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# Research Article
# Vegetation Dynamics and Growth Performance of *Nitraria retusa* among Different Habitats in Egypt

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## Abstract

**Background and Objective:** *Nitraria retusa* is a salt-tolerant and drought-resistant shrub located in the Nitrariaceae family. Floristic composition and soil characters in representative habitats of *Nitraria retusa* were analyzed in terms of habitat variations and vegetation dynamics. **Materials and Methods:** A total of 12 sites were surveyed and nineteen environmental factors were recognized in three main habitats: sandy dunes, salt marshes and wadi channel. Homogeneity of each stand was secured by visual judgment to comprise uniform habitat dominated by *Nitraria retusa*. A list of the accompanied species (inside and outside the studied quadrates) was made to give an idea about the plant diversity in the study area. **Results:** Four main vegetation groups were recorded and their controlling ecological factors were identified. Species diversity gradients in addition to the gradient of human interference were significantly higher in dunes habitat than the other habitats. The growth performance of *Nitraria retusa* was significantly higher in the sand dunes habitat than in the other habitats. **Conclusion:** The Egyptian desert's need for judicious utilization and sustainable development. For this, the influence of other environmental factors needs to be analyzed properly understood.

Key words: Nitraria retusa, vegetation, performance, habitat, edaphic factors, Egyptian desert's, sand bars, habitat heterogeneity

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

*Nitraria retusa* ( Forssk.) Asch. (Arabic name: Ghardag or Ghargad) is a native salt-tolerant and drought-resistant shrub with many erect stems, spreading woody branches, fleshy leaves, white-to-yellowish green flowers and fleshy edible berry-like drupe fruits. Flowering occurs in April and May[1,2]. It inhibits three types of habitat: the salt marshes where it forms saline mounds that stud the flat ground of the salt marsh, the less saline sand bars (actual chains of sandy hillocks fringing the shoreline) and the channels of some main wadis near the coast[3,4].

The positive relationship between habitat heterogeneity and species size structure is amongst the best-documented patterns in ecology[5]. Greater habitat heterogeneity is associated with greater species diversity for many taxa[6,7]. Most studies assume habitat specialization through correlative analyses between habitat and species distributions but manipulative experiments or rigorous analytical techniques such as null models can better determine the relative contribution of habitat specialization to species diversity[7,8].

Growth performance of the shrubby populations in Egypt has been carried out with previous studies[9-12] dealt with the vegetation analysis and species diversity associated with it. No doubt, that variation in the habitats and edaphic factors activities have adversely affect not only species zonation but also species diversity and growth performance of species[13].

The aims of this study are analyzing the vegetation dynamics and assessing the soil-vegetation relationships of species associated with *Nitraria retusa*, also examine the growth performance of *Nitraria retusa* at habitat heterogeneity.

## MATERIALS AND METHODS

**Study areas:** The study was carried out at Desert Research Center, Egypt from August, 2018 to March, 2019). The main habitat types used for this study were salt marshes (Siwa Oasis) at Lat. 29°13' 41'' N and Long. 25°18' 04'' E, fixed sandy dunes (Northern coast, Marsa Matruh) at Lat. 31°36' 50'' N and Long. 25°50' 10'' E and wadi channel (Suez Gulf) at Lat. 29°16' 20'' N and Long. 32°26' 80'' E (Fig. 1).

