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Effect of seashore distance on potential distribution, floristic diversity, and salt marsh migration of mareotic halophytes in Egypt

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Abstract

A key aspect of climate change influencing coastal areas globally is sea level rise, which leads to accelerated habitat shifts. Extreme halophytes are remarkable plants capable of functioning normally on saline soil of the coastal areas. Current research investigates the floristic structure of the extreme halophytic plant communities within 54 sites distributed in coastal and inland salt marsh habitats. To draw attention to the environmental factors that determine species distribution. Also, to detect the effect of the distance from the sea on the floristic composition. The results of the study indicated that as the distance from the coast increases, the abundance of species, genera, and families, attributable to a simultaneous increase in salinity levels decreases. We can conclude that by moving farther away from the sea, the soil salinity increases, inland marsh migration occurs, and floristic diversity decreases as only extreme halophytic species can withstand. Consequently, the process of marsh migration serves a significant role in facilitating the adaptation of salt marshes to the phenomenon of sea-level rise.

Key Words: Coastal areas; distance from the sea; extreme halophytes; sea level rise; soil salinity

Introduction

The issue of soil salinity is becoming one notable factor in the deterioration of land on a global scale. Approximately 7% of the Earth's land surface is affected by soils with high salt content, while soils affected by sodium are more prevalent (Flowers *et al.*, 1997). An elevation in the overall amount of dissolved salts in both water and soil is known as salinization, which results from either natural occurrences or human activities (Ghassemi *et al.*, 1995). According to FAO statistics, salinization affects at least 40% of the planet. Salinization is a significant challenge in various regions, including Australia, India, Egypt, Asia, and the United States (Abbas *et al.*, 2013; FAO, 2015; Ivushkin *et al.*, 2019). Numerous crop species, upon which a significant number of people depend for sustenance, experience adverse impacts due to elevated salinity levels (Wang *et al.*, 2008; Golldack *et al.*, 2014). Zhang *et al.* (2012) have highlighted that approximately 80 million hectares of farmed land are impacted by soil salinity.

Halophytes are plants that thrive in a salty environment. They make up 1% of the world's total flora. They are found primarily in arid and semi-arid regions, in addition to sand-saline wetlands along the tropical and subtropical coasts. The ability of halophytes to tolerate salinity is contingent upon a range of ecological and physiological attributes that facilitate their growth and thriving in environments with elevated levels of salt. Worldwide, the most detrimental abiotic stress on plant production is salty soil (Kumari *et al.*, 2015; Zörb *et al.*, 2019).

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Soils are often categorized as saline when the electrical conductivity of the saturated paste (EC) reaches or exceeds 4 dS/m, which is comparable to 40 mM NaCl. Plants exhibit significant variations in their growth response to salty circumstances, leading to their categorization as either "glycophytes" or "halophytes", describing their ability to thrive in severely salty conditions (Flowers and Colmer, 2008; Mishra and Tanna, 2017).

Soil salinity can arise from a multitude of factors, encompassing both natural and anthropogenic causes. Natural sources include the weathering parent material, wind and rain-deposited sea salt, and tidal flooding of coastal land (Hassani *et al.*, 2021). Human interventions contribute to soil salinity through processes such as the elevation of the water table due to excessive underground irrigation, the utilization of water containing high salt content for irrigation purposes, and inadequate drainage systems (Zhao *et al.*, 2011; Abbas *et al.*, 2013). Furthermore, it was anticipated that a sea level rise of one meter would lead to the inundation of around 12-15% of Egypt's agricultural area. The transformation of agricultural lands into saline environments as a consequence of rising sea levels is an evident threat (Kirwan *et al.*, 2010; Fagherazzi *et al.*, 2019).

Numerous halophyte species, encompassing grasses, shrubs, and trees, can eliminate salt accumulation in diverse salt-affected soils. This is achieved through various mechanisms such as salt exclusion, excretion, or accumulation, facilitated by their adaptations in terms of morphology, anatomy, and physiology. The implementation of halophytes to ameliorate soil salinity holds promise as a viable solution for addressing the fundamental requirements of populations (Zorrig *et al.*, 2012; Hasanuzzaman *et al.*, 2014).

The growth of crops possessing a high degree of salt resistance can be regarded as a financially viable alternative for the utilization of saline soils. Agriculture encompasses the cultivation of non-conventional crops, such as halophytes (Munna, 2005; Zhao *et al.*, 2011).

Numerous endeavours were made to assemble a comprehensive inventory of the global halophytic flora, alongside a compilation of regional halophytes. Nevertheless, the understanding of halophytes remains nascent (Aronson, 1989; Lieth and Hamdy, 1999; Santos *et al.*, 2016). Moreover, halophytes are classified in a variety of ways such as classification based on their habitat, tolerance, and requirements for sodium salts (Waisel, 2012; Grigore, 2021).

Grigore and Toma (2010) presented a novel categorization of halophytes, which is determined by the significance of anatomical adaptations that are associated with the intensity of environmental conditions, particularly soil salinity. halophytes can be distinguished as extreme halophytes, as well as mesohalophytes. Extreme halophytes are a group of species that have developed highly effective adaptations to thrive in settings characterized by high salinity levels. These species typically exist in saline habitats. The species in question possess the most robust anatomical adaptations, which are closely associated with the salinity factor (Obón *et al.*, 2020; Grigore, 2021).

Many halophytic species are used for ecosystem services such as soil desalination, dune fixation, and CO_2 sequestration or for economic interests as a provenance of human food, animal feed, bio-oils, and medication. Halophytes possess the potential to serve as significant plant species with the aptitude to desalinate and restore saline soils, in addition engage in plant-based remediation. By using these valuable practices, it is feasible to make use of previously unutilized and unproductive areas for agricultural purposes, as well as enhance the productivity of existing agricultural land (Koyro, 2003; Bidak *et al.*, 2015; Joshi *et al.*, 2020).

Coastal land managers are actively seeking strategies to conserve and protect salt marsh habitats due to the diverse array and significant scale of ecosystem services they offer, the integrity of these functions is being jeopardized by the escalating sea levels. Coastal ecosystems are undergoing swift migration as a result of the rise in sea levels, resulting in a fundamental restructuring of the coastal environment (Kirwan et al., 2016; Gedan and Fernández-Pascual, 2019; Zinnert et al., 2019; Flester and Blum, 2020). The evaluation of the capacity for overland migration and the identification of constraints associated with this process might provide valuable insights for coastal managers when making decisions regarding the prioritization of protection and restoration initiatives. The objective of this study is to provide the description and analysis of the floristic composition of extreme halophytes in the Egyptian Mediterranean western coast; in coastal and inland salt marsh to assess how changes in land usage and rising sea levels have altered the composition of vegetation and habitat migration. Also, to fill the gap in knowledge related to the extreme halophytic species that are common native plants dominated in salt marsh habitats. To complete the picture of the correlation between halophytes and corresponding environmental variables, and to attract the attention of Egyptian biologists to the existing information and the importance of halophytes as promising natural resources that may be used in future as a non-conventional crop.

