq.) Cogn.	–	–	–	–	–	+	–	–	Ph	Pal	X
Cucurbitaceae	*K. gijef* (J.F. Gmel.) C. Jeffrey	–	–	–	–	–	+	–	–	Ph	Pal	X
Cucurbitaceae	*Zehneria anomala* C. Jeffrey	–	–	–	–	–	+	–	–	Ph	SU	X
Cuscutaceae	*Cuscuta approximata* Bab.	+	–	–	+	–	–	–	–	Ah	ME + IR	W
Cuscutaceae	*C. campestris* Yunck.	+	–	+	–	–	–	–	–	Ah	Cosm	W
Cuscutaceae	*C. chinensis* Lam.	–	–	–	–	–	+	–	–	Ah	SA + SZ	W
Cuscutaceae	*C. epilinum* Weihe	+	–	–	–	–	–	–	–	Ah	ME + IR	W
Cuscutaceae	*C. monogyna* Vahl	+	–	–	–	–	–	–	–	Ah	ME + IR	W
Cuscutaceae	*C. palaestina* Boiss.	–	+	–	+	–	–	+	–	Ah	ME	W
Cuscutaceae	*C. pedicellata* Ledeb.	+	+	+	+	–	+	+	+	Ah	ME	W
Cuscutaceae	*C. planiflora* Ten.	+	+	–	+	+	+	+	–	Ah	ME	W
Ephedraceae	*Ephedra ciliata* Fischer & C.A. Mey.	–	–	–	+	–	+	+	–	S	Pal	X
Ephedraceae	*E. foeminea* Forssk.	–	–	–	+	–	–	–	–	S	Pal	X
Lamiaceae	*Prasium majus* L.	–	+	–	–	–	–	–	–	S	ME	X
Fabaceae	*Clitoria ternatea* L.	+	–	–	–	–	–	–	–	Ph	Pal	W

Family	Species	N	M	O	S	R	GE	De	Dw	GF	CH	ST
Fabaceae	*Lathyrus annuus* L.	+	–	–	+	–	–	–	–	Ah	ME	W
Fabaceae	*L. aphaca* L.	+	+	+	+	–	–	–	–	Ah	ME + IR	W
Fabaceae	*L. gorgoni* Parl.	+	+	–	+	–	–	–	–	Ah	ME	W
Fabaceae	*L. hirsutus* L.	+	+	+	–	–	–	–	–	Ah	ME	W
Fabaceae	*L. marmoratus* Boiss. & Blanche	+	+	–	+	–	–	–	–	Ah	ME	W
Fabaceae	*L. sativus* L.	+	+	+	–	–	–	–	–	Ah	ME	W
Fabaceae	*L. setifolius* L.	–	+	–	–	–	–	–	–	Ah	ME	W
Fabaceae	*L. sphaericus* Retz.	+	–	–	–	–	–	–	+	Ah	ME + IR	W
Fabaceae	*Pisum fulvum* Sm.	–	–	–	+	–	–	–	–	Ah	ME	W
Fabaceae	*P. sativum* L.	+	+	+	–	–	–	–	–	Ah	ME + IR	W
Fabaceae	*Rhynchosia malacophylla* (Spreng.) Bojer	–	–	–	–	–	+	–	–	Ph	SZ	W
Fabaceae	*R. minima* (L.) DC.	–	–	–	+	–	+	–	–	Ph	SA	W
Fabaceae	*Vicia articulata* Hornem	+	+	–	–	–	–	–	–	Ah	ME	W
Fabaceae	*V. ervilia* (L.) Willd.	–	+	–	–	–	–	–	–	Ah	ME	W
Fabaceae	*V. hirsuta* (L.) Gray	–	–	–	–	–	–	+	–	Ah	ME	W
Fabaceae	*V. hybrida* L.	+	+	–	–	–	–	–	–	Ah	IR	W
Fabaceae	*V. lutea* L.	+	+	+	–	–	–	–	–	Ah	ME + IR	W
Fabaceae	*V. monantha* Retz.	+	+	+	+	–	–	–	–	Ah	ME + IR	W
Fabaceae	*V. narbonensis* L.	+	+	+	+	–	–	+	–	Ah	IR	W
Fabaceae	*V. palaestina* Boiss.	–	+	–	+	–	–	–	–	Ah	ME	W
Fabaceae	*V. parviflora* Cav.	+	+	–	–	–	–	–	–	Ah	ME	W
Fabaceae	*V. peregrina* L.	–	+	–	+	–	–	–	–	Ah	ME + IR	W
Fabaceae	*V. sativa* L.	+	+	–	–	–	–	–	–	Ah	ME + IR	W
Fabaceae	*V. tetrasperma* (L.) Schreb.	+	+	–	–	–	–	–	–	Ah	ME + IR	W
Fabaceae	*V. villosa* Roth	–	+	–	–	–	–	–	–	Ah	ME	W
Fabaceae	*Vigna luteola* (Jacq.) Benth.	+	–	–	–	–	–	–	–	Ah	SZ	W
Fabaceae	*V. membranacea* A. Rich.	–	–	–	–	–	+	–	–	Ah	SU	W
Fabaceae	*V. unguiculata* (L.) Walp.	+	–	–	–	–	–	–	–	Ah	SZ	W
Loranthaceae	*Plicosepalus acaciae* (Zucc.) Wiens & Polhill	–	–	–	+	–	+	–	–	F	SA	X

Family	Species	N	M	O	S	R	GE	De	Dw	GF	CH	ST
Loranthaceae	*P. curviflorus* (Benth. exoliv.) Tiegh	–	–	–	–	+	+	+	–	F	SA	X
Menispermaceae	*Cocculus pendulus* (J.R and G. Forst.) Diels	+	–	–	+	–	+	+	–	S	Pal	X
Oleaceae	*Jasminum fluminense* Vell.	–	–	–	–	–	+	–	–	S	ME + IR	X
Oleaceae	*J. grandiflorum*	–	+	–	–	–	–	–	–	S	ME + IR	X
Polygonaceae	*Fallopia convolvulus* (L.) Å. Lőve	+	+	–	–	–	–	–	–	Ah	ME	W
Rubiaceae	*Galium aparine* L.	–	–	–	+	–	–	+	–	Ah	SA	W
Rubiaceae	*G. ceratopodum* Boiss.	–	–	–	+	–	–	–	–	Ah	SA	W
Rubiaceae	*G. tricornutum* Dandy	+	+	+	+	–	–	+	–	Ah	SA	W
Rubiaceae	*Rubia tenuifolia* d'Urv.	–	–	–	+	–	–	–	–	Ph	ME	W
Spindaceae	*Cardiospermum halicacabum* L.	+	–	+	–	–	–	–	–	Ah	Pal	W
Vitidaceae	*Cayratia ibuensis* (Hook. f.) Suesseng.	+	–	–	–	–	+	–	–	S	SU	X
Vitidaceae	*Cissus quadrangularis* L.	–	–	–	–	–	+	–	–	S	IR + SU	X

N Nile, *M* Mediterranean, *O* Oases, *GE* Gabel Elba, *De* Eastern Desert, *Dw* Western desert region, *X* Xerophyte, *W* Weed, *Ph* Perennial herb, *S* Shrub, *Ah* Annual herb, *F* Frutescent, *GF* Growth form, *CH* Chorotype, *ST* Status

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Part II
The Desert and Semi-desert of Mexico

Chapter 9
The Deserts of Mexico

Abstract Arid zones are defined as regions in which water supply is deficient and the degree of rainfall and atmospheric humidity are below world averages. In North America there is an extended continuous arid strip running from southwest Canada going down most Western United States and part of Northern Mexico and reaching the Trans-Mexican Volcanic Belt. Due to its geographical location, more than 60% of the territory of the Mexican Republic is located between 20 and 40° N, corresponding to the belt in which the deserts of the world are distributed, which is the reason why great part of the country is arid. The Mexican Republic is formed by 32 states, and 25 of them are covered by arid areas to a greater or lesser extent. At least five characteristic arid regions are of big importance from the floristic view point: (1) the Sonora and Baja California Desert, (2) the Chihuahuan arid region, (3) the Tamaulipan semiarid region, (4) the Hidalgo semiarid region, and (5) the Poblano–Oaxaca semiarid region.

Each region is characterized by a great variety of features in soil, lithology, and vegetation, with a great proportion of endemic species of both plants and animals. Based on predominant plant species, the most similar regions are the Chihuahuan and Tamaulipan, and the most different are the Sonora and Baja California arid region.

9.1 Location and Physical Environment

Arid zones are defined as regions in which water supply is deficient and the degree of rainfall and atmospheric humidity are below world averages. The presence of arid zones is due to factors that obstruct the transportation of seawater to the mainland by air, among others: atmospheric circulation, topography of the continents, and frequently the ocean currents (Rzedowski 1959).

The Earth's tilt as well as the rotational and translational motion cause differential heating on the surface of the Earth, which generates the formation of two high-pressure belts with airstreams flowing downwards. These belts are located on both sides of the equator at 20° and 40°.

In North America there is an extended continuous arid strip running from southwest Canada going down to most of Western United States and part of Northern Mexico and reaching the Trans-Mexican Volcanic Belt. Towards southern Mexico, there are some small isolated areas (Rzedowski 1959).

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Several authors have described and defined Mexico's arid and semiarid zones using different criteria such as rainfall, number of dry months, types of soil, vegetation, etc. Maldonado (1983) defines arid zones as those in which rainfall is below 300 mm a year, with an irregular distribution throughout the year, an average temperature between 15 and 25 °C, 7–12 months of low water levels, and a vegetation cover under 70%. Smith and Nobel (1986) define arid zones as those regions in which the net primary productivity is under 300 g of dry weight per m^2 $year^{-1}$.

Currently the concept of dry zones includes "arid zones, semiarid, and subhumid lands". The latter are areas in which the ratio between annual rainfall and evapotranspiration ranges between 0.05 and 0.65, according to Decree on the Promulgation of the United Nations World Convention to Combat Desertification (UNCCD), (CONAZA 2016).

According to the criteria set forth by the Convention to which Mexico has adhered, Mexico has 1,056,830 km^2 of arid, semiarid, or subhumid zones that represent 54% of the total surface of the Mexican Republic (Monterroso et al. 1999). However, according to estimations where soil water balance and its availability for plants are considered (Dunne and Leopold 1978), México has a surface of 1,197,991 km^2 with a moisture deficit ranging from very severe (12%), severe (33.6%), to moderate (16%), representing 61.6% of the country's surface (Monterroso and Gómez 2003).

Due to its geographical location, more than 60% of the territory of the Mexican Republic is located between 20 and 40° N, corresponding to the belt in which the deserts of the world are distributed, reason why great part of the country is arid (Huerta-Martínez et al. 2010). The Mexican Republic is formed by 32 states, and 25 of them are covered by arid areas to a greater or lesser extent (Fig. 9.1). The states

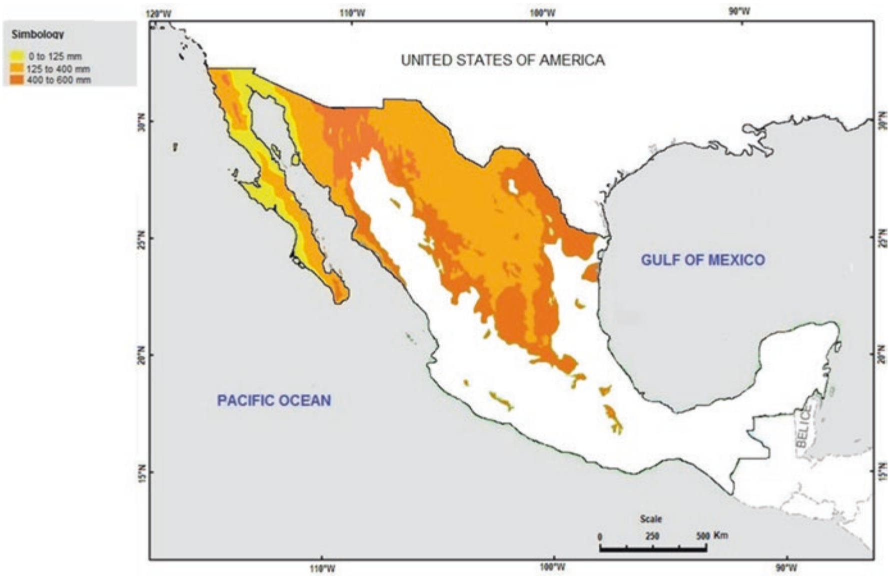

Fig. 9.1 Representation of the very dry, dry, and semidry climates in Mexico according to the mean annual rainfall (Source: CONABIO Web Page, modified)

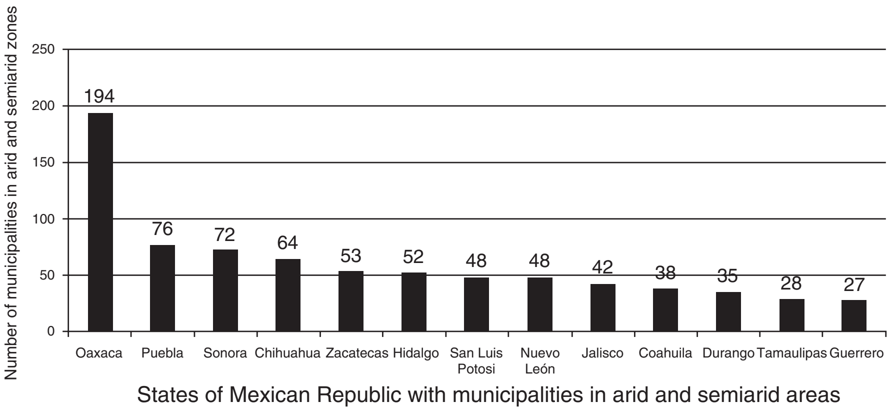

Fig. 9.2 States of the Mexican Republic with the highest number of municipalities in dry or semidry areas (Source: SAGARPA (2014) (The Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food 2014) with modifications)

of Aguascalientes, Baja California Norte, Baja California Sur, Coahuila, and Sonora are mostly all arid. The states of Chihuahua, Colima, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, México, Michoacán, Nuevo León, Oaxaca, Puebla, Querétaro, San Luis Potosí, Sinaloa, Tamaulipas, Tlaxcala, Yucatán, and Zacatecas are partially covered; however, as shown in Fig. 9.1, arid lands are not limited to the desert belt (30°N); they are also present in the tropical portion of Mexico (Cervantes-Ramírez 2016).

As to the states with the most municipalities located in arid and semiarid areas in Mexico, the first one is Oaxaca with 194 of its municipalities; second, Puebla, Sonora, and Chihuahua with 76, 72, and 64 municipalities, respectively; and the last one, Guerrero with 27 arid or semiarid municipalities (Fig. 9.2). According to the National Commission for Knowledge and Use of Biodiversity (CONABIO), there are 99 million hectares that are either arid or semiarid in Mexico, and 384 municipalities have more than 75% of its territory covered by arid lands, while 125 have less than 75% of their surface with this type of habitat. The prevailing macro vegetation is scrub and grasslands; the richness in flora is estimated at 6,000 species, with 3,600 species approximately being endemic (CONABIO 1998).

The National Population and Housing Census of the National Institute for Statistics, Geography and Information Technology (INEGI) in 2010 estimated that slightly more than 41 million people lived in México's arid zones and 87% in urban areas (SAGARPA 2014).

The origin of arid and semiarid zones in Mexico is varied. There are different factors that have an individual or synergic effect on the generation of arid conditions. These are the same ones that determine the existence of arid zones in the world; however, some of them act jointly to give way to the particular arid zones in Mexico, among them are:

(a) *Geographical location*: An extended region of the Mexican territory is located between 14 and 32° latitude north, which is affected by the high-pressure belt of the Northern Hemisphere (30°). The descending air streams warm up, compress, and lose humidity impeding precipitation.

(b) *Atmosphere stabilization*: Created by the cold ocean currents.

(c) *Föhn effect*: This is caused by mountain ranges such as the Sierra Madre Occidental and the Sierra Madre Oriental, causing the winds coming from the Pacific Ocean and the Gulf of Mexico to lose humidity as they ascend. Once over the peak, they come down dry.

(d) *The continentality effect*: Due to the fact that the Mexican territory widens in the northernmost portion, which, combined with the Föhn effect, creates a barrier that humid winds cannot penetrate causing extreme climate conditions (Huerta-Martínez 2002).

It is worth noting that there are different conceptualizations regarding arid and semi-arid zones depending on the diverse indicators taken into consideration. However, the one that stands out is the climate, since it is the determining factor for demarcation.

9.1.1 Climate

The arid and semiarid zones in Mexico are generally characterized by the presence of scarce and erratic rainfall, as well as marked temperature oscillations. These areas in Mexico generally have a B type climate, according to the Köppen classification. There are three main variables according to the modifications made by García (2004):

Climate BW: It is the driest of the climates in Mexico, prevailing in the northern part of the Central Highlands of Mexico with elevations below 1,500 m, in the coastal plains of the Pacific to the north at 25°N and in littoral zones of the Baja California Peninsula, except for the Norwest part in which the climate is BS.

Climate BS: It is located bordering the BW in the northern part of the plateau as well as on the slopes of the Sierra Madre Occidental range which rise from the Pacific Coastal Plains to the north of 23°N and to the northwest of the Baja California Peninsula. It also extends to the inland zones of the central and southern part of the country, which are less exposed to the influence of the humid winds from the sea. Examples of this are in the southern part of the plate, in the lowest parts of the Balsas Basin, and in higher parts of the basins of the Rio Verde, Mixteco, Tlapaneco, Papaloapan, and Tehuantepec rivers.

Climate BS1: It is the least dry of the BS Climates, bordering with the subhumid climates. The number of dry months varies from 8 to 10. It prevails in coastal plains of Tamaulipas, lower windward hillsides of the Sierra Madre Occidental of the states of Sonora and Sinaloa, lower lands of the Mexican Central Plateau (Guanajuato, Querétaro, Hidalgo), the San Juan (Puebla) and Perote (Veracruz) Valleys, a large part of the central valleys of Oaxaca, the Balsas Basin (Guerrero, Michoacán and Puebla), small portions of the coastal areas of Jalisco and Colima, as well as a small part of the Yucatan Peninsula.

9.1.2 Lithology

Volcanic rocks outcrop are present in large extensions of Northeastern and Central Mexico, predominantly in Baja California Sur and along the Sierra Madre Oriental range. They are abundant in the northeast, west, and south of the plateau and in some zones of central Oaxaca. The most common rocks are andesites, rhyolites, and volcanic tuff (Rzedowski 2006). Other well-represented types of rocks are *sedimentary rocks*, which are present in practically all of the Sierra Madre Oriental mountain range and the northeastern and the coastal. They are also found in most of the isolated mountain ranges of the northeast, central, and east of the plateau. Broad extensions of the arid areas of Oaxaca, Puebla, and Guerrero are covered by these types of rocks, forming isolated patches in Baja California, Sonora, Nayarit, Jalisco, Colima, and Michoacán and in most of the Yucatan Peninsula. Limestone is more predominant, although they are often accompanied by lutites and chalky sandstone (Cervantes-Ramírez 2016); in addition, *metamorphic rocks* cover considerable extensions towards the central north of Oaxaca, down to the southwest of Puebla. They are also present in a reduced number of zones in Guerrero. Besides, *intrusive rocks* are prevailing in the state of Baja California and are also present in isolated patches in Baja California Sur, as well as along the pacific coast of Sonora down towards Oaxaca. These types of rocks correspond to granite or similar rocks (Rzedowski 2006).

9.1.3 Soil

Soil in arid and semiarid receive the name of *xerosoles*—from the Greek word *xeros* meaning dry and *solum* meaning soil—which means dry soil. They are also known as aridisols, that is, soils of the arid zones. However, the great variety of geological substratum characteristic of the relief of the local climate conditions have given way to the existence of very diverse types of soils (Cervantes-Ramírez 2016).

In the coast of Sonora and Baja California, as well as in the lowlands frequently flooded by marine water, there is a prevalence of saline soil that form crusts of sodium chloride (common salt) in the dry season. Alternatively, there may be an accumulation of calcium carbonate; this horizon can vary in depth and thickness ranging from a couple of millimetres up to 40 cm. In the extense valleys, it can reach a depth of up to 230 m. and a thickness of 90 m. This petrocalcic horizon corresponds to the *calcimorphic*. This characteristic is common of the soils in Chihuahua. Certain parts of the states of Zacatecas, San Luis Potosí, Aguascalientes, Durango, Coahuila, Chihuahua, and Tamaulipas have the dark kind of soil called phaeozem, which has high fertility levels (Cervantes-Ramírez 2016). Certain areas of San Luis Potosí have outcrops of gypsum (calcium sulphate), which have a strong influence on the flora found there (gypsophile vegetation) (Huerta-Martínez et al. 2004).

Some closed desert basins of the Chihuahua Desert have a high prevalence of soils with high content of salts which are dragged by showers and accumulate in the lower parts of the basins. These showers drag with them alluvial materials that mix with the colluvial ones and originate the fluvisols soils. These soils are abundant in the coal mining areas of Coahuila, in the Region Lagunera, in the basins of the Atoyac and Balsas Rivers, and in some parts of the semiarid zones of Oaxaca, Puebla, Veracruz, and El Bajío region (Cervantes-Ramírez 2016).

9.1.4 General Characteristics of the Floristic Composition

A number of studies have been produced in México to address the classification and description of the vegetation of the country as a mosaic of vegetation associations related to the diverse types of climates and soil prevailing.

Specifically related to arid and semiarid zones about the Sonora Desert, the following stand out: Goldman (1916), Eastwood (1929), Shreve (1926, 1934, 1951), Shreve and Wiggins (1964), McLaughlin (1986), and, more recently, different publications on vegetation communities and the flora of the San Felipe Desert (López 1991; Delgadillo et al. 1992; Peinado et al. 1994a, b, c, 1995). In spite of being the most extensive and having the most arid biome in Mexico, there few studies have been made in relation to the Chihuahua Desert (Montaña 1988); it was delineated and described for the first time by Shreve (1942, 1951). Without a doubt, the multiple publications by Rzedowski (1956, 1965, 1973) are valuable, in particular about San Luis Potosi area located at the south of the Chihuahuan Desert. Later comes the work by Johnston (1977), Brown (1982), and, more recently, Valverde et al. (1996), Huerta-Martínez et al. (2004), Huerta-Martínez and García-Moya (2004), and finally Bartolomé-Hernández (2015) who placed a special emphasis on endemic plants of this vast desert.

Among the classics is the oft-cited work by Miranda and Hernández (1963), who proposed a nomenclature and classification for the types of vegetation in Mexico. They recognized that in the arid and semiarid zones, there are at least seven plant associations based on the physiognomy and floristic composition, which will be briefly described:

1. Thorny scrubland with side thorns: It is a plant formation in which leguminous plants prevail, among which is the *Acacia* genus.
2. Cardonales and tetecheras: This vegetation includes succulent plants between 5 and 10 m high. Different genera or species are prevalent depending on the geographical region: *Neobuxbaumia tetetzo* in the valley of Tehuacan–Cuicatlán Puebla, *Carnegiea gigantea* in the Sonora Desert and *Myrtillocactus geometrizans* in the San Luis Potosi, Queretaro and Hidalgo regions.
3. *Izotales*: A formation characterized by the predominance of *izotes* (*Yucca* spp.), frequent in the central region and the north of the states of San Luis Potosí, Zacatecas, Durango, Coahuila and Nuevo León.
4. *Nopaleras*: In this vegetation formation, there is a dominance of the *Opuntia* genus. It is present in all the central states in the country such as Zacatecas, Aguascalientes, San Luis Potosí and Durango.

5. Thorny scrubland with terminal spines: They are associations of scrubs that do not exceed 2 m high, and many of them have terminal spines. Among the most representative genera are *Condalia*, *Koeberlinia* and *Lycium*.
6. Spineless scrublands: This plant association is characterized by practically a complete prevalence of *Larrea tridentata* (creosote bush). It is common from Queretaro to the north and northeast. It is frequent to find that in addition to the creosote bush, there will be *Celtis pallida* or *Flourensia cernua.*
7. *Magueyales*, *Lechuguillales*, and *Guapillales* (spinous crasi-/rosulifolious): These vegetation associations are formed by groups of plants that have rosette leaves. Some of the species have narrow leaves and have no spines on the edges, such as the *Agave striata*, existing in San Luis Potosí, or *Agave stricta* in Tehuacán. The *lechuguillales*, associations in which *Agave lechuguilla* predominates, is distributed in the northern part. The *guapillales* with a prevalence of *Hechtia glomerata* are extensive, common in San Luis Potosí.

Rzedowski (2006) also grouped all of the plant associations of the arid and semiarid zones in Mexico into a single group of vegetation (xerophytic shrubland) and thoroughly described the flora. Later the National Institute for Statistics, Geography and Information Technology (INEGI 2005) considered the Rzedowski (xerophytic shrubland) classification as a grouping of 14 distinct vegetation types. Grasslands would then be grouped into three distinct vegetation formations under the following physiognomy (Table 9.1).

Table 9.1 Types of vegetation in arid or semiarid climates in Mexico

Groupings of types of vegetation	Types of vegetation INEGI (2005)	Millions of Ha.	% surface of the country
Xerophytic shrubland	Crassicaulescent desert scrub	1.2054	0.61
	Microphyllous desert scrub	19.5962	9.97
	Rosetophyllous desert scrub	10.2146	5.2
	Tamaulipan thorny shrub	2.5569	1.3
	Coastal rosetophyllous scrub	0.4509	0.23
	Sarco-crassicaulescent shrubland	2.3005	1.17
	Fog sarco-crassicaulescent shrubland	0.5657	0.28
	Sarcocaulescent desert	5.2154	2.65
	Piedmont scrub	2.3895	1.21
	Subtropical Shrubland	1.0123	0.51
	Mezquital	2.5164	1.28
	Sandy deserts vegetation	2.1656	1.1
	Gypsophile vegetation	0.046	0.023
	Halophile vegetation	2.7828	1.41
Grassland	Gypsophile grassland	0.0452	0.02
	Halophile grassland	1.8261	0.93
	Natural grassland	6.3245	3.22

Source: Challenger, A., and J. Soberón. 2008. Land ecosystems in Natural Capital of México, vol. I: Current Knowledge of Biodiversity CONABIO (National Commission for the Knowledge and Use of Biodiversity, México, pp. 87–108

9.2 The Sonora and Baja California Desert

The Sonora Desert is part of the vast arid ecosystem corridor of North America, which starts in the state of Washington D.C., USA, and extends down to the state of Hidalgo in Mexico. It also runs down central Texas to the Pacific Coast in the Baja California Peninsula (Ezcurra et al. 2002). It is one of the most important biomes of North America. It receives its name because nearly one-third of its total surface is in the state of Sonora, Mexico (Martínez-Yrízar et al. 2010).

This arid corridor nearly covers a million square kilometres, but it is divided into four large deserts: the Great Basin, the Mojave Desert, the Sonoran Desert, and the Chihuahuan Desert. The latter is mostly located in Mexico. The Great Sonoran Desert encompasses a series of lowlands of less than 1,000 m above sea level (m a.s.l.), around the Gulf of California or Sea of Cortez. Although it is a single entity in the United States, as it extends to Mexico, it splits into a continental arid land region known as the Sonoran Desert and a strip of coastal deserts running down the Baja California Peninsula called the Baja California Desert. This complex desert includes 101,291 km^2 of the Baja California Desert and 223,009 km^2 of the true Sonoran Desert. In total, 29% of this wilderness zones are (93,665 km^2) in the United States and the remaining 71% (230,635 km^2) in Mexico (Ezcurra et al. 2002) (Fig. 9.3).

