INTRODUCTION

Invasive plants have been identified as one of the most severe environmental issues globally (Barney et al., 2013). In Egypt, the growing population necessitates the expansion of agricultural land. This has been accomplished in recent decades by the reclamation of arid regions (Hegazy et al., 2004). Human intervention enforces weedy plants to displace native plants in the reclaimed regions, that are considered as transitional habitats between old cultivated lands and deserts (Baessler & Klotz, 2006). The involvement of bioactive phytochemical constituents (allelochemicals) into chemical weapons of invasion is one of the processes of plant invasion (Zheng et al., 2015). Allelochemicals are a class of beneficial secondary metabolites that includes phenolic acids, glucosinolates, flavonoids, and essential oils (Einhellig, 1995; El-Amier et al., 2014b).

The major element influencing the quantity of natural vegetation in deserts is anthropogenic activity (El-Amier & Abd El-Gawad, 2017). Roads and railways construction are examples of activities that have a direct influence on existing habitats, such as deterioration and/or fragmentation, as well as an indirect influence on vegetation (Spellerberg, 1998; Jackson, 2000). Many researchers described plants communities and vegetation-environment interactions in Egypt’s Nile Delta (El-Amier et al., 2014a; El-Amier & El Hayyany, 2020).

Egypt possesses more than 3500 kilometers of coasts on the Mediterranean and Red Seas. Egypt’s Mediterranean coastline area stretches for roughly 970 km from Sallum eastward to Rafah, with mean width of 20-25 kilometers in the northern-southern direction (Zalrhan & Willis 2009). Higher erosion, water logging and soil salinization are all major concerns in Egypt’s coastal areas, as are anthropogenic activities such as unplanned village building and ecosystem deterioration (El-Amier & Abd El-Gawad, 2017). Moreover, the Nile Delta occupies 2% of its geographical areas and 65% of all agricultural lands (~29,600 km²) is Egypt’s most heavily used region, with 41% of the population (Negm et al., 2016).

ABSTRACT

*Heliotropium curassavicum* is an invasive annual weed plant that spreads quickly, especially on disturbed saline soils and coastal locations in arid and semiarid habitats. This study aimed to assess the vegetation composition of the invasive plant *H. curassavicum*. The soil factors and associated species of this plant were studied in natural coastal desert habitats (northern Nile delta coast) and inland habitats (farm land and canal bank habitats). The floristic composition revealed the occurrence of 109 species (67 annuals, 2 biennials and 40 perennials) belonging to 86 genera and related to 29 families. Asteraceae, Poaceae, Chenopodiaceae, and Fabaceae (53.21% of all species reported) are the most abundant families. Therophytes and cryptophytes are the mainly abundant life forms and the Mediterranean chorotype is the most representative. The cluster analysis of stands expressed four vegetational groups (A, B, C and D). The most dominant species with group A was *Polypogon viridis*, with group B was *H. curassavicum*, with group C (the largest one) was *Cynodon dactylon* and *H. curassavicum* and with group D was *Phragmites australis*. Diversity indices expressed more richness and evenness of vegetation group B (*H. curassavicum* communities). The major soil factors influencing the studied invasive species are soil texture, WHC, organic carbon, cations (Na⁺, K⁺, Ca²⁺, and Mg²⁺), and SAR.

KEYWORDS: *Heliotropium curassavicum*, Invasiveness, Biodiversity, Ecology, Edaphic factor
Heliotropium curassavicum (salt heliotrope) is an annual plant of the family Boraginaceae that is native to India, America, Hawaii, and Argentina, but considered as invasive plant in Africa, Europe, and Asia (Al-Shehbaz, 1991). It is an invasive species in Egypt’s northern Mediterranean coastal area (Hegazy et al., 2008; Abd-ElGawad et al., 2019), and it has recently been discovered colonizing damaged habitats into the Nile Delta (Note from the author). This plant possesses the capability to reproduce vegetatively and sexually, allowing its colonization to a variety of environments (Hegazy, 1994). Plant bioactive components vary in response to changes in environmental circumstances (Elshamy et al., 2019; Abd-ElGawad et al., 2020), which is thought to be an adaptation mechanism since these bioactive chemicals allow plants to invade and colonize new environments (Zheng et al., 2015).