Materials and methods

The coastal region of Egypt along the Mediterranean Sea is ecologically divided into three distinct sections: the western section, known as the Mareotic coast, the middle area, referred to as the Deltaic coast, and the eastern section, known as the Sinai Northern coast (Zahran et al., 1985; Zahran et al., 1990). Salt marshes are a significant feature within the coastal zone of the western Mediterranean, serving as a crucial ecosystem in this particular area. Significant occurrences of sabkhas can be observed at elevations marginally above or below the mean sea level. (El-Shaer and El-Morsy, 2008). In addition, based on salt marsh spread around the world (Murray et al., 2011), the study area was chosen to represent the most comprehensive salt marshes habitat area in the Mareotic region of Egypt (Fig. 1).

The study was carried out at different locations in the western section (30°48'15.4"–31°10'28.1" N, 27°39'58.6"–29°42'41.2" E), that belong to the Mareotic sector which extends for about 500 km, from Sallum Village at Egypt's border with Libya to 20 km west of Alexandria. The area under study is characterized by a warm coastal stripe, wherein the warmest month of summer exhibits a mean temperature below 30 °C, while the coldest month of winter experiences a mean temperature surpassing 10 °C. It is worth noting that sporadic brief rainstorms may transpire during the winter season (October to February; little rainfall: 130-190 millimetres / year that decreases gradually to the south). The mean relative humidity was approximately 66.9 %. The geographical features that significantly influence this area's weather include the coastal orientation, nearness to the Mediterranean Sea, and the local topography. Close to the ocean exerts an influence on atmospheric temperature and humidity, hence impacting the processes of evaporation and condensation (Kassas and Zahran, 1967; Abd-ElGawad et al., 2020).

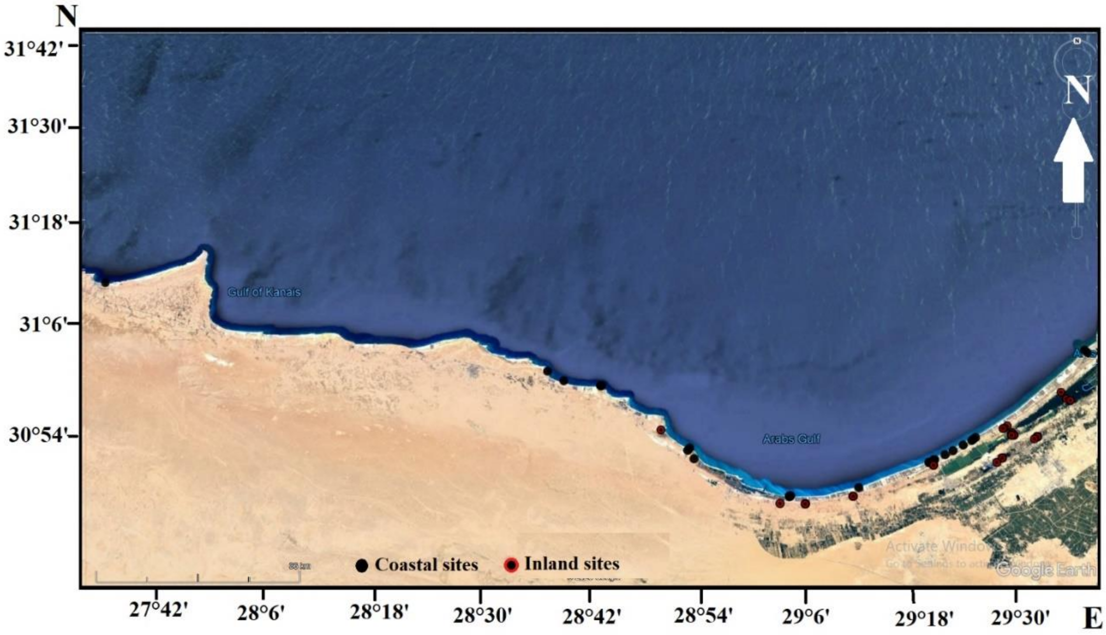

Fig. 1. Spatial distribution of sampled locations across the study region.

Information retrieved from NASA "https://power.larc.nasa.gov/data-access-viewer/" showed that the wind speed range is 4.11 to 4.58 m/s, this information was analysed and used to represent the relative frequency of wind direction at the study area in Figure (2), which showed that the predominant wind direction is the northwest winds.

According to the seashore distance, the investigated area can be subdivided into two habitat types: the coastal salt marshes (at a distance of < 1000 m from the sea shoreline), and the inland salt marshes (distance from the sea shoreline > 1000 m). The geographical coordinates of the sampling sites were determined by using the Global Positioning System GPS which is located on a high-resolution image from Google satellite Maps by the Google Earth Pro program (Fig. 1).

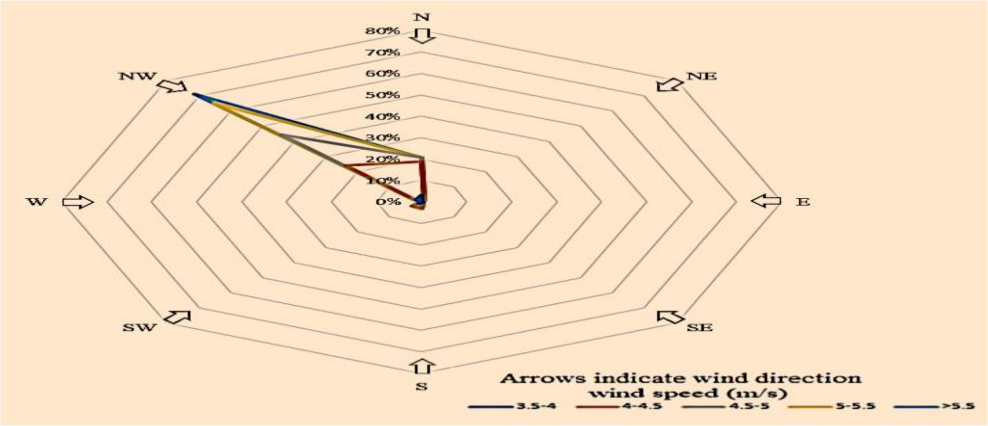

Fig. 2. A wind rose plot showing wind direction of the study area.

A vegetation survey of extreme halophytic plant species was carried out in the year 2021. Fifty-four sites were chosen to demonstrate the variations in vegetation structure that represent the study area's different habitats. Selected sites are distributed as follows: 26 sites in coastal salt marshes and 28 in inland salt marshes. Each site was 40 m × 40 m, estimated according to the minimal area. Floristic records were conducted at each site, utilizing the presence or absence of species as the basis for assessment. The identification of taxa was conducted by utilizing herbarium specimens and associated literature (Täckholm, 1974; Boulos, 2009); The identifications of species underwent modifications via https://wfoplantlist.org/plant-list. The identification of life forms within the documented taxa was conducted by the scheme of Raunkiaer (1934). Species chorology was created based on Eig's classification, which categorizes species into global geographical groupings (Eig, 1931).