In spite of its relative pristine condition and its easy access from Baja California Sur, very little quantitative research has been done on the central portion of this desert. The most comprehensive description to date of Central Baja California continues to be the one Forrest Shreve did more than 70 years ago. The central part

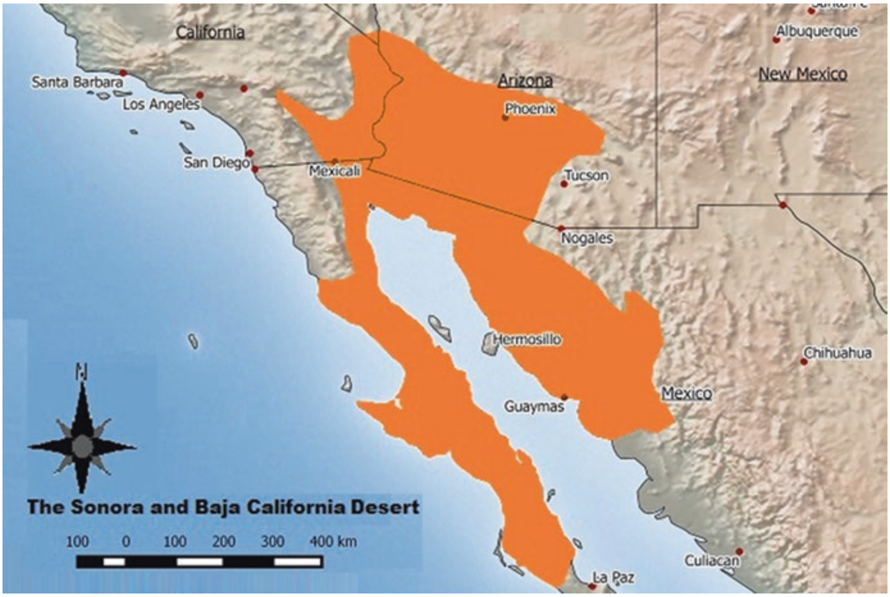

Fig. 9.3 The Sonora and Baja California Desert (self-elaboration)

of this desert lacks detailed analysis of its biodiversity; only portions of the south are protected as biosphere reserves (Philip et al. 2014).

Shreve (1951) identified seven subdivisions of vegetation in the Sonora Desert, based on the characteristics and organization of plant communities, and their distribution in the geographical context. There are four of them in the Mexican part of the desert; one of them (Plains of Sonora) is exclusive to the state. The following is a description of them according to Martínez-Yrízar et al. (2010):

9.2.1 Lower Colorado River Valley

This subdivision of the Sonora Desert approximately covers 3 million hectares. It includes the Rio Colorado Delta, which drains into the Gulf of California, and the lowlands (<400 m). It is one of the most arid regions in Sonora. Rainfall is scarce and unpredictable with less than 75 mm annually. The vegetation in the plains, where soil is predominantly sandy, is made up by a microphyllous desert which is structurally simple, in other words, a region dominated by small-leafed plants such as the creosote bush *Larrea divaricata* and *Ambrosia deltoidea* or *A. dumosa*. Hence, Shreve (1951) named it as the *Larrea–Ambrosia* region. In fact, these plants are the true xerophytes of the desert; they are able to withstand the most severe droughts without wilting.

Aside from the prevailing microphyllous plants, the vegetation also includes some stumpy trees such as the *Olneya tesota*, *Parkinsonia florida and P. microphylla* as well as *Prosopis pubescens* and *P. glandulosa* var. *torreyana*. The scarcity of woody vegetation is compensated by the great abundance of ephemeral plants that sprout after the rain. They cover the desert with a dense and colourful mantle of flowers. In fact, the abundance of seeds is so high in this region, and the base of the trophic food web are granivorous species like the kangaroo rat (*Dipodomys ordii*), woodrats (*Neotoma* spp.), quails (*Callipepla* spp.) and several ant species (Ezcurra et al. 2002). Although, this subdivision has a simple structure, there is a considerable floristic difference among distinct habitats (Felger et al. 2007). Delgadillo-Rodríguez and Macías-Rodríguez (2002) recorded 324 vascular plant species grouped in 206 genera at the San Felipe Desert region located in this subdivision of the Sonoran Desert.

9.2.2 Arizona Highlands

It holds an approximate extension of 1.6 million hectares in the state of Sonora. It represents the subdivision of the Sonoran Desert with the highest elevation in the state (from 150 to 950 m a.s.l.). The rainfall varies from 75 to 300 mm. It also frequently reaches freezing temperatures. It is a crassicaulescent desert, receiving its name because of the abundance of *Platyopuntia* and *Cylindropuntia* as well as low shrubs and leguminous and succulent plants located on the mountains and on the rocky slopes. This subdivision was also named *Parkinsonia*, *Cylindropuntia* and *Opuntia* regions (Shreve 1951), because of the presence of these three genera. Although Cactaceae are very abundant, aside from *Ferocactus* spp., one of the most conspicuous elements is saguaro (*Carnegiea gigantea*), which can form dense and extensive woodlands in the region.

9.2.3 Central Gulf Coast

This subdivision of the Sonoran Desert is present on both sides of the Gulf of California covering an approximate extension of a million hectares. It is known as the *Bursera–Jatropha* region according to Shreve (1951). Díaz-Martínez (2001) considers the vegetation of this subdivision as a low productivity open crassicaulescent desert. It is dominated by thick–smooth bark succulent plants where *Pachycereus pringlei* stands out, given its abundance. It is a large-sized columnar cactus. It also has tree species such as *Acacia willardiana*, *Olneya tesota*, *Bursera hindsiana*, *B. microphylla*, and *Jatropha cinerea* and *J. cuneata*. Some of the oddest desert plants on the American continent can be found here, like the *Fouquieria columnaris*, which is 20 m tall; *F. splendens*; *F. diguetii*; the giant *Pachycormus discolor* with its smooth brown and orange bark; and *Bursera microphylla*, *B. hindsiana*, *Jatropha cinerea* and *Lysiloma candida*, along with other characteristic plants that are less striking species of *Cylindropuntia* and *Opuntia* (Ezcurra et al. 2002). Some of the tree species have characteristic short thickened trunks, irregularly shaped. This subdivision supports very diverse flora and is rich in endemism, especially those in common with the Baja California Peninsula, such as *Fouquieria columnaris*, *Euphorbia xanti*, and *Stenocereus gummosus*.

The typical plants of Baja California located on the Sonoran coast are relicts of the Ice Age. The hottest and dryer interglacials, such as the present Holocene, gave origin to repeated contractions of the ranges of distribution of these plants, dividing them into smaller and more isolated populations, ideal areas for speciation (Van Devender et al. 2010).

9.2.4 Plains of Sonora

This subdivision covers an extension of about 3 million hectares located in the central part of the state of Sonora and between the coast strip and the mountains of the Sierra Madre Occidental range, at an elevation between 100 and 750 m a.s.l. Shreve (1951) called it the *Olneya–Encelia region*. Its vegetation is defined as arbosufrutescent desert dominated by large trees, such as the *Olneya tesota*, *Prosopis velutina*, and *Parkinsonia microphylla*, aside from numerous types of bushes such as *Encelia farinosa* (Martínez-Yrízar et al. 1999, 2010).

9.2.5 Coastal Thorny Shrubland

Distributed at the southern portion of the Sonoran Desert, this shrubland received its name from Gentry's (1942) "thorn forest", because of the prevalence of *Acacia cochliacantha* (Felger et al. 2001). Also found here are *Bursera fagaroides*, *Forchhammeria watsonii*, *Guaiacum coulteri*, *Haematoxylum brasiletto*, *Havardia sonorae*, and *Jacquinia macrocarpa* subsp. *pungens*. Two of the most representative cactus species are *Pachycereus pecten-aboriginum* and *Stenocereus thurberi*. This last species has a broad range of distribution in the state of Sonora, but the highest population densities are located in the central and southern region. It forms a structurally complex community; with high species richness and extensive woodlands locally referred as "pitayeras".

The Baja Californian flora according to Wiggins (1980) contains 2,958 plant species: 686 are considered endemic throughout the whole peninsula. However, many of these species make up the shrublands or *chaparrales* corresponding to the California Floristic Province and are restricted to the Mediterranean type ecosystems of the northwest of Baja California, which are not part of the deserts of the region. The true diversity of the Peninsular Deserts is at about 2,000 species, with some 550 endemic (Ezcurra et al. 2002). Shreve and Wiggins (1975) described 2,621 plant species; nearly 500 of them are endemic. Both deserts—the Sonoran and The Baja Californian—have a floristic diversity of almost 3,300 species, with a combined grade of endemism for the region of nearly 50% (Ezcurra et al. 2002).

Nason et al. (2002) demonstrated that approximately 5 million years ago, the Baja California Peninsula separated from the continental mass forming the Gulf of California. This had an enormous influence on the genetic structure of the region. The information pertaining to the distribution of the phyletic groups of *Lophocereus schottii* suggests two events of historical vicariance: on one hand, the separation of the Baja California peninsula from the landmass is reflected in the phylogenetic topology of the species, and on the other hand, an event of marine transgression at the middle of the peninsula is reflected on the phyletic distribution of the groups in Baja California.

This study suggests that vicariance events have been decisive to the phylogeographic structure of the plants of the region. Data from this and other species (Clark-Tapia and Molina-Freaner 2003) indicate that aside from the effects caused by the historical variance, the Sonora Desert plants have gone through contraction and expansion cycles (migrations) due to the glacial periods.

9.3 The Chihuahuan Arid Region

The other great Mexican desert is the Chihuahuan Desert, which is located in the northern part of the Mexican Plateau with variable altitudes between 1,000 and 2,000–2,200 m a.s.l. It extends across the states of Chihuahua, Coahuila, Durango,

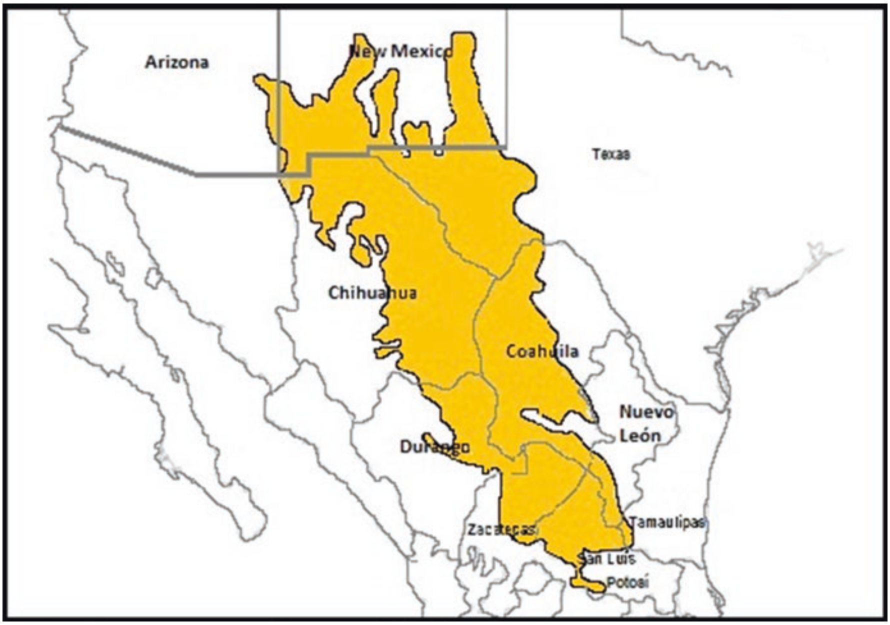

Fig. 9.4 Location of Chihuahuan Desert (Modified from: Bartolomé-Hernández 2015)

Zacatecas, San Luis Potosí, Nuevo León, and Tamaulipas, adjoining the semiarid zone of Hidalgo, extending towards Querétaro, and part of the state of Guanajuato (Fig. 9.4). It is considered to be the largest desert in North America (Cloudsey 1977) and the second with the greatest diversity in the world.

Except for the western part, where igneous material prevails, for the most part, there are sedimentary formations, mainly limestone. There are vast alluvial plains, with deep-, grey-, or light-coloured soils, with sandy or frequently clay-like soils. There are important gypsum outcrops scattered in some parts. The climate is extreme, particularly in the North and Northeast, but to the South there tends to be less seasonal climate difference. Frosts are frequent. Much like the Sonoran zone, the arid Chihuahuan desert has great variations in terms of life forms and plant communities; however, nothing comparable to the first (González-Medrano 2012).

Some of the most representative plant communities are described below:

9.3.1 Alluvial Desertic Shrubland

This community of plants was described by Rzedowski (1956) and later by Huerta-Martínez and García-Moya (2004) as a microphyllous desert scrub. It is a community located in the lower portions of the valleys and basins of the region. It develops in deep soils (<40 cm.); the physiognomy of the vegetation shows a continuum of shrub canopies, mainly of *Larrea tridentata*, which can inhabit up to 100% of the coverage. This type of vegetation has a high incidence of perennial shrubs. The Huizache region in the state of San Luis Potosí has two variations of this type of vegetation: shrubs frequently found in association (1) with *Larrea tridentata* which are *Celtis pallida* and *Koeberlinia spinosa* (Fig. 9.5a) and (2) with *Myrtillocactus geometrizans* on the top stratum, along with *Prosopis* sp. and *Senna wislizeni* (Fig. 9.5b). Other species also present with the two main ones are *Coryphantha* sp., *Echinocereus cinerascens*, *Ferocactus pilosus*, *Glandulicactus uncinatus*, *Jatropha dioica*, *Neolloydia conoidea*, and *Parthenium incanum* (Huerta-Martínez 2002).

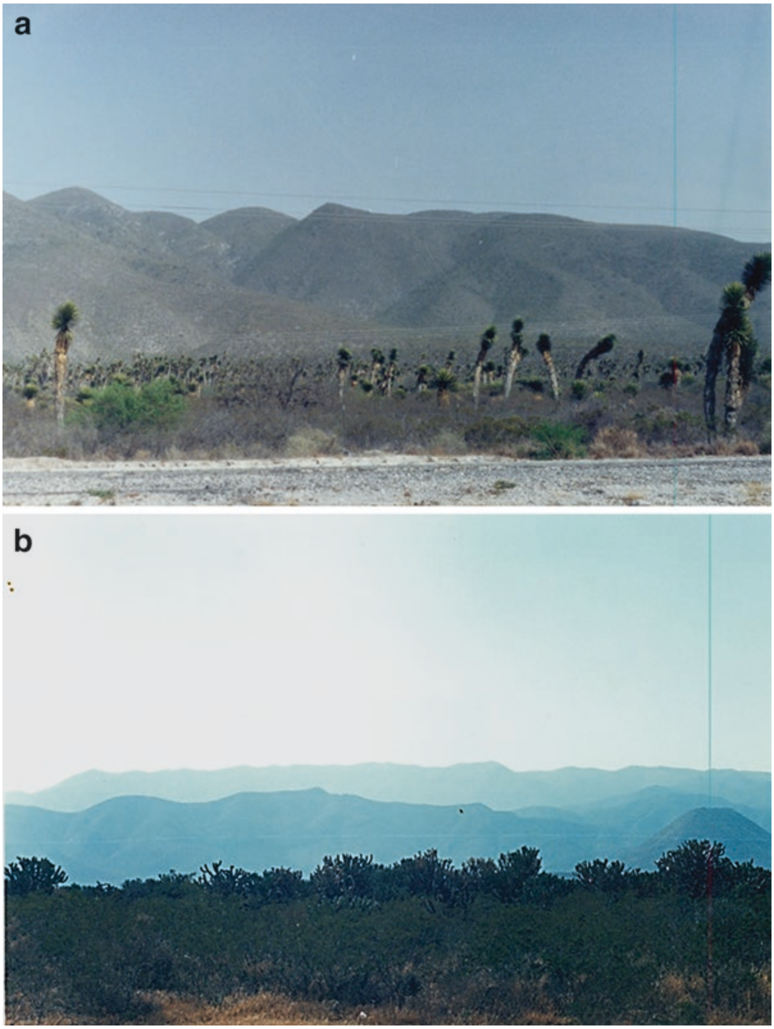

Fig. 9.5 Two variants of alluvial desertic shrubland at the southern portion of Chihuahuan Desert (**a**) with a prevalence of *Yucca filifera* on the top stratum and (**b**) with *Myrtillocactus geometrizans* on the top stratum (Photo: M Huerta)

Fig. 9.6 Calcic desert scrub with prevalence of rosetophyllous species such as *Agave lechuguilla*, *A. striata* and *Hechtia glomerata* (Photo: M. Huerta)

9.3.2 Calcic Desert Scrub

It was named by Rzedowski (1956) and later by Huerta-Martínez and García-Moya (2004) as rosetophyllous shrubland. It is found mainly on the slopes of sedimentary hills and on the top portions of the alluvial fans and in shallow soils with an average depth of 5–8 cm, stony soils, and it is well drained. This type of vegetation has a high wealth of shrub perennial species and a great variety of life forms ranging from 5 m, the tallest of which are represented on the top stratum by *Yucca carnerosana* to globular forms such as *Ferocactus pilosus* and *Echinocactus platyacanthus*. There is, of course, a great number of rosetophils; hence the name among which are *Agave lechuguilla*, *A. striata,* and *Hechtia glomerata* (Fig. 9.6). The shrub stratum is formed by elements from 1 to 3 m high; the species are represented by *Acacia crassifolia*, *Buddleja marrubiifolia*, *Fouquieria splendens*, *Gochnatia hypoleuca*, *Karwinskia humboldtiana*, *Maytenus phyllanthoides*, and *Senna wislizeni.* The vegetative coverage in this type of vegetation can be between 60% and 70%, in which rosetophils are frequently the most conspicuous elements (Huerta-Martínez 2002).

9.3.3 Piedmont Scrub

This vegetation type has special ecological requirements, since it develops in moderately shallow soils with depths of 8–12 cm, with a rock and gravel ratio between 30% and 70%; it is well drained. Generally, it is found below 1,400 m a.s.l. Its physiognomy corresponds to a semi-closed shrubland, generally with a coverage

Fig. 9.7 Piedmont scrub, the shrubs appearing with high dominance, corresponds to *Helietta parvifolia* (Photo: M. Huerta)

of 60%, and the spaces between the brushes is covered by herbaceous vegetation. The dominating strata are formed by high shrubs and low trees that do not exceed 5 m in height: they generally oscillate between 3 and 3.5 m. Trees and shrubs are narrow; the canopy is not very extended. Floristically speaking, they are very homogeneous communities; nevertheless, they present a relatively high richness in perennial shrubs. The most frequent species, which nearly always dominates the landscape, is *Helietta parvifolia*, because of the allelopathic effect on other species (Fig. 9.7). Notwithstanding, frequently we find the following accompanying species, although at a certain distance: *Gochnatia hypoleuca*, *Karwinskia humboldtiana*, *Maytenus phyllanthoides* and *Neopringlea integrifolia*, *Acacia glandulifera*, *Celtis pallida*, *Leucophyllum texanum*, *Mimosa zygophylla*, *Opuntia imbricata*, *O. kleiniae*, and *O. leptocaulis* (Huerta-Martínez 2002).

9.3.4 Gypsophile Grassland

This type of vegetation is poor in plant species. There is a low richness of perennial shrub species found in areas where there are gypsum outcrops, but a prevalence of Gramineae, particularly *Bouteloua chaseii* and *Muhlenbergia purpusii*. The grassland has a homogeneous appearance covering vast extensions, only interrupted by patches; these patches have land subsidence and alluvian fillings (Fig. 9.8), *Yucca filifera* and *Prosopis* sp. are the dominant species. The brush stratum is characterized by *Agave scabra*, *Calliandra eriophylla*, *Dalea filiciformis, Mimosa zygophylla*, *Opuntia* spp., *Cylindropuntia imbricata*, and *C. leptocaulis* (Huerta-Martínez 2002) (Table 9.2).

Fig. 9.8 Gypsophile grassland with dominance of *Bouteloua chaseii*, *Yucca filifera*, and other shrubs in areas with gypsum outcrops (Photo: M Huerta)

Case Study: Vegetation Classification at El Huizache, San Luis Potosí, México (Southern Part of the Chihuahuan Desert)

A classification analysis performed using TWINSPAN, with abundance data on perennial vegetation species, formed seven groups of sites (Fig. 9.9). The first division formed two groups: on the one part, sites 11, 13, 27, 33, 38, 45, 46, 47, 48, 49, and 50, the indicating species for these sites was *Larrea tridentata*. The rest of the sites—located in the upper portion of the diagram—showed *Karwinskia humboldtiana* as the indicating species. In the second division, in the second classification level, the group was formed with sites 7, 8, 9, 10, 26, 34, 35, 36, 37, 39, 40, 41, and 42; the differentiating species was *Neopringlea integrifolia* and *Agave lechuguilla* for the rest of the sites. The third division, also in the second level of classification, groups sites 11 and 13 with *Cylindropuntia imbricata* as the differentiating species and the other group with *Jatropha dioica* as the indicating species. The fourth division, in the third level of classification, groups sites 9, 10, and 26 represented by *Dalea bicolor* and the group represented by *Helietta parvifolia* as the indicating species. In the fifth division, in the third level of classification, *Hechtia glomerata* stands out as the differential species for the group formed by sites 2, 3, 4, 5, 6, 12, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 29, 30, 43, and 44. The other group at this level is formed by sites 1, 16, 28, 31, and 32, which were represented by *Acacia berlandieri*. The sixth division, in the third level of classification, separates sites 47 and 49, with *Prosopis* sp. as differential species from sites 27, 33, 38, 45, 46, 48, and 50; these last ones were represented by *Krameria ramosissima*.

Table 9.2 Two-way matrix performed using TWINSPAN in site classification (upper portion) and species (left side) which conform plant communities at El Huizache, San Luis Potosí. Numbers inside corresponds to cut levels of pseudospecies values (abundance categories) at a given site. Site number must be read vertically

	12 33333444 1111112222222344 123323344454411	
	90678456790122345624578901234590341681273856807913	
Karwinskya humboltiana	3223232322232122225242323-22222-2222-1------------	000
Agave lecheguilla	22----2--2222452-12422-22-222322212-------------22	000
Opuntia stenopetala	22212-2222122223222222212122-2112-2----2-2------1-	000
Hechtia glomerata	222444--24414533223423422223244542--2----3------4-	000
Salvia ballotaeflora	122122-1-122------223222222-122-22-2-----1--------	000
Calliandra eriophylla	-1-45--23--1222-----222--1-22---2211-----2--------	000
Krameria cytisoides	232--23----2----32---1---2-----123-2332-----------	000
Flourensia sp.	112------122-2---22--1--------------1-------------	000
Calliandra sp.	-----2--3-2-2-----------------2-------------------	000
Astrophytum myriostigma	-1------1-----------1-------------1---------------	000
Euphorbia antysiphylitica	2-1----------1----1-----2-----------1-------------	000
Mammillaria candida	-1-11-------1--1-11---------1---------------------	000
Agave striata	333-------23----445--22-----2-22------------------	000
Fouquieria splendens	-----------52--------3-66-----3-----2-------------	000
Gochnatia hypoleuca	333----53--1------2--1-22-------------------------	000
Acacia berlandieri	----22422--------------------------2232-----------	000
Dalea bicolor	222-----------------1-----1-2------2--------------	000
Neopringlea integrifolia	---32-2222234-------------------------------------	000
Parthenium incanum	----2---------------------2-1---------------------	000
Gymnosperma glutinosum	11-----------------------------2------------------	000
Ageratina sp.	222---	000
Dasylirion achrotrichum	-2--------------------------2---------------------	000
Penstemon reseus	-1--	000
Opuntia phaeacantha	--------2---	000
Echinocactus platyacanthus	-2112--------221121212222122-11-111-221---------11	001
Stenocactus dichroacanthus	----------------------------------11-1------------	001
Ferocactus pilosus	-----------1---1-1--------11------1---------------	001
Baccharis sp.	--------------4-5-2-------------------------------	001
Mimosa sp.	--------------2-----2-------2---------------------	001
Caesalpinia pringlei	-21-----------22--232-----32222-------------------	001
Acacia glandulifera	----------------23-------------2----2-------------	001
Prosopis sp.	--------------------2--23----------1--------------	001
Acacia crassifolia	-----------2---------3-222------------------------	001
Lippia berlandierii	---------2-----------21-1-----1-1-----------------	001
Mimosa zygophylla	---------2222--------34434----2222----------------	001
Celtis sp.	-----------------------2-2----------221-----------	001
Salvia sp	--------------------------3-----------------------	001
Maytenus phyllantoides	-------------------------------2------------------	001
Jatropha dioica	1-1------22--12322-22222242212222322221232--22----	011
Echinocereus pectinatus	-------------11----1--------------11--1-1---------	011
Neolloydia conoidea	---1---------------2----1--1-1----11----------1---	011
Koeberlinea espinosa	---------------2-------1------1-221-223-------2-2-	011
Budleia marrubifolia	-----2-------222---1-1-1--2221--1--2-1131---------	011
Opuntia sp	----1--------11----------------------2--1---------	011
Mammillaria sp2	11-1--1--------2---1------11-111---1111---------2-	011
Krameria ramossisima	1-2--2-----22-----1--1232-32222222--3222-32--2----	011
Verbesina sp.	-------------------12-----2-1--1---2---1----------	011
Celtis pallida	---------------2--------------------22----------3-	100
Mammillaris sp4	----------------------------1-------------------1-	100
Condalia mexicana	------------------2-2-2------------1------------4-	100
Mammillaria bocasana	------1---1---------------------1-----------------	100
Bursera fagaroides	---------------1-----------1----------------------	100
Thelocactus hexaedrophorus	-------1----------------------1----1-1------------	100
Opuntia sp.4	-------------------1----------------1-----------1-	100
Lophophora williamsii	-----------------------------------2------1-------	100
Lecophyllum texanum	--------------------------------------3---2-------	100
Ariocarpus trigonus	-----------------------------------2--------------	100
Homalocephala texensis	--1-------	100
Larrea tridentata	-------------3-3--24134443122213322133254565555556	101
Cylindropuntia kleineae	---------------2---------------1-21-2212122-122223	101
Agave scabra	------1-2---------------1-11------2--222--3-22-2--	101
Glandulicactus uncinatus	-----1---1------------------------1--1-2-11----12-	101
Yucca filifera	-----2----------------------------2--123--1---3---	101
Cylindropuntia imbricata	----1----2----------1---------------2---222-2221--	101
Crhysactinia mexicana	1-1-------------------------1-----2----1---2------	101
Prosopis sp.	-------------------3-----------3-----4--------444-	101
Opuntia microdasys	---12-----32	101
Opuntia lindeimerii	---1	101
Myrtillocactus geometrizans	---------------------------------1---------------3	101
Mammillaria sp 3	---------------------------------------1----------	101
Opuntia cantabrigensis	---------------------------------------2----------	101
Opuntia rastrera	--1-------	101
	00000000000000000000000000000000000000011111111111	
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	000111111111100000000000000000000011111000000011	

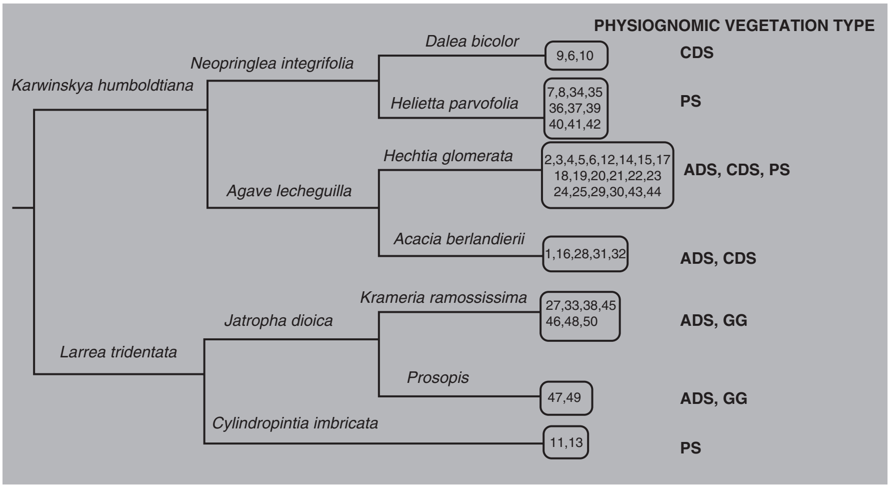

Fig. 9.9 Vegetation classification using TWINSPAN with species abundance data. *CDS* calcic desert scrub, *PS* piedmont scrub, *ADS* alluvial desertic shrubland, *GG* gypsum grassland

According to Medellin (1982), the history of the Chihuahuan Desert includes at least six stages:

1. Colonization of the Chihuahua Desert, which must have occurred with floristic elements previously adapted to a certain degree of aridity, such as the genus *Acacia*, *Aristida*, *Artemisia*, *Atriplex*, *Senna* [*Cassia*], *Dodonaea*, *Ephedra*, *Frankenia*, *Jatropha*, *Lycium*, *Menodora*, *Mimosa*, *Notholaena*, *Peganum*, *Solanum*, *Suaeda*, etc., currently represented by one or several species of all the types of vegetation.
2. Development of paleoendemism is shared by dry areas of North America, among them are *Fouquieria* and *Mortonia*, with several species and monotypic genus such as *Adolphia*, *Chilopsis, Holacantha, Lindleyella* and *Orthosphenia.* Furthermore, the development of the desert grasslands must have started with a whole vegetation endemism, represented by the gypsophile grassland, apparently exclusive of the Chihuahua Desert (González-Medrano 1996).
3. The initial connection to the southern portion of the American continent during the Tertiary period allowed for a first contribution of Neotropical elements adapted to the aridity: *Castela*, *Condalia*, *Flourensia*, *Franseria*, *Gutierrezia*, *Larrea*, *Prosopis* and *Sanvitalia.*
4. Occupation of the marine sedimentary hills or of those constituted by limestone by elements of Neotropical origin. Initially not very well adapted to the aridity, yet with certain previous adaptation to a relative lack of water, such as *Agave*, *Echeveria*, *Hechtia* and *Yucca*.
5. Lava effusion already consolidated by mesophile elements, which gradually adapted to drought conditions. Such elements, also of Neotropical origin, gave

way to a great amount of neoendemisms; among them are some representatives of the crassicaule brush, such as the *Agave*, *Bursera*, *Hechtia*, *Opuntia* and other cactus genera.
6. South American contribution of the mountain flora, specially composed of *Baccharis*, *Brickellia*, and *Zinnia*, which could have given the final touch to all local vegetation types.

