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Halophytes Dispersion Patterns and Soil Salinity Concentration Across the Egyptian North-Western Mediterranean Coast

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Abstract

Global climate change is considered the largest threat to the natural environment. To understand Earth's fundamental climate changes. We must look back for millions of years, without humans, climate altered between glacial and interglacial periods, and thus sea levels rise. Some places are already more vulnerable to climate change impacts, such as the coastal areas, as the rising sea level will increase the risk of flooding and erosion around the coasts affecting the distribution of species, and the dynamics of communities. Quick disperser species such as halophytes appear to be capable of long-distance jumps in the wake of climate change. Accordingly, halophytic plant dispersal to keep up with climate change captured our attention. A vegetation survey was done to assess the ecological situation and the movement of extreme halophytic plant species between spatial locations along the study area. Fifty-four sites were selected to represent the variations in vegetation structure along the salinity gradient. As, the measurement of plant dispersal is vital for understanding plant distribution between different spatial locations, providing an effective model of plant dispersal, and predicting future plant distribution and assemblages.

Keywords: Distribution patterns, Extreme halophytes, Salt marsh, Sea level rise, Soil salinity zones.

Introduction

Global climate change is already considered the largest, most pervasive threat to the natural environment and societies around the world **(Markham, 1996, McCarty, 2001, Council, 2008**). Without humans, for millions of years, climate altered between glacial and interglacial periods. An ice age is a period where global temperatures drop so significantly that glaciers advance and cover over one third of Earth's surface both laterally and longitudinally. During an ice age, glacial is the period where glacial advancement occurs. While an interglacial period is the warmer period of time between ice ages where glaciers retreat, and sea levels rise (**Köhler and van de Wal, 2020, Information, 2021)**. Some places are already more vulnerable to climate impact such as the coastal areas as the conditions like sea level rise will increase the risk of flooding and erosion around the coasts in addition to the warmer temperature that affected the phenology and distribution of species, and the dynamics of communities. These conditions have advanced to the point where whole communities have to relocate and therefore entail long-distance dispersal of the plant species to survive **(Trakhtenbrot *et al.*, 2005, Fagherazzi *et al.*, 2019, Heer *et al.*, 2019, Smith, 2020, Goetz, 2021).** In the paleolithic records, there are a sherd of evidence that the dispersal is an adaptive trait which can be rapid enough to track climate change **(Hamilton and May, 1977, Pitelka and Group, 1997).** Dispersal is defined as the movement of individuals away from their place of birth that allows species to be established in a new area. The overall ability of plant species to spread over a wide area depends on its ability to mobile, survive, and reproduce **(Croteau, 2010, Wu *et al.*, 2022).** Accordingly, species can be categorized into low dispersers and quick dispersers. low dispersers are species with low dispersal capacity and low adaptability, almost reproducing vegetatively only, and are likely to be more affected by habitat fragmentation and climate change and those populations may face extinction **(Walther *et al.*, 2002).** In contrast, quick disperser species such as halophytes can reproduce both vegetatively and by seeds allowing the plant to spread rapidly from its birth area. Also, quick disperser plants appear to be capable of long-distance jumps in the wake of climate change **(Jefferies and Rudmik, 1991, Pitelka and Group, 1997, Croteau, 2010).** Accordingly, halophytic plant dispersal to keep up with climate change captured our attention. Halophytes are plants that naturally survive in saline environments. They account for∼1% of the total flora of the world. They are distributed mainly in arid, semi-arid regions and sand-saline wetlands along the tropical and sub-tropical coasts. These plants are adapted to withstand various environmental harsh conditions such as heat, drought, and the stress of salts. Salinity tolerance in halophytes depends on a set of ecological and physiological characteristics that allow them to grow and flourish in high-saline conditions. **(Shaltout *et al.*, 2003, Flowers and Colmer, 2008, Munns and Tester, 2008, Kumari *et al.*, 2015).** As, the measurement of plant dispersal is vital for understanding plant distribution between different spatial locations, providing an effective model of plant dispersal, and predicting future plant distribution and assemblages. In addition, understanding dispersal distance is critical for identifying the locations of potential conservation sites for species conservation and planning. However, dispersal is difficult to measure and there is a relative lack of plant dispersal studies **(Hodkinson and Thompson, 1997, Bullock *et al.*, 2006, Swift *et al.*, 2021).** Accordingly, the main objectives of this research were to establish a field survey and innovative approaches for understanding the structures and spatial distributions of halophytes. It also aims to demonstrate and highlight the importance of implementing a new flexible approach for measuring, and monitoring the halophytes dispersal pattern, which can inform plenty of global applications in ecology.

Materials and Methods

The Study area

The Mediterranean coastal land of Egypt is divided, ecologically, into three sections: western (Mareotic coast), middle (Deltaic coast), and eastern (Sinai Northern coast). **(Zahran *et al.*, 1985, Zahran *et al.*, 1990**). Salt marshes are prominent Western Mediterranean Coastal zone and form an important ecosystem in the region. Extensive sabkhas are present at levels slightly above or below sea level **(El-Shaer and El-Morsy, 2008)**. In addition, according to the global distribution of salt marshes, the study area was chosen to represent the most comprehensive salt marshes habitat area in Mareotic region, Egypt (Fig. 1).

The study was conducted at different sites in the Western Mediterranean Coastal region of Egypt (30°48'15.4"–31°10'28.1" N, 27°39'58.6"–29°42'41.2" E), that belong to the Mareotis sector which extends for about 500 km long and 25–50 km wide, from Sallum Village at Egypt's border with Libya to 20 km west of Alexandria. It is a region of warm coastal deserts, with the warmest summer month having a mean temperature less than 30 °C, and the coldest winter month having a mean temperature above 10 °C; although occasional short rainstorms occur in winter (October to February; little precipitation: 130-190 millimetres / year that decreases gradually to the south), most days are sunny and mild. The average relative humidity was approximately 66.9%. The orientation of the coast, the closeness of the Mediterranean Sea, and the orography are the main factors contributing to the climate of this region. The nearness of the sea has a direct effect on air temperature and humidity, and consequently on evaporation and condensation, but does not increase the amount of rainfall **(Kassas and Zahran, 1967, Abd-El Gawad *et al.*, 2020, Shaltout *et al.*, 2023)**.