Composite soil samples were obtained at a depth of 25 cm. Each sample was carefully placed into appropriately labeled plastic bags, which contained detailed information about the specific site from where it was collected. These bags were sent to the lab for examination. The specimens were subjected to air drying and subsequently crossed a 2-mm mesh sieve to exclude pebbles or debris. The processed samples were then carefully kept in bags. the prepared soil is used for physical and chemical investigation to determine how a variety of soil characteristics affect the spatial distribution of the species under study (Allen *et al.*, 1974).

The soil parameters measured in each site were: Electrical Conductivity (EC), pH, chlorides, sulphates, sodium, soil moisture content, soil texture, calcium carbonate, organic matter, potassium, calcium, magnesium, available potassium, phosphorus, and nitrogen. The calculation of the Sodium Adsorption Ratio (SAR) and Potassium Adsorption Ratio (PAR) was performed to quantify the impacts of various ions present in the soil (McKell and Goodin, 1984).

The moisture content was calculated and expressed as moisture percent after Youssef (2009). Soil pH and electrical conductivity were assessed in soil-water extracts (1:2) (Allen *et al.*, 1974). The determination of chlorides was conducted using the titration technique according to Jackson and Thomas (1960). Barium chloride solution was used for sulphate estimation (Piper, 2019). The quantification of the extractable cations sodium and potassium was conducted in soil water extracts (Wild *et al.*, 1985). The measurement of calcium and magnesium was performed using atomic emission spectroscopy. The quantification of the overall organic matter content was conducted using the loss on ignition technique. The assessment of soil texture was conducted utilizing the Bouyoucos hydrometer technique (Allen *et al.*, 1974). Collin's calcimeter was used to measure calcium carbonate (Wright, 1934). Titration with hydrochloric acid resulted in determining the amount of bicarbonates (Pierce *et al.*, 1958).

The importance of variation in the environmental variables was assessed by a one-way analysis of variance to determine which factors would influence the distribution of extreme halophytic plant species (SPSS, 2006).

Results

Floristic composition

Regarding the distance from the sea, two habitats have been identified in this survey: the coastal and inland salt marshes. The floristic composition of halophytic plant communities in the two habitats showed great variation (Appendix A). In coastal salt marshes, 148 plant species were recorded related to 105 genera and 33 families inhabiting 26 sites. Dicots are represented by 27 families with 120 species, while six families with 28 species are belonging to monocots. On the contrary side, the inland salt marshes, 86 species related to 67 genera and 22 distinct families within 28 sites, the contribution of monocots was 4 families and 25 species, while dicots were represented by 18 families and 61 species (Table 1).

The most abundant families in the coastal salt marshes were Asteraceae with 24 species accounting for approximately 16 % of the species composition then comes Poaceae (21 species ≈ 14 %), Fabaceae (20 species ≈ 14 %), and Amaranthaceae (19 species ≈ 13 %). On the contrary, there were 13 families with inadequate representation, each with a single species. In inland salt marshes, the prevalent families were Poaceae (21 species ≈ 24 %), and Asteraceae (13 species ≈ 15 %), afterward Amaranthaceae and Fabaceae with 11 species each which represents 26 %. Nevertheless, other families were only made up of a small number of species (Fig. 3).Within the coastal salt marsh, the dominant genus were *Astragalus* which has five species, followed the genus *Lotus* and *Plantago* comprised four species each, while six genera are each composed of three species, and There are 21 genera, each consisting of two species; the remaining 75 genera consist of a single species each. On the other hand, in the inland salt marshes *Avena, Salsola, Lotus,* and *Plantago* were the genera with the highest species numbers.

Regarding the distribution of different taxa within the coastal and inland salt marshes, it was indicated that when the distance from the sea shoreline increases (> 1000 m), the numbers of species, genera, and families decrease (Table 1). The taxonomic diversity of coastal salt marshes is 1.41 for the ratio of (species/genera) and 3.18 for the ratio of genera/families. On the other hand, the value within inland salt marshes was 1.28 for the species/genera ratio and the genera/families ratio was 3.05 (Table 1).

Vegetation analysis of coastal salt marsh habitats showed that perennial plant species predominated with 84 species representing about 57 % of the total species. Among the most common perennial species are *Limoniastrum monopetalum* and *Tetraena alba*. While the annuals are 64 species (43 %) also the most common are *Reichardia tingitana* and *Senecio glaucus*. On the other hand, the inland salt marsh is inhabited by 43 perennials and 43 annuals. Among the common perennials are *Arthrocnemum macrostachyum* and *Phragmites australis*. While the common annuals are: *Sphenopus divaricatus* and *Minuartia geniculata* (Table 1).

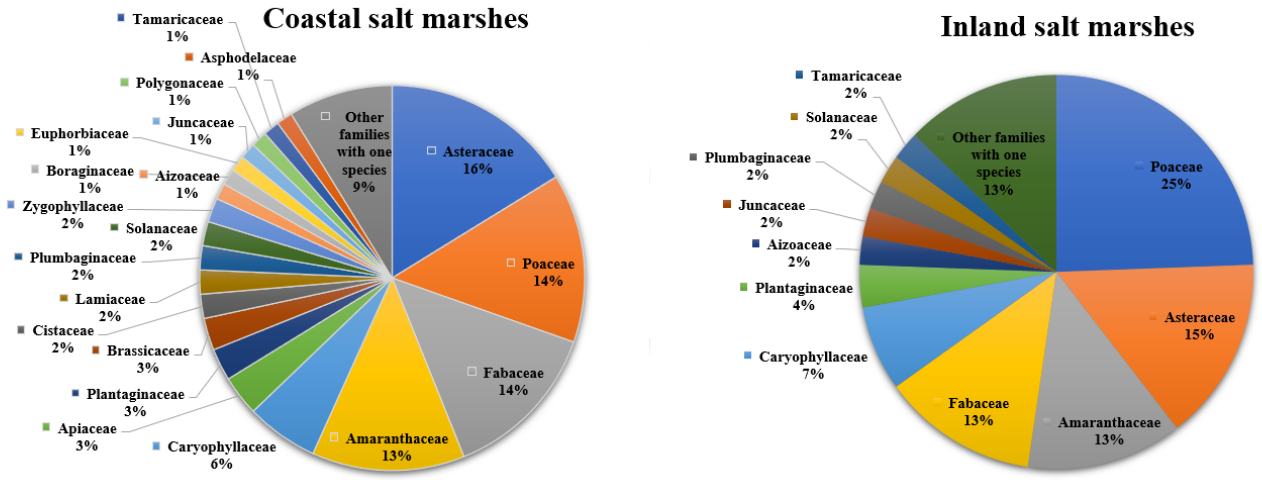

Fig. 3. The proportional contribution of plant families along the coastal and inland salt marshes.