9.4 The Tamaulipan Semiarid Region

This zone covers central and northeast of Tamaulipas, north of Nuevo Leon and the northeast of Coahuila. Some of the most characteristic vegetation communities are described below.

9.4.1 The Sclerophyllous Brush or Chaparral

This plant community has received different names from different authors: Rzedowski (1961) called it oak scrub *chaparral*; Rojas-Mendoza (1965) called it sclerophyllous subperennifolio shrubland with *Quercus*, *Cercocarpus* and *Cowania*. They are distributed at different elevations, from 1,850–1,900 m to 2,880 m a.s.l. The best example is found in the municipalities of Tula, Palmillas, Jaumave and Gómez Farías. In the higher parts of the San Marcos River Basin in the municipality of Ciudad Victoria, there are small patches of this vegetation in the state of Nuevo León and Coahuila; it is well represented.

The physiognomy of this community displays differences according to the substrate where it grows; when it is established on igneous material, it reaches a larger size than when it is on limestone substrate, reaching the height of a tall shrub. There is a structurally differentiated set of shrubs of less than 1 m high and another one of annual or perennial herbs poorly represented. In most cases, the community is evergreen, but if it drops leaves, it is for very short periods of time. The chaparrales located on the igneous substrate have less species than those on limestone. In both cases, it is frequent to see that communities develop with a dominance of one or two species, generally an oak, or sometimes some *Ericaceae*, such as *Arctostaphylos pungens* (González-Medrano 2012).

Shrubs growing on igneous material are less frequent than those growing on sedimentary material. Some of the shrub species growing on igneous material—considering tall shrubs and small trees—are *Quercus potosina*, *Quercus crassifolia*, *Quercus eduardii*, *Rhus pachyrrhachis*, *Garrya ovata*, *Cercocarpus* sp., *Fraxinus greggii*, *Arctostaphylos pungens* and *Arbutus xalapensis*.

Among the short shrubs are *Abelia coriacea*, *Arctostaphylos polifolia*, *Ceanothus greggii*, *Dalea tuberculata*, *Stevia lucida*, and *Eupatorium calaminthaefolium*.

Shrublands growing on limestone substrate tend to be shorter, less developed, and very rich in species. Among the most frequently found shrub species are *Amelanchier denticulata*, *Bauhinia coulteri*, *Berberis gracilis*, *Colubrina greggii*, *Casimiroa pringlei*, *Cercocarpus mojadensis*, *Cercocarpus* sp., *Lindleya mespiloides*, *Forestiera rotundifolia*, *Senna wislizeni*, *Mimosa leucaenoides*, *Myrtus ehrenbergii*, *Eysenhardtia polystachya*, *Sophora secundiflora*, *Vauquelinia karwinskii*, *Vauquelinia latifolia* and *Yucca carnerosana*. Some of the most common subshrubs are *Bauhinia ramosissima*, *Bouvardia ternifolia*, *Hesperozygis marifolia*, *Pithecellobium*, *Gymnosperma glutinosum*, *Eupatorium espinosarum* and *Chrysactinia mexicana* (González-Medrano 2012).

In the rosetophyllous desert shrub of Tamaulipas, the substrate on which it grows has no influence on the richness diversity and cover. However, the floristic composition does present a difference derived from the two types of soils. Density is also significantly higher on limestone soil (Alanís-Rodríguez et al. 2015).

9.4.2 Subinerm Tall Matorral

This type of vegetation has been recognized as submontane matorral. It is found at variable elevations starting 300 m on the low hills of the northeastern Coastal Plains, till up to close to 1,800 m in the downwind regions of the Sierra Madre Oriental range. In physiognomic terms, they form dense communities of shrubs, and the canopies are frequently intertwined. Nevertheless, occasionally in dryer places, its physiognomy changes and becomes less exuberant. Sometimes among the community emerge plants belonging to the genera *Yucca*, *Nolina* and *Dasylirion*.

About the structure of this vegetation type, highlights a formation of 2 m high shrubland, sometimes having individuals that can reach up to 4 and 5 m high. A subordinated formation to this is the subshrub 1 m or less tall, in which herbaceous and graminoides intermix. Floristically, these shrublands can be very rich. Because of the floristic composition, several associations can be distinguished. In rocky soil, with steep slopes and limestone soils, some of the bushes can reach more than 2 m high: *Helietta parvifolia*, *Prosopis juliflora*, *Acacia rigidula*, *Acacia berlandieri*, *Gochnatia hypoleuca*, *Bernardia myricifolia*, *Amyris madrensis*, *Amyris texana*, *Celtis pallida*, *Cordia boissieri*, *Cercidium macrum*, *Yucca filifera, Fraxinus greggii* and *Pithecellobium pallens*.

Shrubs range from less than 1 m to more than 2 m tall, belonging to the following species, among others: *Leucophyllum frutescens*, *Porlieria angustifolia*, *Karwinskia humboldtiana*, *Krameria ramosissima*, *Forestiera angustifolia*, *Citharexylum brachyanthum*, *Castela tortuosa*, *Croton cortesianus*, *Lippia alba*, *Turnera diffusa*, *Opuntia leptocaulis* and *Zanthoxylum fagara*. Given the diversity in environments and heights where this shrubland grows, it has some variations, for example, on low hills with igneous material; aside from the tall shrubs which give this community its physiognomy, cacti in the form of candlesticks intersperse with it, and among them are *Stenocereus griseus*, *Cephalocereus palmeri* and even *Myrtillocactus geometrizans*.

9.4.3 Tamaulipan Thorny Shrubland

This name designates one of the most characteristic vegetation communities of the northeast of Mexico, since it covers part of the central east of Coahuila, the adjoining region of Nuevo Leon and the lower parts of the Central Plateau, the north and northeast of Tamaulipas, as well as the south-south-east of Texas. Muller (1947) refers to it as a vegetation community that grows in the central east part of Coahuila. He called it the Tamaulipan thorn shrubland, and some of its most characteristic species are *Acacia rigidula* (*Acacia amentacea*), *Amyris texana*, *Leucophyllum frutescens*, *Cercidium floridum*, *Castela texana*, *Colubrina texensis*, *Porlieria angustifolia*, *Achaefferia angustifolia* and *Zanthoxylum fagara*. In some areas with deeper soils and greater availability of humidity, it develops a dense community with trees of *Prosopis*, *Celtis*, *Cercidium*, *Parkinsonia* and *Bumelia* genera as well as *Cercidium praecox* and *Pithecellobium ebano*, giving the appearance of a lowland forest, which was called Tamaulipan thorn forest that corresponds to the *mezquitales*. Some of the most characteristic species are *Acacia rigidula*, *Acacia berlandieri*, *Leucophyllum frutescens*, *Porlieria angustifolia*, *Karwinskia humboldtiana*, *Prosopis glandulosa*, *Prosopis reptans* var. *cinerascens*, *Cordia boissieri*, *Schaefferia cuneifolia*, *Cercidium floridum*, *Lippia ligustrina*, *Parkinsonia aculeata*, *Castela tortuosa*, *Colubrina texensis* and *Zanthoxylum fagara*.

Another group of frequent species of the Tamaulipan thorn forest are *Celtis pallida*, *Opuntia lindheimeri*, *Opuntia leptocaulis*, *Opuntia imbricata*, *Condalia lycioides*, *Echinocereus cinerascens*, *Jatropha dioica*, *Koeberlinia spinosa*, *Agave lechuguilla*, *Microrhamnus ericoides*, *Lycium berlandieri*, *Eysenhardtia texana*, *Sophora secundiflora*, *Bernardia myricifolia*, *Condalia obovata*, *Sideroxylon lanuginosum*, *Diospyros texana*, *Forestiera angustifolia*, *Citharexylum berlandieri*, *Salvia ballotaeflora*, *Leucophyllum minus*, *Viguiera stenoloba*, *Yucca treculeana*, *Yucca filifera* and *Manfreda* sp.

9.5 The Hidalgo Semiarid Region

Covering part of the states of México, Hidalgo and Querétaro and neighbouring places, it is located in the intermountain valleys and ravines. The cause of aridity in this region is its downwind position from the Sierra Madre Oriental mountain range. The differences in the physiognomy have influenced the vegetation. The presence of water streams in the valley (permanent or intermittent) makes the aridity conditions less harsh, diversifying the environmental conditions; hence, the plant communities established there (González-Medrano 2012). They are described below.

9.5.1 Tall Thorny Scrub

This vegetation community grows in greater aridity conditions. It is present in the Tolimán, Vizarrón and Cadereyta valleys in Querétaro. *Larrea divaricata* associates with *Prosopis laevigata*, *Opuntia imbricata*, *Celtis pallida*, *Karwinskia humboldtiana*, *Fouquieria splendens*, *Acacia farnesiana* and *Lophophora diffusa* and are the most representative species there.

In this plant community, it is common to find the multi-branched cacti: *Stenocereus dumortieri* and *Myrtillocactus geometrizans*. The Mezquital Valley is formed by the Actopan, Ixmiquilpan and Zimapán valleys. It represents the characteristic landscape of the arid zone of Hidalgo. The physiognomy is very varied: in the lower parts of the valleys, with deep alluvial soils, with thorny shrubs, such as *Prosopis* spp., *Acacia* spp., and *Mimosa* spp., and frequently with individuals of *Yucca filifera.*

In the limestone hills, rosetophyllous shrublands grow similar to the ones located at the north, in which *Agave lechuguilla*, *Agave striata* and *Hechtia podantha* are the most common elements. The prominent globular cacti—*Echinocactus grandis*—are also outstanding elements of these landscapes. In terms of flora, these shrubs are very rich. In igneous lands the dominating vegetation is crasicaule shrub, dominated by *Opuntia streptacantha* or by *Opuntia leucotricha*, frequently with large individuals of *Myrtillocactus geometrizans* and *Stenocereus dumortieri*.

The shrub strata is represented by *Prosopis laevigata*, *Acacia tortuosa*, *Hesperothamnus ehrenbergii*, *Tephrosia tenella*, *Karwinskia mollis*, *Acacia farnesiana*, *Bursera fagaroides*, *Cassia wislizeni*, *Leucophyllum ambiguum*, *Calliandra oaxacana*, *Neopringlea integrifolia*, *Phyllanthus* sp., *Croton rzedowskii*, *Artemisia mexicana*, *Celtis pallida*, *Tecoma stans*, *Cnidoscolus* sp. and *Calliandra biflora*. In addition to those above mentioned, the most common Cactaceae are *Opuntia imbricata*, *O. tomentosa*, *O. cantabrigiensis*, *O. streptacantha*, *O. robusta*, *Echinocereus ehrenbergii*, *Ferocactus histrix* and *Dolichothele longimamma*. The most common shrubs and trees are *Tecoma stans*, *Neopringlea integrifolia*, *Perymenium subsquarrosum*, *Stachytarpheta acuminata*, *Euphorbia antisyphilitica*, *Polyaster boronoides*, *Cassia wislizeni*, *Bursera morelensis*, *Ipomoea wolcottiana*, *Senecio salignus* and *Karwinskia mollis*.

9.5.2 Rosetophyllous Thorny Scrub

This type of vegetation is characteristic of the limestone hills located in the Mezquital Valley. They are found at an elevation of approximately 1,900 m, with an annual rainfall of 556 mm and a mean annual temperature of 17 °C. The plant community is dominated by *Agave lechuguilla*, *A. striata*, *Flourensia resinosa* and *Machaonia coulteri*. There is a group of low shrubs (less than 2.5 m), among which are *Berberis ilicina*, *Bouvardia ternifolia*, *Bursera schlechtendalii*, *Condalia mexicana*, *C. oleinum*, *Dasylirion acrotriche*, *Decatropis bicolor*, *Eysenhardtia polystachya*, *Flourensia resinosa*, *Forestiera angustifolia*, *Fouquieria campanulata*, *Fraxinus greggii*, *Gochnatia hypoleuca*, *Leucophyllum ambiguum*, *Mimosa biuncifera*, *Montanoa tomentosa*, *Mortonia hidalguensis* and *Zanthoxylum affine*.

The sub-shrubby and herbaceous perennial strata are formed by *Agave lechuguilla*, *A. striata*, *Chrysactinia mexicana*, *Croton dioicus*, *C. ehrenbergii*, *Dalea dorycnoides*, *Dalea filiformis*, *Echinocactus ingens*, *Ephedra aspera*, *Eupatorium espinosarum*, *E. scordioides*, *Haplopappus venetus*, *Hechtia scariosa*, *Jatropha dioica*, *Koeberlinia spinosa*, *Lippia graveolens*, *Parthenium incanum*, *Pithecellobium revolutum*, *Opuntia microdasys*, *O. stenopetala*, *Rhus microphylla* and *Salvia coulteri*.

9.6 The Poblano–Oaxaca Semiarid Region

The semiarid Poblano–Oaxaca zone stretches throughout part of the east, southeast, and south of the state of Puebla, as well as parts of the northeast of Oaxaca (Fig. 9.10). The plant communities of the valley are varied and complex. Valiente-Banuet et al. (2000), described 29 distinct vegetation associations, ranging from the *mezquitales* found in river basins to the varied and complex columnar Cactaceae forests broadly distributed in the region, as well as the tropical deciduous forest located in the most humid part, and the temperate vegetation (Chaparral) in the upper part of the valley (Valiente-Banuet et al. 1998). This small and semi-isolated valley is a complex plant mosaic, which has developed in a region with a great biotic diversity and a great ratio of endemism (Davila et al. 2002). The vascular flora of the Tehuacán–Cuicatlán Valley contains 180 families, 891 genus, and 2,621 species (Dávila et al. 1993).

The gymnosperm group is represented in the valley by nine species, in five genera included in four families. Different species of *Pinus* dominate in the upper part of the valley, generally at 2,000 m and above. In the transition zones, between xerophytic vegetation and the pine or pine oak forests, the *Juniperus, Ephedra* and *Dioon* are characteristic elements of the region; this last genus has three endemic species: *Dioon califanoi*, *D. caputoi* and *D. rzedowskii* (Dávila et al. 1993).

Angiosperms are the plant-dominating group in the region. A total of 33 families have been recorded, with 183 genera and 509 species of monocotyledonous plants, among which are the Poaceae, Bromeliaceae, Agavaceae and Orchidaceae families; some of the most diverse genera are *Muhlenbergia*, *Hechtia*, *Agave*, *Yucca*, *Beaucarnea* and *Nolina* and *Encyclia* (Dávila et al. 1993).

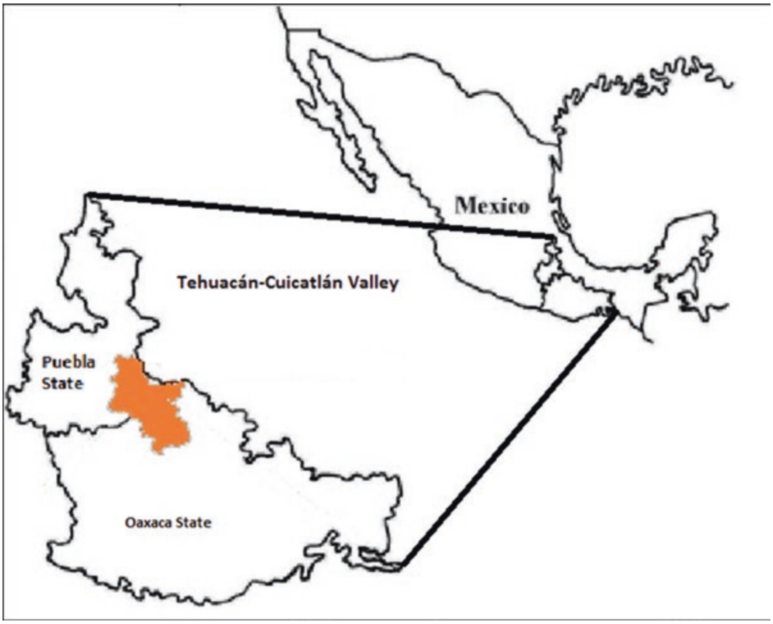

Fig. 9.10 Location of the Poblano–Oaxaca semiarid region (self-elaboration)

Furthermore, a total of 128 families, 679 genera, and 2012 species of dicotyledonous plants have been recorded in the Tehuacán–Cuicatlán Valley; some of the most important families are Cactaceae, Fabaceae and Asteraceae, and in these families there are very important genera such as *Opuntia*, *Neobuxbaumia*, *Acacia*, *Mimosa*, *Viguiera* and *Verbesina.* Currently, there are at least 318 endemisms recorded in 180 genera (Dávila et al. 1993). The Tehuacán–Cuicatlán Valley holds about 10% of the plant diversity in Mexico in an approximate area of 10,000 km^2 (Davila et al. 2002).

In contrast to the regions mentioned above, in this one, the shrub and arborescent elements are mainly deciduous; the *tetecheras* are much more common in the shallow ravines surrounding the Tehuacan Valley; they are plant communities dominated by *Neobuxbaumia tetetzo*, an unbranched cacti known as *tetecho*, and it is endemic of the Tehuacan region and its surroundings. Highlights due to its thickened stalks towards the base, and its terminal leaf rosette: *Beaucarnea gracilis*. The *Bursera* genus and *Brahea dulcis* are abundant, in particular, towards the Sierra Mixteca. It represents a great economic interest since it is used in hat manufacturing (González-Medrano 2012). These *tetecheras*, or tall thorny crasicaule shrublands, are floristically rich. Some of the most important species in this community are *Mimosa luisana, Agave karwinskii, A. marmorata, Neobuxbaumia tetetzo, Bursera aloexylon*, *Cordia curassavica, Fouquieria formosa, Calliandra eriophylla, Ipomoea arborescens, Caesalpinia melanadenia, Ferocactus flavovi-*

rens, Karwinskia humboldtiana, Castela tortuosa, Acacia coulteri, Iresine calea, Coryphantha pallida, Malpighia mexicana, Bursera fagaroides, Echinocactus platyacanthus, Ferocactus recurvus and *Myrtillocactus geometrizans* var. *grandiaerolatus* (Osorio et al. 1996). In Zapotitlán de las Salinas, Puebla, the plant species forming the thorny shrublands with terminal spines are *Mimosa luisana, Cordia curassavica, Agave karwinski, Mammillaria carnea, Caesalpinia melanadenia, Cercidium praecox, Bursera aloexylon, Ipomoea arborescens, Opuntia filifera, Ferocactus flavovirens, Karwinskia humboldtiana, Fouquieria formosa, Cnidoscolus tehuacanensis, Castela tortuosa* and *Agave marmorata* (Osorio-Beristain et al. 1996).

Aside from the floristic richness, the endemism ratio is an important feature of the region: from the 180 families present, 76 have at least one endemic species. Three species of the Cycadaceae family, mentioned above, from the *Dioon* genus are endemic to the valley. In total 74 angiosperm families have at least one endemic species (15 monocotyledonous and 59 dicotyledonous). Among the monocotyledonous, families which have three or more endemic species are Agavaceae (5 species), Cyperaceae (5 species), Iridaceae (4 species) and Bromeliaceae (13 species). Among the dicotyledonous, families which have 10 or more endemic species are Asclepiadaceae (10 species), Leguminosae (11 species), Acanthaceae (13 species), Lamiaceae (18 species), Crassulaceae (25 species) and Cactaceae (28 species) (Davila et al. 2002).

At the genus level, seven of them are endemic for the valley, and most are monotypical: *Gypsacanthus* (Acanthaceae), *Oaxacania* (Asteraceae), *Escontria* (Cactaceae), *Mitrocereus* (Cactaceae), *Polaskia* (Cactaceae), *Fosteria* (Iridaceae) and *Gibasoides* (Commelinaceae). Furthermore, there are 205 genera (about 23% of the total present in the area) with at least one endemic species. Genera with three or more endemic species are *Tillandsia* (3 species), *Schoenocaulon* (4), *Agave* (5), *Hechtia* (10) *Phoradendron* (3), *Acacia* (3), *Polygala* (3) *Matelea* (5), *Acourtia* (5), *Perymenium* (5), *Verbesina* (5), *Euphorbia* (5), *Jatropha* (5), *Dalea* (6), *Viguiera* (6), *Sedum* (8), *Quercus* (9), *Mammillaria* (11), *Salvia* (13) and *Echeveria* (14 species). At a species level, at least 365 endemic vascular species have been recorded for the Tehuacán–Cuicatlán Valley; in other words, approximately 13.9% of the vascular flora known to the Valley is endemic (Davila et al. 2002).

According to the species stated above, each region has its characteristic species; some of them are shared in two or more regions, but most of them are representatives for its own region; it leads to a great variety of species, and if we could make a similarity analysis using qualitative data for species in the six regions, we could see that even when all are arid or semiarid lands, the percentage of similarity always is below than 36 % (0.36), corresponding to Chihuahuan Desert Region and Tamaulipan Desert Region being the two most similar; on the other hand, Sonora and Baja California Desert are the regions with less similarity of all (less than 0.10) (Fig. 9.11).

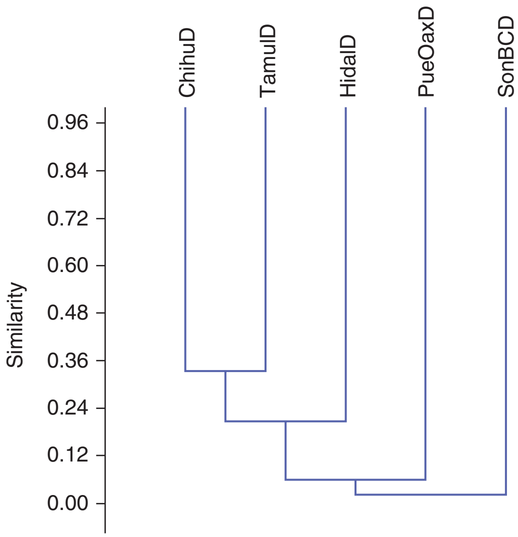

Fig. 9.11 Similarity analysis using presence/absence data of characteristic species in each region of the arid and semiarid region of Mexico (self-elaboration)

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Chapter 10
Plant–Environment Relationships in Mexican Arid and Semiarid Regions

Abstract Biotic interactions may shape deeply the structure of ecological communities and ecosystem functioning since species are interconnected in a direct and indirect manner through a complex web of interactions. Species are usually engaged in antagonistic or mutualistic networks. Two of the most studied plant–plant interactions are competition and facilitation which represent in turn negative and positive interactions; both have been described as drivers in arid and semiarid vegetation structure. In addition, plant–animal interactions such as pollination and seed dispersal (frugivory) have been described as responsible for distribution patterns of many plant species especially in desert ecosystems, such as Cactaceae species. Abiotic interactions are not less important, limited water supply has driven plants to a habitat specialization evolution, physical and chemical soil properties play a determinant role explaining plant distribution, plants influence soil at a local scale, and soil influences vegetation at landscape scale. Three environmental gradients have been detected as the factors influencing vegetation at El Huizache, San Luis Potosí, landscape characteristics (recognized as the most important group of variables), climate, and soil. Among plant species living in arid and semiarid regions of Mexico, Cactaceae family is the most emblematic group; this group of species has a great number of endemic; for this reason, it is considered as a priority in terms of biological conservation; in Mexico, this group has several risks such as over-exploitation, changes in land use, fragmentation of habitats, and the reduction in the populations causing many species to become extinct.

10.1 Biotic Interactions

All living organisms interact with other species through a wide variety of mechanisms. These interactions may shape deeply the structure of ecological communities and ecosystem functioning since species are interconnected in a direct and indirect manner through a complex web of interactions (Paine 1966). The impacts that affect one species may be passed directly or indirectly to other components of the system, and these impacts may even be of a different sign (effect) or intensity (Holbrook and Schmitt 2004). Due to the above, studying populations in an isolated or separate manner is not considered a proper approach (Roughgarden and Diamond 1986). Natural phenomena varied as mimicry, the presence of secondary compounds in plants,

M.M. Abd El-Ghani et al., *Plant Responses to Hyperarid Desert Environments*,
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symbiosis, resource allocation, pollination, and seed dispersal cannot be discussed without making reference to biotic interactions. Every species uses resources and space used by other species as well, thus resulting in competition. The majority of species are attacked by parasites and pathogens (negative interactions), and many other species are engaged in mutualisms (positive interactions); therefore, interactions between populations must be considered always as important, even in studies where the main objective is single populations (Huerta-Martínez 2002).