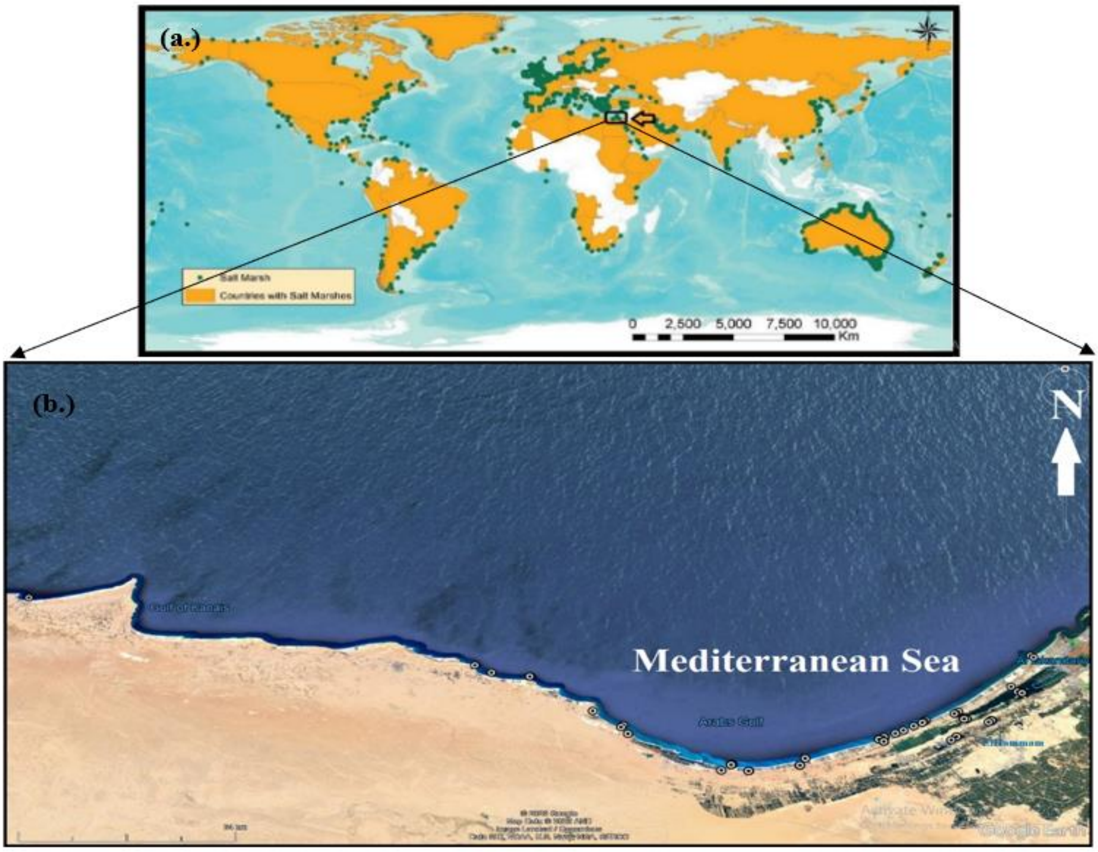


Fig. 1. Location of the study area (a); global distribution of salt marshes (Murray *et al.*, 2011) and the arrow referring to the study area. (b); and the geographic spread of the 54 studied stands.

Floristic analysis

A vegetation survey to assess the ecological situation and the movement of extreme halophytic plant species between spatial locations was carried out in the year 2021 along the study area. Fifty-four sites were selected to represent the variations in vegetation structure representing the different habitats of the study area (along the salinity gradient) perpendicular to the shoreline to about 6.5 km southward. Each site was 40 m × 40 m, estimated according to the minimal area. In each site, floristic records were described with the cover-abundance index **(Braun-Blanquet, 1932)**. Taxa were identified based on voucher herbarium specimens and reference books **(Tackholm and Boulos, 1974, Boulos, 2009**); the species nomenclature was updated using “https://wfoplantlist.org/plant-list”. Species geographical distribution was made to determine the listed species in world geographical groups according to (**Eig, 1931**). The voucher herbarium specimens of the recorded species were prepared and deposited in ALEX herbarium, Faculty of Science, Alexandria University, Egypt.

Soil analysis

Composite soil samples were taken at a depth of 25 cm were collected. Each sample was packed in labelled polyethylene bags with site information and brought to the laboratory. The samples were air-dried, then passed through a sieve with a 2-mm mesh to remove gravel and debris and stored in bags (**Allen *et al.*, 1974**). Soils are prepared for physical and chemical analysis to assess the effect of soil variables on the spatial distribution of the studied species.

The soil parameters measured in each site were: electrical conductivity (EC), pH, chlorides, sulphates, sodium, soil texture, calcium carbonate, organic matter, potassium, calcium, Magnesium, available phosphorus, and nitrogen. The Sodium Adsorption Ratio (SAR) were calculated to express the combined effects of different ions in the soil **(McKell and Goodin, 1984)**.

Soil salinity (EC) and soil reaction (pH) were measured in soil-water extracts (1:2) as described by **(Fresenius *et al.*, 1988)**. The estimation of chlorides was carried out by titration method according to (Jackson and Thomas, 1960). Sulphate content was estimated using barium chloride solution **(Piper, 2019)**. The extractable cations sodium and potassium were determined in soil water extracts **(Wild *et al.*, 1979**), while calcium and magnesium were estimated using atomic absorption spectrometer. The total organic matter was estimated by loss on ignition method. The soil texture was determined by the Bouyoucos hydrometer method **(Allen *et al*., 1974)**. Calcium carbonate was carried out using Collin's calcimeter **(Wright, 1934**). Bicarbonates were determined by titration using Hydrochloric acid **(Pierce *et al.*, 1958)**.

Data analysis

Several studies showed that salinity changes were the most influential metric for distinguishing species habitats and halophyte zones in the marsh site **(Silvestri *et al.*, 2005, Moffett *et al.*, 2010, Hassaine *et al.*, 2014, Shen *et al.*, 2023**). Accordingly, the studied area was divided into zones according to soil salinity classes and soil capability classification (Degree of Limitation) **(Li *et al.*, 2012, Ivushkin *et al.*, 2019)** (Table 1).