Table 1. Floristic composition of the 2 habitat types.

Floristic diversity	**Coastal salt marshes**	**Inland salt marshes**
First dominant	*Limoniastrum monopetalum* (L.) Boiss.	*Arthrocnemum macrostachyum* (Moric.) K. Koch
Second dominant	*Tetraena alba* (L.f.) Beier & Thulin	*Phragmites australis* (cav.) Trin. ex steud.
Number of Sites	26	28
Number of families	33	22
Number of genera	105	67
Number of Species	148	86
Species/Genera	1.41	1.28
Genera/families	3.18	3.05

Six types of life forms have been recorded; the prevalent life form observed was therophytes with 64 species and constituted about 43 % of the total recorded species, followed by chamaephytes (38 species ≈ 25 %), hemicryptophyte (25 species ≈ 17 %), phanerophytes (13 species ≈ 9 %), geophytes (7 species ≈ 5 %), and the parasites were composed of a single species in the coastal salt marshes. Life form in the inland salt marshes is grouped under five types: therophytes (43 species ≈ 50 %), chamaephytes (16 species ≈ 19 %), hemicryptophytes (14 species ≈ 16 %), phanerophytes (10 species ≈ 12 %), and geophytes with only 3 species (Fig. 4).

The composition of life forms in the two habitats of the research region primarily consisted of therophytes plants, with a partial presence of chamaephytes, hemicryptophytes, phanerophytes, and geophytes.

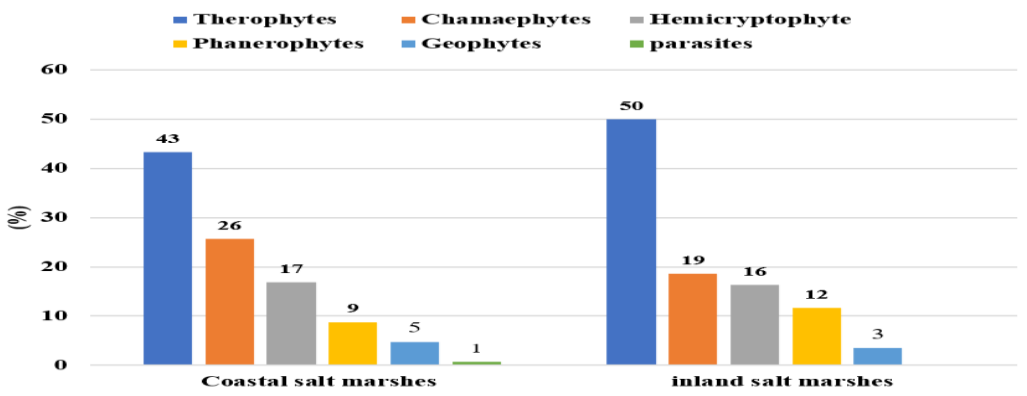

Fig. 4. The life form of species identified in coastal and inland salt marshes.

Chorological affinities

The floristic categories exhibit considerable variation across different habitats as shown in (Fig. 5 and table 2). Chorological analysis revealed the abundance of the Mediterranean taxa in the coastal salt marshes with 102 species which represent about 69 % of the total species. These taxa are either Mono-regional (25 species ≈ 17 %), Bi-regionals (36 species ≈ 24 %), or Pluri-regionals (41 species ≈ 28 %). While in the inland salt marsh, the number of Mediterranean elements is 56 species (65 %). It is classified into 12 species (14 %) Mono-regional, Bi-regionals (18 species ≈ 21 %), and Pluri-regionals (26 species ≈ 30 %).

In coastal salt marshes, the Saharo-Arabian taxa comprised 75 species accounting for 51 % of the total species. These taxa were either Mono-regional (17 species ≈ 12 %), Bi-regionals (9 species ≈ 6 %) or Pluri-regionals (29 species ≈ 20 %), while in inland salt marsh habitat the Mono-regional Saharo-Arabian element is represented by 9 species ≈ 10 %, Bi-regional elements accounted for (16 species ≈ 19 %), and Pluri-regionals accounted for (21 species ≈ 24 %).

The worldwide chorotype (Cosmopolitan, Palaeotropical, and Pantropical) was represented by 15 species (10 %) in coastal salt marshes, while 12 species (14 %) were found in inland salt marshes. It was found that the Mediterranean elements extending to the Saharan-Arabian element have a significantly higher presence than the Mediterranean taxa, which extends into the Euro-Siberian component (Fig. 5 and Table 2).

Table 2. The number of recorded species and the proportion of each floristic category in the study region. COSM: Cosmopolitan, PAL: Palaeotropical, PAN: Pantropical, MED: Mediterranean, SA: Saharo- Arabian, IT: Irano- Turanian, ES: Euro-Siberian, SU: Sudanian, SZ: Sudano-Zambezian, AUST: Australia.

Floristic category	Habitat type			
	Coastal salt marshes		Inland salt marshes	
	Species number	percentage	Species number	percentage
Mono-regional				
MED	25	16.89	12	13.95
SA	17	11.49	9	10.47
AUST	2	1.35	1	1.16
IT	2	1.35	-	-
Total	**46**	**31.08**	**22**	**25.58**
Bi-regionals				
MED+SA	20	13.51	8	9.3
MED+IT	12	8.11	9	10.47
MED+ES	4	2.7	1	1.16
SA+IT	6	4.05	5	5.81
SA+SU	1	0.68	2	2.33
SA+SZ	2	1.35	1	1.16
SZ+IT	1	0.68	-	-
Total	**46**	**31.08**	**26**	**30.23**
Pluri-regionals				
MED+IT+ES	12	8.11	5	5.81
MED+SA+IT	21	14.19	17	19.77
MED+SA+ES	2	1.35	1	1.16
MED+SA+SU	1	0.68	-	-
MED+SA+SZ	1	0.68	-	-
MED+SA+IT+ES	2	1.35	2	2.33
MED+SA+IT+SZ	2	1.35	1	1.16
Total	**41**	**27.71**	**26**	**30.23**
Worldwide				
COSM	11	7.43	9	10.47
PAL	2	1.35	1	1.16
PAN	2	1.35	2	2.33
Total	**15**	**10.13**	**12**	**13.96**