Species are usually engaged in antagonistic or mutualistic networks; that is why understanding the structure and functioning of these networks has drawn significant attention (Eklöf et al. 2013). Destinations of interacting species are not independent one from the other; therefore, the removal of a keystone species may in turn cause secondary removal of other species in ecological communities (Memmott et al. 2004; Kaiser-Bunbury et al. 2010). Despite the above, the importance of biotic interactions in the distribution of species at a wide scale has been dismissed (Wisz et al. 2013).

10.1.1 Plant–Plant Interactions

Competition within plant communities in arid and semiarid regions is evident. Such competition may include many species, and furthermore, in many occasions, it seems to be crucial to determine the structure of communities (Fowler 1986) due to the fact that such competition interaction may cause the absence, presence, or modifies the abundance of certain species in a community and consequently their spatial distribution.

The point of view which states that competition determines the structure, dynamics and productivity of communities has prevailed over the last five decades. Authors like Tilman (1982), Goldberg and Barton (1992) and Flores and Yeaton (2003) have gathered important evidence that supports the notion that competition relations are a driving force in the regulation of community dynamics. In the Chihuahuan Desert, *Larrea tridentata* individuals are located at almost regular intervals between each other which is likely the result of a strong competition for water in this environment, resulting in a greater dominance by this species, which in Mexico is known as *gobernadora* (female for governor—he who rules*) because it controls or "governs" the establishment of other species in the interspaces and in the microphyllous desert scrub.

Nevertheless, during the last decades, data has been collected on the involvement of positive interactions or facilitation processes as phenomena that have an influence on the distribution of plants, their diversity and their reproduction (Hunter and Aarssen 1988). It is believed that facilitation and competition interactions are of the utmost importance in arid and semiarid areas (Whitford 2002). But only few studies have assessed how the changes on abiotic conditions modify the importance regarding facilitation and competition in these environments (Pugnaire and Luque 2001; Maestre et al. 2003).

Positive interactions between plant species are widely distributed among natural communities and have been recognized as the main guideline in ecosystem processes (Bruno et al. 2003). McAuliffe (1986) found that in the Sonora Desert, the seedlings

Fig. 10.1 *Ferocactus pilosus* growing under *Prosopis* canopy (Photo: M. Huerta)

of *Cercidium microphyllum* grow preferably under the canopy of *Ambrosia* sp. Similarly, Franco and Nobel (1988) and Valiente-Banuet and Ezcurra (1991) found that some species from dry areas, usually cacti, required the presence of a nurse plant to facilitate their establishment. The same phenomenon is observed in the Chihuahuan Desert, where cacti like *Ferocactus pilosus* are established under canopies of *Prosopis* sp. and *Acacia* sp. and species like *Astrophytum myriostigma* under the canopy of *Larrea tridentata* (Figs. 10.1 and 10.2).

This nurse plant alters substantially the conditions of the physical medium. For instance, soil temperatures are kept lower, while withering is reduced as well as the risk of predation under the canopy of the nurse plant (McAuliffe 1986). The substrate modification process due to the presence of the nurse plant was described for the first time by García-Moya and McKell (1970) and called it "islands of fertility". Since then, numerous descriptions of the process as well as experimental studies on the structures and functions of these islands have been produced. For example, Valiente-Banuet (1991) documented the effect of the nurse plant on plant establishment in the Sonora Desert where the seedling of *Larrea tridentata* specifically establishes under the canopy of *Ambrosia dumosa* scrubs. Similarly, the seedlings of *Carnegiea gigantea* establish mainly under *Cercidium microphyllum* (Flores-Martínez et al. 1994; Medeiros and Drezner 2012). In the Tehuacán Valley, the specific associations of three globular cacti have been observed—*Mammillaria collina*, *M. casoi* and *Coryphantha pallida*—as well as of two giant columnar cacti (*Neobuxbaumia tetetzo* and *Cephalocereus hoppendstedtii*) (Valiente-Banuet et al. 1991). A similar phenomenon was described by Escobar-Santos and Huerta-Martínez (1999), in the region of Los Llanos de Ojuelos, Jalisco, confirming that *Ferocactus histrix* shows an association with different species and rocks which may act as nurses (Fig. 10.3).

Fig. 10.2 *Astrophytum myriostigma* growing under *Larrea* canopy (Photo: M. Huerta)

Fig. 10.3 *Ferocactus histrix* growing under rocks and *Opuntia* canopy which act as nurses (Photo: M. Huerta)

The spatial arrangement of cacti seedlings, which tend to show a significantly greater establishment under canopies of trees and shrubs than in open areas, is of great importance in arid and semiarid areas since open spaces are characterized by extreme microclimatic conditions. The seedlings found in these microhabitats are of great importance from a demographic point of view since these are the ones with the greatest probabilities to reach adulthood (Chambers and MacMahon 1994).

The nurse–nursed plant association has been described as temporary, i.e. the nurse supplies the nursed plant a number of conditions for survival during the most vulnerable growing stages. But as the nursed plant grows, this positive association becomes negative (competition) to the point that the nursed plant ousts the nurse, which dies, a phenomenon described by Flores-Flores and Yeaton (2000).

Field studies have shown that facilitation and competition actually take place simultaneously (Maestre et al. 2003), and the theoretical models predict that their relative importance may vary inversely throughout abiotic stress gradients (Brooker and Callaghan 1998). In the theoretical models for plant–plant interaction, it is implicit the assumption that the environment's severity is attenuated by the facilitating species (nurse). If this does not occur, the competition interactions will dominate even under high abiotic stress (Tielbörger and Kadmon 2000). Therefore, a change from facilitation to competition may occur under high abiotic stress when the levels of the most limitative factor are so low that the benefits supplied by the facilitating species cannot exceed its own consumption of resources (Maestre and Cortina 2004).

10.1.2 Plant–Animal Interactions

Angiosperms or plants with flowers encompass approximately a sixth of all known plants and insects almost two-thirds of the animal species (Wilson 1992). These two major taxonomic groups dominate the Earth's flora and fauna, and their interactions form key processes in terrestrial ecosystems. Probably the most obvious of these interactions is the one between plants with flowers and the insects that visit and pollinate them (Huerta-Martínez et al. 2012a, 2012b).

Not every insect is a pollinator and not every pollinator is an insect. The majority of pollinators are from species that belong to the Hymenoptera, Diptera, Lepidoptera and Coleoptera orders, but these are joined by other species of insects from other orders and vertebrates as well, in particular some birds and bats (Proctor et al. 1996). The studies on pollination in the Sonora Desert, specifically related to major cacti species, were conducted by Fleming and his colleagues more than two decades ago. Fleming studied *Carnegiea gigantea*, as well as *Pachycereus pringlei*, *Stenocereus thurberi* and *Lophocereus schottii*. The first three species produce big, cream-coloured flowers that open at night and contain substantially large amounts of pollen and nectar. Their morphology, opening and nectar production patterns clearly suggest that these flowers evolved to be pollinated by bats, *i.e.* they present the quiropterofilia syndrome. In contrast, *Lophocereus schottii* produces delicate and pink flowers that also open at

Fig. 10.4 Pitaya fruits (*Stenocereus queretaroensis*), showing the vivid colours (Photo: M. Huerta)

night but often lack nectar. It is clear that these flowers do not target nectarivorous bats but other types of pollinator (Fleming 2000).

Species like *Ferocactus histrix*, *F. latispinus* and *Echinocactus dichroacanthus* which spread out in the semiarid region of the state of Jalisco show floral characteristics clearly related to insects, mainly bees from the *Macrotera azteca* species, while different *Opuntia* species like *Opuntia robusta* and *Opuntia streptacantha* show a clear preference for *Diadasia rinconis* and *Apis mellifera* (Huerta-Martínez and Escobar-Santos 1998).

In addition to the pollination interaction, frugivory takes place and, with this, seed dispersal as well. These two events are examples of mutualistic interactions (mutual benefits). In the arid and semiarid areas of Mexico, these interactions determine by far the structure of plant communities while regulating the abundance of animal species participating in the interaction.

Many cacti in semiarid areas produce fruit rich in water and sugars (Pimienta-Barrios 1994) and in many occasions present vivid colours (Fig. 10.4). Birds, mammals and ants eat these fruits, which may act as effective seed dispersal vectors (Mandujano et al. 1997). Nevertheless, the impact of frugivory and seed dispersal in the dynamics of plant communities in semiarid areas is little known due to the lack of quantitative studies on the space–time variability of frugivory in these ecosystems (Chambers and MacMahon 1994).

The general notion is that the seeds dispersed by vertebrates (birds or mammals) are not damaged, but on the contrary somehow they benefit from this. Vertebrate intake usually impacts germination rate (the time seeds need to germinate), as Escobar-Santos (2000) observed on *Ferocactus histrix* (Table 10.1), where the intake of seeds by *Lepus* sp. required only 3 days for starting germination in contrast with control which needed 8 days, and Hernández-Ramírez (2002) on *Stenocereus queretaroensis* (Table 10.2), where it showed that seed faeces of bats and ringtails needed only 4 days in contrast to control which required 10 days for starting

Table 10.1 Germination patterns of *Ferocactus histrix* seeds from different animal faeces vs. control (self-elaboration)

	% of seed germination of *Ferocactus histrix* seeds extracted from faeces of different vertebrates species vs. control			
Days	Control	*Tamias* sp.	*Sylvilagus* sp.	*Lepus* sp.
1	0	0	0	0
2	0	0	0	0
3	0	0	0	60
4	0	0	60	80
5	0	60	80	85
6	0	62	83	90
7	0	70	85	90
8	85	94	90	90
9	87	95	95	93
10	90	98	98	95
11	95	98	98	96
12	98	98	98	98
13	98	98	98	98

Table 10.2 Germination patterns of *Stenocereus queretaroensis* seeds from different animal faeces vs. control (self-elaboration)

	% of seed germination of *Stenocereus queretaroensis* seeds extracted from faeces of different vertebrates species vs. control			
Days	Control	Rabbit	Bat	Ringtail
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	20	10
5	0	10	35	30
6	0	17	57	47
7	0	46	60	57
8	0	60	65	68
9	0	75	67	70
10	5	85	71	75
11	19	90	77	75
12	26	93	77	75
13	30	95	77	76
14	45	95	77	76
15	50	95	77	76
16	63	95	77	76
17	70	95	77	76
18	75	95	77	–
19	80	95	–	–
20	83	95	–	–
21	83	–	–	–
22	85	–	–	–
23	85	–	–	–
24	85	–	–	–
25	85	–	–	–

germination; moreover, rabbits increased the germinability (amount of seeds that actually germinate), which have been demonstrated in some other examples (Figuerola and Green 2004). But with the columnar cactus *Isolatocereus dumortieri*, one of the dominant species in the Metztitlán Ravine, in the semiarid region of Hidalgo state, in Central México, that is not the case. This cactus has green and apical dehiscent fruits with small seeds, which corresponds to the bat dispersal syndrome; hence, seed intake by bats seems to be the natural dispersal mechanism (according to van der Pijl 1982). Germination experiments showed that seed intake by bats from the species *Leptonycteris yerbabuenae* reduces significantly the germination rate from 72% (seeds taken directly from the fruit) to 44% in seeds treated with chlorhydric acid and 25% in seeds extracted from bat faeces. Despite the above, the real contribution of seed intake by bats is that the seeds escape from predation (Janzen 1971) and colonize new distant sites. By means of this dispersal method, the seeds of *I. dumortieri* were dispersed ≥3 km, but in the case of seeds collected in caves where bats rest, it was estimated they could belong to populations of *I. dumortieri* located more than 18 km away (Rojas-Martínez et al. 2015).

10.2 Abiotic Interactions: Environment and Vegetation

The vegetation structure of natural ecosystems is determined by biotic factors (e.g. competition, facilitation, and predation) (Bertnes and Callaway 1994; Hacker and Gaines 1997), as well as abiotic (Dunson and Travis 1991; McAuliffe 1994; Valverde et al. 1996; Hahs et al. 1999) although the effects of these factors depend on the habitats where the plants grow (McAuliffe 1994). Usually the factors that impose restrictions on plant development (e.g. hydric stress, high temperatures and salinity) play important roles in vegetation structure (Interlandi and Kilham 2001). In arid environments, actually water availability and low nutrient levels in soil are the main environmental factors that impact the development of plant communities and, in consequence, plant abundance and productivity (Flores and Briones 2001). Despite the fact that low soil fertility plays an important role in the structure of communities in those habitats, the studies that document the influence of edaphic factors on the structure of vegetation in semiarid environments in México are few, and the majority have focused on the physical properties of the soil, but chemical properties have garnered much less attention (Huerta-Martínez et al. 2012).

Among the papers that document the role played by environmental factors, in particular climate and soil, without a doubt the classics by Rzedowski (1956, 1962, 1965, 1973, 2006), as well as by Miranda and Hernández (1963), stand out. Presently, in the configuration of plant communities in México, two major types can be differentiated: one is directly influenced by the geological substrate or soil type (edaphically controlled communities)—halophyte vegetation and gypsophile grasslands are in this type—while the other is influenced by the climatic factor (xerophytic vegetation, tropical evergreen forests) (González-Medrano 1996). Plant fluctuation in response to the climatic variation is considered universal. In a broader sense, the climate may define the species that will survive in a specific environment (Miles 1981), while autogenic factors may determine communities' directional changes (Cramer and Hytteborn 1987).

Environmental heterogeneity results from variations in abiotic factors, which in turn may be reflected in the abundance and distribution patterns of plant species (Stewart et al. 2000). This is due to the fact that the space–time variations in the environment have an influence on plants' establishment as well as on their development, reproduction and survival. This space–time heterogeneity is one of the main characteristics of arid and semiarid areas (Breshears et al. 1998), in which seasonality is one of the causes and the differences between these factors condition the coexistence of plant species, since the presence, duration and intensity of rainfalls become a limiting resource (Tongway et al. 2004).

Several authors argue that the formation of environmental mosaics is determined by topographic and edaphic variations indicating that there is a strong relation between relief and distribution and abundance patterns of species (Titus and Tsuyuzaki 2003). Additionally, this topographic variation is closely related to the slope and soil depth (Paruelo et al. 2005). The formation of microenvironments is the result of this topographic variation, and it has been proven that these play an important role in maintaining diversity since the presence of a wide variety of these may create a wide range of favourable conditions for more species (Smith and Smith 2001). This type of responses along the phasing out on the use of resources in space and time allows some species to dominate some microenvironments and in other cases just maintain a population of minimum size (Guo and Brown 1996). A number of studies have described the presence of indicator species associated to a microenvironment and its microclimatic conditions, which often become the main component of a system, and it is assumed that they control the community's structure in space and time (Menge et al. 1994; Tanner et al. 1994; Lindenmayer et al. 2000). In general, these species present a correlation in their distribution and abundance with certain intervals of a given abiotic factor as suggested by the law of tolerance and law of the minimum (Becker et al. 1998; Simberloff 1998).

Huerta-Martínez et al. (2004) documented through an indirect gradient analysis (Bray-Curtis Ordination) that there is actually a combination of landscape, climatic and edaphic factors that influence plant communities' structure in a semiarid area in Central México (South Chihuahuan Desert). The first ordination axis represented a landscape gradient (positively correlated to slope exposure, geology, slope inclination and rock and stone percentage and negatively correlated to latitude, longitude and soil depth); the second axis is positively correlated to climatic variables (mean precipitation in January, February, July, August, September, November and December, mean annual precipitation, Lang's index). The third axis represented an edaphic gradient positively correlated with electric conductivity, manganese, zinc, pH, nitrates and calcium (Table 10.3).

These findings supported the hypothesis that geology has a decisive influence on the composition of plant communities in the state of San Luis Potosí, México (Rzedowski 1956) and that the processes that limit plant abundance and distribution in short elevational gradients are directly related to the landscape, which is shown

Table 10.3 Correlation coefficients between environmental variables and ordination axes, without outliers

	Axes		
Variables	1	2	3
Latitude	**−0.411**	−0.260	−0.216
Longitude	**−0.473**	0.090	**0.434**
Soil depth	**−0.608**	−0.055	−0.064
Potassium content	**−0.654**	−0.267	−0.236
Exposure	**0.487**	−0.109	0.199
Geology	**0.611**	0.233	0.243
Slope inclination	**0.674**	0.115	0.156
% rocks	**0.395**	0.064	−0.054
Iron content	0.365	0.250	0.135
January mean temperature	**0.435**	−0.222	−0.010
Organic matter	**0.614**	0.365	−0.096
Stoniness	**0.374**	**0.518**	0.106
January mean precipitation	0.032	**0.415**	0.079
February mean precipitation	0.251	0.362	0.195
July mean precipitation	0.165	**0.429**	0.112
August mean precipitation	0.029	**0.422**	0.018
September mean precipitation	−0.093	**0.406**	0.104
November mean precipitation	0.099	**0.426**	0.111
December mean precipitation	0.196	0.351	0.113
Annual mean precipitation	0.093	**0.425**	0.120
Lang's index	0.089	**0.432**	0.088
Electrical conductivity	−0.050	0.127	**0.392**
Manganese	0.197	0.195	**0.406**
Zinc	0.066	0.086	**0.414**
Elevation	0.004	0.248	**0.497**
pH	−0.333	−0.301	**−0.412**
Nitrates	−0.200	−0.030	**−0.428**
Calcium	−0.249	−0.236	**−0.618**
Disturbance	−0.269	−0.222	**−0.430**

Source: Huerta-Martínez et al. 2004
Bold indicates significance at $p < 0.05$, 45 d.f.

in Table 10.4, according to the correlation coefficients between axes and plant species (Huerta-Martínez et al. 2004).

In this same line, a cluster analysis made with vegetation data (Huerta-Martínez and García-Moya 2004) actually showed that the main division is associated to alluvial and sedimentary geological substrates (Fig. 10.5). In another work made on these plant communities using only soil variables to show their relationship with the vegetation in two spatial scales, a high variation percentage (80%) was found justified by Bray–Curtis ordination (Huerta-Martínez et al. 2012). This denotes that the edaphic factor is decisive for vegetation patterns. Frequently these edaphic factors

Table 10.4 Correlation coefficients between species and ordination axes in a Bray–Curtis ordination without outliers

	Axes		
Species	1	2	3
Larrea tridentata	**−0.830****	−0.203	−0.183
Cylindropuntia kleiniae	**−0.470***	−0.094	−0.089
Agave striata	**−0.527***	−0.061	−0.206
Cylindropuntia imbricata	**−0.563***	−0.156	−0.225
Yucca filifera	**−0.443***	−0.053	−0.123
Prosopis sp.	**−0.393***	**−0.381***	−0.189
Neopringlea integrifolia	**0.493***	−0.026	−0.246
Karwinskia humboldtiana	**0.392***	0.293	0.195
Helietta parvifolia	**0.356***	0.079	**−0.723****
Hechtia glomerata	**0.526***	**−0.674****	0.030
Gymnosperma glutinosum	0.013	**−0.406***	0.094
Maytenus phylantoides	0.008	**−0.446***	0.085
Krameria cytisoides	0.097	**0.510***	0.216
Dalea bicolor	0.056	**0.399***	0.235
Ageratina sp.	0.065	**0.630****	0.120
Helianthemum glomeratum	0.058	**0.460***	0.134
Penstemon roseus	0.039	**0.502****	0.085
Gochnatia hypoleuca	0.170	**0.416***	**−0.463***
Thelocactus hexaedrophorus	0.045	0.098	**−0.450***
Salvia ballotaeflora	0.221	0.050	**0.415***

Source: Huerta-Martínez et al. 2004 with some modifications
Bold indicates statistical significance *$p < 0.05$; **$p < 0.01$; 45 d. f.

are important when they relate somehow with variables that impact water availability (e.g. climate, topography and substrate) (Rzedowski 1956). The physical characteristics of the soil, such as water dynamics, maybe have the same importance as chemical properties, and the differences in soil texture can impact water availability which may result in effects on species and biological form distribution in semiarid areas; soils with fine texture have greater water retention capability and because in these environments precipitation is sparse, less water penetrates the deeper layers of the ground compared with soils with coarser textures (Huerta-Martínez et al. 2012).

Soil heterogeneity in this semiarid area in Central Mexico influences the structure of the vegetation at a regional level, which in turn leads to the wide establishment of three different types of vegetation (Fig. 10.6). The physical and chemical properties of the soil change and determine the prevalence of different plant species; these properties are rocks, gravel, iron, soil depth, potassium, pH, organic matter, stones, sodium, electric conductivity, nitrates, calcium, manganese and zinc. But the relationship has a reciprocal effect since the presence of some shrubs like *Krameria cytisoides* modifies every soil property except pH at a local scale (Huerta-Martínez et al. 2012).

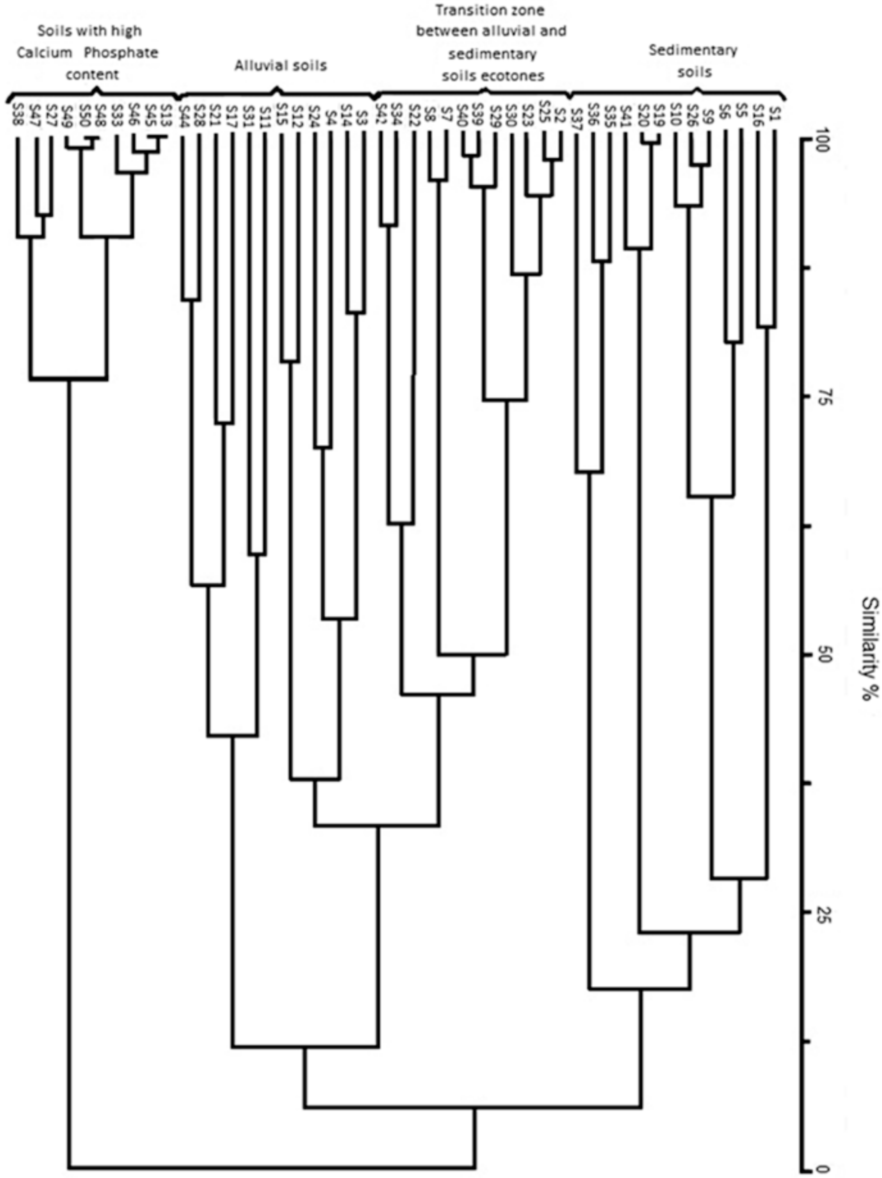

Fig. 10.5 Cluster diagram using vegetation data at southern portion of Chihuahuan Desert (Source: Huerta-Martínez and García-Moya 2004 with modifications)

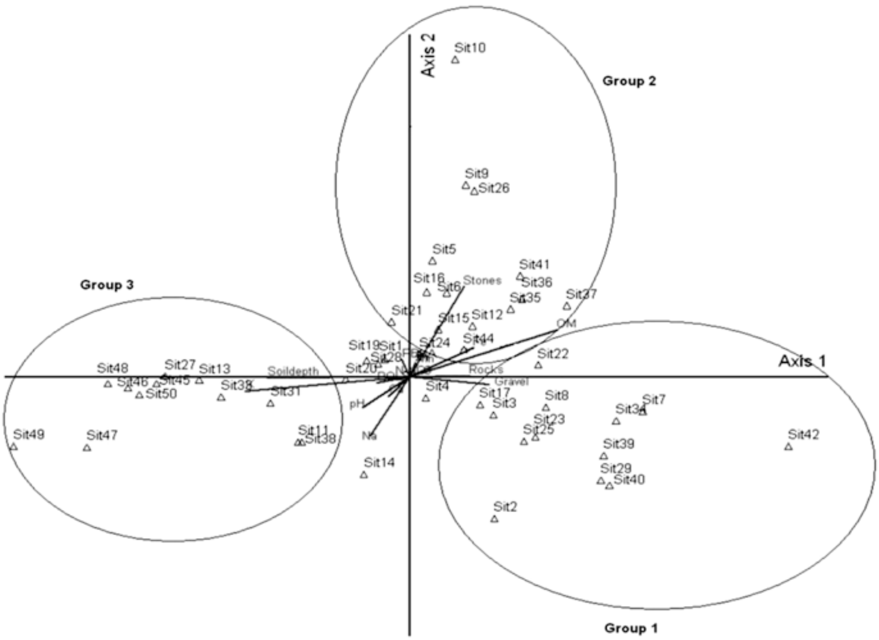

Fig. 10.6 Bray–Curtis ordination using vegetation data and soil variables, at South Chihuahuan Desert (Source: Huerta-Martínez et al. 2012)

10.3 The Cactaceae: An Emblematic Family in Mexican Deserts

It is possible that one of the curiosities Christopher Columbus presented to Queen Isabel as a gift after his first trip to the New World in 1492 was a cactus (from the *Melocactus* genus) (Barthlott 2015). In Mexico's arid and semiarid areas, there is a great number of endemic plant species, many of them belonging to the Cactaceae family. This fact has led to consider them as a priority in terms of biological conservation. Many of these species have been overexploited with commercial or decorative purposes. Additionally, changes in land use regulations have caused the loss and fragmentation of habitats and a reduction in the populations of these plants to the point of being considered frequently as endangered species (Huerta-Martínez and García-Moya 2004). Cacti are a peculiar angiosperm family, which are practically restricted to the American continent except for *Rhipsalis baccifera*, which is also found in Africa and Asia. Culturally speaking, cacti represent an important element in Mexico as it can be seen in the country's coat of arms (Fig. 10.7), which has an eagle standing on a cactus (*Platyopuntia* genus) devouring a snake. This was the sign foretold by the priests that would indicate to the ancient Mexicans the place where they were to find the capital of the Aztec Empire.

Fig. 10.7 Mexican flag, the coat of arms shows an eagle on a cactus devouring a snake (Photo: M. Huerta)

10.3.1 Habitat and Distribution

Cactus grow in a broad range of environmental conditions; according to altitude, these plants can be found from the sandy coast at sea level up to 5,000 m in the Andes, and according to latitude, they are present from the south of Canada to the south of Argentina, with a latitudinal amplitude of more than 100° (Mutke 2015). Even though Cactaceae are the iconic element of the deserts of the New World, this family lives in a variety of ecosystems (they can also grow in tropical rainforests—certain species with epiphytical habits and some shrubs and arborescent species like *Pereskia* in the southeast of Brazil and Central America). In general, Cactaceae are bad competitors under good soil fertility and humidity. Most of the species are located in limited water availability ecosystems, at least during some months of the year. Soil conditions would include outcrops, saline, gypsum or limestone substrates or sand fields (Mutke 2015).