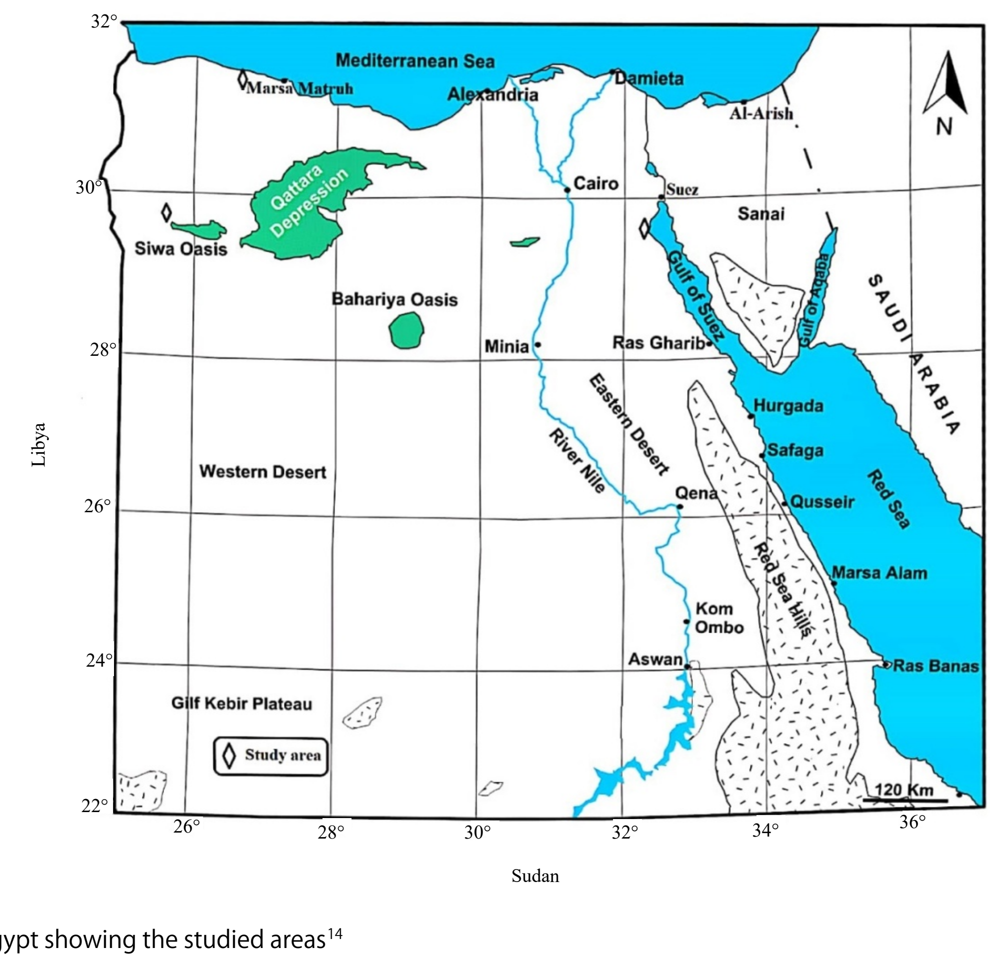


Fig. 1: Map of Egypt showing the studied areas[14]

**Vegetation survey:** Vegetation surveys and assessing the ecological situation of plants were carried out in the year 2018 at three sites. Twelve quadrates (each of 20×20 m) were selected to represent the main habitats of *Nitraria retusa*. Homogeneity of each stand was secured by a visual judgment to comprise uniform habitat dominated by *Nitraria retusa*. A list of the accompanied species (inside and outside the studied quadrates) was made to give an idea about the plant diversity in the study area. The density and cover of each species have been estimated in each selected stand[15]. Relative values of density and cover were calculated for each plant species and summed up to give an estimate of its important value (IV) in each stand, which is out of 200. Nomenclature, identification and floristic categories were carried out according to reseracheres[1,2,16]. Life forms were identified according to the scheme[17].

**Inventory of growth performance:** For achieving the growth performance of *Nitraria retusa*, the height and mean crown diameter of each individual of the studied species in the whole stand was measured (based on 2 diameter measurements/ind.), the size index of each of *Nitraria retusa* individuals was calculated as the average of its height and diameter (H+D/2). The main, lateral branches and No. of leaves/tree, tree circumference (at DBH), leaf length and leaf area are measured. The number of seedlings was counted[9,10].

**Soil analysis:** From each habitat, a composite soil sample was collected as a profile of 50 cm depth and air-dried. All samples were analyzed for soil texture, pH, Electrical Conductivity (EC), organic carbon, calcium carbonates, Na, K, Ca, chlorides and sulphates[18,19].

**Data analysis:** The floristic data matrix of species was subjected for classification by two-way indicator species analysis (TWINSPAN, version 4.5) and Detrended Correspondence Analysis (DCA) into groups[20]. The relation between the vegetation and soil gradients was assessed using Canonical Correspondence Analysis (CCA)[21]. Plant diversity indices included Species Richness (SR), Shannon-Weiner diversity index (H') and Simpson index. These diversity indices were estimated for each vegetation group[22-24]. Linear correlations coefficient (r) was calculated for assessing the relationship between the estimated soil variables on one hand and the community variables. The obtained data were statistically evaluated using CANOCO v. 4.5.

## RESULTS

**Floristic analysis:** The total numbers of the recorded plant species surveyed in the present study are 53 species (3 annuals, one biennial and 49 perennial) related to 21 families. The largest families were Asteraceae and Poaceae comprising 7 species each, followed by Fabaceae 6 species, Chenopodiaceae 5 species Brassicaceae, Tamaricaceae and Zygophyllaceae comprising 3 species each, Apiaceae comprising 2 species. Other families were represented in only one species (Appendix 1). Life forms of the species recorded are grouped under eight types (Table 1 and Fig. 2). The majority of the recorded species are chamaephytes (25 species = 47.2%) followed by hemicryptophytes and nanophanerophytes (7 species = 13.2%) then by geophytes and therophytes (4 species = 7.55%) and helophytes (2 species = 3.77%). The lowest value of life forms is recorded as phanerophytes which attained (one species = 1.89%).

**Chronological affinities:** Chronological analysis of the surveyed flora (Table 2) revealed that 22 species (49% of the total flora) were Monoregional and (28.3% of the total flora) were bi-regional and (13.2% of the total flora) were pluri-regional and (9.43% of the total flora) were worldwide elements Monoregional chorotypes extending their distribution all over the Saharo-Arabian, Sudano-Zambezian and Mediterranean regions amounted to 49% of the recorded flora. On the other hand, Cosmopolitan, Panotropical and Paltropical chorotypes constituted five species. While Saharo-Arabian chorotype, either pure or penetrated other regions, was represented by 34 species of the total recorded flora.