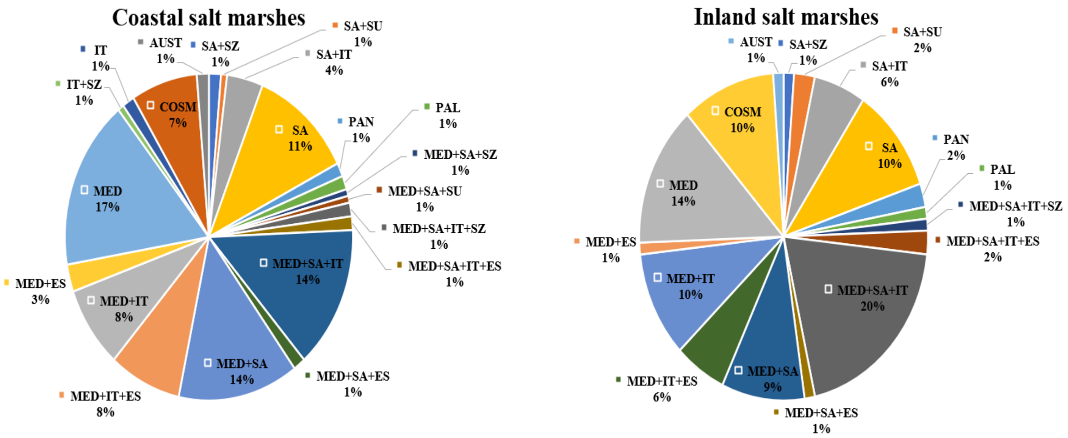

Fig. 5. Chorological analysis of the plant species in the coastal and inland salt marshes (abbreviations according to Table 2).

The soil characters

Considerable variation in the environmental parameters among the sites of coastal and inland salt marsh habitats. Most of the environmental factors were affected significantly, except for elevation, soil water content, pH, and organic matter. For more details, see Table (3). The soil texture in the two habitat types primarily consists of sand, and it exhibited a statistically significant variance ($p < 0.01$) between the coastal and inland salt marshes. Distance from the sea, Electric Conductivity (EC), and sodium showed the most highly significant variations among the two habitat types. The inland salt marsh attained the highest value of EC (27.05 dS/m), soil water content (12.07 %), sodium (184.05 mEq/L), chloride (102.90 mEq/L), calcium ions (20.01 mEq/L), Sodium Adsorption Ratio (SAR) (29.31), while had the lowest of elevation (3.5 m), calcium carbonates (23.85 %), and organic matter (0.27 %). Obviously, inland salt marsh habitats have higher salinities than coastal ones.

Table 3. The mean ± standard deviation of different environmental parameters of the two studied habitats. The F-values are indicated. (ns = not statistically significant).

Environmental parameter	Coastal salt marshes	Inland salt marshes	F-value	p-value
Elevation (m)	4.19 ± 2.17	3.50 ± 2.83	0.968^{ns}	0.330
Distance from the sea (m)	491.15 ± 252.67	3750.71 ± 1952.65	68.790***	0.000
Soil moisture content %	11.5 ± 5.34	12.07 ± 7.88	0.092^{ns}	0.763
Electrical Conductivity (dS/m)	8.49 ± 8.83	27.05 ± 15.71	27.022***	0.000
Sand %	88.45 ± 10.06	76.89 ± 12.63	13.232**	0.001
Silt %	6.96 ± 7.68	11.50 ± 6.36	6.072*	0.017
clay %	4.85 ± 3.27	11.87 ± 8.01	16.615***	0.000
Soil pH	8.55 ± 0.42	8.58 ± 0.29	0.084^{ns}	0.773
Organic matter%	0.40 ± 0.37	0.27 ± 0.14	3.118^{ns}	0.083
Calcium carbonates%	35.05 ± 17.31	23.85 ± 16.58	5.679^{*}	0.021
Calcium (mEq/L)	10.92 ± 10.73	20.01 ± 11.59	8.571**	0.005
Magnesium (mEq/L)	28.5 ± 30.51	61.34 ± 41.06	10.585**	0.002
Sodium (mEq/L)	53.2 ± 66.68	184.05 ± 123.2	22.205***	0.000
Potassium (mEq/L)	2.96 ± 3.61	7.71 ± 5.54	13.124**	0.001

Bicarbonates (mEq/L)	2.75 ± 2.66	3.10 ± 2.34	0.250^{ns}	0.619
Chlorides (mEq/L)	55.05 ± 121.35	102.90 ± 66.31	3.171^{ns}	0.081
Sulphates (mEq/L)	23.11 ± 22.82	54.27 ± 27.01	20.037***	0.000
Available nitrogen (mg/Kg)	3.70 ± 2.96	5.33 ± 4.08	2.701^{ns}	0.106
Available phosphorus (mg/Kg)	11.11 ± 7.43	17.40 ± 8.51	8.006**	0.007
Available Potassium (mg/Kg)	444.23 ± 266.05	908.04 ± 426.31	21.763***	0.000
Sodium Adsorption Ratio	11.23 ± 11.52	29.31 ± 19.36	16.440***	0.000
Potassium Adsorption Ratio	0.71 ± 0.70	1.36 ± 1.16	5.775^{*}	0.020

Discussion

Soil salinity is increasingly becoming a significant concern in numerous regions worldwide, particularly in arid areas, because of various factors, both natural and anthropogenic reasons. A significant proliferation of halophytes has occurred in mostly arid environments (Breckle, 2002; Evans and Geerken, 2004; Khan and Qaiser, 2006). In addition, climate change is influencing the expansion and steadiness of salt marsh habitats around the planet. The soil salinity and flooding patterns may be altered by sea level rise, allowing for the expansion of extreme halophytic plant species. The presence of these disturbances significantly influence the ecological dynamics of halophyte distribution and the inland migration of marshes (Crosby *et al.*, 2016; Valiela *et al.*, 2018; Smith, 2020).

The distribution of halophytic plant species in Egypt is wide-ranging. This distribution can be attributed to the abundance of saline environments located near the Mediterranean Sea, and based on the global distribution of salt marshes, the studied sites were chosen to represent coastal and inland salt marshes to demonstrate the impact of closeness to the sea on extreme halophytes distribution and salt marsh migration potential.

The coastal salt marsh environment has the most species documented (148 species) which represent 89 % of the total species. While the inland salt marsh is comprised of 86 species that represent about 52.12 %. It is worth mentioning that the predominant flowering plant class was dicotyledons. This result is accepted as dicot halophytes exhibit greater salinity tolerance in comparison to monocots (Flowers and Colmer, 2008; Sharma *et al.*, 2016).

The species-rich families in the coastal salt marshes were Asteraceae, Poaceae, Fabaceae, and Amaranthaceae. While, in inland salt marshes the largest families were Poaceae, Asteraceae, Amaranthaceae, and Fabaceae. These families are widespread within the flora of the Mediterranean North African region (Quézel, 1978). This finding is consistent with Aronson (1989) who reported that Asteraceae and Amaranthaceae are representing the highest proportion of xerophytes and salt-tolerant genera and species in the Mediterranean region. In addition, Poaceae and Asteraceae are families with a wide ecological range of distribution because of their adaptation to harsh conditions and they exhibit efficient wind-mediated seed dispersal. Moreover, Poaceae plants can tolerate drought and salinity pressure (van Rheede van Oudtshoorn *et al.*, 1999; El-Zeiny *et al.*, 2022).