Few studies have been made on the ecological distribution of Cactaceae. However, there is evidence that the geological substrate has an exclusion effect on certain species. This phenomenon has been referred to as calcicole/calcifuge, which was documented by Rzedowski (1955) for vegetation of San Luis Potosí; it refers to the fact that many species prefer to live in other than sedimentary substrates (which tend to have high concentrations of calcium carbonate). Subgenus *Platyopuntia* are species markedly calcifuge, but *Cylindropuntia* subgenus, on the other hand, seems to be less selective of the substrate. Candlestick species have some members that are calcicoles and prefer sedimentary substrates (e.g. *Cephalocereus senilis*, *Neobuxbaumia tetezo* and *Pachycereus hollianus*). In the case of calcicole globular cacti, the one with greater distribution and a specific preference is *Echinocactus platyacanthus*, while *Ferocactus* genus includes species that are noticeably calcicole (*F. glaucescenses*, *F. pilosus* and *F. pringlei*) and others that are calcifuge (*F. histrix* and *F. latispinus*) (Del Castillo 1996). A similar effect takes place in the south of the

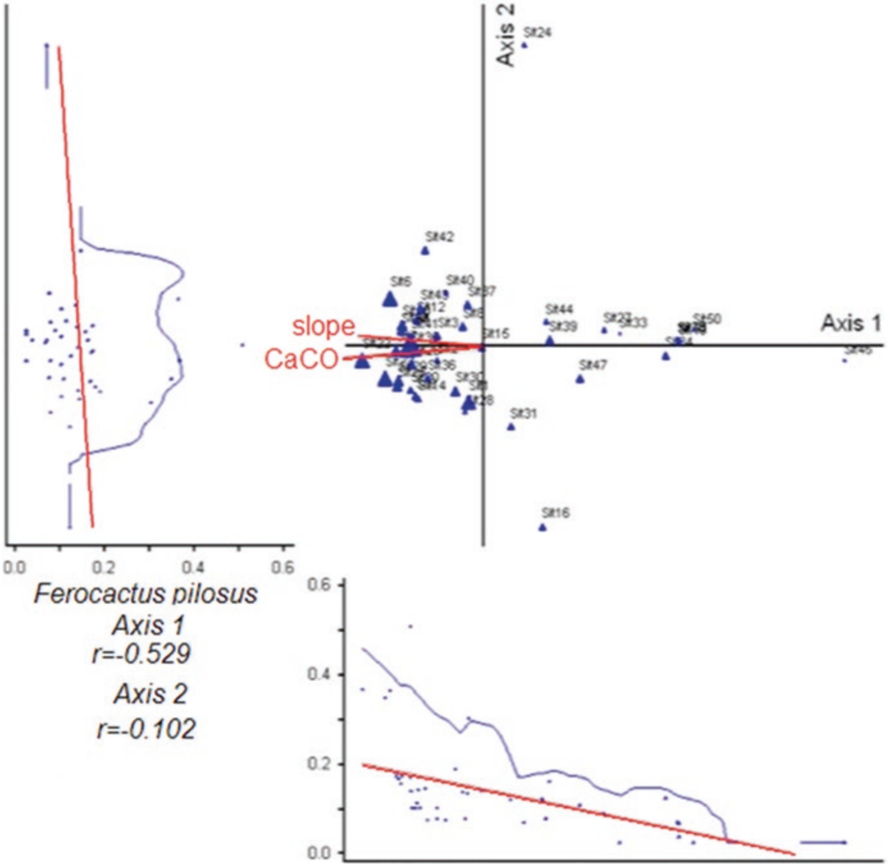

Fig. 10.8 Bray–Curtis ordination scatterplot, showing preferences of *Ferocactus pilosus* in sites with high concentrations of calcium carbonate. *Triangle* size indicates abundance of species (the bigger the size, the more abundant it is) (self-elaboration)

Chihuahuan Desert with some cacti species although unrelated to the calcium itself, but rather the forms of calcium are present in the soil. *Ferocactus pilosus* prefers soils in which calcium carbonate is abundant, whereas *Glandulicactus uncinatus* strives in soils abundant in calcium phosphate (Figs. 10.8 and 10.9).

Cactus diversity patterns can also be affected by other environmental factors (such as precipitation and temperature), prevalent in certain regions of Mexico (Godínez-Álvarez and Ortega-Baes 2007). Moreover, the variability of these environmental factors can reduce the survival, growth and reproduction of cacti, consequently limiting their distribution and abundance (Gibson and Nobel 1986; Flores and Yeaton 2003). Precipitation is, without a doubt, the main factor affecting seedling emergence and survival, and the spatial and temporal variations of these factors explain the establishment patterns in cacti (Ortega-Baes et al. 2010).

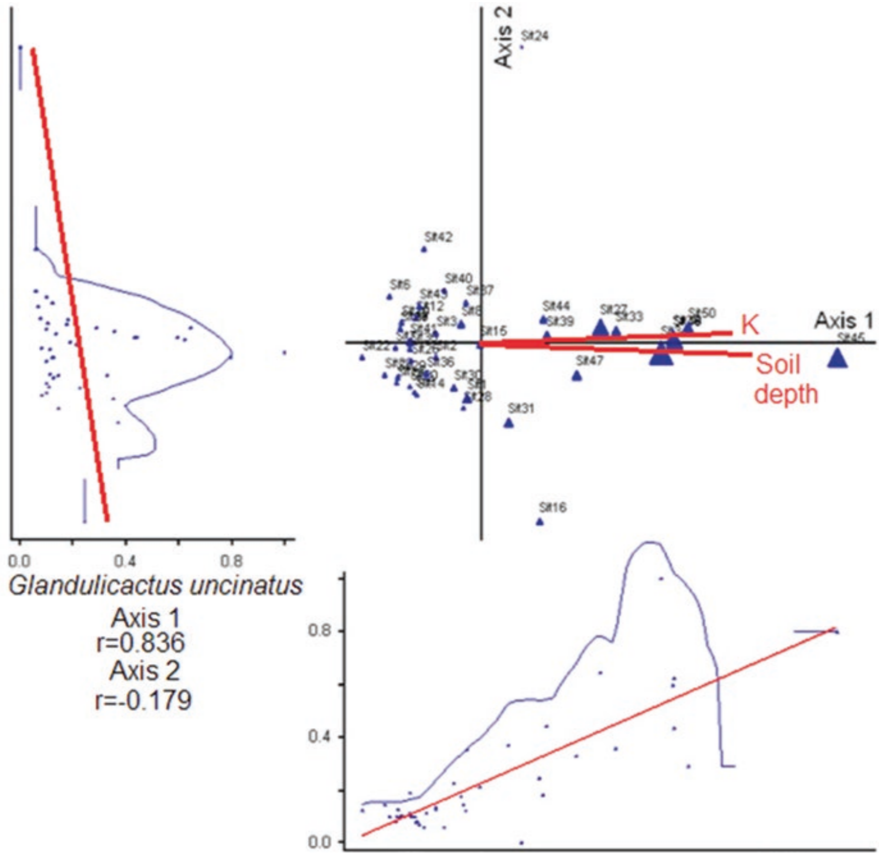

Fig. 10.9 Bray–Curtis ordination scatterplot, showing preferences of *Glandulicactus uncinatus* in sites with high concentrations of calcium phosphate. *Triangle* size indicates abundance of species (the bigger the size, the more abundant it is) (self-elaboration)

10.3.2 Group Diversity

The four North American centres of species richness in Mexico and South of United States are located in dry ecoregions: (1) Chihuahuan centre and the tallgrasses in the Central Plateau (367 species and 43 genera); (2) Puebla–Oaxaca centre with diverse climates and habitats (107 species and 27 genera), as well as two minor areas; (3) close to the Pacific Coast in the state of Jalisco (Jalisco centre) (35 species and 17 genera); and (4) on the limit between the Sonora Desert and the Sinaloa dry woodlands (Sonora–Sinaloa centre) (33 species and 13 genera) (Mutke 2015). El Huizache region (22°13′00″–23°10′00″ N, 100°10′00″–100°13′00″ W) has an outstanding variety of cacti (75 species). This area with approximately 2,855 km^2 is considered to be the most diverse in terms of cacti and endemic species wealth at a global level (Hernández et al. 2001).

During the 1990s and the beginning of the last decade, several researchers reported the general distribution pattern of cacti in the Chihuahuan Desert (Hernández and Godínez 1994; Hernández and Barcenas 1995, 1996; Gómez-Hinostrosa and Hernández 2000; Hernández et al. 2001). These works indicated that the largest concentration of members of this family is located in the south part of this major desert area, parts of the state of San Luis Potosí, and south of Coahuila, Nuevo León, and Tamaulipas. Nevertheless and unfortunately, the knowledge on the spatial patterns of cacti in the Chihuahua Desert is still incomplete (Goettsch and Hernández 2006).

The representatives of this plant family have a wide variety of life forms. They may be arborescent, candlestick, globular shaped, columnar, crawling, and tuffed and may even be rosette shaped (Fig. 10.10) (Ortega-Baes et al. 2010). There is no doubt that this peculiarity, in addition to the beauty of the flowers, is what has called the attention of foreign and domestic collectors.

The current classification of the Cactaceae family recognizes four subfamilies: *Pereskioideae*, *Maihuenioideae*, *Opuntioideae* and *Cactoideae* (Nyffeler 2002). The first of these subfamilies includes species of the *Pereskia* genus with 17 species and is spread in both hemispheres. *Maihuenioideae* has a single genus with two species distributed in Argentina and Chile. The *Opuntioideae* subfamily has 186 species scattered throughout the American continent; these species are articulated cacti with flat

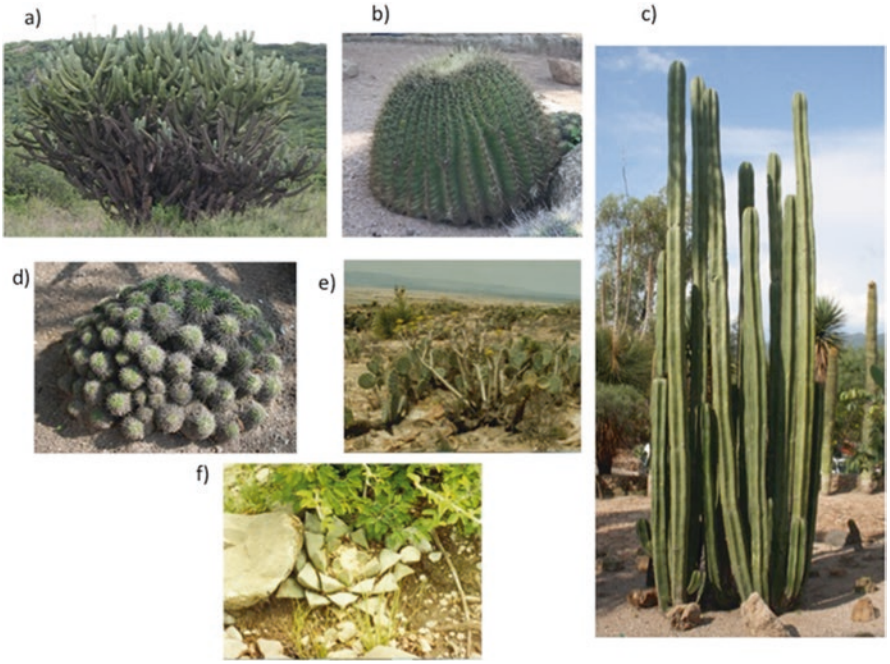

Fig. 10.10 Some life forms of Mexican cacti (**a**) candlestick, (**b**) globular, (**c**) columnar, (**d**) tuffed, (**e**) crawling, and (**f**) rosette (Photos: M. Huerta)

or cylindrical stems and globular segments. The *Cactoideae* subfamily has the highest diversity with 1,222 species, which are widely distributed throughout America. This subfamily has the highest number of endemic species with a total of 982 species that represent 88% of this group (Baes-Ortega et al. 2010). According to Rebman (2015), seven new species must be added to the *Cylindropuntia* genus (*Cylindropuntia alcahes* (F. A. C. Weber) F. M. Knuth var. *gigantensis* Rebman, *C. alcahes* var. *mcgillii* Rebman, *C. cedrosensis* Rebman, *C. ganderi* (C. B. Wolf) Rebman & Pinkava var. *catavinensis* Rebman, *C. libertadensis* Rebman and *C. waltoniorum* Rebman) and a new *Platyopuntia* species (*Opuntia clarkiorum* Rebman) which is endemic of the Baja California Peninsula and adjacent islands.

10.3.3 Risks and Threats for Cacti

Since cacti are of a great decorative value due to their different and attractive biological forms and colourful flowers, many people want to get specimens from wild populations for their personal collections and for trade. For this reason, cacti have attracted the attention of conservationists and researchers. As a result of the relative progress on the knowledge of the biology of many species of this family and commercial over-exploitation of these plants for international and domestic markets, cacti were one of the first vegetative groups to receive legal protection by international organizations. The whole family is included in Annexes I and II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Ibisch and Mutke 2015).

Cacti are a group with cultural significance perceived as one of the most charismatic plant taxa. This has led to a long history of use by human beings, including the aforementioned public and private collections of decorative plants. This has resulted in serious conservation problems for this group. Surprisingly, only 11% of the species in this group had been assessed by the IUCN Red List of Threatened Species until 2013. According to this assessment, 99 species (6.7%) were classified as critically endangered, 177 (12%) as endangered, and 140 (9.4%) as vulnerable (Goettsch et al. 2015).

The reasons for these figures may have different causes, that is, causes inherent to the biology of the species or exogenous causes. But very frequently, they are due to a combination of both—inherent and exogenous. Among the first group, demographic factors can be found; cacti populations frequently consist of individuals with the same size classes, but with large gaps between size classes, indicating a population structure related to massive events but little recruiting frequency, apparently associated to indulgent periods of abundant rainfall (Godínez-Alvarez et al. 2003), in addition to dispersal mechanisms which occasionally may or may not be efficient, as in the case of the aforementioned relationship of *Isolatocereus dumortieri* with *Leptonycteris yerbabuenae*, where the ultimate effect is reducing germinability.

Even though there are not many works that analyse demographic trends using matrix projections, it is possible to observe that in the few that have assessed the population growth rate (λ), the value is close to the unit indicating that at least these populations (*Carnegiea gigantea*, *Neobuxbaumia tetetzo*, *Neobuxbaumia macrocephala*, *Escontria chiotilla*, *Mammillaria magnimamma*, *Mammillaria crucigera*, *Coryphantha robbinsorum* and *Opuntia rastrera*) are close to the numerical balance even though in some long-standing species changes may be perceived only after decades (for further details, see Godínez-Alvarez et al. 2003), and finally the facilitation relationship from which many cacti depend upon. This is another factor that has an influence on the populations providing limited availability of safe spots for the germination of seeds and for the establishment and survival of seedlings.

The second type of causes is directly related with human activities, among them changes to land use regulations. These changes can be made to promote agriculture which seems to be a widely spread threat, impacting species on the north of Mexico. Cacti on coastal areas like the Baja California Peninsula and the coast of Jalisco are threatened by the loss of natural habitats to promote housing and commercial developments. This last point along with agriculture is affecting cacti along the Mexican Pacific coast (Goettsch et al. 2015). Figure 10.11 shows the known distribution map for *Melocactus curvispinus*, an endemic species with a very restricted habitat, since it grows on the coast, precisely on the few areas that have not the development of important tourist infrastructures, but because of the participation of private companies with enormous economic power, there is the possibility of building great hotels in these areas in the coming years. Road construction is another factor that causes changes to land use, which results in the loss of habitat that fosters the development of specimens (those individuals growing precisely where a road goes through), leaving the rest of the population in a state of vulnerability and within reach of humans who may easily collect them from wild populations, causing reductions in their numbers and the resulting genetic impact.

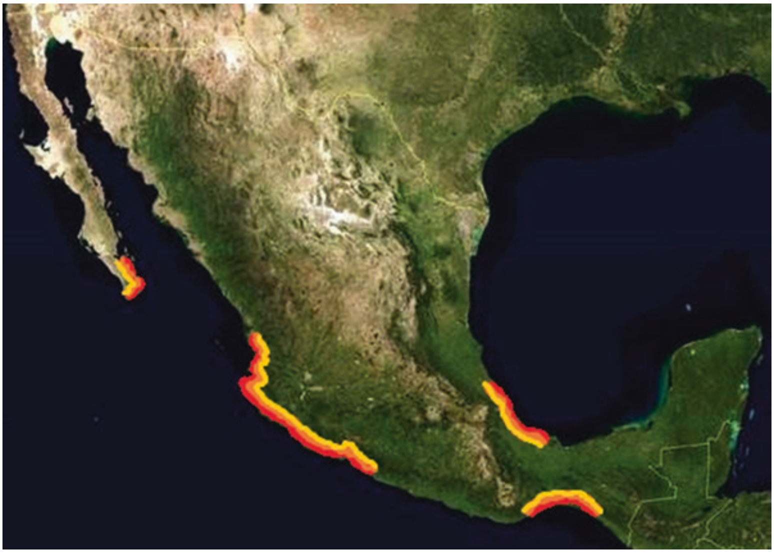

Fig. 10.11 *Melocactus curvispinus* known and potential distribution map; note that this species is restricted to four coastal areas in Mexico (self-elaboration)

It is well known that the conservation status of the majority of the cacti in México is unknown. Just few of them have been assessed as it was explained above, and it is usually limited to the species of arid areas. Furthermore, the studies made have been only on charismatic species to assess the population attribute, highlighting the need to broaden the list of studied species according to the conservation criteria.

There are considerable efforts in conservation of this important group of plants in Mexico, which are represented by at least two representative botanical gardens; one of them is located at Queretaro state, in the Municipality of Cadereyta; it is named “Ing. Manuel González de Cosío” who was a Governor of the state. The garden is an institution focused on the study, conservation, and use of Mexican flora; specially that from Queretaroan semidesert, its aims are to contribute to the scientific knowledge about botanical resources for their sustainable use, to teach the ecological and economic importance of plant resources from the state, and to make possible the formation of plant collections form Queretaroan semidesert (Fig. 10.12).

Fig. 10.12 Aspect of regional botanical garden of Cadereyta de Montes, Queretaro (Photo: M. Huerta)

Fig. 10.13 General view of the Dra. Helia Bravo Hollis botanical garden at Tehuacan–Cuicatlán Valley (Photo: M. Huerta)

The other is located at Tehuacan–Cuicatlán Valley, named “Helia Bravo Hollis” in honour to one of the most prominent Mexican botanists who focused on the study of cacti. The aims of this botanical garden are conservation and development of wild flora and fauna in addition to teaching, cultural diffusion, and scientific research of cacti (Fig. 10.13).

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Part III
The Desert of China

Chapter 11
The Deserts of China

Abstract This chapter provides features of environmental factors and phytogeographical divisions for desert vegetation in China. There are three kinds of desert vegetation in China: semi-desert, true desert, and extremely arid desert. The desert vegetation is distributed on different land forms with diversified soil feature, extending in NW China with mean annual precipitation less than 200 mm. Dominant species in the desert vegetation in China include eight life forms.

11.1 Location and Physical Environment

11.1.1 Location

Desert is mainly distributed in the northwestern part of China, including Xinjiang Uygur Autonomous Region, western part of Qinghai Province, western part of Tibet Autonomous Region, western part of Gansu Province, central and northern parts of Ningxia Hui Autonomous Region, and western part of Inner Mongolia Autonomous Region. The area of desert vegetation in China reaches 1.92 million square kilometre, accounting for 20% of the countries' territory (Chen 1987). It ranges from 74 to 109°E and 33 to 48°N (Fig. 11.1).

11.1.2 Landform

The landform is very complicated in the desert region. It is characterized by great mountains and basins. Elevation ranges from −154 m a.s.l. (Abi Lake) to >5,000 m a.s.l. There are four landform types:

1. Plateau or highland, including western part of Qinghai–Tibetan Plateau and western part of Inner Mongolian Plateau (also called Alxa Plateau or Alashan)
2. Basin, including Tarim Basin in southern Xinjiang, Jungar Basin in northern Xinjiang, and Qaidam Basin in Qinghai Province
3. Mountains, including Kunlun Mountain between Qinghai–Tibetan Plateau and Tarim Basin, Tianshan Mountain between Tarim Basin and Jungar Basin, Qilian

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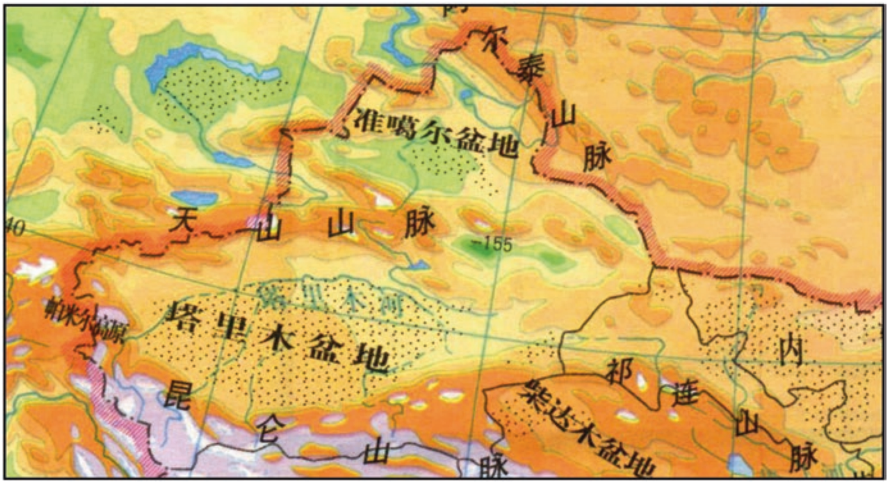

Fig. 11.1 Distribution of desert vegetation in China. The *blue line* indicates Qitai-Beitashan line which is the border between Central Asian and Inner Asian elements

Mountain between Qinghai–Tibetan Plateau and Inner Mongolian Plateau (Alxa), and Helan Mountain between Loess Plateau and Inner Mongolian Plateau (Alxa)

4. Alluvial plain that mostly distributed on the foot of the mountains (Fig. 11.1)

11.1.3 Climate

The desert in China is mainly located in the temperate zone. According to climate, the desert in China has traditionally classified into three types:

1. Temperate desert with cool and dry climate, including northern Xinjiang and Alxa in Inner Mongolia.
2. Warm temperate desert with warm and dry climate, including southern and eastern Xinjiang.
3. Highland desert with cold and dry climate, mainly distributed on the Qinghai–Tibetan Plateau, including Qaidam Basin and northwestern Tibet. Different from the tropical and subtropical deserts in other parts of the world, there is a cold winter in the desert region in China (Wu et al. 1980).

11.1.4 Soil/Parent Materials

In most regions, there is no soil but parent materials. According to rock–soil features, there are nine types of desert in China:

1. Sand desert: There are several huge sandy lands in China. Taklamakan, Gurban Tunggut, Kumtag, Qaidam, Badan Jaran, Tengger, Ulan Buh, and Qubqi are dis-

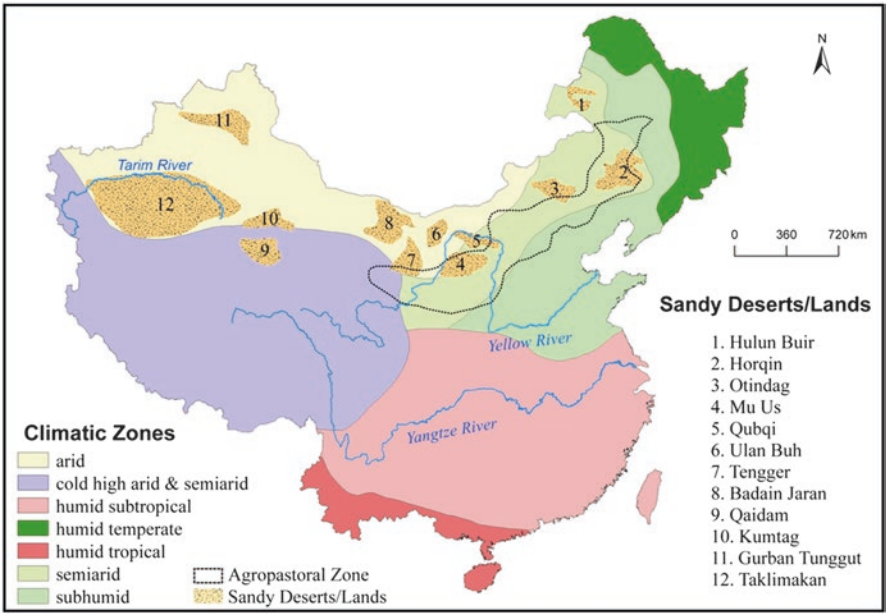

Fig. 11.2 Climatic zones and distribution of sand desert in China

tributed from the west to the east. The Taklamakan Sand Desert is the second largest one over the world (Fig. 11.2).

2. Sand–gravel desert (gobi): The huge area of gobi in the central part of the desert in China, including Alxa, western Qaidam Basin, Jungar Basin, Tarim Basin, and Mongolian-Gobi. Due to extremely low precipitation, there is almost no soil formation in this region. Vegetation cover is very low, with almost no vegetation in several hundred square kilometres in some areas.
3. Crushed stone–gypsum: It is distributed in very limited region.
4. Rocky desert: This desert type appears normally on mountainous regions, for example, North Mountain of Hexi Corridor (the border of Alxa Plateau), western Qilian Mountain, eastern Tianshan Mountain, Kuluktag Mountain, Yabulai Mountain, and Mazatage in Tarim Basin.
5. Loamy desert: It is found on the foot of Tianshan Mountain.
6. Loamy-loess desert: This desert type is distributed on Kashgar of western Tianshan and part of the foot of Tianshan Mountains, where loess deposition appears.
7. Takir desert: It is limited to delta of some rivers, including Tarim River, Yeerqiang River, Manas River, and so on.
8. Scabland desert: This desert type is only found in Qaidam Basin.
9. Salty desert: There are huge areas in Qaidam Basin, northern Xinjiang, southern Xinjiang, and Alxa where ancient end lakes are distributed (Chen 1987).

11.2 General Features of Phytogeographical Divisions

11.2.1 Phytogeographical Divisions

There have been different ways of categorizing desert vegetation in China. The most commonly accepted classification is semidesert, typical desert, and extremely arid desert according to climate–vegetation–soil features (Chen 1987).

1. Semidesert (Subdesert)

   Semidesert is distributed on the eastern foot of Helan Mountain, with annual precipitation range 100–200 mm. Plant communities named after dominant species include *Caragana tibetica*, *Ceratoides latens*, *Caragana brachypoda–Zygophyllum xanthoxylon*, *Caragana korshinskii*, *Reaumuria songorica*, *Salsola passerina*, *Tetraena mongolica*, *Ammopiptanthus mongolicus*, *Artemisia sphaerocephalo*, and *Calligonum alashanicum*. The common feature of semiarid desert is the appearance of steppe element under the shrub layer, including *Stipa breviflora*, *Stipa glareosa*, *Stipa gobica*, *Cleistogenes mutica*, *Oxytropis scaberrimus*, and *Lespedeza davurica*. Soil in the semidesert changes from brown calcic soil and light brown calcic soil to grey calcic soil and light grey calcic soil along the precipitation gradient. In its western part, grey desert soil and sandy soil occur.