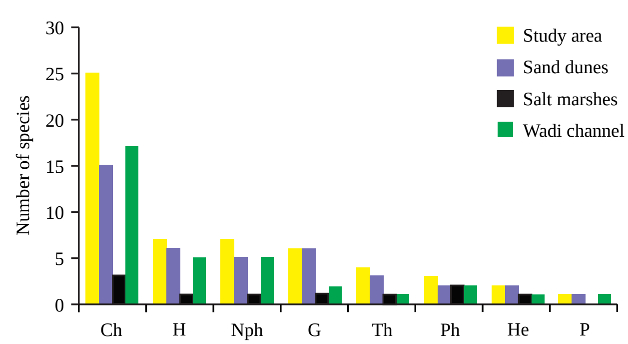


Fig. 2: Life form spectra of the recorded species in the three habitats dominated by *Nitraria retusa*

Ph: Phanerophytes, Ch: Chamaephytes, Hm: Hemicryptophytes, Ge: Geophytes, He: Helophytes, Pa: Parasites, Th: Therophytes, Nph: Nanophanerophytes

Table 1: Life form spectra of the recorded species in the three habitats dominated by *Nitraria retusa*

| Life forms | Sand dunes | Salt marshes | Wadi bed | Total number |
|---|---|---|---|---|
| Ch | 15 | 3 | 17 | 25 |
| Hm | 6 | 1 | 5 | 7 |
| Nph | 5 | 1 | 5 | 7 |
| Ge | 4 | 1 | 1 | 4 |
| Th | 3 | 1 | 1 | 4 |
| Ph | 2 | 2 | 2 | 3 |
| He | 2 | 1 | 1 | 2 |
| Pa | 1 | 0 | 1 | 1 |
| Total | 38 | 10 | 33 | 53 |

Ph: Phanerophytes, Ch: Chamaephytes, Hm: Hemicryptophytes, Ge: Geophytes, He: Helophytes, Pa: Parasites, Th: Therophytes, Nph: Nanophanerophytes

Table 2: Number of species and percentage of various floristic categories of the habitats dominated by *Nitraria retusa*

| Floristic category | Sand dunes | Salt marshes | Wadi bed | Total number | Type |
|---|---|---|---|---|---|
| COSM | 3 | 2 | 0 | 3 | Worldwide |
| PAL | 1 | 1 | 1 | 1 | |
| PAN | 1 | 0 | 0 | 1 | |
| ME+ES+SA | 2 | 0 | 1 | 2 | Pluriregional |
| ME+IT+ES | 1 | 0 | 1 | 1 | |
| ME+IT+SA | 4 | 1 | 2 | 4 | |
| IT+SA | 1 | 0 | 2 | 3 | Biregional |
| ME+ES | 1 | 0 | 0 | 1 | |
| ME+IT | 1 | 0 | 3 | 3 | |
| ME+SA | 5 | 2 | 7 | 8 | |
| ME | 9 | 0 | 1 | 9 | Monoregional |
| SA | 7 | 2 | 11 | 13 | |
| SA+SZ | 2 | 1 | 4 | 4 | |
| Total | 38 | 9 | 33 | 53 | |

COSM: Cosmopolitan, Pal: Paltropical, Pan: Pantropical, SA: Saharo-Arabian, ME: Mediterranean, SZ: Sudano-Zambezian, IT: Irano-Turanian, ES: Eurosiberian

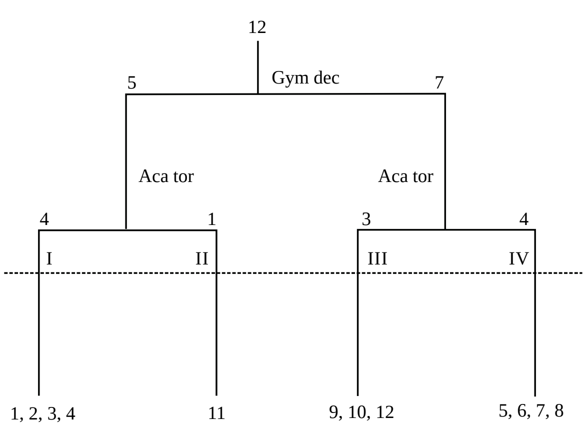


Fig. 3: TWINSPAN dendrogram of the 12 sampled stands dominated by *Nitraria retusa* based on the important values of species

Group I (*Nitraria retua* group), Group II (*Nitraria retusa* and *Acacia tortilis* group), Group III (*Nitraria retusa* group) and Group IV (*Nitraria retusa* and *Arthrocnemum macrostachyum* group)

**Classification of vegetation:** The application of TWINSPAN classification on 53 plant species recorded in 12 stands representing the study area yielded four vegetation groups (Fig. 3). Two species were recorded with variable presence values in the four groups. It included *Nitraria retusa* and *Zygophyllum*.

**Sand dune habitat:**

- **Group I (*Nitraria retua* group):** This habitat was represented by one group, was diversified (34 species) among the recognized groups with 4 stands, with species richness of species/stands of 8.5, Simpson index 0.96 and Shannon-Wiener diversity index of 0.82. The other important species are *Ammophila arenaria*, *Polygonum aviculare*, *Zygophyllum album* and *Suaeda vera* recorded in this group (Table 3). Stands of this habitat were found on soil rich in its clay, organic matter, pH and $CaCO_3$ and lowest levels of Na and Ca (Appendix 2)

**Wadi channel habitat:** This type of habitat represented by two groups as follow:

- **Group II *(Nitraria retusa* and *Acacia tortilis* group):** It was the smallest among the separated vegetation groups. It was comprised of 8 species recorded from one stands, with species richness of species/stands of 8, Simpson index 0.86 and Shannon-Wiener diversity index of 0.77. The other important species, *Lygeum spartum*, *Ochradenus baccatus*, *Crucianella maritima*, *Atriplex halimus*, *Cistanche phelypaea* and *Zygophyllum album* (Table 3)