Invasive species continue to pose a significant threat to a variety of biological systems and species diversity across the world. Therefore, vegetation studies on invasive weed offer the quantitative data needed to design comprehensive weed community management plans, as well as the baseline data needed to track any changes in the weed flora (Frick & Thomas, 1992; Gadallah et al., 2019). However, the vegetation composition and available data on invasive species in Egypt are still insufficient. The current study looks at the vegetation in the Nile Delta that is dominated by Heliotropium curassavicum. The major goal is to investigate the variety of vegetation and species in invasive plant communities in relation to habitats types.

**MATERIALS AND METHODS**

**Study Area**

The studied area was separated into two groups: coastal desert (represented by Delta Coast) and inland habitat (represented by farrow land and canal bank) (Figure 1). The Egyptian Mediterranean coastal desert is divided into three regions: western, delta, and eastern. The Deltaic Coast is defined by the occurrence of three shallow lakes that receive most of the Nile Delta’s drainage water. This section stretches for roughly 200 km from Abu-Quir (31°19′27.5″N 30°04′00.6″E) to Port-Said (31°16′09″N 32°18′19.1″E). The Nile Delta’s coastal zone featured new cities construction, desert reclamation, and agricultural activities, among other things. In numerous sites, the growth of the invasive plant H. curassavicum is associated with cultivated lands (such as Barley, maize, tomato, sesame, and watermelons).

On the other hand, the Mediterranean Sea’s impact modifies the climate along Egypt’s north coast. Despite the fact that the climate of the Nile delta shore is comparable to that of the western and eastern Mediterranean, there is a distinction in vegetation composition. In addition to seawater, it is impacted by leakage water from the Damietta and Rosetta River Nile branches in addition to the northern lakes (Zahran & Willis, 2009).

**Vegetation Analysis**

During the months of March and May in 2019 and 2020, 45 sampling stands (10 meters × 10 meters) were randomly chosen to express a broad scale of physiographic and environmental variability in the coastal and inland environments (Nile Delta). In each plot, the density and cover of plants were recorded as adopted by Shukla and Chandel (1989). For each plant species, relative density, cover and importance values (IV) were calculated. To represent the H. curassavicum in the study sites, a floristic list was obtained from the 45 sites: 29 along the Deltaic Mediterranean coast and 16 from the inland habitats. Tackholm (1974) and Boulos (1999-2005) are used to identify the species reported. According to Zohary (1966 and 1972), the chorology of the plant species was localized and life forms were described in harmony with the scheme of Raunkiær (1934 - 1937).

**Plants Diversity**

The Shannon Wiener diversity index \(H\), Simpson Diversity Index \(D\), and Shannon evenness index \(E\) were determined for each community and used to compute species richness and evenness:

\[
H = \sum_{i=1}^{s} P_i \ln(P_i)
\]

\[
D = \sum \left[ \frac{n_i \times (n_i - 1)}{N \times (N - 1)} \right]
\]

\[
E = \frac{H}{\ln s}
\]

\( P_i = n_i/N, n_i = \text{the number of stands and } N = \text{the total number of species}. \)

**Soil Analysis**

Three soil samples were obtained at depths of 0-20 cm from each of the 45 study sites. The samples were spread sheets of paper then air dried. For each soil sample, a soil solution (1:5) was produced.
Piper’s (1947) method was used to evaluate the texture, water holding capacity (WHC), porosity, organic carbon, and sulphate content of the soil. The electrical conductivity, pH, calcium carbonate and chloride were estimated according to the assay described by Jackson (1962). Titration with 0.1N HCl was used to determine carbonate and bicarbonate (Pierce et al., 1958). Sodium and potassium cations were detected by a Flame Photometer (Model PHF 50 Biologie Spectrophotometer), while the levels of calcium and magnesium were measured by atomic absorption spectrometer (Perkin-Elmer, Model 2380 USA) (Allen et al., 1974).

Statistical Analysis

The vegetation associated with *H. curassavicum* was classified and ordinated by TWINSPLAN analysis using the Community Analysis Package (CAP) software application (version 2.3) (Hill & Smilauer, 2005). The relationship between vegetation and soil gradients was examined using Canonical Correspondence Analysis (CCA) (Ter Braak, 1988). Soil analyses results were analyzed by ANOVA and Least Significant Difference (LSD) at 0.05 probability level using COSTAT 6.3 program. Using SPSS 16 for Windows, the linear correlation coefficient (r) was computed to assess the relationship between the obtained soil parameters and the community variations.