2. Typical Desert (True Desert)

   Typical desert is widely distributed on central Gansu Province and northern Xinjiang Uygur Autonomous Region.

   In the south-eastern part of true desert distribution, the annual precipitation ranges 50–100 mm falling in June to September. The zonal soil is grey desert soil and grey-brown desert soil, with vastly distributed sandy soil. The prevailing plant community type is mono-dominated by *Reaumuria songorica*; in addition, there are also plant communities dominated by *Potaninia mongolica*, *Salsola passerina*, *Nitraria sphaerocarpa*, *Sympegma regelii*, *Anabasis brevifolia*, *Salsola laricifoliae*, *Calligonum mongolica*, *Artemisia sphaerocephala*, and *Caragana intermedia*. On the basin of ancient lake covered with sand, *Haloxylon ammodendron* is also distributed.

   In the northwestern part of the true desert, the precipitation reaches 100–150 mm and evenly distributed across season (spring 36%, summer 31%, autumn 21%, winter 12%). The most widely distributed soil is sandy soil. There are also small areas of grey desert soil, grey-brown desert soil, and brown desert soil. Plant communities in the northwestern part is diversified, with dominant species of *Artemisia borotalensis*, *Artemisia gracilescens*, *Nanophyton erinaceum*, *Ceratoides latens*, *Haloxylon ammodendron*, *Haloxylon persica*, *Anabasis brevifolia*, *Anabasis salsa*, *Reaumuria songorica*, *Calligonum* spp., and *Tamarix* spp.

3. Extremely arid desert: The precipitation is less than 50 mm and in some areas less than 10 mm in this subzone. However, evaporation is larger than 2,000 mm. Soil evolution is very weak in this subzone. The soils are coarse and salty, with high gypsum content and low organic matter content. Sum of plant species is less

than 100 in this subzone. Most of them are remnant species from the ancient Tethys flora. The characteristic species are *Iljinia regelii*, *Ephedra przewalskii*, *Sympegma regelii*, and *Nitraria sphaerocarpa*. The extremely arid desert consisted of four parts: Normin Gobi–Juyan Lowland, Tarim Basin, East Xinjiang–Beishan Mountain, and northwestern part of Qaidam Basin (Chen 1987).

The flora in China's extremely arid desert is quite unique (Anon 1990). Owing to dry climate and geographical isolation, some species from Tertiary Tethys Sea origin, such as *Gymnocarpos przewalskii*, *Ephedra przewalskii*, *Sympegma regelii*, *Reaumuria songorica*, *Nitraria sphaerocarpa*, and *Zygophyllum xanthoxylon*, are distributed in this area.

4. Cold and dry desert: This type is limited to the northwestern part of the Kunlun Mountain and Pamir Plateau. In the Kunlun Mountain, the major plant community is dominated by *Ceratoides compacta*. In the Pamir Plateau, the dominant species include *Ceratoides* spp., *Ephedra* spp., *Artemisia* spp., *Sympegma regelii*, *Kalidium foliatum*, and *Halogeton glomeratus* (Chen 2014).

Another way of vegetation classification is based on the life form of dominant species. Eight desert types have been categorized (Chen 2014):

1. Desert of small subtree with degenerated leaves: This type includes *Haloxylon ammodendron* desert and *Haloxylon persicum* desert. The former one commonly occurs on fixed or semi-fixed sandy dunes, while the latter one on mobile or semi-mobile sandy dunes. The height of both of them can reach 5 m with coverage of 15–30%. Therefore, they are called "forest" by local people.
2. Desert of shrubs with evergreen leather leaves: This type includes *Ammopiptanthus mongolicus* desert and *Ammopiptanthus nanus* desert. The former is distributed in western Inner Mongolia with coverage of up to 14%. The accompany species include *Caragana roborowskii*, *Salsola laricifolia*, and *Amygdalus mongolica.* Some steppe species, such as *Stipa brevifolia*, *Ptilagrostis peliotii*, *Stipa bungeana*, and *Cleistogenes songorica*, also enter the plant communities. It can be recognized as semidesert in Chen's classification (Chen 1987). The latter one is mainly distributed on the western Tianshan Mountain with elevation ranging from 1,800 to 2,500 m. The accompany species include *Convolvulus tragacanthoides*, *Kaschgaria komarovii*, *Anabasis aphylla*, *Asterothamnus alyssoides*, *Ephedra equisetina*, and so on.
3. Desert of shrub with degenerated leaves: This type also includes two subtypes, *Ephedra* desert and *Calligonum* desert. The *Ephedra* desert is dominated by *Ephedra przewalskii*, *Ephedra lepidosperma*, and so on. *Ephedra przewalskii* is a typical desert community in Inner Asia. *Calligonum* desert commonly appears as pioneer plant community which is widely distributed on sand land and sand-covered gobi.
4. Desert of succulent shrub: This type includes *Gymnocarpos przewalskii* desert, *Sarcozygium xanthoxylon* desert, *Nitraria tangutorum* desert, *Nitraria roborowskii* desert, *Nitraria potaninii* desert, *Nitraria sphaerocarpa* desert, and *Tetraena mongolica* desert. This type is widely distributed on semidesert, typical

desert, and extremely arid desert. Their covers differ from 2% to 15% depending on the precipitation, landform, as well as dominant species.

5. Desert of xerophyllous shrub: This type includes *Helianthemum ordosicum* desert, *Potaninia mongolica* desert, *Amygdalus mongolica* desert, and *Caragana tibetica* desert. The dominant species are mostly endemic species in Inner Asia, and these deserts are mainly distributed locally. The vegetation cover ranges from 8% to 25%, depending on the local precipitation.
6. Desert of succulent semishrub: This type includes *Reaumuria songorica* desert, *Salsola* spp. desert, *Sympegma regelii* desert, *Iljinia regelii* desert, *Nanophyton erinaceum* desert, *Anabasis* spp. desert, and *Brachanthemum* desert. *Reaumuria songorica* desert is the most widely distributed desert in both Inner Asia and Central Asia. Its cover ranges from 5% to 25%, depending on the precipitation. A subtype of desert of succulent semishrub is halophytic semishrub desert, including *Halocnemum strobilaceum* desert, *Halostachys caspica* desert, *Atriplex patens* desert, *Suaeda glauca* desert, and *Kalidium foliatum* desert. The halophytic semishrub desert is mostly distributed around end lakes of inland rivers as well as lowland in the alluvial plain.
7. Desert of xerophyllous semishrub: This type includes *Ceratoides latens* desert, *Seriphidium gracilescens* desert, *Seriphidium borotalense* desert, *Seriphidium terrae-albae* desert, and *Tanacetum santolina* desert. These deserts are mostly distributed on the semidesert with sandy and gravel soil parent materials. They can also enter into the typical desert and are distributed on low elevational mountain platforms and hills as a transition from desert to mountain steppe. The vegetation cover is high and sometimes reaches up to 50%.
8. Desert of cushion dwarf semishrubs: This type includes *Ceratoides compacta* desert, *Ajania tibetica* desert, and *Seriphidium rhodanthum* desert.

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Chapter 12
Vegetation and Environment

Abstract This chapter provides an overview of desert flora and plant communities. The vegetation-environment relationships were explained with two case studies, true desert in the Jungar Basin and extremely arid desert in the Anxi Extremely Arid Desert National Nature Reserve. There are 610 species in the desert of China, which can be classified into Central Asian element and Inner Asian element. The plant communities are abundant caused by diversified topography and soil features.

12.1 Desert Plants

12.1.1 Plant Species

There are 76 families, 291 genera, and 610 species in the desert of China (Lu et al. 2012). Of which more than 50 species act as dominant species. Most of the dominant species for desert in China belong to Chenopodiaceae, followed by Compositae, Leguminosae, Tamaricaceae, Polygonaceae, and Zygophyllaceae.

1. Chenopodiaceae: including genera such as *Anabasis*, *Arthrophytum*, *Atriplex*, *Ceratocarpus*, *Halogeton*, *Haloxylon*, *Horaninowia*, *Halostachys*, *Kalidium*, *Nanophyton*, *Suaeda*, and so on
2. Compositae: including genera such as *Artemisia* (including subgenus *Seriphidium*), *Brachanthemum*, and so on
3. Leguminosae: including genera such as *Alhagi*, *Ammopiptanthus*, *Caragana*, *Eremosparton*, *Hedysarum*, and so on
4. Tamaricaceae: including genera such as *Reaumuria*, *Tamarix*, and so on
5. Polygonaceae: including genera such as *Calligonum* and so on
6. Zygophyllaceae: including genera such as *Sarcozygium*, *Reaumuria*, *Zygophyllum*, and so on

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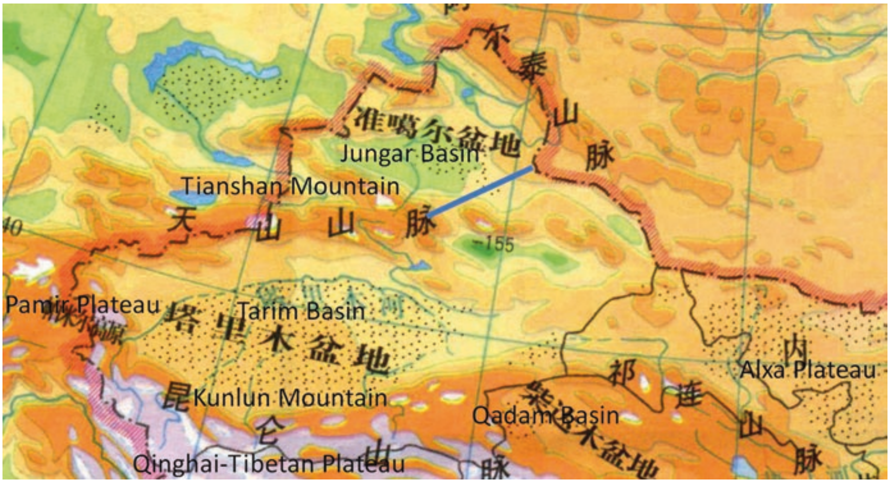

Fig. 12.1 Distribution of desert vegetation in China. The *blue line* indicates Qitai–Beitashan line which is the border between Central Asian and Inner Asian elements

12.1.2 Flora

The desert in China is characterized by two floristic elements: Central Asian element (Iran–Turan) and Inner Asian elements (Inner Mongolia–Alxa). There is a clear border between these two elements, which is approximately located between Qitai and Beitashan (Figs. 12.1).

Central Asian element (Iran–Turan) includes species such as *Camphorosma lessingii*, *Horaninowia ulicina*, *Ceratocarpus arenarius*, *Halocnemum strobilaceum*, *Halostachys caspica*, *Artemisia gracilescens*, *Artemisia terrae-albae*, *Nanophyton erinaceum*, *Eremosparton songoricum*, *Haloxylon persicum*, *Anabasis salsa*, *Arthrophytum iliense*, *Halimodendron halodendron*, *Alhagi sparsifolia*, and *Artemisia santolina*. These species cannot enter the west of Jungar Basin and Tarim Basin.

Most of the Inner Asian species cannot enter into the Jungar Basin, for example, *Prunus mongolica*, *Hedysarum scoparium*, *Hedysarum mongolicum*, *Caragana korshinskii*, *Potaninia mongolica*, *Ammopiptanthus mongolicus*, *Caragana tibetica*, *Salsola passerina*, *Artemisia ordosica*, *Calligonum alashanicum*, *Brachanthemum gobicum*, *Psammochloa*, *Pugionium*, and so on (Chen et al. 1983).

There are also dozens of ephemeral plants west of the border, mostly from the family Cruciferae. However, it is hard to find ephemeral plants east of the border.

12.1.3 Life Form

According to life form of dominant species in the desert, the desert vegetation in China has been classified into four types (Wu et al. 1980). The dominant life form in the desert of China is shrub and semishrub. Below is the list of dominant species for each life form.

1. Small tree: *Haloxylon persica* and *Haloxylon jungarica*
2. Shrub: *Ephedra przewalskii*, *Zygophyllum xanthoxylon*, *Nitraria sphaerocarpa*, *Nitraria roborowskii*, *Calligonum roborowskii*, *Gymnocarpus przewalskii*, *Ammopiptanthus mongolicus, Potaninia mongolica*, *Tetraena mongolica*, *Helianthemum soongoricum*, *Caragana korshinskii*, *Caragana tibetica*, *Calligonum mongolicum*, *Caragana leucocladum*, *Calligonum rubicundum*, and *Ammodendron argentum*
3. Subshrub and small subshrub: *Reaumuria songorica*, *Ceratoides latens*, *Salsola passerina*, *Salsola abrotanoides*, *Sympegma regelii*, *Iljinia regelii*, *Nanophytom erinaceum*, *Anabasis aphylla*, *Anabasis salsa*, *Anabasis brevifolia*, *Halostachys belangeriana*, *Halocnemum strobilaceum*, *Atriplex cana, Suaeda physophora*, *Suaeda microphylla*, *Kalidium schrenkianum*, *Kalidium cuspidatum*, *Artemisia sphaerocephala*, *Psammochloa mongolica*, *Artemisia arenaria*, *Artemisia santolina*, *Artemisia terrae-albae*, *Artemisia borotalensis*, *Artemisia kashgarica*, *Artemisia parvula*, *Brachanthemum gobicum*, *Asterothamnus centrali-asiaticus*, *Ajania fruticulosa*, *Ajania fastigiata*, *Ajania fruticulosa*, *Ceratoides compacta*, *Ajania tibetica*, and *Artemisia rhodantha*
4. Cushion small subshrub: *Ceratoides compacta*, *Ajania tibetica*, and *Artemisia rhodantha*

12.2 Plant Communities

Two case studies have been conducted in the desert region in China: one is typical desert in the Jungar Basin (Xu et al. 2006; Liu et al. 2008) and the other is extremely arid desert in Anxi Extremely Arid Desert National Nature Reserve (Liu et al. 2002).

12.2.1 Typical Desert in the Jungar Basin

Manas River Basin provides a representative case for the typical desert in the Jungar Basin. The typical desert on the Manas River Basin in the Jungar Basin was classified into seven types (Liu et al. 2008):

1. *Seriphidium (Artemisia) borotalense–Halogeton glomeratus* community: Dominated by *Seriphidium borotalense* and *H. glomeratus*, this community type is distributed on the alluvial fans and river terraces with loess as soil parent material.
2. *Reaumuria songorica* community: The shrub layer is dominated by *Reaumuria songorica*, while the herb layer is dominated by *Bassia sedoides*. *Haloxylon ammodendron* and *Tamarix laxa* are occasionally found in the shrub layer. It is commonly distributed on the foot of the sand dunes and at the edge of the fluvial plain.
3. *Haloxylon ammodendron* community: The shrub layer is dominated by *Haloxylon ammodendron*, while the herb layer is dominated by psammophytes such as *Aristida pennata.* This community type is commonly distributed on the lower part of the sand dunes.
4. *Haloxylon ammodendron–Tamarix ramosissima* community: This community type is co-dominated by *Tamarix ramosissima* and *Haloxylon ammodendron*. It is commonly distributed on the valleys between sand dunes.
5. *Haloxylon persicum* community: This community type is quite similar with the *Haloxylon ammodendron* community. But it is commonly distributed on the upper part of tall sand dunes, particularly in the transition between the fluvial plain and the sandy desert.
6. *Tamarix ramosissima* community: The shrub layer is dominated by *Tamarix ramosissima*, while the herb layer is dominated by *Sophora alopecuroide* and *Achnatherum splendens.* It is commonly distributed along the river channels.
7. Salt shrubs community: This community type is dominated by *Kalidium foliatum*, *Halostachys caspica*, and so on, depending on the salty content in soil. This community type is commonly distributed on the transitional zone between the alluvial fans and the fluvial plain and lowlands on the fluvial plain.

12.2.2 Extremely Arid Desert in the Gobi

Anxi Extremely Arid Desert National Nature Reserve is located in the Gobi. The plant community types are diversified in the extremely arid desert in Anxi Nature Reserve, but only *Nitraria sphaerocarpa* community is limited to the extremely arid desert. *Nitraria sphaerocarpa* is most frequently distributed on the gobi surface. As a monodominant or even single-species community, it occurs when the annual precipitation is less than 50 mm, matching the elevation of less than 1,500 m. When precipitation is increased, *Nitraria sphaerocarpa* is mixed with other shrub species. This distribution pattern is similar to that in the western part of Inner Mongolia (Anon 1990).

There are two plant community types distributed at the transition from extremely arid desert to typical desert:

1. *Anabasis brevifolia* desert

This desert type has obviously two layers: the shrub layer and the herb layer. It is distributed only in the northern part of the reserve. The shrub layer is dominated by *Nitraria sphaerocarpa* and *Reaumuria songorica*, while the herbaceous layer is dominated by *Stipa glareosa*, showing a transition between the arid desert (also named true desert) and the extremely arid desert.

2. *Salsola abrotanoides* desert

The species composition and structure of this community type are similar to the *Anabasis brevifolia* community. It is distributed mostly in those sites with more clay and silt than sand and gravel.

The following four plant community types are common in both the typical desert and extremely arid desert. They are:

1. *Haloxylon ammodendron* desert

In the extremely arid desert, the *Haloxylon ammodendron* desert is a mixture of different species. *Haloxylon ammodendron* occupies the tree layer with cover values from less than 1 % to over 10 %. The shrub layer is dominated by *Reaumuria songorica* and *Nitraria sphaerocarpa.* Herbaceous species, such as *Stipa glareosa*, also occur in some cases.

2. *Reaumuria songorica* desert

The *Reaumuria songorica* desert is distributed between 1,500 and 2,500 m a.s.l., with *Reaumuria songorica* and *Nitraria sphaerocarpa* both acting as dominant species, accompanied by *Salsola passerina*, *Ephedra przewalskii*, and so on.

3. *Sympegma regelii* desert

The *Sympegma regelii* desert is distributed at middle altitudes (1,800–2,200 m a.s.l.). It is a mixture of species from other desert communities. *Nitraria sphaerocarpa*, *Reaumuria songorica*, *Salsola passerina*, *Zygophyllum xanthoxylon*, *Ephedra equisetina*, *Gymnocarpus przewalskii*, *and Asterothamnus centraliasiaticus* commonly occur.

4. *Tamarix* spp. shrubland

Eight *Tamarix* species were recorded. Two of them, *Tamarix karelinii* and *Tamarix remosissima*, usually dominate, with vegetation cover usually over 10 % and sometimes reach 60 %. The herbaceous layer is dominated by such species as *Glycyrrhiza inflata*, *Sophora alopecuroides*, and *Kalidium foliatum* with low cover values.

12.2.3 Azonal Vegetation

In both the extremely arid desert and typical, there are also azonal vegetation types distributed along the rivers or on lowlands. They are:

1. *Populus euphratica* forest

As a riverine community, *Populus euphratica* is the sole species in the tree layer. Understory species are dominated by *Tamarix* spp., *Glycyrrhiza eurycarpa*, *Agropyron* spp., *Sophora alopecuroides*, and *Apocynum venetum*. The species composition is similar to its typical distribution in the Tarim Basin.

2. *Achnatherum splendens* grassland

The *Achnatherum splendens* grassland occurs usually in salinized soils. Its upper sub-layer is dominated by *Achnatherum splendens* with a height of over 1 m. In the lower sub-layer, *Sophora alopecuroides*, *Glycyrrhiza* spp. and *Alhagi maurorum* var. *sparsifolium*, and others occur.

3. *Alhagi maurorum* var. *sparsifolium–Nitraria sibirica* shrubland

This plant community type characterizes the oasis–desert transitional zones.

12.3 Vegetation–Environment Relationships

12.3.1 Climate

Of all the environmental factors, climate is the determinant for desert vegetation in China. The desert vegetation in China is located in the centre of Asia, where it is far from oceans. Precipitation can only reach the Qitai–Beitashan line which is the border between Central Asian and Inner Asian elements (Fig. 12.1). Abundant ephemeral species west of this line indicates the association of vegetation between western Xinjiang Uygur Autonomous Region and Central Asian countries. A short rainy season at the end of April with water brought from the west enhances the growth of ephemeral species. However, this rainfall can hardly reach the Qitai–Beitashan line, and therefore it is hard to find ephemeral species east of this line.

Precipitation from the Pacific Ocean cannot reach the western part of Gansu Province, while precipitation from the west cannot reach the eastern of Xinjiang Uygur Autonomous Region, leaving the regions in between extremely arid, even no precipitation in some years, resulting in a huge area of Gobi with scarce vegetation.

Another example is the difference between Jungar Basin and Tarim Basin. Gurban Tunggut Sand Land and Taklamakan Sand Land are distributed on these two basins separately. The vegetation between these two sand lands is totally different. The vegetation cover on Gurban Tunggut Sand Land can reach 20 % or more, while there is almost no vegetation on the Taklamakan Sand Land. The Pamir Plateau west of the Tarim Basin serves as a barrier that isolates the Taklamakan Sand Land from the water from the west. However, valleys on the Tianshan Mountain with east–west trend permit water from the west to enter the Gurban Tunggut Sand Land.

12.3.2 Elevation

Mountains are widely distributed in the desert region of China. With river originated from glaciers on the mountains towards alluvial plains, a chain of mountain–oasis–desert is formed. This kind of landscape repeats in Tianshan Mountain, Qilian Mountain, and Kunlun Mountain. From low to high elevations, vegetation belts of desert, steppe, forest, and alpine vegetation appear in turn.

In the typical desert, different community types were distributed in the study area generally along an elevation gradient. Landform changes from alluvial plain and alluvial fan to loamy terrace with elevation rising up. On the alluvial plain, there is huge area of sandy dunes. Therefore, the change of elevation is associated with landform, which co-determines the distribution of plant communities, for example, *Seriphidium (Artemisia) borotalense–Halogeton glomeratus* community is distributed on higher elevations than other plant communities (Liu et al. 2008).

In the extremely arid desert, the community types are changed from *Nitraria sphaerocarpa* desert to *Reaumuria songorica* desert, followed by *Sympegma regelii* desert from lower altitude to higher altitude (Liu et al. 2002).

12.3.3 Water Table and Salinity

On high soil salinity sites, plant communities are represented mainly by *Tamarix ramosissima* as shrub. *Reaumuria songorica* prefers relatively high soil salinity and fine soil. The *Haloxylon persicum* community is distributed in habitats of high soil sandy grain content, low water table, and low soil moisture content. The frequently occurring species in the typical desert can be separated into three categories according to their relations with water table and salinity (Xu et al. 2006):

1. Species on high soil salinity and high soil moisture: *Lycium ruthenicum*, *Suaeda heterophylla*, and *Peterosimonia sibirica*
2. Species on high soil salinity, a somewhat high or medium water table: *Tamarix ramosissima*, *Reaumuria. songorica*, and some species of Chenopodiaceae such as *Salsola offinis*, *Anabasis aphylla*, *Bassia sedoides*, *Suaeda physophora*, and *Suaeda glauca*
3. Species on low salinity conditions and a low water table: *Haloxylon persicum* and *Carex physodes*, *Alhagi maurorum*, and *Tamatrix elongata*

12.3.4 Soil Texture

Seriphidium borotalense–Halogeton glomeratus community, which is mostly distributed on the alluvial fans, has very low sand percentages but high TOC and silt percentages. Plant communities distributed on the fluvial plain, including the salt shrubs community, *Tamarix ramosissima* community, *Haloxylon ammodendron–Tamarix ramosissima* community, and *Reaumuria songorica* community, have medium percentages of silt, fine sand, and coarse sand as well as TOC content. High total salt content also characterizes the salt shrub community. The *Haloxylon ammodendron* community, which are mostly distributed on the neighbouring sandy dunes, have low total salt content, low TOC, and low percentages of silt.

12.3.5 Topographic Conditions

The most typical effect of topographic conditions on vegetation distribution is found on the gobi. On the Gobi deserts, the land surfaces are not flat. Gullies washed by floods can be frequently found. The gullies have more silt and clay than surrounding gobi surfaces due to water washes. The topographic difference between gully and gobi surface leads to differentiated water supplies, particularly in the rainy season. There is more water in washed gullies than on the gobi surface during the rainy season. The difference in water supply results in a vegetation complex consisted of different plant communities as well as same plant community with different vegetation cover. It is found that gullies have generally more species than the gobi surfaces. But species richness has also relations with plant community types. For example, the *Nitraria sphaerocarpa* desert has only one species in both gullies and gobi surfaces. The vegetation cover usually exceeds 10 % in gullies but below 10 % in the surrounding gobi surfaces (Liu et al. 2002). Some species, for example, *Calligonum mongolicum* and *Gymnocarpus przewalskii*, are usually confined in gullies. These species have been demonstrated to tolerate drought stress worse than *Nitraria sphaerocarpa*, *Reaumuria songorica*, and *Sympegma regelii* (Wu 1995).

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Part IV
The Deserts of Pakistan

Chapter 13
The Deserts of Pakistan

Abstract Pakistan is a subtropical country spread over an area of 79.6 million hectares (mha) lying between 24° and 37° N and 61° and 75° E. Most of the area is semiarid to arid, extending over 70 mha (87.94% of its land mass), receiving 250 mm annual rainfall. The deserts of Pakistan cover 11 mha (13.82%) of the land situated in the central and southeastern regions. These areas are broadly separated and are located between 100 and 1000 m above sea level. These deserts are monsoon in type, referring to a wind system marked with seasonal fluctuation in response to temperature variations between continents and oceans. The southeast-directed winds of the Arabian Sea supply heavy summer rains. The aridity is characteristic of a desert, with erratic rainfall occurring in clusters. The most dominant and frequent tree species in the desert habitat include *Acacia senegal*, *Acacia nilotica*, *Azadirachta indica*, *Capparis decidua*, *Prosopis cineraria*, *Salvadora oleoides*, *Tamarix aphylla*, and *Tecomella undulata*, with *Prosopis cineraria* being the most dominant and frequent. Among shrubs, *Acacia jacquemontii*, *Aerva javanica*, *Calotropis procera*, *Calligonum polygonoides*, *Dipterygium glaucum*, *Euphorbia caducifolia*, *Fagonia indica*, *Haloxylon salicornicum*, *Leptadenia pyrotechnica*, and *Crotalaria burhia* are dominant. Ephemerals are an important component of the desert habitat, here represented mostly by *Boerhavia procumbens*, *Convolvulus prostratus*, *Gisekia pharnaceoides*, *Heliotropium strigosum*, *Indigofera argentea*, *Indigofera cordifolia*, *Indigofera linifolia*, *Limeum indicum*, *Mollugo cerviana*, *Senna ialica*, and *Tephrosia purpurea*. Grasses are very prominent inhabitants in deserts, including *Aristida* spp., *Cenchrus biflorus*, *Cenchrus ciliaris*, *Eragrostis* spp., *Panicum turgidum*, *Pennisetum divisum*, *Saccharum spontaneum*, and *Stipagrostis plumosa*. *Abutilon bidentatum*, *Abutilon pakistanicum*, *Alysicarpus monilifer*, *Alysicarpus tetragonolobus*, *Caralluma edulis*, *Cenchrus prieurii*, *Commiphora wightii*, *Convolvulus scindicus*, *Gisekia pharnacioides*, *Ephedra ciliata*, *Gynandropsis gynandra*, *Monsonia heliotropioides*, *Rhynchosia schimperi*, and *Tecomella undulata* are some of the threatened species that are used by the inhabitants to meet their various socioeconomic needs. Pragmatic conservation measures are required to protect such habitats, because they represent threatened or rare and endemic species that are of economic importance to the local communities and thus are used unsustainably.