Table 3: Plant diversity, dominant and important species in each habitat dominated by *Nitraria retusa*

| Community | Number of stands | Total species | Shannon-evenness | Simpson diversity | Dominant species | Other important species |
|---|---|---|---|---|---|---|
| I | 4 | 34 | 0.82 | 0.96 | *Nitraria retusa* (47.30±15.94) | *Ammophila arenaria* (13.25±2.36)*<br>*Polygonum aviculare* (12.03±11.34)<br>*Zygophyllum album* (11.55±8.05)<br>*Suaeda vera* (10.89±1.30) |
| II | 1 | 8 | 0.77 | 0.86 | *Nitraria retusa* (50.00)<br>*Acacia tortilis* (46.20) | *Lygeum spartum* (24.40)<br>*Ochradenus baccatus* (23.40)<br>*Crucianella maritima* (17.40)<br>*Atriplex halimus* (12.40)<br>*Cistanche phelypaea* (13.40)<br>*Zygophyllum album* (11.00) |
| III | 3 | 33 | 0.85 | 0.89 | *Nitraria retusa* (48.17±11.83) | *Acacia tortilis* (36.43±13.67)<br>*Halocnemum strobilaceum* (24.47±3.27)<br>*Zygophyllum album* (11.53±6.51)<br>*Reaumuria hirtella* (10.47±9.08) |
| IV | 4 | 16 | 0.79 | 0.81 | *Nitraria retusa* (55.50±14.30)<br>*Arthrocnemum macrostachyum* (47.73±3.73) | *Halocnemum strobilaceum* (32.20±5.26)<br>*Alhagi graecorum* (19.33±2.87)<br>*Tamarix aphylla* (12.75±6.39)<br>*Phragmites australis* (12.33±8.59)<br>*Zygophyllum album* (10.60±9.08) |

*Values are Means±Standard variation, Group I: *Nitraria retua* group, Group II: *Nitraria retusa* and *Acacia tortilis* group, Group III: *Nitraria retusa* group and Group IV: *Nitraria retusa* and *Arthrocnemum macrostachyum* group

- **Group III (*Nitraria retusa* group):** The size of this group was represented by the three stands that included 33 species. The average species richness in this group is 11 species/stands, Simpson index 0.89 and Shannon-Wiener diversity index of 0.85. The other important species were *Acacia tortilis*, *Halocnemum strobilaceum*, *Zygophyllum album* and *Reaumuria hirtella* (Table 3). The stands of this habitat inhabited soil with the highest content of sand, clay and Ca and lowest levels of silt, clay, pH, EC, K and Cl (Appendix 2)

**Salt marshes habitat:**

- **Group IV (*Nitraria retusa* and *Arthrocnemum macrostachyum* group):** This group was the most diversified among the recognized groups. It comprised 16 species recorded from 4 stands, with an average species richness of 4 species/stands, Simpson index 0.81 and Shannon- Wiener diversity index of 0.79. It inhabited soil with the highest water-holding capacity. The other important species were *Halocnemum strobilaceum*, *Alhagi graecorum*, *Tamarix aphylla*, *Phragmites australis* and *Zygophyllum album* (Table 3). Stands of this habitat were found on soil the highest content of silt, pH, EC, Na and Cl and the lowest level of clay (Appendix 2)

**Ordination of stands:** The application of DCA on 12 stands along axes 1 and 2 indicated that the vegetation groups yielded by TWINSPAN classification are distinguishable and have a clear pattern of segregation on the ordination plane except for groups C and D interconnected (Fig. 4). Stands of group I are separated at the upper part of the middle of the DCA diagram. Group II is clear segregated (the right side) along the two axes of DCA. While Group III is separated from the middle part axis 1 of the DCA diagram. On the other hand, group IV is segregated at the Left part along with the axis 2 of the DCA diagram.

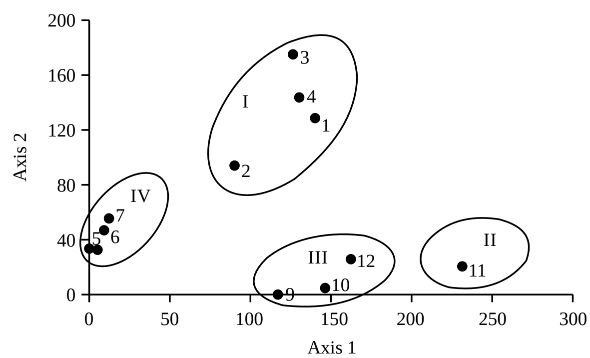


Fig. 4: Detrended Correspondence Analysis (DCA) ordination diagram of the 12 sampled stands
Group I (*Nitraria retua* group), Group II (*Nitraria retusa* and *Acacia tortilis* group), Group III (*Nitraria retusa* group) and Group IV (*Nitraria retusa* and *Arthrocnemum macrostachyum* group)

**Soil-vegetation relationships:** The correlation between vegetation and soil characteristics is shown on the ordination

Table 4: Comparison of growth performance (mean±SE) of *Nitraria retusa* at dunes, Salt marshes and Wadi channel

| Habitats | Sand dunes | Salt marshes | Wadi channel | F-value | p-value |
|---|---|---|---|---|---|
| **Characters** | | | | | |
| Height (cm) | 1.26±0.08 | 0.99±0.05 | 0.60±0.06 | 1.16 | 0.43** |
| Size index | 5.14±0.21 | 0.35±1.0 | 0.16±8.38 | 1.3 | 0.41** |
| Trunk circumference | 1.51±0.68 | 0.77±0.03 | 0.63±0.03 | 3.2 | 0.18** |
| No. main branches | 4.08±0.36 | 5.58±0.58 | 2.50±0.19 | 5.45 | 0.00** |
| No. lateral branches | 135.1±16.5 | 754.8±67.1 | 82.7±12.8 | 4.98 | 0.00** |
| Leaf number | 6317.3±772.5 | 3301.3±412.84 | 1220.9±123.5 | 1.07 | 0.00** |
| Leaf length (cm) | 1.73±0.07 | 1.62±0.06 | 1.72±0.07 | 2.13 | 0.09ns |
| Leaf area (cm) | 1.09±0.03 | 1.20±0.05 | 1.11±0.07 | 1.14 | 0.41ns |
| No. seedlings | 3.33±1.20 | 2.33±0.88 | 3.0±0.58 | 0.33 | 0.84ns |