Plant life forms have emerged as a result of evolutionary adaptations to environmental and climatic conditions (Kassas, 1955; Ayyad and El-Ghareeh, 1982). According to our findings, therophytes were the prevalent living type in salt marsh ecosystems, followed by chamaephytes. The prevalence of therophytes appears to be a result of their adaptation to the arid climate, topographical variations, and biotic factors (Heneidy and Bidak, 2001). Therophytes were the common type in arid and semi-arid regions, showing outstanding adaptations to moderate amounts of moisture in the winter and long periods of dryness in the summer. Salinity did not impose any limitations on their distribution. Therophytes frequently constituted a substantial proportion, ranging from 40% to 50%, of the overall species composition within the Mediterranean region (Ayyad and El-Ghareeh, 1982; Da Costa *et al.*, 2007; El-Amier *et al.*, 2015). The elevated values observed in chamaephytes may be attributed to their capacity to withstand various stressors, such as drought, salinity, and human and animal interference (Khalik *et al.*, 2013; Mashaly *et al.*, 2015; Alzamel, 2022).

Growth forms encompass the structural morphotypes that plants have developed over time through evolutionary processes. These growth forms enable plants to effectively interact with their surrounding environment using of various morphological, physiological, and phenological adaptations (Arrigoni, 1996). The proportion of the life span varied in the study area. In coastal salt marshes, the perennials are the most predominant species (84 species; 75 % of the total species), followed by the annual species (64 species; 43 % of the total species). In the inland salt marshes, annuals and perennials attained the same presence percentages which account for 43 species that represent 50 % each.

The prevalence of perennial plants in the habitat can be ascribed to the characteristics of the habitat type, climatic conditions, and soil that are insufficient for the emergence of many annual species. The relatively high presence of annuals can be linked to their short life cycle, which allows plants to withstand high levels of disturbance and harsh circumstances (Harper, 1977; El-Amier *et al.*, 2016). Furthermore, it is prevalent for annual species to associate with perennials in arid and semi-arid settings. Perennial plants typically mitigate the adverse environmental conditions present beneath their canopies and augment the fertility of the soil. As a result, perennial canopies typically provide more secure environments for the establishment of annuals, resulting in higher densities and greater productivity of annuals in their area compared to adjacent areas devoid of vegetation (Cortina and Maestre, 2005; Quevedo-Robledo *et al.*, 2010).

Furthermore, it is interesting to note that halophytes can be found in a broad spectrum of climates, from coastal regions to mountain slopes. The observation suggests that the majority of tropical halophytes exhibit perennial growth patterns, while the majority of wet temperate halophytes exhibit annual growth patterns (Khan, 2003).

In the present study, the chorological analysis determined a considerable presence of different Mediterranean and Saharo-Arabian elements in both of coastal and inland salt marsh habitats. While the representation of other floristic categories in different habitats was found to be poor or absent. This observation suggests that the research area's chorological analysis aligns reasonably well with Egypt's north-south climate regions. The findings of the present study regarding chorological analysis support the notion that Egypt serves as a convergence point for floristic elements originating from a minimum of four distinct phytogeographical regions: African Sudano-Zambesian, Asian Irano-Turanian, Afro-Asian Sahro-Arabian, and Euro-Afro-Asian Mediterranean (El-Hadidi, 1993; Mashaly *et al.*, 2015). The prevalence of interregional species, including bi-regionals and pluri-regionals, over mono-regional species can be attributed to the existence of interzonal habitats, such as anthropogenic sites. Furthermore, the prevalence of Saharo-Arabian chorotypes, whether in their pure form or by infiltration into other regions, is indicative of the influence exerted by both Mediterranean and Saharo-Sindian chorotypes on the vegetation within the studied region. Consistent findings were observed in previous studies e.g., Galal and Fawzy (2007), El-Ghani *et al.* (2013), and El-Amier *et al.* (2016). The natural habitats of halophytes, which may be found all over the planet, include salt marshes, seashores, estuaries, and saline deserts (Epstein *et al.*, 1980). These plants can tolerate a diverse spectrum of salinity levels, extending beyond the concentration that exists in seawater (Yensen, 2006). The soil in which halophytes often thrive has an increase in salt because of accelerated water evaporation, especially during the summer season. Consequently, the surface of the soil exhibits elevated levels of salinity (Khan and Ungar, 1998).

In the current study, the soil salinity exhibited a large range varied from 8.49 dS/m as in the coastal salt marshes to 27.05 dS/m in inland salt marshes, which reflects that almost all the selected sites are saline. According to the soil salinity classes, almost all the soil specimens collected from the area under study can be classified as strongly or extremely saline (Ivushkin *et al.*, 2019). For more details, see Table (4).

Table 4. Soil salinity classes according to Ivushkin *et al.* (2019).

Classification	Non-Saline	Slightly Saline	Moderately Saline	Strongly Saline	Extremely Saline
EC/dS m^{-1}	0–2	2–4	4–8	8–16	>16

The main determinant influencing the presence of salinity in the studied area can be ascribed to the phenomenon of capillary rise, as well as the process of soil surface water evaporation, which subsequently led to the deposition of salts (Schofield and Kirkby, 2003; Özcan *et al.*, 2009). It is of interest to denote that in the present study, the areas closest to the shoreline (> 1000 m) which represent the coastal salt marshes have the lowest soil salinity compared to the inland saltmarshes where the wind speed ranged from 4.11 to 4.58 m/s. This result is accepted as several studies have shown a considerable influence of wind on the creation of saline droplets in coastal regions when the wind speed exceeds the limit range of 7 to 11 m/s (Spiel and De Leeuw, 1996; Feliu *et al.*, 2001). In addition, the effect of sea spray created in marine atmospheres is primarily limited to a few meters away from the coast and depletes quickly inland. The influence of gravity on the transportation of chlorides through wind results in a decrease in chloride levels as seashore distance increases (Gustafsson and Franzén, 2000; Morcillo *et al.*, 2000).

The soils that provide a habitat for halophytic plants are characterized by a sandy texture and exhibit low levels of accessible moisture for most of the year. Typically, these soils exhibit a relatively low organic matter level and possess an alkaline soil (Batanouny and Ezzat, 1971; Youssef, 2009). In the present study, organic matter in soil sites ranged from 0.14 % to 0.88 % and PH was ranged from 7.1 to 8.7 which means the soil sites are mostly alkaline. Results showed low available soil moisture in the selected soil sites which agrees with Youssef (2009).

One-way analysis of variance was conducted to assess the impact of soil factors on the species distribution and results showed that electrical conductivity (EC), sodium, and sulphates have a significant effect on the species distribution. This result goes in line with Rozema *et al.* (1985) and Liangpeng *et al.* (2007) as they indicated that resistance to high salinity (EC) was the primary factor associated with the dispersion of halophytic plant species.