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13.1 Introduction and Physical Environment

Pakistan is a subtropical country spread over an area of 79.6 million hectares (mha) lying from 24° to 37° N and 61° to 75° E. Most of the area is semiarid to arid, stretching over 70 mha (87.94% of its land mass), and receives 250 mm of annual rainfall. The deserts of Pakistan cover 11 mha (13.82%) of the land situated in the central and southeastern regions of the country (Akram and Abdullah 1990). Sand dunes may form up to 150 m above ground level. These dunes are broadly separated and located between 100 and 1000 m above sea level. These deserts are the monsoon type, which refers to a wind system marked with seasonal fluctuation in response to temperature variations between continents and oceans. The southeast-directed winds of the Arabian Sea supply heavy summer rains. The major deserts are shown in Fig. 13.1.

13.1.1 Thal Desert

The Thal Desert is located in Punjab between the Sindh and Jhelum Rivers near the Pothohar Plateau, with a total length of 190 miles and width of 70 miles. This area is a tropical sandy plain that touches the salt range in the north, the Indus River floodplains in the west, and the Jhelum and Chenab River floodplains in the east. The climate is semiarid, with annual rainfall from 133 to 300 mm and hot

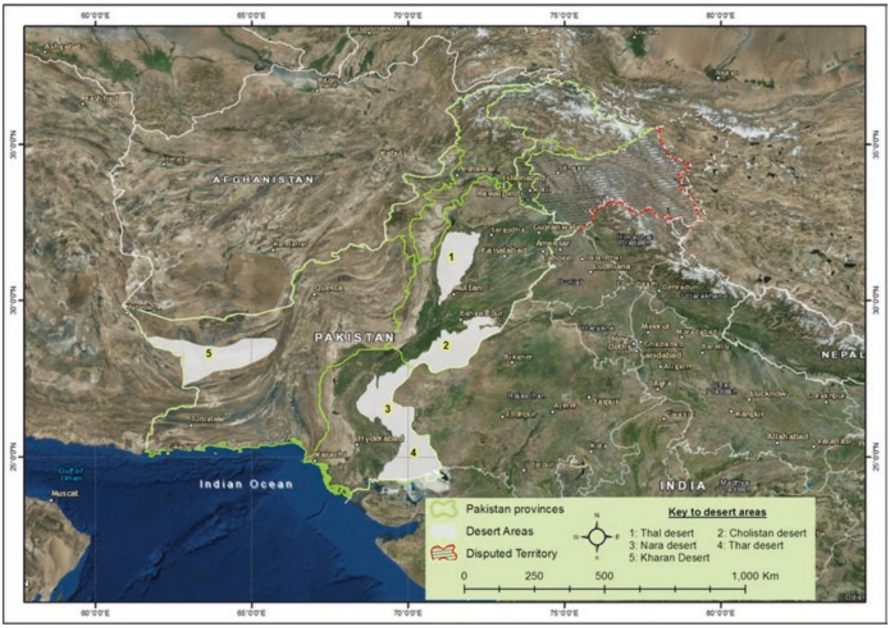


Fig. 13.1 Map of Pakistan showing the location of deserts

temperatures ranging from 0 to 44 °C. This desert consists of four types including dunes, slopes, saline sodic land, and flats. The area is divided into different parts, that is, Khushab, Mianwali, Layyah, Jhang, Bhakkar, and Muzaffarabad. The major towns of Thal are Hayderabad Thal, Mankera, Piplan, Koat Aazam, Mehmood Shaheed Thal, Mari Shah Sakhira, Muzaffargarh, Dullewala, Kundiyan, Sarai Muhajir, Rangpur, and Noorpur Thal. Most of the area is occupied by ephemerals/annual herbs, perennial grasses, and scattered shrubs interspersed with small trees. The common trees of this region include jand (*Prosopis cineraria*), wan (*Salvadora oleoides*), karen (*Capparis decidua*), kikar (*Acacia nilotica*), farash (*Tamarix aphylla*), and ber (*Zizyphus mauritiana*). Other common plants include *Acacia jacquemontii*, *Aerva javanica*, *Aristida adscensionis*, *Aristida funiculata*, *Cenchrus biflorus*, *Cenchrus ciliaris*, *Cymbopogon jwarancusa*, *Gisekia pharnacioides*, *Haloxylon salicornicum*, *Limeum indicum*, *Ochthochloa compressa*, *Saccharum spontaneum*, *Stipagrostis plumosa*, *Tribulus terrestris*, *Tribulus longipetalus*, *Zaleya pentandra*, and *Zizyphus nummularia* (Qureshi 2013).

13.1.2 Cholistan Desert

The Cholistan Desert, locally known as *Rohi*, is spread over 2.6 mha; measuring 480 km in length and between 32 and 192 km in width, it extends up to the Nara Desert in Sindh Province. It lies between 27°42′ to 29°45′ N and 69°52′ to 75°24′ E. More than 81% of the desert is under small and large sand dunes, and 19% consists of alluvial flats and sand hummocks (Akram et al. 2008). The word *Cholistan* is derived from *Cholna*, which means moving. This desert is a cradle of the Hakra civilization; once it was a prosperous land but is now a gigantic barren land. Topographically, on the basis of geomorphology, it is divided into two regions: the lesser Cholistan covers about 7770 km^2 comprising large saline, hard, and compact areas (locally known as *dahars*), alternating with low sandy ridges in the northern region; greater Cholistan covers an area of 18,130 km^2 in the southern region. The area consists of stabilized, semi-stabilized, or shifting dunes with undulating plains. The soils are classified as either saline with pH 8.2–8.4 or saline sodic with pH 8.8–9.6 (Arshad et al. 2008).

The vegetation of Cholistan Desert is xerophytic in nature, adapted to extreme temperature and moisture fluctuations along with a wide array of edaphic conditions. Vegetation cover is comparatively better in the eastern arid region (200 mm rainfall) than the hyperarid southern region (100 mm rainfall). The compact saline flatland '*dahars*' are dominated by *Haloxylon recurvum*, *Haloxylon salicornicum*, and *Suaeda fruticosa*; *Salsola baryosma*, *Sporobolus ioclados*, *Aeluropus lagopoides*, *Capparis decidua*, *Cymbopogon jwarancusa*, *Ochthochloa compressa*, and *Prosopis cineraria* are also common in undulated areas. Similarly, the sand dunes are dominated by *Calligonum polygonoides*, *Aerva javanica*, *Panicum turgidum*, and *Lasiurus scindicus* (Arshad and Akbar 2002).

13.1.3 Nara Desert

The Nara Desert lies between 26° and 28° N and 68°and 70° E in Sindh Province, Pakistan. This is a hot, sandy desert with mean minimum and maximum temperatures of 20 °C and 45 °C, respectively. Rainfall ranges from 88 to 135 mm, generally received during the monsoon. The vegetation is typically xerophytic in nature, composed of *Aerva javanica*, *Calligonum polygonoides*, *Capparis decidua*, *Crotalaria burhia*, *Dipterygium glaucum*, *Indigofera argentea*, *Leptadenia pyrotechnica*, *Limeum indicum*, *Salvadora oleoides*, *Prosopis cineraria*, and *Tamarix aphylla*, and with common grasses such as *Aristida adscensionis*, *Ochthochloa compressa*, and *Stipagrostis plumosa*.

13.1.4 Tharparkar Desert

The Tharparkar Desert is situated between 24.16–25.78° N and 69.05–71.12° E. Phytogeographically, this landscape is an extension of the Saharo-Sindian region typically marked with xerophytic vegetation. In the south is the sandy salt marsh of the Rann of Kutch, along the western border runs the eastern *Nara* canal, and, in the east, it is bordered by Rajasthan Desert, India (i.e., Jodhpur and Jaisalmer). Thar derives its name from *Thul* that means sand ridges. Most of the people believe that the origin of this desert is around 10,000 years old. This desert is spread over an area of 2.65 million hectares (mha) and is categorized as tropical thorn desert. The climate is typically arid in nature with erratic rainfall (150–400 mm), generally received during the monsoon. The temperature varies from 5 to 45 °C. The groundwater is 200–300 m deep and is saline and brackish.

The sparse vegetation consists of xerophilious grasses such as *Eragrostis* spp., *Aristida adscensionis*, *Cenchrus biflorus*, *Cenchrus ciliaris*, *Cymbopogon jwarancusa*, *Panicum* spp., *Lasiurus scindicus*, *Aeluropus lagopoides*, and *Sporobolus* spp. Scrub vegetation consists of low trees such as *Acacia senegal*, *Prosopis cineraria*, *Prosopis juliflora*, *Tamarix aphylla*, *Zizyphus mauritiana*, and *Capparis decidua* and shrubs such as *Aerva javanica*, *Calligonum polygonoides*, *Calotropis procera*, *Crotalaria burhia*, *Haloxylon recurvum*, and *Haloxylon salicornicum*.

13.1.5 Kharan Desert

The Kharan Desert, a distinctly sandy desert, lies between 28°25′58.80″ to 27° N and 63°51′36.00″ to 66° E in the Balochistan Province of Pakistan. Physically, it is covered with sand dunes interspersed with weathered rocks dominated by scrub vegetation. The moving dunes reach heights between 15 and 30 m and cover an area of about 48,051 km^2. The desert consists of moving sand dunes reaching heights from 15 to 30 m with a floor of small rocks. The vast barren area of this desert extends from the Alborz Mountains in the northern direction to the plateau in Balochistan about 1200 km to the southeast. The altitude of this desert ranges from 1000 m in the north to 250 m in the southwest. Hot dusty winds blow constantly from mid-May to mid-September. Rainfall takes place during the winter season in southwestern Balochistan, but in the southeastern desert the monsoons bring little rain. Extreme heat and thunderstorms are characteristic features of this arid land. Summers are very hot during the day and winters are cool–mild. Average annual rainfall in the desert is about 100 mm. Ecologically, the study area is a part of the Siestan Desert of Iran that covers the Chagai and the Kharan Desert.

Phytogeographically, the study area is in the Saharo-Sindian region. The vegetation is sparse and mainly consists of stunted thorny or prickly shrubs and perennial herbs capable of drought resistance. Natural vegetation is xerophytic in nature with a deeply penetrating root system. Because of the harsh climatic conditions, the ephemerals appear during the rainy season and complete their life cycle before the advent of summer, leaving the bulk of the open, sandy plains barren yet again. Most perennial species sprout and set seeds during this period. The most common plants of this desert are *Astragalus sericostachys*, *Astragalus stocksii*, *Convolvulus spinosus*, *Fagonia indica*, *Haloxylon ammodendron*, *Haloxylon griffithi*, *Haloxylon persicum*, *Otostegia aucheri*, *Peganum harmala*, *Rhazya stricta*, *Salsola richteri*, *Tamarix arcanthoides*, and *Zygophyllum eurypterum*, with the grasses *Cymbopogon jwarancusa*, *Ochthochloa compressa*, *Pennisetum divisum*, *Sorghum halepense*, and *Nepeta glomerulosa.*

13.2 Microhabitats and Vegetation Types

13.2.1 Microhabitats

Three physical features such as sandy hills, steep slopes, and vast low-lying flat plains are very common in all sandy deserts of Pakistan. The accretion of sand in the gigantic mass outlines hills known as sand dunes or ridges. The dunes have three permanent features: crest, the topmost portion; slopes, the middle portion; and foot/flatland, the base of the dune (Qureshi and Bhatti 2005). All these deserts are distinctly marked with sand dunes, slopes, and undulating plains, with saline lands along with some low-storied weathered rocky mountains.

Pakistani deserts are distinguished by a series of rolling sand dunes that vary in height across the desert. The sands are particularly mobile because of the severe winds in the region, which sweep the sands over areas of fertile soil. The factors responsible for making of such dunes are wind that blows steadily against an obstacle, which results in the collection of sand on the windward side, forming a long slope of sand. On the other side, the leeward side, the dune drops in a sharp curving cliff (Qureshi and Bhatti 2005). The desert possesses six distinct microhabitats based on physiognomic features as follows.

13.2.1.1 Sand Hills/Crest

Sand dunes are the main characteristic feature of all deserts (Fig. 13.2). There is a vast expanse of sand hills, some of them rising to more than 500 ft, which run parallel to each other and are oriented from northeast to southwest. It seems that the original formation of the sand dune was at right angles to the direction of the southwest monsoon current. In due course, however, the same monsoon current produced longitudinal ridges running parallel to each other. Their height ranges from a few meters to more than 100 m.

13.2.1.2 Slopes

Slopes are the middle portion of the sand dunes. It has been observed that most types of plant species growing on the slopes/flanks of sand dunes were quite similar to those growing on the crests, except that a few trees were also growing on the slopes (Fig. 13.3).

13.2.1.3 Flat Plains

The foot or basement of the sand dunes is the prominent flat landscape found in all the deserts of Pakistan (Fig. 13.4). The dominant fractions of alluvial soil in the depressions are clay and silt. Low-lying flat areas, encircling the sand dunes,

Fig. 13.2 Crest habitat

Fig. 13.3 Slope habitat

Fig. 13.4 Flatland

support a mixed population of tall and old trees presenting a forest landscape. Livestock spend the hotter hours of the day under the shade of these trees.

13.2.1.4 Saline Lands

Saline lands have developed as a result of stagnating rainwater in the flat lands in the depressions. In the intervening valleys, alluvial soil brought by rains accumulated in the depressions (Fig. 13.5). The evaporation of water from such larger depressions results in deposition of salts and formation of saline/sodic lands.

13.2.1.5 Salt Lakes

Saltwater lakes are prevalent in the Nara, Tharparkar, and Cholistan Deserts (Fig. 13.6). The habitat is dominated by grasses, reeds, and cattails. These plants typify emergent vegetation, which has its roots in soil covered or saturated with water and its leaves held above water.

13.2.1.6 Hilly Range

Hilly ranges are located in some deserts, including the Rohri hills in the Nara Desert, Karoonjhar hills in the Tharparkar Desert, and Alborz hills in the Kharan Desert (Fig. 13.7a, b). The highest peak of these hills may attain approximately 1169 ft

Fig. 13.5 Saline land

Fig. 13.6 Salt lake in Nara Desert

above sea level. These hills consist of granitic crystalline rocks belonging to the Dharwar and other Precambrian systems related to the neighboring Aravalli range. The top of the hills and the slopes are dominated by bushes and sub-shrubs.

13.2.2 Vegetation Types

The harsh climate, soil types, and extreme temperature fluctuations in the deserts severely inhibit the growth of vegetation. Most of the native plants have adapted to xeric conditions. The density of vegetation in this desert increases from west to east following the increase in rainfall. The majority of the deserts are covered by dry open grassland (Fig. 13.8), shrubland (Fig. 13.8b), and forestland (Fig. 13.8c), and ephemerals.

The most dominant and frequent tree species in the desert habitat include *Acacia senegal*, *Acacia nilotica*, *Azadirachta indica*, *Capparis decidua*, *Prosopis cineraria*, *Salvadora oleoides*, *Tamarix aphylla*, and *Tecomella undulata*, with *Prosopis cineraria* being dominant and the most frequent. Among the shrubs, *Acacia jacquemontii*, *Aerva javanica*, *Calotropis procera*, *Calligonum polygonoides*, *Dipterygium glaucum*, *Euphorbia caducifolia*, *Fagonia indica*, *Haloxylon salicornicum*, *Leptadenia pyrotechnica*, and *Crotalaria burhia* are dominant. Ephemerals are an important component of desert habitat, mostly *Boerhavia procumbens*, *Convolvulus prostratus*,

Fig. 13.7 (**a**) Hilly range in Tharparkar Desert. (**b**) Hilly range

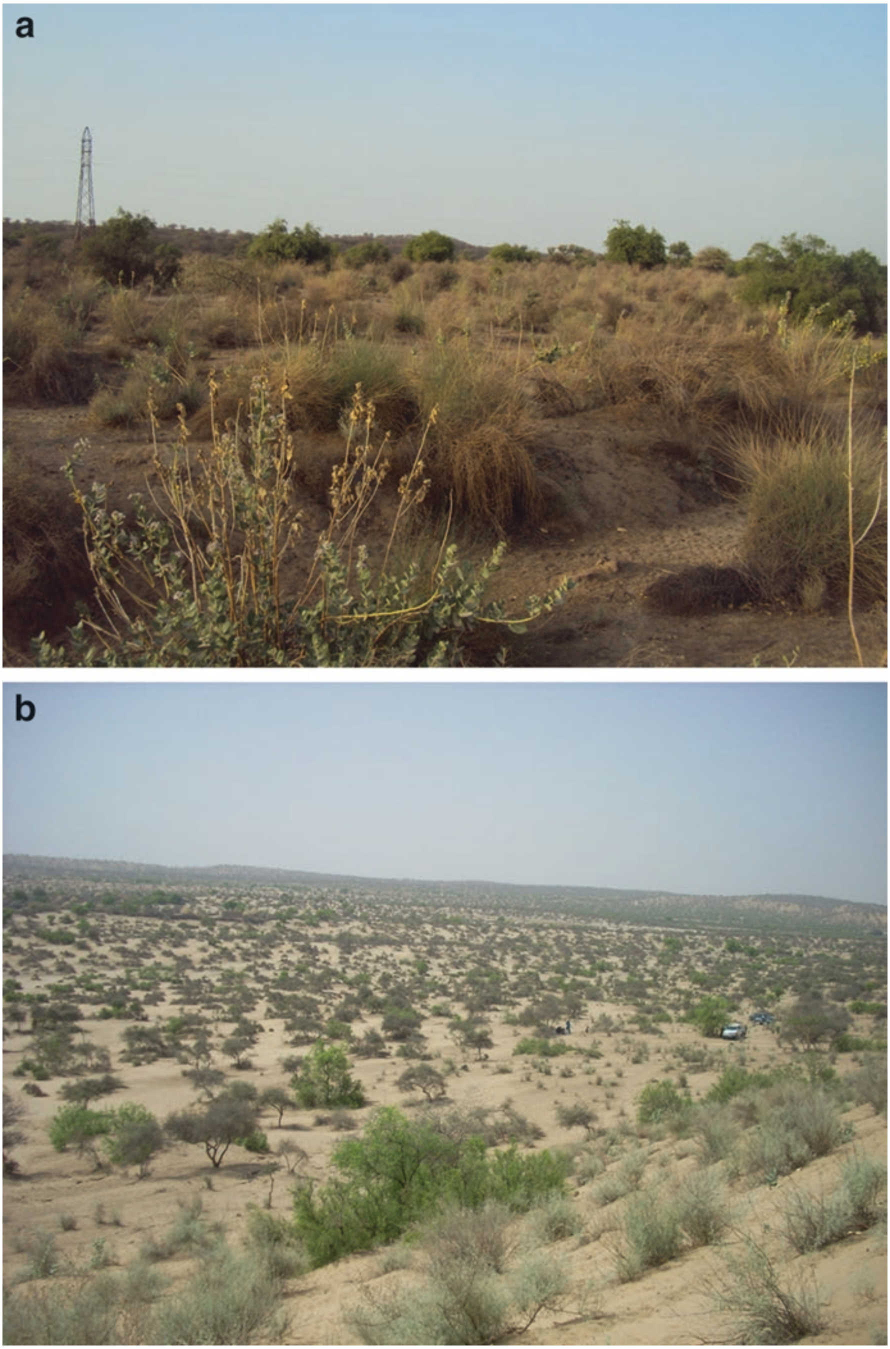


Fig. 13.8 (**a**) Grassland. (**b**) Shrublands. (**c**) Forestland

Fig. 13.8 (c) (Continued)

Gisekia pharnaceoides, *Heliotropium strigosum*, *Indigofera argentea*, *Indigofera cordifolia*, *Indigofera linifolia*, *Limeum indicum*, *Mollugo cerviana*, *Senna ialica*, and *Tephrosia purpurea*. Grasses are very prominent inhabitants in deserts, including *Aristida* spp., *Cenchrus biflorus*, *Cenchrus ciliaris*, *Eragrostis* spp., *Panicum turgidum*, *Pennisetum divisum*, *Saccharum spontaneum*, and *Stipagrostis plumosa*.

Some of these species, such as *Convolvulus prostratus*, *Cressa cretica*, *Leptadenia pyrotechnica*, *Salvadora* spp., *Tephrosia purpurea*, *Solanum surattense*, and *Citrullus colocynthis*, have medicinal value. *Prosopis cineraria*, *Zizyphus nummularia*, *Capparis decidua*, *Acacia leucophloea*, and *Tecomella undulata* are some species known for their high fodder values.

13.3 Plant Biodiversity of Tharpakar Desert, Sindh

13.3.1 Phytogeography and Floristic Composition

The Tharparkar Desert typically represents Saharo-Sindian floristic elements although the small western portion may represent Indian elements (Ali and Qaiser 1986). The desert generally is transformed into a green tinge after the rains in the spring as well as in monsoon seasons. The ephemerals (pseudo-xerophytes), which are a main feature of the deserts, cannot sustain high temperature and the long drought and soon escape, after producing seed for the next favorable season (Qureshi 2012). The vegetation of this region is mainly dry and open, consisting mainly of stunted, thorny, or prickly shrubs and perennial herbs, with scattered grasslands capable of tolerating drought. The annual herbs (ephemerals) quickly emerge during the rainy season and complete their life cycle within a couple of weeks, and the majority of the area is once more transformed into open sandy plains, desolate and barren.

Sandy plains are the most important segments of the desert covered with a varying degree of stability. Various plant associations exist in different areas of this desert. In general, trees and shrubs such as *Acacia jacquemontii*, *Acacia senegal*, *Aerva javanica*, *Calligonum polygonoides*, *Calotropis procera*, *Crotalaria burhia*, *Capparis decidua*, *Leptadenia pyrotechnica*, *Prosopis cineraria*, *Salvadora oleoides*, *Sericostoma pauciflorum*, *Tecomella undulata*, and *Zizyphus nummularia* are a permanent feature of this desert. Very commonly growing herbs are *Boerhavia procumbens*, *Convolvulus prostratus*, *Echinops echinatus*, *Farsetia hamiltonii*, *Tephrosia purpurea*, *Heliotropium crispum*, *Indigofera linifolia*, *Indigofera cordifolia*, *Tribulus longipetalus*, *Tribulus terrestris*, *Citrullus colocynthis*, *Citrullus lanatus*, and *Cucumis melo* var. *agrestis*. In the case of typical climbers, *Coccinia grandis*, *Cocculus pendulus*, *Momordica dioica*, *Mukia maderaspatana*, and *Pergularia daemia* are common examples. The grasses and sedges include *Aristida adscensionis*, *Aristida funiculata*, *Cenchrus ciliaris*, *Cenchrus biflorus*, *Cenchrus prieurii*, *Cenchrus setigerus*, *Dactyloctenium aegyptium*, *Dactyloctenium sindicum*, *Eragrostis* spp., *Cyperus* spp., *Lasiurus scindicus*, and *Stipagrostis plumosa.* The slopes and interdunal areas possess the same vegetation composition as that of the plains and flatlands; however, the occurrence of particular species may fluctuate with the presence of moisture and the strength of the sand dunes. The unstabilized dunes lack any vegetation; however, during the rainy seasons, annual herbs sprout there, including *Cleome viscosa*, *Polycarpaea corymbosa*, *Corchorus tridens*, *Tribulus longipetalus*, *Gisekia pharnaceoides*, *Mollugo cerviana*, *Mollugo nudicaulis*, *Pedalium murex*, *Amaranthus spinosus*, and *Euphorbia* spp. A common root parasite, *Cistanche tubulosa*, is found associated with *Calligonum polygonoides*, *Calotropis procera*, and *Capparis decidua.*

The rocky outskirts vary from shallow depressions to elevated areas and foothills. Very common trees and shrubs of the rocky plains include *Acacia senegal*, *Blepharis scindica*, *Calotropis procera*, *Capparis decidua*, *Euphorbia caducifolia*, *Leptadenia pyrotechnica*, *Prosopis cineraria*, *Salvadora oleoides*, and *Zizyphus nummularia*. Herb species such as *Cleome scaposa*, *Cleome viscosa*, *Euphorbia prostrata*, *Euphorbia granulata*, *Euphorbia clarkeana*, *Fagonia indica*, *Indigofera linifolia*, *Indigofera cordifolia*, *Heliotropium strigosum*, *Mollugo cerviana*, *Mollugo nudicaulis*, *Sericostoma pauciflorum*, and *Tribulus terrestris* are very commonly seen. *Dactyloctenium sindicum*, *Melanocenchris jacquemontii*, and *Tragus roxburghii* are common grasses in such habitat. Some valuable plants growing particularly on rocky slopes include *Asparagus racemosus*, *Caralluma edulis*, and *Euphorbia caducifolia.*

13.3.2 Ecological Amplitude

Aerva javanica is widely distributed in this desert and, except for lakes, the rest of the microhabitats contained this species. Other important species of the area include *Acacia jacquemontii*, *Acacia nilotica*, *Calligonum polygonoides*, *Calotropis procera*, *Capparis decidua*, *Crotalaria burhia*, *Cymbopogon jwarancusa*, *Dipterygium glaucum*, *Euphorbia caducifolia*, *Leptadenia pyrotechnica*, *Prosopis cineraria*, *Salvadora oleoides*, *Salvadora persica*, *Tamarix aphylla*, *Tephrosia purpurea*, and *Zizyphus nummularia*.

13.3.3 Endemic Species

Some endemic/threatened plants, such as *Aerva javanica*, *Calligonum polygonoides*, *Capparis decidua*, *Caralluma edulis*, *Cenchrus biflorus*, *Citrullus colocynthis*, *Commiphora wightii*, *Crotalaria burhia*, *Ephedra foliata*, *Farsetia hamiltonii*, *Lasiurus sindicus*, *Leptadenia pyrotechnica*, *Prosopis cineraria*, *Salvadora oleoides*, *Suaeda fruticosa*, *Tamarix aphylla*, and *Tecomella undulate*, are recorded from the study area. Bhandari (1990) reported a few threatened plants from the Thar Desert, such as *Abutilon bidentatum*, *Abutilon pakistanicum*, *Alysicarpus monilifer*, *Alysicarpus tetragonolobus*, *Caralluma edulis*, *Cenchrus prieurii*, *Commiphora wightii*, *Convolvulus scindicus*, *Gisekia pharnacioides*, *Ephedra ciliata*, *Gynandropsis gynandra*, *Monsonia heliotropioides*, *Rhynchosia schimperi*, and *Tecomella undulata*.

13.4 Conservatory Body

Part of the study area, Rann of Kutch, has been declared a Wildlife Sanctuary vide Government of Sindh Notification No. WL&FT (DCF-GEN-151)/1980 dated August 17, 1980 (Fig. 13.9). The wildlife sanctuary covers an area of 8300 km^2. The Rann of Kutch has also been declared a “Ramsar Site,” that is, among the Wetlands of International Importance under the convention on wetlands as habitat for waterfowl popularly known as the Ramsar Convention.