Significance levels are shown as **p<0.05

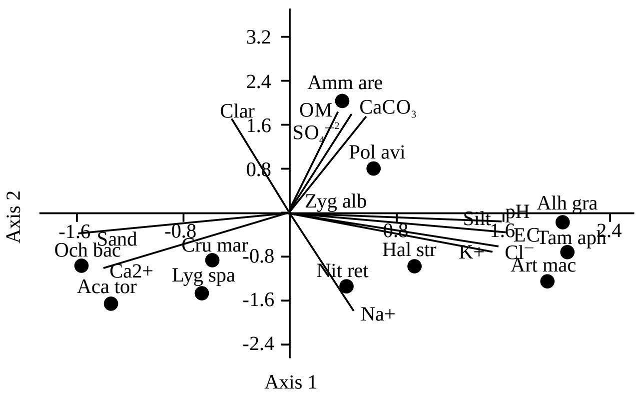


Fig. 5: Canonical Correspondence Analysis (CCA) ordination diagram of plant species with soil variables. The indicator and preferential species are abbreviated to the first three letters of the genus and species, respectively

diagram produced by Canonical Correspondence Analysis (CCA) of the biplot of species-environment. As shown in (Fig. 5) it is clear that the percentages of sand, silt, clay, $CaCO_3$, Cl, $SO_4$ and cations (Na, K and Ca) are the most effective soil variables, which showed highly significant correlations with the first and second axes of CCA ordination diagram. The dominant (*Nitraria retua*) and abundant species (*Ammophila arenaria*, *Polygonum aviculare*, *Zygophyllum album* and *Suaeda vera*) of group I are separated at the upper right side of the CCA-biplot diagram. These species in group I showed a close relationship with sand, organic matter and $CaCO_3$. The dominant species (*Nitraria retusa* and *Acacia tortilis*) and abundant species (*Lygeum spartum*, *Ochradenus baccatus* and *Crucianella maritima*) in groups II and III are separated at the lower left side. These species in groups II and III showed a close relationship with sand and Ca. The dominant species (*Nitraria retusa*) and abundant species (*Halocnemum strobilaceum*, *Alhagi graecorum*, *Tamarix aphylla* and *Phragmites australis*) in groups IV are separated at the right side. These species in group IV showed close relationship silt, pH, EC, Na and Cl.

**Growth performance of *Nitraria retusa*:** The growth performance of *Nitraria retusa* was significantly higher in dunes habitats than in the other habitats (Table 4). *Nitraria retusa* twice as tall had main and lateral branches and attain nearly 2 times than the salt marshes and 6 times than the wadi channel. The size index and trunk circumference were higher in dunes than the other habitats. The total number of leaves compared with those growing in salt marshes and wadi channels. Besides, the reset of growth performance had a high value in the dunes than the other habitats.

## DISCUSSION

The study on the relationship between vegetation patterns and their habitat heterogeneity is important to recover and rehabilitate the desert vegetation, stabilize the desert ecosystem and prevent desert expansion, also help in sustainable development. The studied localities represents a natural xeric habitat, which mainly dominated by *Nitraria retusa*. The natural plant in the present study is composed of 53 species (3 annuals, one biennial and 49 perennials) related to 26 families. The dominance of the perennials may be attributed to the nature of the habitat types, climatic and soil conditions[25,26]. The major families were Asteraceae, Poaceae, Fabaceae and Chenopodiaceae, which contributed collectively to about 47.2% of the total recorded plant species. This indicated that these four families are leading taxa and constitute the major bulk of the flora of the three habitats. Other researchers[27,28] also reported similar results. Asteraceae is the largest and most widespread family of the flowering plants in the world[29]. In addition, Poaceae recorded the highest number of species because of its ability to grow in various habitats.

The life-form spectra are important physiognomic attributes, which is widely used by ecologists and chronologists in the vegetation and floristic studies[30]. Life forms of the flora in the present study showed that chamaephytes are the most represented form may be attributed to distinct defense against the physiological stresses and ability of these species to resist sand accumulation and grazing[31,32]. The life form spectra provide information, which may help in assessing the response of vegetation to variations in environmental factors[33]. Magurran[24] pointed out that 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 many families as opposed to few.

From the floristic point of view, Egypt is the meeting point of floristic elements belonging to at least four phytogeographical regions: The African Sudano-Zambezian, the Asiatic Irano-Turanian, the Afro-Asiatic Sahro-Arabian and the Euro-Afro-Asiatic Mediterranean[34]. The floristic analysis of the present study indicated that the Saharo-Arabian taxa are represented by a relatively high percentage of plant species (64.2%) may be attributed to their capability to penetrate this region and to the influence of man and the history of agriculture. These taxa were either Pluriregional, Biregional or Monoregional. This was confirmed by previous stdueis[25-27].