RESULTS AND DISCUSSION

Floristic Analysis

One hundred and nine plant species (67 annuals, 2 biennials and 40 perennials) from 86 genera and 29 families were listed in this study (Appendix 1). During the winter season, this region of the country received the most rain (Zahran and Willis, 2009). Annual plants possess higher reproduction capacity in addition to their morphological, ecological, and genetic plasticity (Grime, 1979; Kowarik, 1985). In accordance with the literature, Asteraceae, Poaceae, Chenopodiaceae, and Fabaceae (22, 18, 11 & 7 species, respectively), Brassicaceae and Polygonaceae (6 species each), and Euphorbiaceae (4 species) were the most numerous groups (4 species). They made up 67.89 % of all species reported and account for the majority of the floristic composition in this area; whereas the nine families contain 20.18 % of the species and 13 monospecific families. In the Mediterranean and Northern Africa flora, these are the most prevalent families (Abd El-Gawad & Shehata, 2014; El-Amier et al., 2014a). Together, the Asteraceae and Poaceae families are the world’s biggest and most diverse flowering plant family (Walters & Keil, 1996; Christenhusz & Byng, 2016). Taxonomic diversity in the studied area is 1.27 for species/ genera ratio and 2.97 for genera/families. In general, there is a small family size: just three families contain more than ten species, while 26 have fewer than ten. Clearly, genus *Euphorbia*, *Amaranthus*, and *Cyperus* contain the highest number of species (4, 3 and 3 species, respectively), while *Launaea*, *Zygophyllum*, *Bassia*, *Carduus*, *Conyza*, *Mesembryanthemum*, *Plantago*, *Polygono*, *Rumex* and *Senecio* genera contain only two species (Appendix 1).

Seventy eight species (32 perennials, 2 biennials and 33 annuals) were recorded in the Deltaic Mediterranean coastal desert and 58 species (20 perennials and 38 annuals) in the inland habitats (roadsides and furrow land in the Nile Delta). *Convolvulus arvensis*, *Cynanchum acutum*, *Cynodon dactylon*, *Imperata cylindrica*, *Lolium perenne*, *Phragmites australis*, *Phyla nodiflora* and *Symphyotrichum squamatum* were the most abundant perennial species associated with *H. curassavicum* in the two habitats while, *Echinops spinosus*, *Zygophyllum aegyptiwm*, and *Zygophyllum albam* were the perennial species found in the coastal desert that were linked with the examined plant. Each of these species recorded higher importance values (IV) (Appendix 1). The number of invasive species in the Nile Delta is higher than in Egypt’s other phytogeographical zones. This may be due to the fact that the Nile area has a long history of human civilization, and the indigenous peoples of Egypt have had the time and opportunity to alter the natural vegetation via their agricultural operations. The invasive species, on the other hand, do poorly in the Red Sea and Gebel Elba areas, owing to their distance from heavy human effect, as well as their dry habitat (Shaltout et al., 2016).

Therophytes made up the bulk of the species observed (60% of the total species), followed by cryptophytes (17.39 %), hemicyrptophytes (10.45 %), and chamaephytes (8.70 %), with nanophanerophytes accounting for 2.61 %. Therophytes were the most dominant species among the recorded life forms (Appendix 1) and appears to be a response to hot-dry climate, topographic variability and biotic effect that distinguish the study area (Heneidy & Bidak, 2001). At the time, cryptophytes are also the most common life form (Appendix 1). This could be described in terms of plant habits, as nearly all of these plants are rhizomatous, which are thought to be more resistant to breakdown when submerged in water. The same conclusions have almost been obtained by El-Demerdash (1984), Shaltout et al. (1994) and El-Amier et al. (2021). Figure 2 depicts the life forms of the associated species with the investigated plant in the studied habitats.