Table 1. 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

Additionally, the starting point for all halophytes study is the recognition of so-called soil salinity zones that can be thought of as levels that can be correlated between geographical regions where the halophytic dispersion changes in some measurable way (cf. **(Wade *et al.*, 2011))**. The geographical resolution is determined by the lowest and highest occurrence of the morphospecies evolution. Additional biohorizons include prominent changes in floristic and phytogeographical characteristics. The biohorizons (boundaries) zones allow recognition of broad and easily identifiable intervals of habitat accommodation in different geographical regions that can be widely correlated with confidence. The practice of naming and/or sequentially numbering biozones provides the ecologist with a useful mnemonic and easy means of communication (Fig. 2).

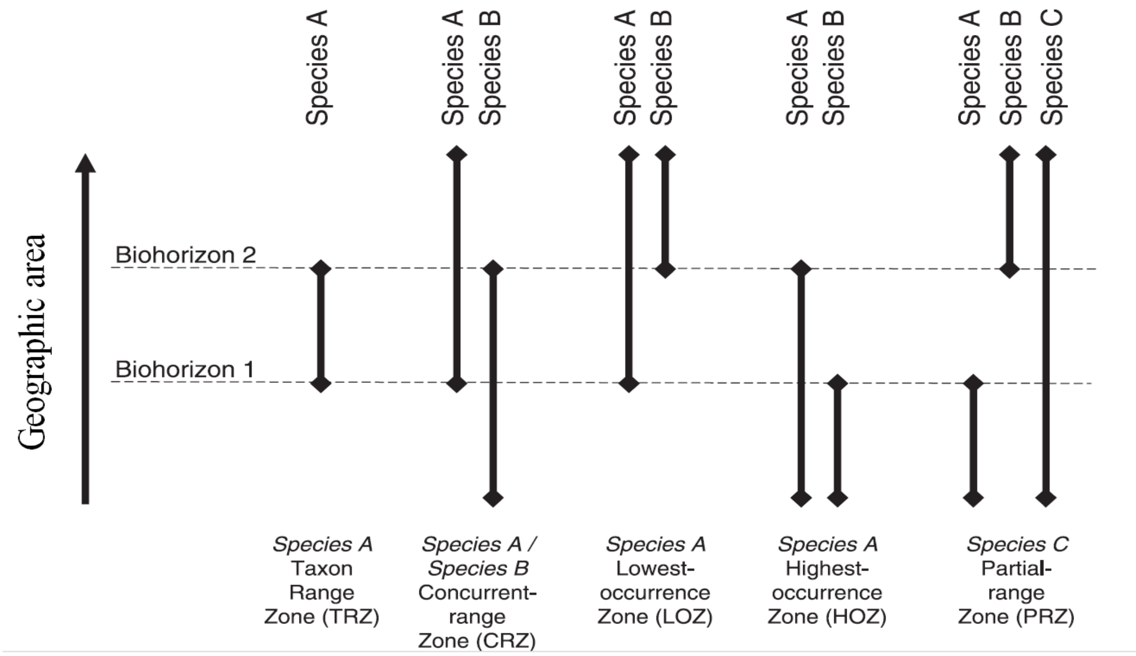


Fig. 2. Nomenclature of biogeographical zones (modified; (Wade *et al*., 2011)).

From the study of the spatial distribution of natural populations of plants, three types of distribution patterns were identified: random, aggregate, and regular **(Pielou, 1960, Bouxin, 1974**). Accordingly, we follow the work of **(Kaiho, 2022)** to estimate dispersal and determine the distribution pattern in each zone along the study.

First, we calculated the diversity reduction percentage in each zone, to define the percentage of species with low dispersal capacity, using the formula of the total number of extinction species for a mass extinction interval divided by the total number of species in a sub-stage just before the extinction. Similarly, we count the number of species disappearances to identify plant species that have a random dispersal pattern; then the tolerance species is estimated to identify plant species that have aggregate dispersal pattern, and finally, the number of species that are restricted in each zone is calculated to identify species with regular dispersal pattern. Also, to detect which environmental factors might affect the distribution of halophytic plant species; the significance of variation in the environmental variables was assessed using a one-way analysis of variance **(SPSS, 2006)**.

Results and Discussion

Biogeographical zones and species dispersal analysis

The trend of soil salinity, which is more pronounced in the study area, could have affected the spatial distribution of halophytes in the region. Accordingly, the studied area (super-zone) was divided into six zones according to salinity concentration, and the six types of zones were so-called logically based on the geographic lowest and highest occurrences of the morphospecies evolution (Fig. 2).

The recorded halophytic species are subdivided into six habitat groups according to soil salinity values as follows: I. Non salt marsh habitat (0-2 dS/m), II. low salt marsh habitat (2-4 dS/m), III. moderate salt marsh habitat (4-8 dS/m), IV. strong salt marsh habitat (8-16 dS/m), V. low extreme salt marsh habitat (16-32 dS/m), and VI. moderate extreme salt marsh habitat (32-64 dS/m).

The recorded species (164 species) are divided into two types according to their salinity tolerance. Accordingly, the selected significant extreme halophytic species (84 species) have been chosen based on their ability to live and adapt in extreme soil salinity (> 16 dS\m). The habitat salinity ranges of the extreme halophytic species (84 species) are determined (Fig. 3). In addition, the extreme halophytes are subdivided into 3 types as follows: strong, moderate, and low. In which, the strong extreme halophytes have been chosen based on the following conditions: 1) they can live and adapt in extreme soil salinity (> 16 dS\m), 2) they correspond to > 16% of cover-abundance in -at least- one sample, 3) they are present in -at least- 16% of the site samples, 4) they have either pluri- or bi-regional geographic distribution, and 5) they have perennial growth form. While the moderate extreme halophytes have the same conditions except the growth form is annual. Furthermore, the low extreme halophytes have at least one condition (salinity tolerance, > 16 dS\m) (Fig. 3).