The results of the vegetation analysis had then been related to environmental data. Alternatively, vegetation habitat relationships have been derived from a single analysis of combined floristic and environmental variables[21]. The phytosociological investigation revealed that the vegetation structure of the three habitats was classified by TWINSPAN into four (I-IV) groups distributed in the three habitats. Each group comprises many sampling stands, which are similar in terms of vegetation and characterized by dominant and/or codominant species as well as, by many indicator and/or preferential species. Group I represented the fixed sand dunes habitat was dominated by *Nitraria retusa*, group II and III represented the wadi channel habitat, was co-dominated by *Nitraria retusa* and *Acacia tortilis*, group IV represented the salt marshes habitat, was dominated by *Nitraria retusa*. The identified vegetation groups, in the present study, were more or less agree with the previously mentioned studies[10,11,14,34].

The most important soil gradients correlated with the distribution of vegetation as recognized by previous studies[26,28,35] are soil salinity (EC), moisture gradient, soil fertility, organic carbon and phosphorus content, soil texture (sand, silt and clay) and pH value. In the present study, the application of Canonical Correspondence Analysis (CCA biplot) indicated that, the most important soil variables correlated with the distribution of vegetation types in the study area include soil texture (sand and silt), calcium carbonate, organic carbon, Na and Cl.

In this study, Leaf number, No. main and lateral branches of *Nitraria retusa* have been found to differ significantly among different habitats, however, plant height, size index and a number of seedlings can be directly compared among habitat types. The results of the study is similar to the findings of previous studies[9,10,12,36] that the differences in growth performance can be the result of varying environmental factors (e.g., salinity, nutrient limitation and soil characteristics) among habitat types. Understanding the relationship between the edaphic factors and the distribution of plant species helps us to apply this finding in management, reclamations and development of semi-arid land grass ecosystems.

## CONCLUSION

The present study provides an analysis of the floristic composition and vegetation structure of *Nitraria retusa* community growing in different habitats of Egypt to help in the management and conservation of these natural resources. It shows a wide soil range and occupies diverse habitats. Therefore, the conservation of natural habitats of this desert is of vital importance. The recorded 53 plant species in the present study can play a vital role in the economic and medicinal purposes. Hence, the Egyptian desert needs for judicious utilization and sustainable development. The distribution and growth performance of plant species is subjected to varying conditions of salinity concentrations, nutrient levels and substrate structure. However, the influence of other environmental factors needs to be analyzed properly understood.

## SIGNIFICANCE STATEMENT

This study discovers the effect of habitat heterogeneity on the growth and vegetation associated *Nitraria retusa* that can be beneficial for the economic and medicinal purposes of studying species. This study will help the researcher to uncover the critical areas of plant growth and distribution that many researchers were not able to explore. Thus, a new analysis on growth performance of *Nitraria retusa* may be arrived at.

Appendix 1: Floristic composition of the three habitats dominated by *Nitraria retusa* in f Egypt, and mean of the importance values (out of 200) of the recorded species in different vegetation groups resulting from TWINSPAN classification

| | | | | | Habitat type | | | Vegetation groups | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Species | Life span | Life form | Chorotype | Sand dunes | Salt marshes | Wadi bed | I | II | III | IV |
| Amaryllidaceae | *Pancratium maritimum* (L.) | Per | G | ME | + | | | 4.88±6.03 | | | |
| Apiaceae | *Deverra tortuosa* (Desf.) DC. | Per | Ch | SA | + | | + | 6.80±5.83 | | 1.20±2.08 | |
| Asclepiadaceae | *Asclepias sinaica* (Boiss.) Muschl. | Per | Ch | ME+SA | | | + | | | 3.43±5.95 | |
| Asteraceae | *Achillea fragrantissima* (Forssk.) Sch. Bip. | Per | Ch | SA+IT | | | + | | | 2.64±4.58 | |
| | *Artemisia judaica* L. | Per | Ch | SA | | | + | | | 3.61±4.19 | 2.88±0.68 |
| | *Centaurea aegyptiaca* L. | Bi | Th | SA | | | + | | | 9.15±8.13 | 7.54±5.31 |
| | *Echinops spinosissimus* (Turra) | Per | H | ME+SA | + | | + | 0.23±0.47 | | 5.20±7.26 | |
| | *Hyoseris radiata* (L.) | Per | H | ME | + | | | 1.91±2.80 | | | |
| | *Inula crithmoides* (L.) | Per | Ch | ME+ES+SA | + | | + | 3.90±3.49 | | 2.50±4.33 | 2.87±1.84 |
| | *Otanthus maritimus* (L.) Hoffmanns. and Link | Per | Ch | ME | + | | | 3.57±4.13 | | | |
| Boraginaceae | *Echium angustifolium* (Mill.) | Per | H | ME | + | | | 2.50±2.56 | | | |
| Brassicaceae | *Cakile maritima* (Scop.) | Ann. | Th | ME+ES | + | | | 1.01±1.117 | | | 1.55±1.04 |
| | *Farsetia aegyptia* Turra | Per | Ch | SZ+SA | | | + | | | 0.22±0.39 | |
| | *Moricandia nitens* (Viv.) | Per | Ch | IT+SA | | | + | | | 1.40±2.43 | |
| Caryophyllaceae | *Gymnocarpus decandrum* Forssk | Per | Ch | ME+SA | | | | | | | |
| Chenopodiaceae | *Atriplex halimus* (L.) | Per | Nph | ME+SA | + | | + | 5.91±1.47 | 12.40 | 2.76±4.77 | |
| | *Arthrocnemum macrostachyum* (Moric.) | Per | Ch | ME+SA | + | + | + | | | 2.31±4.00 | 47.73±3.73 |
| | *Halocnemum strobilaceum* (Pall.) M.Bieb. | Per | Ch | ME+IT+SA | + | + | + | | | 24.47±3.27 | 32.20±5.26 |
| | *Salsola kali* L. | Ann. | Th | COSM | + | + | | 2.62±3.19 | | | 8.53±10.58 |
| | *Salsola tetrandra* Forssk. | Per | Ch | SA | + | | + | 7.08±8.78 | | 1.56±1.50 | |
| | *Suaeda vera* (Forssk. ex J.F. Gmel.) | Per | Ch | ME+SA+ES | + | | | 10.89±1.30 | | | 8.76±0.74 |
| Cistaceae | *Helianthemum lippii* (L.) Pers. | Per | Ch | ME+IT+SA | + | | + | 1.99±1.63 | | 0.21±0.36 | |
| Convolvulaceae | *Cressa cretica* L. | Per | H | ME+IT | | | + | | | 0.39±0.68 | |
| Ephedraceae | *Ephedra alata* Decne. | Per | Ch | ME+SA | | | + | | | 2.18±2.49 | |
| Euphorbiaceae | *Euphorbia paralias* (L.) | Per | Ch | ME | + | | | 4.24±2.87 | | | |
| Fabaceae | *Acacia tortilis* (Forssk.) Hayne | Per | Ph | SA+SZ | | | + | | 46.20 | 36.43±13.67 | |
| | *Alhagi graecorum* Boise. | Per | H | PAL | + | + | + | 0.58±1.15 | | 1.59±2.76 | 19.33±2.87 |
| | *Ononis vaginalis* (Vahl.) | Per | Ch | IT+SA | + | | | 7.43±9.48 | | | |
| | *Prosopis juliflora (Swartz) DC* | Per | Ph | SA | + | + | | | | | 5.05±5.84 |
| | *Retama raetam* (Forssk.) Webb and Berthel | Per | Nph | ME+IT+SA | + | | | 4.38±6.08 | | | |
| | *Lotus polyphyllus* (E.D.) Clarke. | Per | Ch | SA | + | | | 7.84±6.97 | | | |