Chorological Affinities of the Associated Vegetation

According to a chorological study, the studied habitats have the most Mediterranean elements (Deltaic coast: 53 species = 48.62%, and interior habitat: 21 species = 19.27%) (Table 1). The Mediterranean chorotype of the studied flora’s wide reveals the Mediterranean climate of the study area. The obtained results are consistent with the findings of the majority of comparable investigations (Barakat et al., 2014; El-Amier, 2016; El-Amier & Abd El-Gawad, 2017). Cosmopolitan and Saharo-Sindian elements accounted for 11 and 7 species of the total (10.09% and 6.42%, respectively) in the Deltaic coast. While, Cosmopolitan and Pantropical have 17 and 9 species (15.60% and 8.57%, respectively) in inland habitats (Table 2). In the Deltaic coast, cosmopolitan and Saharo-Sindian elements accounted for 11 and 7 species (10.09% and 6.42% of the total species), respectively. Whereas, in inland habitat, Cosmopolitan and Pantropical had 17 and 9 species (15.60% and 8.57%, respectively) (Table 1).
Classification of the Vegetation

At the second level of classification, TWINSPAN analysis techniques identified four primary vegetational groups, with the different overall numbers of species across groups (Figure 3 and Table 2). Each detected vegetation category was given a name based on the dominant species. Two of the documented species, *C. dactylon* and *P. australis*, were found to possess a wide ecological distribution range and to be present in all of the identified vegetation types.

**Group (A): Polypogon Viridis Group**

29 species were identified in this group from 4 stands in the inland habitats (roadsides and furrow land in the Nile Delta) except site 22; it is linked to *H. curassavicum* as important species, with a mean species richness of 3.21 species/stand, Simpson index of 0.97 and Shannon diversity index of 0.87 (Table 2). These stands were in soils with higher content of silt, clay, WHC, OC and CaCO$_3$ and moderate content of cations and anions (Table 3). The other abundant species include *Amaranthus hybridus* (indicator species), *Euphorbia heterophylla*, *Bidens pilosa* and *Sonchus oleraceus*. The other indicator species in this group was *Bromus diandrus*.

**Group (B): Heliotropium Curassavicum Group**

54 species were identified in this group from 15 stands in the inland and Deltaic Mediterranean coastal strip habitat. It has a mean species richness of 3.69 species/stands, Simpson index of 0.97 and Shannon diversity index of 0.89 (Table 2). These stands present in soil with higher electrical conductivity and moderate contents of the other examined soil variables (Table 3). Sporadic species included 17 species, of *Apium leptophyllum*, *Calendula arvensis*, *Capsella bursa pastoris*, *Coryza bonariensis*, *Cynodon dactylon*, *Cynodon dactylon*, *Eclipta alba*, *Emex spinosa*, etc (Appendix 1). The abundant species include *Cynodon dactylon*, *S. oleraceus*, *P. nodiflora*, *Rumex dentatus* and *C. arvensis*.

**Group (C): Cynodon Dactylon and Heliotropium Curassavicum Group**

This group showed higher diversity as it comprises 74 species identified from 23 stands, from the inland habitat and Deltaic Mediterranean coastal strip, with a mean species richness of 3.61 species/stands, Simpson index of 0.95 and Shannon diversity index of 0.89 (Table 2). The abundant species include *Cynodon dactylon*, *S. oleraceus*, *P. nodiflora*, *Rumex dentatus* and *C. arvensis*.

Table 1: Number of species and percent of the floristic categories in the coastal and inland habitats

| Floristic categories | Study area | Phytogeographical regions | Coastal | Inland |
|----------------------|------------|---------------------------|---------|--------|
|                      | No.       | %                         | No.     | %       |
| Worldwide            |           |                           |         |         |
| COSM                 | 19        | 17.43%                    | 11      | 12.64%  |
| NEO                  | 3         | 2.75%                     | 2       | 2.30%   |
| PAN                  | 9         | 8.26%                     | 5       | 5.75%   |
| PAL                  | 7         | 6.42%                     | 3       | 3.45%   |
| Pluriregional        |           |                           |         |         |
| ME+IR-TR+ER-SR      | 14        | 12.84%                    | 12      | 13.79%  |
| ME+IR-TR+SA-SI      | 2         | 1.83%                     | 2       | 2.30%   |
| ME+IR-TR+SA-SI      | 6         | 5.50%                     | 6       | 6.90%   |
| Biregional           |           |                           |         |         |
| ME+IR-TR            | 10        | 9.17%                     | 8       | 9.20%   |
| ME+SA-SI            | 10        | 9.17%                     | 10      | 11.49%  |
| ME+ER-SR            | 3         | 2.75%                     | 3       | 3.45%   |
| ME+PAL              | 1         | 0.92%                     | 1       | 1.15%   |
| IR-TR+SA-SI         | 3         | 2.75%                     | 3       | 3.45%   |
| IR-TR+S-Z           | 1         | 0.92%                     | 1       | 1.15%   |
| SA-SI+S-Z           | 2         | 1.83%                     | 1       | 1.15%   |
| Monoregional         |           |                           |         |         |
| ME                   | 11        | 10.09%                    | 11      | 12.64%  |
| SA-SI                | 7         | 6.42%                     | 7       | 8.05%   |
| AUST                 | 1         | 0.92%                     | 1       | 1.15%   |
| Total                | 109       | 100%                      | 87      | 100%    |