It's important to emphasize that in the present study, *Arthrocnemum macrostachyum* and *Phragmites australis* were the most dominant extreme halophytic species in the inland salt marshes; this result goes in line with several studies that pointed out that those species are highly tolerant species which able to resist extreme salt concentration as the maximum salinity range is equal to 200 ds/m (Menzel and Lieth, 2013; Obón *et al.*, 2020; eHALOPH, 2023; Global Biodiversity Information Facility, 2023; International Plant Names Index, 2023).

Data obtained from the NASA website "https://sealevel.nasa.gov/understanding-sea-level/regional-sea-level/overview" showed that seas around the world are rising 3.3 millimetres every year. Furthermore, one consequence of climate change is an increase in the levels of the Earth's oceans, and it is considered one of the major factors that participate in dramatically altering the ecology of salt marsh habitat by increasing soil salinity as well as the global temperature is seeing a rise due to the increased release of greenhouse gases, resulting in the trapping of heat within the Earth's atmosphere. This phenomenon, commonly referred to as global warming, has led to the melting of polar ice sheets and the warming of ocean waters. (Peter, 1997; Smith, 2020).

Salt marshes can adapt to rising sea levels by expanding horizontally into adjacent terrestrial ecosystems. As the ocean level rises, salty sea water is forced inland, resulting in the perpetual inundation of previously arid regions with salt water. In the event of such occurrences, the marsh flora and fauna inhabiting these regions are unable to sustain their existence, resulting in the submergence of the marshland. Furthermore, the soil in inland habitats located further away from the salt marsh may experience increased salinity due to heightened flooding events. The inundation of saltwater has detrimental effects on agricultural fields; however, it is advantageous for the growth and development of marsh vegetation. Agricultural land is negatively impacted by seawater inundation, whereas marsh vegetation benefits. Therefore, the phenomenon resulted in the loss of agricultural land, but the salt marsh vegetation can move towards inland areas and establish growth in the previously occupied farming regions. Marsh migration describes this phenomenon (Hoover *et al.*, 2010; Goetz, 2021).

Salt marshes located near open water are at risk of submergence due to the rise in sea levels. However, marsh migration is a significant mechanism by which these salt marshes can adapt and withstand the impacts of rising sea levels. This explains the result obtained in this study as we can conclude that as the seashore distance increases, the soil salinity increases, inland marsh migration occurs, and floristic diversity decreases as only extreme halophytic species can withstand the high level of disturbance and harsh conditions (Kirwan *et al.*, 2010; Fagherazzi *et al.*, 2019).

The changeover in land value occurs because of the transition from one land cover type to another, specifically due to the horizontal displacement of salt marshes as sea levels rise. If the financial and environmental benefits offered by the salt marsh exceed those of the inland habitat, the obstruction of marsh migration will be unlikely. However, if the value of the inland habitat is greater, coastal towns will attempt to impede marsh migration by the construction of sea walls and other rigid structures. (Borchert *et al.*, 2018; Fagherazzi *et al.*, 2019).

It is of interest to denote that, there are more than 2500 halophytic species have been identified globally. These species are a specialized group of plants that can thrive and reproduce in saline soils. Among them, several could be utilized as profitable crops due to their ecological and economic value. For instance, *Atriplex halimus* and *Suaeda vermiculata* are only two of the many halophytic plants used in traditional medicine across the globe (Bidak *et al.*, 2015; Kabbash, 2016). These plants offer various goods and services, including food, fodder, biofuel, medicine, and ornamentals (Abdelly *et al.*, 2006; Mohsen *et al.*, 2015). Furthermore, the halophytic plant species cover a large field of applications, making their development costs worthwhile. By investing a few million dollars over several years in the development of halophytes, the resulting value to the community can far exceed the initial investment. Moreover, the appreciation in land value resulting from the cultivation of a profitable halophyte crop can sufficiently compensate for the development costs.

Conclusion

The current study shows that as seashore distance increases, there is a corresponding increase in soil salinity, marsh migration occurs inland, and a decrease in floristic composition. This decline in diversity because only extreme halophytic species can tolerate high levels of disturbance and harsh environmental circumstances. Consequently, the trend of global migration of temperate salt marsh habitats involves the migration of these ecosystems towards inland areas away from the shorelines in the wake of sea level rise.

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Appendix A. List of plant species recorded in the coastal and inland habitat along the study area.

Family	Species	Coastal salt marsh plant	Inland salt marsh plant
Aizoaceae	*Mesembryanthemum crystallinum* L.	+	+
	Mesembryanthemum nodiflorum L.	+	+
Amaranthaceae	*Anabasis articulata* (Forssk.) Moq	+	-
	Anabasis oropediorum Maire	+	-
	Arthrocnemum macrostachyum (Moric.) K. Koch	+	+
	Atriplex coriacea Forssk.	+	+
	Atriplex halimus L.	+	+
	Atriplex semibaccata R. Br.	+	-
	Bassia indica (Wight) A. J.Scott	+	-
	Bassia muricata (L.) Asch	+	-
	Chenopodium album L.	+	-
	Chenopodium murale L.	+	-
	Halocnemum strobilaceum (Pall.) M. Biel.	+	+
	Noaea mucronata (Forssk.) Asch. & Schweinf.	+	-
	Salsola longifolia Forssk.	+	+
	Salsola tetragona Delile	+	+
	Salsola tetrandra Forssk.	+	+

	Sarcocornia fruticosa (L.) A.J.Scott	+	+
	Suaeda pruinosa Lange	+	+
	Suaeda vermiculata Forssk. ex J.F.Gmel.	+	+
	Traganum nudatum Delile	+	+
Apiaceae	*Bupleurum semicompositum* L.	+	+
	Daucus syrticus Murb.	+	-
	Deverra tortuosa (Desf.) DC.	+	-
	Eryngium campestre L.	+	-
	Eryngium creticum Lam.	+	-
Apocynaceae	*Cynanchum acutum* L.	+	+
Arecaceae	*Phoenix dactylifera* L.	+	+
Asparagaceae	*Asparagus horridus* L.	+	-
Asphodelaceae	*Asphodelus ramosus* L.	+	-
	Asphodelus tenuifolius Cav.	+	-
Asteraceae	*Anacyclus monanthos* (L.) Thell.	+	+
	Anthemis microsperma Boiss. & Kotschy	+	-
	Artemisia herba-alba Asso	+	-
	Artemisia judaica L.	+	-
	Artemisia monosperma Delile	+	+
	Atractylis carduus (Forssk.) C. Chr.	+	-
	Calendula arvensis M.Bieb.	-	+
	Carthamus eriocephalus (Boiss.) Greuter	+	-
	Carthamus lanatus L.	+	-
	Echinops glaberrimus DC.	+	-
	Echinops spinosissimus Turra	+	-
	Erigeron bonariensis L.	-	+
	Filago desertorum Pomel	+	+
	Glebionis coronaria (L.) Cass. ex Spach	-	+
	Ifloga spicata (Forssk.) Sch.Bip.	+	+
	Laphangium luteoalbum (L.) Tzvelev	+	-
	Launaea fragilis (Asso) Pau	+	-
	Launaea nudicaulis (L.) Hook.f.	+	+
	Launaea resedifolia Druce	+	+
	Limbarda crithmoides (L.) Dumort Bassia	+	+
	Picris asplenioides L.	+	-
	Pluchea dioscoridis (L.) DC.	+	+
	Reichardia tingitana (L.) Roth	+	+
	Scorzonera undulata Vahl	+	-
	Senecio aegyptius L.	+	-
	Senecio glaucus L.	+	+
	Sonchus oleraceus (L.) L.	+	-
Boraginaceae	*Echiochilon fruticosum* Desf.	+	-
	Echium angustifolium Mill.	+	-