Appendix 1: Continued

| | | | | | Habitat type | | | Vegetation groups | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Species | Life span | Life form | Chorotype | Sand dunes | Salt marshes | Wadi bed | I | II | III | IV |
| Nitrariaceae | *Nitraria retusa* (Forssk.) Asch. | Per | Ph | SA | + | + | + | 47.30±15.94 | 50.00 | 48.17±11.83 | 55.50±14.30 |
| | *Peganum harmala* L. | Per | H | ME+IT+ES | + | | + | 1.15±1.34 | | 1.92±2.25 | |
| Orobanchaceae | *Cistanche phelypaea* (L.) | Per | P | ME+SA | + | | + | 4.78±5.61 | 13.40 | 0.06±0.10 | |
| Plumbaginaceae | *Limonium pruinosum* (L.) Chaz. | Per | H | SA | + | | + | 1.78±3.55 | | 0.42±0.73 | |
| Poaceae | *Aeluropus lagopoides* (L.) | Per | Ch | ME+IT+SA | + | | | 8.93±2.90 | | | |
| | *Ammophila arenaria* (L.) | Per | Ch | ME | + | | | 13.25±2.36 | | | |
| | *Elymus farctus* (Viv.) | Per | G | ME | + | | | 2.45±2.89 | | | 1.88±2.67 |
| | *Lygeum spartum* (L.) | Per | G | ME+IT | + | | + | 0.15±0.30 | 24.40 | | |
| | *Pennisetum divisum* (Forssk. ex J.F.Gmel.) Henrard. | Per | He | SA | + | | + | 1.25±1.45 | | 0.05±0.09 | |
| | *Phragmites australis* (Cav.) Trin. | Per | He | COSM | + | + | | | | | 12.33±8.59 |
| | *Sporobolus pungens* (Schreb.) | Per | G | PAN | + | | | 0.37±0.74 | | | |
| Polygonaceae | *Polygonum aviculare* (L.) | Ann | Th | COSM | + | | | 12.03±11.34 | | | |
| Resedaceae | *Ochradenus baccatus* Delile. | Per | Nph | SA | | | + | | 23.40 | 3.63±6.29 | |
| Rubiaceae | *Crucianella maritima* (L.) | Per | Ch | ME | + | | + | 1.38±2.77 | 17.40 | 6.83±11.84 | |
| Solanaceae | *Lycium shawii* (Roem. and Schult.) | Per | Nph | SA+SZ | + | | + | 6.93±8.12 | | 3.19±4.63 | |
| Tamaricaceae | *Reaumuria hirtella* Jaub. and Spach | Per | Ch | ME+IT | | | + | | | 10.47±9.08 | |
| | *Tamarix aphylla* (L.) Karst. | Per | Nph | SA+SZ | + | + | + | 3.13±6.25 | | 0.97±1.69 | 12.75±6.39 |
| | *Tamarix nilotica* (Ehrenb.) Bunge | Per | Nph | SA | | | + | | | 6.44±5.69 | 3.44±4.31 |
| Thymelaceae | *Thymelaea hirsuta* (L.) | Per | NPh | ME | + | | | 6.63±8.00 | | | |
| Zygophyllaceae | *Fagonia arabica* L. | Per | Ch | SA | | | + | | | 0.87±1.51 | |
| | *Fagonia mollis* Delile | Per | Ch | SA | | | + | | | 4.17±3.76 | |
| | *Zygophyllum album* (L.) | Per | Ch | ME+SA | + | + | + | 11.55±8.05 | 11.00 | 11.53±6.51 | 10.60±9.08 |