Figure 2: Plant life-form in the study area, and two habitats

Figure 3: TWINSPAN dendrogram of 45 stands according to the importance value and the 4 vegetation groups (A-D) separated. EV: Eigen value
Table 2: Plant diversity, dominant and important plant species of the tow studied habitats of *Heliotropium curassavicum*

| Vegetation group | Stand No. | Total Species | Simpson | Shannon–Wiener | Shannon-evenness | Dominant species | Other important species |
|------------------|-----------|---------------|---------|----------------|------------------|------------------|------------------------|
| A                | 4         | 29            | 0.97    | 3.21           | 0.87             | Polypogon viridis | *Heliotropium curassavicum* (21.26±0.46) |
|                  |           |               |         |                |                  |                  | *Amaranthus hybridus* (18.74±0.71) |
|                  |           |               |         |                |                  |                  | *Euphorbia heterophylla* (12.92±1.44) |
|                  |           |               |         |                |                  |                  | *Bidens pilosa* (12.11±0.82) |
|                  |           |               |         |                |                  |                  | *Sanchus oleraceus* (11.97±1.23) |
|                  |           |               |         |                |                  |                  | *Cynodon dactylon* (18.71±0.84) |
|                  |           |               |         |                |                  |                  | *Sanchus oleraceus* (8.13±0.87) |
|                  |           |               |         |                |                  |                  | *Phyla nodiflora* (7.84±1.57) |
|                  |           |               |         |                |                  |                  | *Rumex dentatus* (7.66±1.36) |
|                  |           |               |         |                |                  |                  | *Convolvulus arvensis* (7.31±1.36) |
|                  |           |               |         |                |                  |                  | *Zygophyllum albanum* (11.33±1.09) |
|                  |           |               |         |                |                  |                  | *Hordium murinum* (11.08±1.32) |
|                  |           |               |         |                |                  |                  | *Cakile maritima* (10.09±0.98) |
|                  |           |               |         |                |                  |                  | *Phragmites australis* (9.59±0.85) |
|                  |           |               |         |                |                  |                  | *Senecio glaucus* (9.46±1.21) |
| B                | 15        | 54            | 0.97    | 3.69           | 0.89             | *Cynodon dactylon* (15.83±1.00) |
|                  |           |               |         |                |                  |                  | *Heliotropium curassavicum* (15.60±0.36) |
| C                | 23        | 74            | 0.95    | 3.61           | 0.81             | *Zygophyllum albanum* (11.33±1.09) |
|                  |           |               |         |                |                  |                  | *Hordium murinum* (11.08±1.32) |
|                  |           |               |         |                |                  |                  | *Cakile maritima* (10.09±0.98) |
|                  |           |               |         |                |                  |                  | *Phragmites australis* (9.59±0.85) |
|                  |           |               |         |                |                  |                  | *Senecio glaucus* (9.46±1.21) |
| D                | 3         | 11            | 0.91    | 3.07           | 0.85             | *Phragmites australis* (45.26±0.44) |

Table 3: Mean values, standard error (±SE) and ANOVA values of the soil parameters in the vegetation groups (A-D) of the study area