A total number of 165 species are found in 54 sites along the super-zone. These taxa were either Mono-regional (49 species = 29.70%), Bi-regionals (51 species = 30.91%), and Pluri-regionals (65 species = 39.39%). The super-zone's nomenclature is based on the geographic lowest and highest occurrences of the morphospecies evolution (Fig. 2). This zone is referred to as Phragmites australis Taxon-range Zone. Definition: Total range of the nominate taxon between its Lowest occurrence and highest occurrence. The salinity range was from 0 to 64 dS\m. Diversity reduction%: 93.94% (155 species); spatial distribution pattern: Aggregated distribution: 113 tolerance species, Regular distribution: 52 restricted species, Random distribution: 41 disappearance species. For more details (see Tables 2-4 and Figs. 2-5).

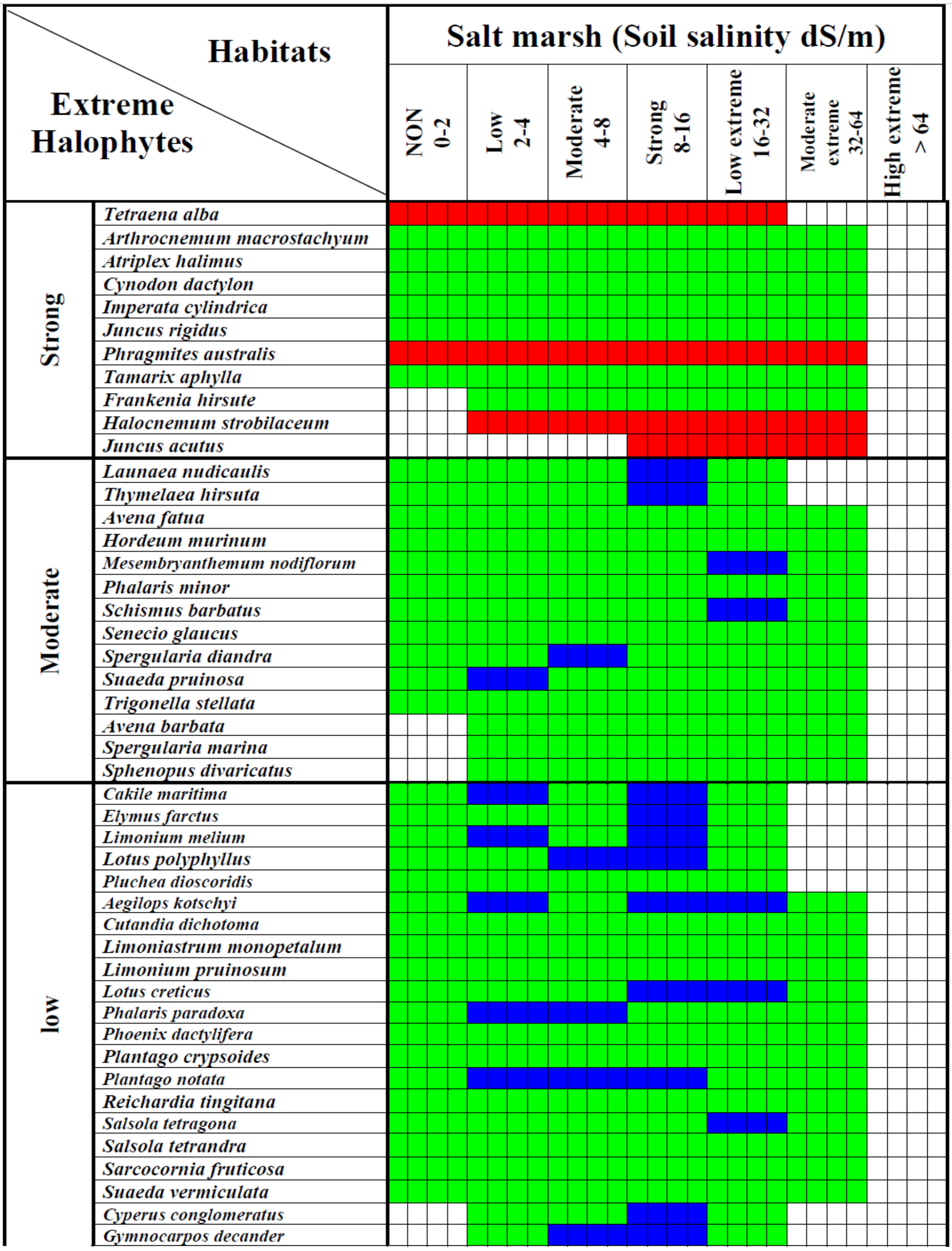
Based on soil salinity classes, the super-zone was divided into six distinct zones, which are characterized as follows:

I. Zone Soil Salinity 1 (Zone SS1): Non salt marsh habitat: 0-2 dS\m

Nomenclature: *Phragmites australis* / *Halocnemum strobilaceum* Lowest occurrence zone. Definition: habitat interval between the lowest occurrence of *Phragmites australis* and the lowest occurrence of *Halocnemum strobilaceum*. Dispersion parameter: Presence%: 5 sites (9.25% of the total number of sites); Halophytic assemblage: 83 species (50.30% of the total number of species); Geographical distribution pattern: Mono-regional (24 species = 28.92%), Bi-regionals (30 species = 36.14%), and Pluri-regionals (29 species = 34.94%); Diversity reduction%: 21.69% (18 species); spatial distribution pattern: Aggregated distribution: 65 tolerance species, Regular distribution: 18 restricted species, Random distribution: No disappearance species. For more details, see Tables 2-4, Figs. 2-5.