Brassicaceae	*Brassica tournefortii* Gouan	+	-
	Cakile maritima Scop.	+	-
	Carrichtera annua (L.) DC.	+	-
	Matthiola longipetala (vent.) DC.	+	-
Caryophyllaceae	*Gymnocarpos decander* Forssk.	+	-
	Herniaria hemistemon J.Gay	+	-
	Minuartia geniculata (Poir.) Thell.	+	+
	Polycarpaea repens (Forssk.) Asch. & Schweinf.	-	+
	Polycarpon tetraphyllum (L.) L.	-	+
	Silene rubella L.	+	-
	Silene uniflora Roth	+	-
	Spergula fallax (Lowe) E.H.L. Krause	+	+
	Spergularia diandra (Guss.) Heldr.	+	+
	Spergularia marina (L.) Griseb	+	+
	Spergularia media (L.) C.Pres	+	-
Casuarinaceae	*Casuarina equisetifolia* L.	-	+
Cistaceae	*Helianthemum kahiricum* Delile	+	-
	Helianthemum lippii (L.) Dum.Cours.	+	-
	Helianthemum stipulatum (Forssk.) C.Chr.	+	-
Cyperaceae	*Cyperus conglomeratus* Rottb.	+	-
Euphorbiaceae	*Euphorbia paralias* L.	+	-
	Ricinus communis L.	+	-
Fabaceae	Acacia saligna (Labill.) Wendl.	+	+
	Alhagi graecorum Boiss.	+	+
	Astragalus annularis Forssk.	+	-
	Astragalus boeticus L.	+	-
	Astragalus peregrinus Vahl	+	-
	Astragalus spinosus (Forssk.) Muschl.	+	+
	Astragalus stella L.	+	-
	Hippocrepis areolata Desv.	+	-
	Hippocrepis cyclocarpa Murb.	+	-
	Lotus corniculatus L.	+	+
	Lotus creticus L.	+	+
	Lotus halophilus Boiss. & Spruner	+	+
	Lotus polyphyllus E.D.Clarke	+	-
	Medicago polymorpha L.	+	+
	Medicago truncatula Gaertn.	+	+
	Melilotus indicus (L.) All.	-	+
	Onobrychis crista-galli (L.) Lam.	+	+
	Ononis vaginalis M.Vahl	+	-
	Retama raetam (Forssk.) Webb	+	-
	Trigonella stellata Forssk.	+	+
	Urospermum picroides (L.) Scop. ex F.W.Schmidt	+	-

Frankeniaceae	*Frankenia hirsuta* L.	+	+
Geraniaceae	*Erodium crassifolium* L'Hér. ex Aiton	+	+
Juncaceae	*Juncus acutus* L.	+	+
	Juncus rigidus Desf.	+	+
Lamiaceae	*Salvia aegyptiaca* L.	+	-
	Salvia lanigera Poir.	+	-
	Thymbra capitata (L.) Cav.	+	-
Malvaceae	*Malva parviflora* L.	-	+
Nitrariaceae	*Nitraria retusa* (Forssk.) Asch.	+	-
Orobanchaceae	*Orobanche ramosa* L.	+	-
Papaveraceae	*Fumaria densiflora* DC.	+	-
Plantaginaceae	*Plantago albicans* L.	+	-
	Plantago crypsoides Boiss.	+	+
	Plantago lagopus L.	+	-
	Plantago notata Lag.	+	+
	Plantago ovata Forssk.	-	+
Plumbaginaceae	*Limoniastrum monopetalum* (L.) Boiss.	+	+
	Limonium melium (Nyman) Pignatti	+	-
	Limonium pruinosum (L.) Chaz.	+	+
Poaceae	*Aegilops kotschyi* Boiss.	+	+
	Avena barbata Pott ex Link	+	+
	Avena fatua L.	+	+
	Avena sterilis L.	-	+
	Brachypodium distachyon (L.) P.Beauv.	+	-
	Bromus diandrus Roth	+	-
	Bromus rubens L.	+	-
	Cutandia dichotoma (Forssk.) Trab.	+	+
	Cynodon dactylon (L.) Pers.	+	+
	Digitaria ciliaris (Retz.) Koeler	+	+
	Elymus farctus (Viv.) Runemark ex Melderis	+	-
	Hordeum murinum L.	+	+
	Imperata cylindrica (L.) Raeusch	+	+
	Lolium perenne L.	-	+
	Lolium temulentum L.	+	+
	Lygeum spartum Loefl. ex L.	+	-
	Parapholis marginata Runemark	+	+
	Phalaris minor Retz.	+	+
	Phalaris paradoxa L.	+	+
	Phragmites australis (cav.) Trin. ex steud.	+	+
	Piptatherum miliaceum (L.) Coss.	-	+
	polypogon monspeliensis (L.) Desf.	-	+
	Polypogon viridis (Gouan) Breistr.	-	+
	Rostraria cristata (L.) Tzvelev	-	+

	Schismus barbatus (L.) Thell.	+	+
	Sphenopus divaricatus (Govan) Rchb.	+	+
	Sporobolus pungens (Schreb.) Kunth	+	-
Polygonaceae	*Polygonum equisetiforme* Sm.	-	+
	Polygonum glaucum Nutt.	+	-
	Polygonum maritimum L.	+	-
Primulaceae	*Lysimachia arvensis* (L.) U.Manns & Anderb.	-	+
Resedaceae	*Reseda alba* L.	+	-
Rubiaceae	*Crucianella maritima* L.	+	-
Solanaceae	*Lycium europaeum* L.	+	+
	Nicotiana glauca Graham	+	+
	Solanum nigrum L.	+	-
Tamaricaceae	*Tamarix aphylla* (L.) karsten	+	+
	Tamarix senegalensis DC.	+	+
Thymelaeaceae	*Thymelaea hirsuta* (L.) Endl.	+	-
Typhaceae	*Typha latifolia* L.	+	+
Zygophyllaceae	*Tetraena alba* (L.f.) Beier & Thulin	+	+
	Zygophyllum aegyptium Hosny	+	-
	Zygophyllum creticum (L.) Christenh. & Byng	+	-
Total		**148**	**86**