| Soil variable          | A                     | B                     | C                     | D                     | F-value | P-value |
|------------------------|-----------------------|-----------------------|-----------------------|-----------------------|---------|---------|
| Sand (%)               | 51.62±7.23            | 58.11±5.90            | 86.30±4.04            | 39.35±0.78            | 10.99   | 0.0001 ***|
| Silt (%)               | 28.21±4.26            | 25.91±3.75            | 7.95±2.32             | 38.64±0.46            | 11.89   | 0.0000 ***|
| Clay (%)               | 20.18±2.99            | 15.99±2.27            | 5.75±2.03             | 22.01±1.03            | 8.98    | 0.0003 ***|
| Porosity (%)           | 32.88±0.44            | 30.84±0.99            | 39.33±1.57            | 30.37±0.98            | 17.52   | 0.0000 ***|
| WHC (%)                | 60.64±5.19            | 51.87±4.05            | 32.94±2.91            | 53.27±2.27            | 7.08    | 0.0011 ***|
| CaCO₃ (%)              | 7.19±0.67             | 5.34±0.90             | 3.66±0.61             | 5.57±0.77             | 5.59    | 0.0039 ** |
| OC (%)                 | 4.38±0.78             | 4.10±0.66             | 1.14±0.44             | 4.00±0.54             | 5.12    | 0.0060 ** |
| pH                     | 8.24±0.16             | 8.20±0.12             | 8.31±0.15             | 7.56±0.03             | 3.03    | 0.0461 *  |
| EC mS cm⁻¹             | 659.75±55.30          | 814.27±99.87          | 745.57±163.03         | 790.67±43.40          | 0.36    | 0.7859 ns |
| Cl⁻ (%)                | 0.46±0.07             | 0.50±0.15             | 0.76±0.19             | 0.13±0.00             | 1.76    | 0.1786 ns |
| SO₄²⁻ (%)              | 0.48±0.10             | 0.46±0.09             | 0.55±0.12             | 0.28±0.02             | 0.87    | 0.4685 ns |
| HCO₃⁻ (%)              | 0.26±0.02             | 0.21±0.01             | 0.48±0.38             | 0.21±0.01             | 0.86    | 0.4750 ns |
| Na⁺ (mg g⁻¹)           | 77.18±7.70            | 101.18±14.44          | 256.04±33.93          | 41.75±2.77            | 19.32   | 0.0000 ***|
| K⁺ (mg g⁻¹)            | 54.64±9.20            | 38.12±5.92            | 75.21±5.97            | 25.43±2.39            | 5.24    | 0.0054 ***|
| Ca²⁺ (mg g⁻¹)          | 53.52±7.67            | 44.17±5.19            | 142.19±17.02          | 32.34±4.81            | 20.44   | 0.0000 ***|
| Mg²⁺ (mg g⁻¹)          | 38.09±6.73            | 32.42±4.68            | 99.85±11.59           | 22.34±1.28            | 21.37   | 0.0000 ***|
| SAR                    | 11.58±0.55            | 15.83±1.45            | 22.46±2.01            | 8.07±0.09             | 15.32   | 0.0000 ***|
| PAR                    | 7.98±0.91             | 5.88±0.59             | 7.44±0.82             | 4.84±0.18             | 2.06    | 0.1282 ns |

EC = Electrical conductivity, OC = Organic carbon, ns = no significance at P < 0.05. *: significance at P < 0.05, **: significance at P < 0.01, ***: significance at P < 0.001

Shannon diversity index of 0.81 (Table 2). Sand, porosity, pH, sodium, potassium, calcium, magnesium, chloride, bicarbonate and sulphate were at their highest levels in these stands (Table 3). Sporadic species comprised 47 species (or about 43.12% of the listed species in this group) that included *Aegilops bicornis, Alhagi graeceorum, Amaranthus graecizans, Carduus getulus, Carduus pycnocephalus, Carthamus tenuis, Cyperus capitatus* and *Launaea nudaecalis* (Appendix 1). The abundant species in this group include *Z. albium, Hordium murinum, Cakile maritima, P. australis* and *Senecio glaucus*.

**Group (D): Phragmites Australis Group**

It is the smallest group, representing the Deltaic Mediterranean coastal strip habitat. It contains 11 species identified from three stands, with the lowest species richness of 3.07 species/stands, Simpson index of 0.91 and Shannon diversity index of 0.85 (Table 2). These sites were characterized by higher percentages of fine particles (silt and clay), CaCO₃ and organic carbon, but the majority of soil variables tested were at lower levels in these stands (Table 3). The abundant species in this group include...
Arthrocenmum macrostachyum, Atriplex portulacoides, Cynodon dactylon, Halocnemum strobilaceum, Heliotropium curassavicum and Pluchea dioscoridis (Appendix 1).