II. Zone Soil Salinity 2 (Zone SS2): low salt marsh habitat: 2-4 dS\m

Nomenclature: *Halocnemum strobilaceum / Zygophyllum aegyptium* Concurrent-range Zone. Definition: Concurrent range of the nominate taxa between the lowest occurrence of *Halocnemum strobilaceum* and highest occurrence of *Zygophyllum.*


Habitats
Extreme Halophytes
Salt marsh (Soil salinity dS/m)
NON 0-2
Low 2-4
Moderate 4-8
Strong 8-16
Low extreme 16-32
Moderate extreme 32-64
High extreme > 64
Strong
Tetraena alba
Arthrocnemum macrostachyum
Atriplex halimus
Cynodon dactylon
Imperata cylindrica
Juncus rigidus
Phragmites australis
Tamarix aphylla
Frankenia hirsute
Halocnemum strobilaceum
Juncus acutus
Moderate
Launaea nudicaulis
Thymelaea hirsuta
Avena fatua
Hordeum murinum
Mesembryanthemum nodiflorum
Phalaris minor
Schismus barbatus
Senecio glaucus
Spergularia diandra
Suaeda pruinosa
Trigonella stellata
Avena barbata
Spergularia marina
Sphenopus divaricatus
low
Cakile maritima
Elymus farctus
Limonium melium
Lotus polyphyllus
Pluchea dioscoridis
Aegilops kotschyi
Cutandia dichotoma
Limoniastrum monopetalum
Limonium pruinosum
Lotus creticus
Phalaris paradoxa
Phoenix dactylifera
Plantago crypsoides
Plantago notata
Reichardia tingitana
Salsola tetragona
Salsola tetrandra
Sarcocornia fruticosa
Suaeda vermiculata
Cyperus conglomeratus
Gymnocarpos decander

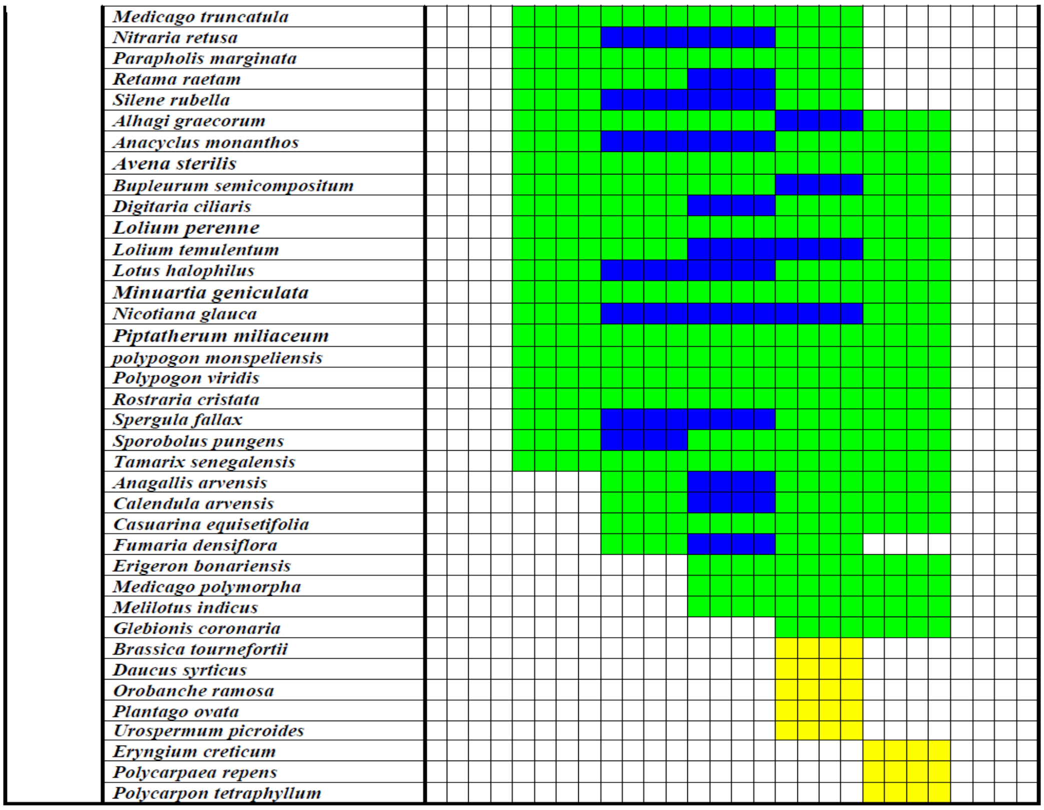


Fig. 3. Extreme halophytic dispersion across the soil salinity classes. Where, Red range: zonal markers (indicator species); yellow range: restricted species; blue range: disappearance species.

aegyptium. Dispersion parameter: Presence%:10 sites (18.51% of the total number of sites); Halophytic assemblage: 109 species (66.06% of the total number of species); Geographical distribution pattern: Mono-regional (34 species =31.19%), Bi-regionals (37 species = 33.95%), and Pluri-regionals (38 species = 34.86%); Diversity reduction%: 20.18% (22 species); spatial distribution pattern: Aggregated distribution: 87 tolerance species, Regular distribution: 15 restricted species, Random distribution: 9 disappearance species. For more details, see Tables 2-4, Figs. 2-5.

Table 2. Characteristics of the identified zones along the study area.

Zones	Nomenclature		Number of sites	Salinity range (dS/m)	Number of species	Geographical distribution pattern		
	Nominate taxa	Zone type				Monoregional	Biregional	pluriregional
SS1	*Phragmites australis / Halocnemum strobilaceum*	Lowest occurrence Zone	5	(0-2)	83	24 (28.92 %)	30 (36.14 %)	29 (34.94 %)
SS2	*Halocnemum strobilaceum / Zygophyllum aegyptium*	Concurrent-range Zone	10	(2-4)	109	34 (31.19 %)	37 (33.95 %)	38 (34.86 %)
SS3	*Phragmites australis*	Partial-range Zone	6	(4-8)	89	24 (26.97 %)	27 (30.34 %)	38 (42.69 %)
SS4	*Juncus acutus / Mesembryanthemum crystallinum*	Concurrent-range Zone	10	(8-16)	71	18 (25.35 %)	22 (30.99 %)	31 (43.66 %)
SS5	*Mesembryanthemum crystallinum / Tetraena alba*	Highest occurrence Zone	8	(16-32)	72	23 (31.94 %)	17 (23.61 %)	32 (44.45 %)
SS6	*Tetraena alba/ Phragmites australis*	Highest occurrence Zone	15	(32-64)	63	18 (28.57 %)	19 (30.16 %)	26 (41.27 %)
Total superzone	*Phragmites australis*	Taxon-range Zone	54	(0-64)	165	49 (29.70 %)	51 (30.91 %)	65 (39.39 %)

Table 3. Diversity reduction percentage and the number of different halophytic species distribution for the identified zones along the study area.