Per.: Perennial, Ann.: Annuals, Bi: Biennial, Th.: Therophytes, Ch. = Chamaephytes, H: Hemicryptophytes, He: Helophytes, G: Geophytes, Nph: Nanophanerophytes, COSM: Cosmopolitan, PAL: Paltropical, PAN: Pantropical, ME: Mediterranean, SA: Saharo-Sindian, IT: Irano-Turanian, ES: Euro-Siberian, SZ: Sudano-Zambezian

Appendix 2: Soil variables of the three studied habitats dominated by *Nitraria retusa*

| Habitat | Sampling sites | Soil texture | | | Chemical characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | OM | $CaCO_3$ | pH | EC | $Cl^-$ | $SO4^{2-}$ | $Na^+$ | $Ca^{2+}$ | $K^+$ |
| Sand dunes | 1 | 74.7 | 20.5 | 4.8 | 1.34 | 43 | 7.76 | 1452 | 2.4 | 0.79 | 2.08 | 1.1 | 0.73 |
| | 2 | 75.1 | 19.7 | 5.2 | 1.31 | 49 | 7.67 | 1389 | 2.33 | 0.81 | 1.99 | 1.2 | 0.75 |
| | 3 | 75.5 | 18.9 | 5.6 | 1.28 | 55 | 7.58 | 1326 | 2.26 | 0.83 | 1.9 | 1.3 | 0.77 |
| | 4 | 75.9 | 18.1 | 6.0 | 1.25 | 61 | 7.49 | 1263 | 2.19 | 0.85 | 1.81 | 1.4 | 0.79 |
| | Mean | 75.30$^{b}$ | 19.30$^{b}$ | 5.40$^{a}$ | 1.30$^{a}$ | 52.00$^{a}$ | 7.63$^{b}$ | 1357.50$^{b}$ | 2.30$^{b}$ | 0.82$^{a}$ | 1.95$^{c}$ | 1.25$^{c}$ | 0.76$^{b}$ |
| | ±SE | 0.13 | 0.26 | 0.13 | 0.01 | 1.94 | 0.03 | 20.33 | 0.02 | 0.01 | 0.03 | 0.03 | 0.01 |
| Wadi cannel | 5 | 88.9 | 5.75 | 5.35 | 0.55 | 16.7 | 7.21 | 354 | 0.29 | 0.07 | 2.79 | 7.82 | 0.33 |
| | 6 | 87.3 | 8.6 | 4.1 | 0.51 | 14.1 | 7.25 | 285 | 0.32 | 0.08 | 2.76 | 7.44 | 0.37 |
| | 7 | 85.7 | 11.45 | 2.85 | 0.47 | 11.5 | 7.15 | 316 | 0.35 | 0.09 | 2.73 | 7.06 | 0.41 |
| | 8 | 84.1 | 14.3 | 1.6 | 0.43 | 8.9 | 7.05 | 253 | 0.38 | 0.11 | 2.7 | 6.68 | 0.45 |
| | Mean | 86.50$^{a}$ | 10.03$^{c}$ | 3.48$^{a}$ | 0.49$^{b}$ | 12.80$^{b}$ | 7.17$^{c}$ | 302.00$^{c}$ | 0.34$^{c}$ | 0.09$^{b}$ | 2.75$^{b}$ | 7.25$^{a}$ | 0.39$^{c}$ |
| | ±SE | 0.52 | 0.92 | 0.40 | 0.01 | 0.84 | 0.02 | 10.79 | 0.01 | 0.00 | 0.01 | 0.12 | 0.01 |
| Salt marshes | 9 | 78.3 | 20.5 | 1.2 | 0.21 | 10.6 | 7.85 | 2134 | 4.74 | 0.05 | 4.03 | 4.1 | 1.35 |
| | 10 | 76.1 | 22.6 | 1.3 | 0.34 | 14.3 | 7.78 | 2100 | 4.55 | 0.06 | 3.89 | 3.6 | 1.27 |
| | 11 | 73.9 | 24.7 | 1.4 | 0.47 | 18 | 7.71 | 2066 | 4.36 | 0.07 | 3.75 | 3.1 | 1.19 |
| | 12 | 71.7 | 26.8 | 1.5 | 0.6 | 21.7 | 7.64 | 2032 | 4.17 | 0.08 | 3.61 | 2.6 | 1.11 |
| | Mean | 75.00$^{b}$ | 23.65$^{a}$ | 1.35$^{c}$ | 0.41$^{b}$ | 16.15$^{b}$ | 7.75$^{a}$ | 2083.00$^{a}$ | 4.46$^{a}$ | 0.07$^{b}$ | 3.82$^{a}$ | 3.35$^{b}$ | 1.23$^{a}$ |
| | ±SE | 0.71 | 0.68 | 0.03 | 0.04 | 1.19 | 0.02 | 10.97 | 0.06 | 0.00 | 0.05 | 0.16 | 0.03 |
| $LSD_{0.05}$ | | 3.28*** | 4.33*** | 1.57*** | 0.17*** | 8.96*** | 0.16*** | 94.20*** | 0.24*** | 0.03*** | 0.20*** | 0.76*** | 0.11*** |

OM: Organic matter and EC: Electrical conductivity

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