Sampling Sites Ordination

Figure 4 depicts the DCA-generated sampled stands ordination. The TWINSPPAN vegetation groups were highly distinct and had a coherent pattern of segregation on the ordination plane, while the groups A and B split at the middle portion of the right side of the DCA diagram, that was obviously segregated along the two axes of DCA. The largest group, Group C is split on the left side. Group D stands are clearly separated on the lower side from the other groups along the two axes of the DCA diagram. It’s worth noting that the strong parallels in floristic composition and natural habitats between the above-mentioned plant types may explain interspecific connections.

Soil–vegetation Relationships

Canonical Correspondence Analysis (CCA) was used for investigating the link between vegetation and soil characteristics. The CCA ordination biplot with vegetation groups (A-D) and the investigated soil parameters are shown in Figure 5. The phyto-diversity of natural communities can be influenced by soil texture, salinity, and organic carbon (El-Sheikh, 1989; Pinke et al., 2010). In this study, soil texture, WHC, organic carbon, cations (Na⁺, K⁺, Ca⁴⁺, and Mg²⁺), and SAR were obviously the most influencing soil parameters with strong significant relationships with the first and second axis. This agrees more or less with the findings of Maswada and Elzaawely (2013), El-Amier et al. (2014a) and Abd-ElGawad et al. (2020) in the Mediterranean area of the Nile Delta.

In the upper right side of the CCA diagram, P. australis, which was the dominant species in group D and important species (A. macrostachyum, A. portulacoides, H. strobilaceum, Z. albam, H. murinum and S. glaucus) in groups C and D showed close relationships with sand, pH, cations (Na⁺, K⁺, Ca⁴⁺, and Mg²⁺) and SAR. In the upper left side of the diagram, P. viridis was the dominant species in group A, H. curassavicum, which was dominant and codominant species in groups B and C, respectively, and important species (E. heterophylla, P. nodiflora, P. olerceus, R. dentatus and S. oleracous) in groups A and B, all expressed a close relationship with fine fractions (silt and clay), WHC, organic carbon, CaCO₃, and PAR. While the codominant species (C. dactylon) and important species (C. maritima) of group C are separated at the lower right side of the diagram. These species expressed a clear relationship with sand, SO₄²⁻ and Ca. Meanwhile, in the lower left side, C. arvensis and P. dioscoridis, which were important species in groups B and D, exhibited no relationships with soil factors.

CONCLUSIONS

Invasive plant species can obstruct native plant establishment and growth, as well as have an influence on soil cover, nutrient cycling, and hydrology. Controlling invasive species is thus vital, although sometimes costly, step toward ecosystem restoration. The current study analyzed the vegetation structure and soil properties of a single invasive plant in the Nile Delta of Egypt in order to aid in the ecological management and protection of these natural resources. More study on modifying soil biota and species diversity to improve invasion resistance is also needed.

AUTHOR’S CONTRIBUTION

All authors contributed equality in carrying out the research study and the development of this paper.

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### Appendix 1: Floristic composition of the plant species of the different habitats in the study area