Zones	Species distribution							Total	Diversity reduction (extinction) %
	Halophytes				Extreme Halophytes				
	NON	LOW	Moderate	Strong	LOW	Moderate	Strong		
SS1	18	7	11	8	20	11	8	83	18 (21.69 %)
SS2	0	22	14	11	39	13	10	109	22 (20.18 %)
SS3	0	0	22	7	37	13	10	89	22 (24.72 %)
SS4	0	0	0	19	29	12	11	71	19 (26.76 %)
SS5	0	0	0	0	49	12	11	72	21 (29.17 %)
SS6	0	0	0	0	41	12	10	63	53 (84.13 %)
Total superzone	18	22	22	19	59	14	11	165	155 (93.94 %)

Table 4. Number of halophytic species for each spatial distribution pattern in the identified zones.

Zones	Aggregated distribution (Tolerance species)	Regular distribution (Restricted species)	Random distribution (Disappearance species)
SS1	65	18	0
SS2	87	15	9
SS3	67	7	19
SS4	52	4	23
SS5	51	5	9
SS6	60	3	0
Total superzone	113	52	41

III. Zone Soil Salinity 3 (Zone SS3): moderate salt marsh habitat: 4-8 dS\m. Nomenclature: *Phragmites australis* Partial-range Zone.

Definition: habitat interval characterized by the partial range of the nominate taxon between the high occurrence of *Zygophyllum aegyptium* and lowest occurrence of *Juncus acutus*. Dispersion parameter: Presence%: 6 sites (11.11% of the total number of sites); Halophytic assemblage: 89 species (53.94% of the total number of species); Geographical distribution pattern: Mono-regional (24 species = 26.97%), Bi-regionals (27 species = 30.34%), and Pluri-regionals (38 species = 42.69%); Diversity reduction%: 24.72% (22 species); spatial distribution pattern: Aggregated distribution: 67 tolerance species, Regular distribution: 7 restricted species, Random distribution: 19 disappearance species. For more details, see Tables 2-4, Figs. 2-5.

IV. Zone Soil Salinity 4 (Zone SS4): strong salt marsh habitat: 8-16 dS\m

Nomenclature: *Juncus acutus* / *Mesembryanthemum crystallinum* Concurrent-range Zone. Definition: Concurrent range of the nominate taxa between the lowest occurrence of *Juncus acutus* and highest occurrence of *Mesembryanthemum crystallinum*. Dispersion parameter: Presence%: 10 sites (18.51% of the total number of sites); Halophytic assemblage: 71 species (43.03% of the total number of species); Geographical distribution pattern: Mono-regional (18 species = 25.35%), Bi-regionals (22 species = 30.99%), and Pluri-regionals (31 species = 43.66%); Diversity reduction%: 26.76% (19 species); spatial distribution pattern:

Aggregated distribution: 52 tolerance species, Regular distribution: 4 restricted species, Random distribution: 23 disappearance species. For more details, see Tables 2-4, Figs. 2-5.

V. Zone Soil Salinity 5 (Zone SS5): low extreme salt marsh habitat: 16-32 dS\m.

Nomenclature: *Mesembryanthemum crystallinum \ Tetraena alba* Highest occurrence. Definition: habitat interval between the highest common occurrence of *Mesembryanthemum crystallinum* and the highest occurrence of the *Tetraena alba* index. Dispersion parameter: Presence%: 8 sites (14.81% of the total number of sites); Halophytic assemblage: 72 species (43.64% of the total number of species); Geographical distribution pattern: Mono-regional (23 species = 31.94%), Bi-regionals (17 species = 23.61%), and Pluri-regionals (32 species = 44.45%); Diversity reduction%: 29.17% (21 species); spatial distribution pattern: Aggregated distribution: 51 tolerance species, Regular distribution: 5 restricted species, Random distribution: 9 disappearance species. For more details, see Tables 2-4, Figs. 2-5.

VI. Zone Soil Salinity 6 (Zone SS6): moderate extreme salt marsh habitat: 32-64 dS\m.

Nomenclature: *Tetraena alba \ Phragmites australis* Highest occurrence Zone. Definition: habitat interval between the highest occurrence of *Tetraena alba* and the highest occurrence of the *Phragmites australis* index. Dispersion parameter: Presence%: 15 sites (27.78% of the total number of sites); Halophytic assemblage: 63 species (38.18% of the total number of species); Geographical distribution pattern: Mono-regional (18 species = 28.57%), Bi-regionals (19 species = 30.16%), and Pluri-regionals (26 species = 41.27%); Diversity reduction%: 84.13% (53 species); spatial distribution pattern: Aggregated distribution: 60 tolerance species, Regular distribution: 3 restricted species, Random distribution: No disappearance species. For more details, see Tables 2-4, Figs. 2-5.

Soil salinity can affect the community structure and diversity of wild communities **(Andreasen and Skovgaard, 2009, Pinke *et al.*, 2010, El-Amier and Abdul-Kader, 2015, Abdel-Farid *et al.*, 2020)**. As a result, the proportion of diversity reduction (extinction%) increased with the increase of salinity along the identified zones (Table 3). Any population in a community, at a given scale of observation, presents three types of distribution patterns: aggregated, regular, and random. Aggregation is a common pattern of species distribution **(Pielou, 1960, Bouxin, 1974)**. Accordingly, our result showed that the halophytic species along the study area followed this general pattern (Table 4). As salinity increases, A minority of species can adapt to this harsh condition. Accordingly, restricted species that represent regular distribution pattern decrease along the six identified salinity classes (Table 4). Along the super-zone, the plant communities present anthropogenic activities that may lead to the disappearance of species from some parts of their salinity range along zones. Also, a random distribution pattern may occur because of the random fall of seed **(Pielou, 1960, Bouxin, 1974)**.

It is worth mentioning that in the present study, the case of perennial strong extreme halophytes (10 species*: Arthrocnemum macrostachyum, Atriplex halimus, Cynodon dactylon, Imperata cylindrica, Juncus rigidus, Phragmites australis, Tamarix aphylla, Frankenia hirsuta, Halocnemum strobilaceum, Juncus acutus*) was not affected by disappearance with the presence of human activity. As they have high dispersal capacity and adaptability to harsh conditions. In addition, soil salinity becoming a major problem worldwide due to a variety of natural and man-caused factors **(Breckle, 2002, Evans and Geerken, 2004, Khan and Qaiser, 2006)**. These 10 extreme halophytes can survive and withstand the increase in salinity

(> 64 dS/m), also several studies pointed out that those species are highly tolerant species that can adapt to extreme salt concentrations up to 200 ds/m **(Menzel and Lieth, 2013, Obón *et al.*, 2020, Global Biodiversity Information Facility, 2023)**.