13.5 Anthropogenic Activities and Possible Remedial Measures

13.5.1 Anthropogenic Pressure

Anthropogenic activities (infrastructure development, deforestation, forage collection, illegal harvesting for fuel and timber, medicinal plant collection, etc.), coupled with natural calamities, such as inconsistent and erratic rainfall, low humidity,

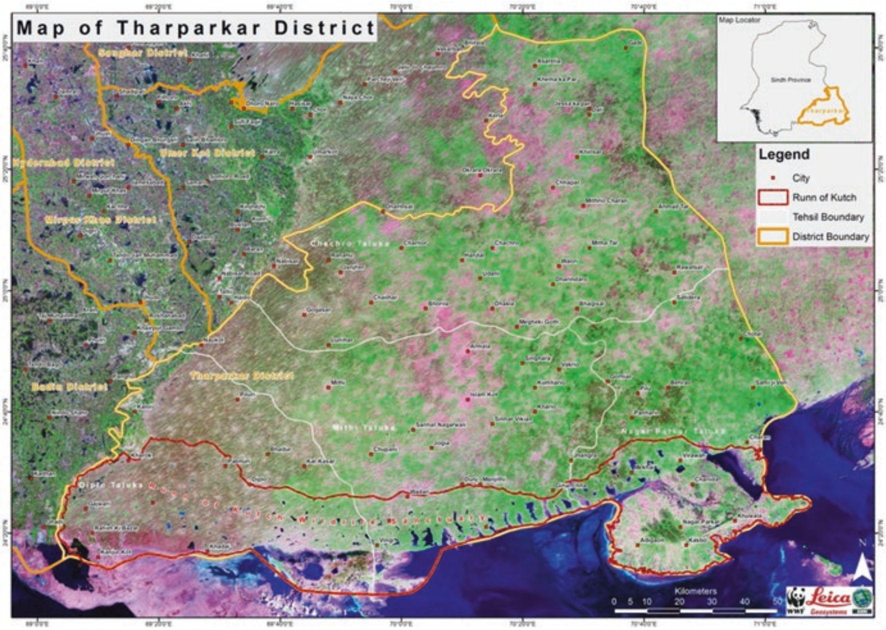


Fig. 13.9 Rann of Kutch Wildlife Sanctuary

extreme temperatures, droughts, and thunderstorms, are exerting continuous stress on the natural vegetation, resulting in desertification. Some of the anthropogenic activities are discussed next.

13.5.1.1 Human Needs

Various daily life requirements of the local communities are fulfilled by using the local vegetation. The inhabitants of this desert use the native flora in folk medicine, as fuel wood, forage, food, roof thatching, agricultural implements, timber/furniture, matrix/rope making, broomsticks, and in washing clothing, fencing/hedges, shade, ornamental/recreational uses, soil binders, windbreaks, and poisons (Qureshi 2004). Some of their pictures are shown in Fig. 13.10a–c.

13.5.1.2 Hut Formation

Most of the desert dwellers construct huts as a cylinder topped by a conical thatched roof (Fig. 13.11). The frames of the huts are mostly made from the wood of *Acacia senegal*, *Capparis decidua*, or *Prosopis cineraria*. The branches of *Leptadenia pyrotechnica* are used for thatching the roofs.

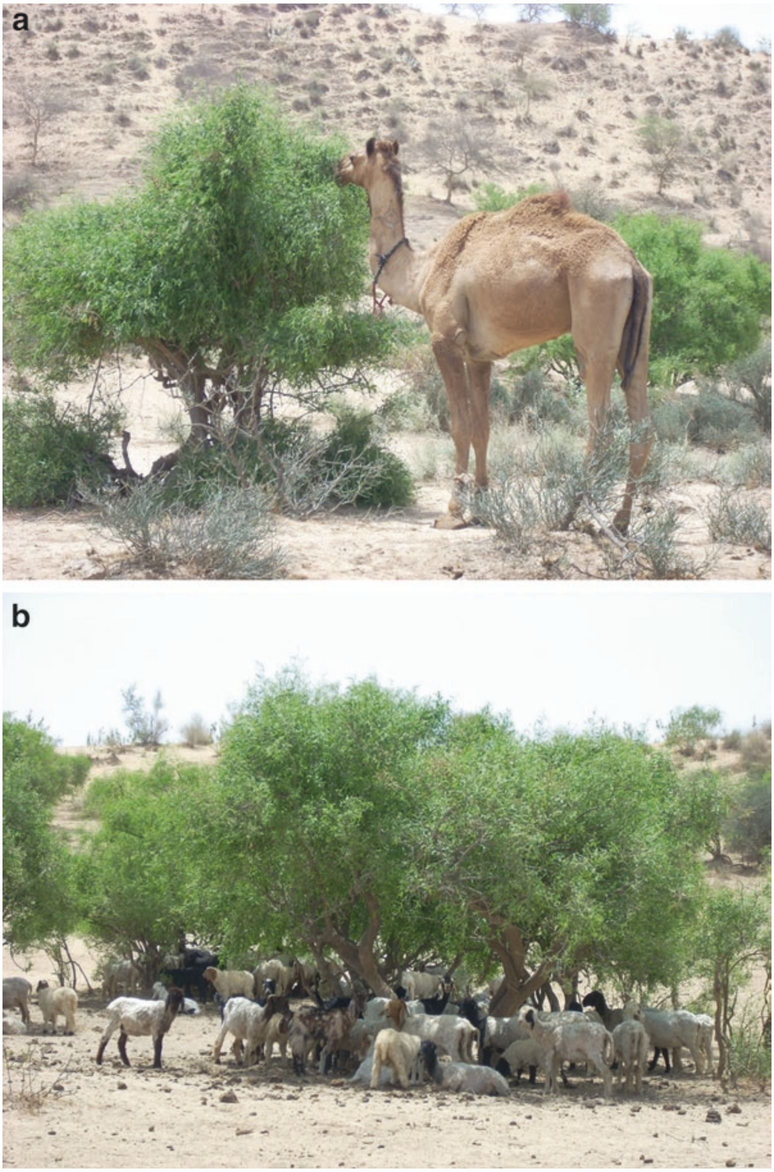


Fig. 13.10 (**a**) Camel browsing on *Salvadora oleoides*. (**b**) Grazing. (**c**) Fuel wood collection

Fig. 13.10 (c) (Continued)

Fig. 13.11 Hut construction

13.5.1.3 Livestock Feed, Fuel, and Medicine

The desert area is a good place for cattle farming. This rangeland is rich in palatable plant species, and local communities are mostly dependent on feeding their livestock, as it is a major source for earning their livelihood. People also employ local flora for fuel wood, timber for construction, small implements, and fencing, and as medicinal plants.

Lohero (*Tecomella undulata*) and *Kandi* (*Prosopis cineraria*) are two endemic species of the area that are heavily lopped/chopped for a fodder source to livestock as well as for timber and fuel. The wood of another species, *Capparis decidua*, is used for construction, agricultural tools, and boatbuilding because of its insect-resistant properties.

Some of the medicinal plants, such as *Abrus precatorius*, *Caralluma edulis*, *Citrullus colocynthis*, *Momordica balsamina*, *Cassia angustifolia*, and *Tribulus terrestris*, are extracted from the wild and sold in the market. A gummy material, *Gugul*, is obtained from *Commiphora wightii* and sold in regional markets for use in herbal pharma as well as for fumigants in temples.

All the aforementioned human activities, coupled with the high wind velocity, have led to the risk of extinction for many plant species. The protection and management of degraded habitats and vegetation is critical to preserve the plant biodiversity of this desert. Further, there is a trend for gradually decreasing populations of endemic species resulting from overexploitation of native flora for the accomplishment of different needs of the local and national communities.

13.5.2 Remedial Measures

Based on the aforementioned human activities, some remedial measures are suggested to protect this desert ecosystem.

13.5.2.1 Introduction of Native Tree Species

Various trees, such as *Acacia senegal*, *Acaccia nilotica*, *Albizia lebbeck*, *Azadirachta indica*, *Capparis decidua*, *Cordia rothii*, *Dalbergia sissoo*, *Prosopis cineraria*, *Salvadora oleoides*, *Techomella undulata*, *Zizyphus jujuba*, and *Zizyphus mauritiana*, are indigenous in this desert. These trees are scattered in the desert, and their populations are declining from their continuous consumption. Although these species are extremely slow growing, the trees may be introduced in depleted areas.

13.5.2.2 Sand Dune Stabilization

Rolling and shifting sand is a characteristic feature of the desert that can be stabilized by planting and seeding of shrubs and trees, mainly near human settlements. The sand dunes can be fixed through parallel strips starting from the crest to the flat of the dunes. The two species *Zizyphus nummularia* and *Crotalaria burhia* can be erected for micro-windbreaks. The aforementioned indigenous trees may prove successful in sand dune stabilization. Shrubs such as *Calligonum polygonoides* and *Ricinus communis*, and grasses such as *Lasiurus sindicus*, *Panicum turgidum*, and *Saccharum spontaneum*, are also useful to provide protection against erosion. The shrubs *Aerva javanica*, *Calligonum polygonoides*, and *Leptadenia pyrotechnica* are very useful species for this purpose (Qureshi 2011).

13.5.2.3 Germplasm Conservation

It is worth mentioning that the livelihood of the local communities in the deserts is exclusively dependent on the keeping of livestock. The deserts are rich in a variety of grasses, forbs, and shrubs that provide nutrient-rich feed to the livestock. It is recommended that flat plains should be protected from grazing to conserve germplasm and seed banks (Qureshi 2011).

13.5.2.4 Encroachment by Mesquite

Mesquite (*Prosopis juliflora*) is encroaching on the desert landscapes of the country. This exotic species is not palatable and is only used as fuel wood. Mesquite is increasing very rapidly in desert habitats and, if proper measures are not taken, it will alter the desert ecosystem. Some areas near salt lakes are actually impossible to access because of the profuse growth of this species (Qureshi 2011).

13.6 Phytogeography and Soil–Plant Relationships of the Nara Desert, Pakistan

13.6.1 Location and Physical Environment

The Nara Desert lies between 26–28° N and 68–70° E, situated in Sindh Province, at altitudes between 50 and 115 m. The desert spreads from Taluka Ubaro, Daharki, Mirpur Mathelo and Khan Pur Mahar of Ghotki District, to Rohri and Saleh Pat Taluka of Sukkur District, Nara Taluka of Khairpur District, and Taluka Khipro and Sanghar of District Sanghar. The eastern side boundaries of all these talukas have been marked by Rajasthan, India (Qureshi and Bhatti 2005).

13.6.1.1 Soil

Soils of the study area were formed in Aeolian sands originally deposited in Pleistocene times. A minor extent of soils has been formed in a narrow alluvial plain of the Nara Canal, which has its origin as a small inundation river. The soils in the desert are generally nonsaline to saline/sodic with pH between 7.8 and 9.5. All soils are deficient in organic matter, which ranges between 0.01% and 0.47%.

13.6.1.2 Temperature

The region experiences extreme hot temperatures. The average temperature in summer is about 45°C in the desert area and 35–40°C in the plains.

13.6.1.3 Rainfall

The whole desert remains dry until the beginning of the monsoon by the middle of May. The monsoon tides are received from the Bay of Bengal and Arabian Sea. More than 90% of the rainfall is received during June to September. Most of the rain is trapped in the month of July (90–95%). The average annual rainfall varies from 88 to 135 mm. About 5–10% of the rainfall takes place in the form of showers during the winter season and thunderstorms particularly during June–July (Qureshi 2011).

13.6.1.4 Relative Humidity

The minimum relative humidity is documented in the summer season, particularly in April and May in which it ranges between 35% and 60% in the morning hours and from 10% to 30% in the afternoon. The maximum humidity occurs during the rainy season, particularly mid-July to mid-August (90%). During the winter season, particularly mid-December to February, the relative humidity varies from 50% to 60% in morning to 25% to 35% in the afternoon (Anonymous 2002).

13.6.1.5 Wind Velocity

During the hot and rainy seasons, winds drive between southwest and west. Dust storms are very common during the summer season, particularly in the northern arid areas. Maximum dust storms happen during May and June and are very light and variable during the post-monsoon period and winters, that is, October to February (Qureshi 2011).

13.6.2 Flora and Phytogeography

13.6.2.1 Flora

Floristically, the area possesses 267 species distributed across 167 genera and 59 families (Qureshi 2012), including 4 monocotyledon families. Of these, the Poaceae family contributes the largest number of taxa (28 genera, 47 species), followed by

Cyperaceae (4 genera, 14 species). Of 51 dicotyledonous families, Fabaceae contributed the most taxa (12 genera and 26 species), followed by Asteraceae (10 genera, 13 species).

Eleven life forms or habits of the flora have been recorded from the Nara Desert. Most of the area was dominated by herbs (114 species, 42.70%), followed by grasses (47 species, 17.60%), shrubs (35 species, 13.11%), sub-shrubs (29 species, 10.86%), sedges (14 species, 5.24%), and trees (13 species, 4.87%). The desert generally takes on a green tinge after the rains in the early spring. The ephemerals cannot sustain the burning heat and the long-lasting drought and soon escape, after producing seed for the next favorable season. The vegetation composition includes common trees and shrubs such as *Aerva javanica*, *Calligonum polygonoides*, *Crotalaria burhia*, *Dipterygium glaucum*, *Leptadenia pyrotechnica*, *Prosopis cineraria*, *Salvadora oleoides*, *Tamarix aphylla*, and *Zizyphus nummularia* (Qureshi and Bhatti 2008).

13.6.2.2 Phytogeography

Most of the floristic elements are Saharo-Sindian in origin. However, a small patch of the western portion may represent Indian elements (Ali and Qaiser 1986). The whole area represents typically xerophytic vegetation. The area has been divided into the following broad phytogeographical zones:

1. Northeastern sandy arid lands (Sainewari, Sardar Garh)
2. Semiarid transitional plains (Nara Taluka)
3. Hill ranges (Rohri Hills)
4. Southwestern sandy tract (Achhro Thar, Khipro)

The northern part lies between sandy arid plains in the west and a semiarid transitional plain in the east. Gulling is also a common feature in the submontane region. The northern region consists of fertile soil running up toward the border as the plain area of interior drainage. This piece of land is full of sand hills, sand slopes, and several low depressions in which salt and soda are deposited on drying.

13.6.3 Vegetation and Microhabitats

The vegetation over the major area is characterized by xerophytic adaptation, mostly constituted of *Aerva javanica*, *Calligonum polygonoides*, *Capparis decidua*, *Crotalaria burhia*, *Dipterygium glaucum*, *Leptadenia pyrotechnica*, *Prosopis cineraria*, *Tamarix aphylla*, and *Salvadora oleoides*, intermixed with *Aristida adscensionis*, *Limeum indicum*, and *Stipagrostis plumosa* mostly growing in crest, slope, and flat habitats. Salt lakes are mostly inhabited by grasses such as *Desmostachya bipinnata*, *Phragmites karka*, *Saccharum bengalense*, and *Typha* spp., intermixed with *Tamarix indica* and *Tamarix passernioides*. The hilly ranges are inhabited by *Anticharis glandulosa*, *Fagonia indica*, *Haloxylon stocksii*, *Iphiona grantioides*, *Schweinfurthia papilionacea*, and *Zygophyllum simplex*. Six different habitats (Qureshi 2004) are recognized based on the topography of the area, as follows.

13.6.3.1 Crest Habitat

Heaped sand forms the topography of this habitat, which varies from undulating to moderately steep with elevation ranging from 70 to 120 m. Floristically this habitat possessed less floral diversity in terms of plant species as compared to the rest of habitats. The floristic composition of this habitat includes *Aerva javanica*, *Calligonum polygonoides*, *Dipterygium glaucoma*, *Indigofera argentea*, *Limeum indicum*, *Tribulus longipetalus*, *Aristida adscensionis*, *Aristida funiculata*, *Panicum turgidum*, *Lasiurus sindicus*, *Stipagrostis plumosa*, *Cyperus arenarius*, and *Cyperus conglomeratus*.

13.6.3.2 Slope Habitat

This habitat represents the same type of plant species as those of the crest habitat. This habitat displays the diversity of different life forms because a few trees such as *Capparis decidua*, *Salvadora oleoides*, *Prosopis cineraria*, and *Tamarix aphylla* were recorded in addition to the flora of the crest habitat. The typical vegetation type of this habitat comprises *Calligonum polygonoides*, *Aerva javanica*, *Dipterygium glaucum*, *Limeum indicum*, *Indigofera argentea*, *Tribulus longipetalus*, *Aristida adscensionis*, *Aristida funiculata*, *Panicum turgidum*, *Lasiurus sindicus*, *Stipagrostis plumosa*, *Cyperus arenairus*, and *Cyperus conglomeratus*.

13.6.3.3 Sandy Plain

This relatively plains area is encircled by sand dunes. The area is covered with a mixed population of tall and old trees of *Capparis decidua*, *Prosopis cineraria*, *Salvadora oleoides*, and *Tamarix aphylla*, presenting the look of a forest. Maximum numbers of species are recorded from this habitat. The most common plant species in this habitat include *Aerva javanica*, *Aristida adscensionis*, *Aristida funiculata*, *Boerhavia procumbense*, *Calligonum polygonoides*, *Capparis decidua*, *Cassia italica*, *Cenchrus ciliaris*, *Cleome brachycarpa*, *Cleome scaposa*, *Corchorus depressus*, *Cymbopogon jwarancusa*, *Cynodon dactylon*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Heliotropium strigosum*, *Limeum indicum*, *Polygala erioptera*, *Salsola imbricata*, *Stipagrostis plumosa*, *Tephrosia uniflora*, *Tribulus longipetalus*, and *Zaleya pentandra*.

13.6.3.4 Saline/Sodic Land

This habitat is formed by water drying in a depression leaving a residue of salts. These habitats are mostly found in interdunal areas of the desert. Parts of the soil of this habitat contain gypsum in the subsoil in the form of fine scattered specks or crystals locally known as *Kharror*. Aizoaceous plants (*Sesuvium sessoides*, *Trianthema triquetra*, *Zaleya pentandra*), boraginaceous plants (*Heliotropium* spp.), chenopodiaceous plants (*Haloxylon stocksii*, *Salsola imbricata*, *Suaeda fruticosa*), and *Alhagi maurorum*, *Chrozophora plicata*, *Cressa cretica*, *Salvadora persica*, *Tamarix indica*, and *Zygophyllum simplex* form a common vegetation cover of this habitat. Among the grasses, *Aeluropus lagopoides*, *Desmostachya bipinnata*, and *Saccharum spontaneum* are very common.

13.6.3.5 Lake/Wetland Habitat

Seepage of water from the Nara Canal resulted in the formation of this habitat, mostly recorded on both banks of the canal. The rise of water in wetlands (*Dhand*) solely depends upon the water availability in Nara Canal, which lies in the same topographical region. The edges of lakes are dominated with an understory plant community with *Saccharum bengalense*, *Saccharum spontaneum*, *Tamarix passernioides*, and *Typha* spp. Also, *Aeluropus lagopoides*, *Cynodon dactylon*, *Cyperus laevigatus*, *Desmostachya bipinnata*, and *Phragmites karka* are common vegetation in this habitat. These plants typify emergent vegetation, which has its roots in soil covered or saturated with water and its leaves held above water.

13.6.3.6 Hilly Tract

This tract is a distinct habitat in the plains with a sandy, gravelly composition and compact soils. The range of this area is an arid zone in which sandy plants and hill-loving plants (lithophytes) can easily acclimatize. The majority of plants are xerophytic in nature, but many plants are of the halophytic group. The most common trees of this habitat are *Salvadora oleoides*, *Tecomella undulata*, *Capparis decidua*, and *Maerua crassifolia*. The shrubs of this habitat include *Zizyphus nummularia*, *Leptadenia pyrotechnica*, *Grewia tenax*, and *Cadaba farinosa*. Among the herbs, *Blepharis sindica*, *Cleome scaposa*, *Fagonia indica*, and *Zygophyllum simplex* are very common.

13.6.4 Plant–Soil Relationships

13.6.4.1 Texture

There is a strong correlation of the chemical and physical nature of the soil with vegetation type in the Nara Desert (Fig. 13.12). The soils of crest and slope habitats are highly sandy in nature. Therefore, the soils warm rapidly in the spring season,

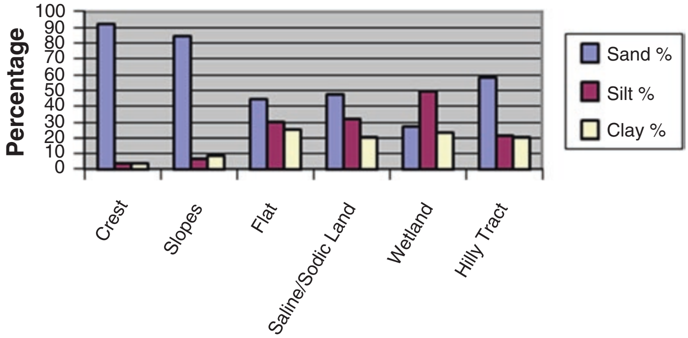
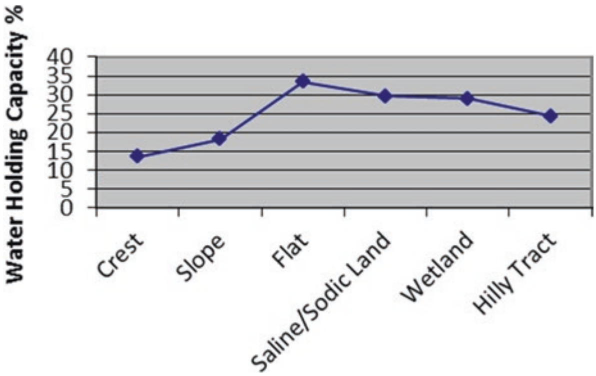


Fig. 13.12 Textural composition

Fig. 13.13 Water-holding capacity (%)



which favors seed germination. This soil allows water to drain quickly if it rains, and as a result, nutrients tend to be washed away. Therefore, it is supposed that those plants that are highly responsive to lesser inputs can withstand this type of soil. The plain areas possess sandy loam, loamy sand, and loamy soils so that the maximum numbers of species are recorded from this microhabitat. The saline/sodic land contains a silt fraction-dominated soil that may range from silt loam to silt clay loam. and therefore only halophytes are adopted to grow there. Wetland/lakes are have a rich content of clay particles and soil may range from loam to clay loam, so wet-loving species are common in this habitat. The hilly range is dominated by gravelly, sandy, and loamy sand soil so calcium-loving species as well as those adapted to rocky areas are very common.

13.6.4.2 Water-Holding Capacity

The water-holding capacity of the soil depends on its physical characteristics, including texture, structure, and soil depth (Fig. 13.13). Texture refers to the relative distribution of the particles (clay, sand, silt). In general, the finer the texture, the greater is the water retention. Sandy soils have no structure; clayey soils have different forms of structure, and the spaces between particles enable circulation of air and water. The larger these spaces, the greater is the permeability. Water-holding capacity is strongly affected by the amount of clay and organic matter in the soil, as it is positively correlated with these particles and negatively related to sand particles. As the percentage of clay and organic carbon content increases in the soil, water-holding capacity also increases. Low fractions of silt and clay particles and organic matter result in a lowered cation-exchange capacity of the soil and hence a decreased ability to retain ions against the leaching process.

13.6.4.3 pH

There was no great difference in pH for the established habitats, ranging from 7.8 to 8.9 with a mean of 8.33 (Fig. 13.14). In fact, the soil of all the habitats is alkaline in nature, which might result from the sandy nature of the soil.

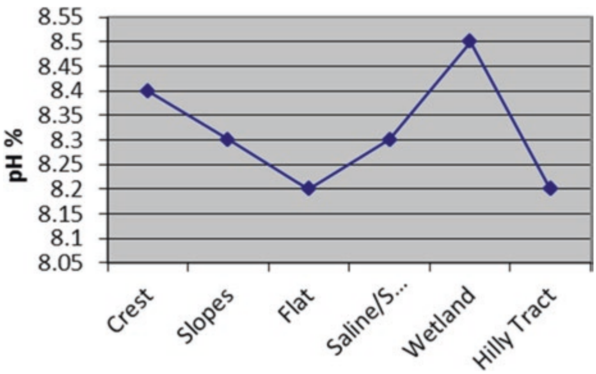
13.6.4.4 Electrical Conductivity (dS/m^{-1})

Maximum electrical conductivity (EC) was observed in the wetland habitat followed by saline/sodic land (Fig. 13.15). Salt accumulation is very common in saline/sodic land because of the high evapotranspiration rate. Salt lakes or wetland habitat possess high EC (dS/m^{-1}), which results from the presence of high concentrations of salts in soluble forms. The soil under good vegetation cover has a higher value of EC (dS/m^{-1}) as compared to the soils of area with sparse vegetation.

13.6.4.5 Organic Carbon Content

Soil rich in organic carbon content was found in the plains areas as a result of the thick stands of vegetation (Fig. 13.16). Many graveyards of dead trees have been found between these valleys. The accumulation of a large amount of litter beneath

Fig. 13.14 pH



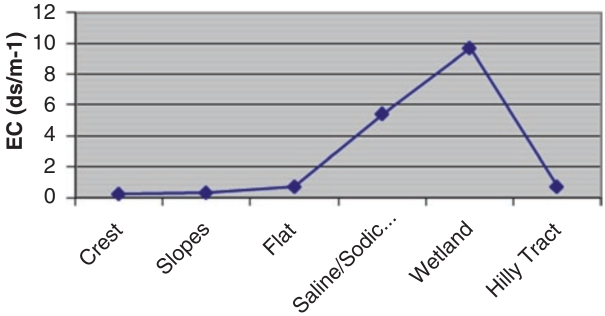
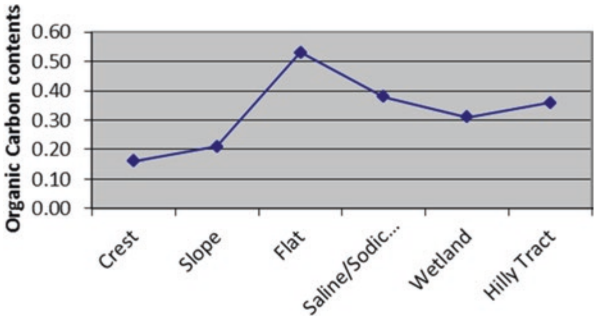


Fig. 13.15 Electrical conductivity

Fig. 13.16 Organic carbon content (%)



the trees, especially of *Tamarix aphylla* and *Prosopis cineraria*, has caused an increase in the amount of organic matter, which ultimately affects the physical and chemical composition of soil. Soil organic carbon concentration decreased away from well-vegetated areas to sparsely vegetated areas or areas devoid of vegetation. Soils associated with trees had organic carbon content as much as two times higher than soils from nonvegetated areas, which appears to be related to differences in the aboveground litter. Bare soils possessed the lowest amounts of organic matter because of the absence of vegetation or a lesser vegetation cover.

13.7 Conclusion and Recommendations

The deserts of Pakistan are unique landscapes endowed with a wealth of xerophytes and some endemic flora. These desert ecosystems provide good pastureland to be used as the best source for rearing livestock. Moreover, these ecosystems supply fuel, shelter, nutrition, and medicine for the dwellers. However, these unique ecosystems are losing their potential as the result of the high stress exerted by grazers and browsers, increasing use of land for agriculture, fuel, and timber, and by range resource collectors for various needs. Some of the concrete recommendations that are being proposed for the sustainable use of this rangeland follow:

1. Vegetation composition and GIS (geographic information system) studies of all deserts should be carried out to assess the patterns of distribution of the flora.
2. A rotation grazing system should be implemented by the government organization for sustainable use of these rangelands.
3. The genetic diversity of range and forage grasses, legumes, and other forbs needs to be collected and preserved for future generations.
4. Immediate rehabilitation measures of eroded areas are needed as soon as possible.
5. Plantation of fodder tree species and reseeding of palatable grasses through community participation are needed to surmount grazing pressures.

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Erratum to: Plant Responses to Hyperarid Desert Environments

**Monier M. Abd El-Ghani, Francisco Martín Huerta-Martínez,
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The published version of this book included errors in format and content of the Soil Tables throughout the book. These formatting and content errors have been corrected throughout the book.

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