The soil characters

Significant differences in the examined soil variables within the six salinity classes were demonstrated in Table 5. The soil texture in all zones is formed mainly of coarse fractions (sand) and partly of fine fractions (silt and clay). Also, the pH values were alkaline across all groups. Almost all soil salinity parameters as EC, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, $SO4^{-2}$, and SAR showed high significant variation between zones. Some other soil variables showed no significant correlation such as pH, organic matter, calcium carbonate, available phosphorus, and nitrogen. One-way analysis of variance was applied to test the effect of edaphic factors on the species distribution and results showed that almost all salinity parameters especially the electrical conductivity (EC) has a highly significant effect on the distribution of halophytic species within a community. 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 most important factor correlated with the distribution of halophytic plant species.

Table 5. Mean of the soil characteristics of the 6 habitats identified in the study area. The F - values are indicated (ns = not significant (P > 0.05); * P < 0.05; ** P < 0.01; *** P < 0.001).

Soil character	Habitat						F-value	p-value
	SS1	SS2	SS3	SS4	SS5	SS6		
Sand %	93.12	89.80	78.32	79.92	85.04	75.97	2.71*	0.03
Silt %	4.40	4.60	11.33	8.20	6.75	14.93	4.19**	0.003
clay %	2.48	5.60	10.35	11.88	8.83	9.23	1.68^{ns}	0.16
pH	8.70	8.57	8.50	8.55	8.44	8.61	0.39^{ns}	0.85
EC (dS/m)	0.64	2.98	6.35	12.06	22.08	40.67	51.51***	0.00
OM %	0.55	0.35	0.20	0.32	0.40	0.27	1.09^{ns}	0.38
CaCO3 %	28.74	35.13	30.55	24.39	32.95	26.22	0.49^{ns}	0.78
Ca^{+2} (mEq/L)	1.06	8.85	9.42	15.46	17.87	26.42	7.85***	0.00
Mg^{+2}(mEq/L)	5.93	12.46	26.89	34.16	60.71	87.71	13.81***	0.00
Na^{+} (mEq/L)	3.08	17.01	50.38	68.11	158.06	273.56	32.54***	0.00
K^{+}(mEq/L)	0.72	1.66	2.33	3.77	9.16	9.85	9.37***	0.00
Cl^{-} (mEq/L)	7.00	15.85	31.54	47.88	84.74	184.88	8.84***	0.00
HCO_3^{-} (mEq/L)	1.44	1.54	1.92	3.32	4.85	3.4733	2.60*	.037
$SO4^{-2}$ (mEq/L)	1.38	13.87	27.57	43.46	55.52	62.062	10.46***	.000
N (mg/Kg)	4.20	2.62	2.63	4.62	6.13	5.82	1.6^{ns}	0.18
P (mg/Kg)	9.78	12.79	11.68	15.49	13.14	17.94	1.037^{ns}	0.41
SAR	1.99	6.13	12.05	13.49	31.41	38.87	13.45***	0.00

Data obtained from the NASA website https://sealevel.nasa.gov/understanding-sea-level/regional-sea-level/overview showed that seas around the world have risen at an average rate of 3.3 millimetres per year. In addition, Sea level rise is considered one of the major factors that participate in dramatically altering the ecology of salt marsh habitat **(Peter, 1997**, **Smith, 2020**). As, When the sea level rises, salty ocean water moves inland, and areas that used to be dry are flooded with saltwater all the time. When this happens, the halophytes in these areas cannot survive, the marshes closest to open water will drown, and farther inland habitats become salty from increased flooding, this is a good condition for marsh plants that can move and establish inland **(Hoover *et al.*, 2010, Kirwan *et al.*, 2010, Fagherazzi *et al.*, 2019, Goetz, 2021)**. Thus, although the anthropogenic factor seems to be responsible for the distribution of species, the sea level change and soil salinity are responsible for the halophytic dispersion in salt marches areas worldwide.

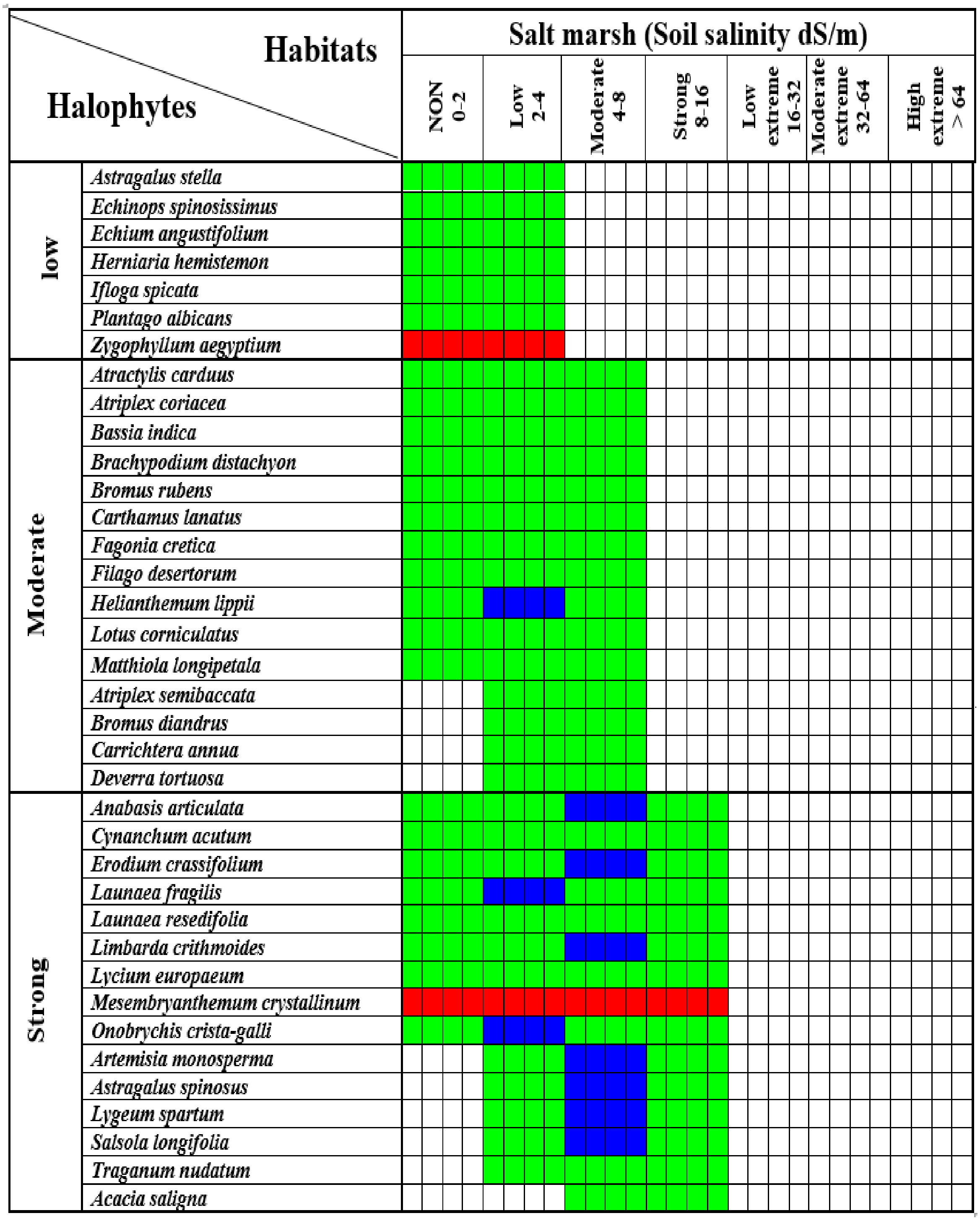


Fig. 4. Tolerance halophytic dispersion across the soil salinity classes. Where, Red range: zonal markers (indicator species); blue range: disappearance species.

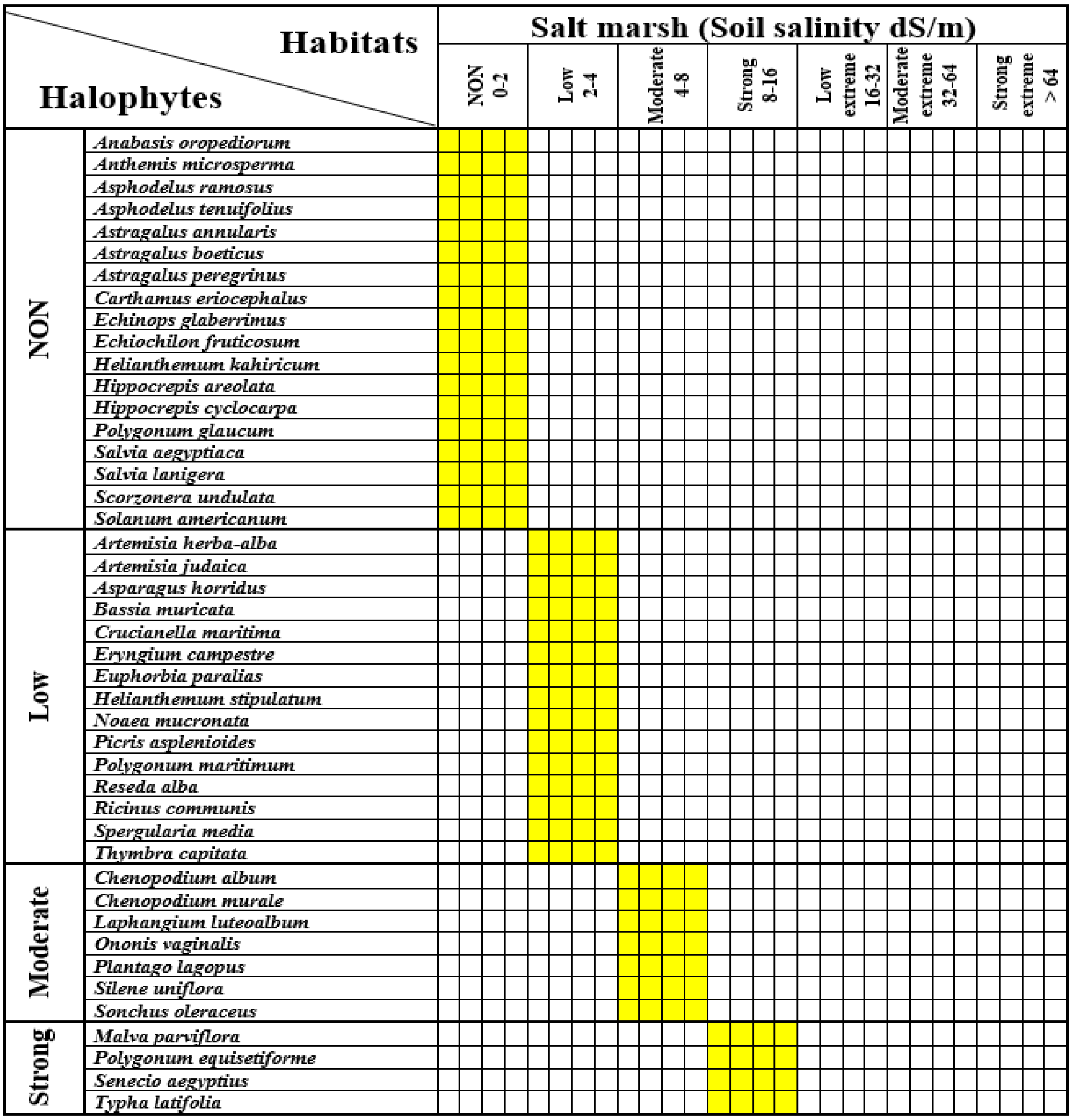


Fig. 5. Restricted halophytic dispersion across the soil salinity classes.

Conclusion

Global Halophytes dispersion: during transgression, the halophytes are dispersed outside the Mediterranean\oceans\lakes shorelines, and vice versa during regression.

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