| Species | Family | Life form | Chorotype | Phytogeographical regions | P% |
|---------|--------|-----------|-----------|---------------------------|----|
| **Perennials** | | | | | |
| Alhagi graecorum Boiss. | Fabaceae | H | PAL | Coastal + | 4.44 |
| Artemisia capillaris L. | Compositae | Ch | ME+SA-SI | Inland - | 8.89 |
| Atriplex portulacoides L. | Chenopodiaceae | Ch | ME+IR-TR+SA-SI | Coastal + | 8.89 |
| Atriplex nummularia L. | Chenopodiaceae | Ch | ME+IR-TR+SA-SI | Inland + | 6.67 |
| Calligonum comosum (L., Her.) Sokov. | polygonaceae | Nph | SA-SI+IR-TR | Coastal + | 6.67 |
| Cistanche phelypaea (L.) Cout. | Orobanchaceae | G, P | ME+SA-SI | Coastal + | 6.67 |
| Convolvulus arvensis L. | Convolvulaceae | H | COSM | Coastal + | 17.78 |
| Cynanchum acutum L. | Asclepiadaceae | H | ME+IR-TR | Coastal + | 15.56 |
| Cynodon dactylon (L.) Pers. | Poaceae | G | PAN | Coastal + | 55.56 |
| Cyperus rotundus L. | Cyperaceae | G | PAN | Coastal + | 11.11 |
| Cyperus articulatus L. | Cyperaceae | G | PAN | Coastal + | 2.22 |
| Cyperus capitatus Var. | Cyperaceae | G | ME | Coastal + | 2.22 |
| Echinocloa stagnina (Retz.) P.Beauv. | Poaceae | G, He | PAL | Coastal + | 2.22 |
| Echinops spinosus L. | Asteraceae | H | ME+SA-SI | Coastal + | 13.33 |
| Halocnemum strobilaceum (Pall.) M. Bieb. | Chenopodiaceae | Ch | ME+IR-TR+SA-SI | Coastal + | 4.44 |
| Heliotropium curassavicum L. | Boraginaceae | H | NEO | Coastal + | 100 |
| Imperata cylindrica (L.) Raeusch | Poaceae | H | ME+PAL | Coastal + | 11.11 |
| Juncus acutus L. | Juncaceae | He | ME+IR-TR+ER-SR | Coastal + | 6.67 |
| Limbara crithmoides (L.). Dumort. | Asteraceae | Ch | ME+ER-SR+SA-SI | Coastal + | 6.67 |
| Launaea mucronata (Forsk.) Muschl. | Asteraceae | H | ME+SA-SI | Coastal + | 6.67 |
| Launaea nudicaulis (L.) Hook.f. | Asteraceae | H | SA-SI | Coastal + | 4.44 |
| Leptochloa fusca (L.) Kunth. | Poaceae | G, He | PAN | Coastal + | 6.67 |
| Lolium perenne L. | Poaceae | Th | ME+IR-TR+ER-SR | Coastal + | 17.78 |
| Lotus polyphyllus E.D.Clarke. | Fabaceae | Th | ME | Coastal + | 2.22 |
| Mentha longifolia (L.) Huds. | Lamiaeae | H | PAL | Coastal + | 2.22 |
| Oxalis corniculata L. | Oxalidaceae | H | COSM | Coastal + | 8.89 |
| Paspalidium geminatum (Forsk.) Stapf | Poaceae | He | PAL | Coastal + | 2.22 |
| Persicaria salicifolia Brous. ex Willd. | Polygonaceae | G | PAL | Coastal + | 2.22 |
| Phragmites australis (Cav.) Trin. exSteud. | Poaceae | G, He | COSM | Coastal + | 40 |
| Phyla nodiflora (L.) Greene | Verbenaceae | Ch | PAN | Coastal + | 13.33 |
| Plantago major L. | Plantaginaceae | H | COSM | Coastal + | 4.44 |
| Pluchea discoidea (L.) DC. | Asteraceae | Nph | SA-SI+S-Z | Coastal + | 13.33 |
| Polygonum aquifolium Sm. | Polygonaceae | G | ME+IR-TR | Coastal + | 2.22 |
| Stipa graminata (Forsk.) De Winter | Poaceae | G | SA-SI | Coastal + | 2.22 |
| Suada prostrata Lang | Chenopodiaceae | Ch | ME | Coastal + | 6.67 |
| Symphyotrichum squamatum (Asch.) Dandy | Asteraceae | Ch | NEW | Coastal + | 11.11 |
| Tamariya nitolica (Ehrenb.) Bunge | Tamaricaceae | Nph | SA-SI+S-Z | Coastal + | 4.44 |
| Veronica anagallis-aquatica L. | Scrophulariaceae | He | COSM | Coastal + | 2.22 |
| Zygophyllum aegyptium Hosny | Zygophyllaceae | Ch | ME | Coastal + | 11.11 |
| Zygophyllum album L.F | Zygophyllaceae | Ch | ME+SA-SI | Coastal + | 17.78 |
| **Biennials** | | | | | |
| Rorippa palustris (L.) Besser, Enum. Pl.Volyn. | Brassicaceae | Th | ME+IR-TR+ER-SR | Coastal + | 4.44 |
| Spergularia marina (L.) Griseb. | Caryophyllaceae | Th | ME+IR-TR+ER-SR | Coastal + | 4.44 |
| **Annuals** | | | | | |
| Aegilops bicornis (Forss) Jaub.&Spach | Poaceae | Th | ME+SA-SI | Coastal + | 8.89 |
| Amaranthus graecizans L. | Amaranthaceae | Th | ME+IR-TR | Coastal + | 2.22 |
| Amaranthus dubius L. | Amaranthaceae | Th | PAL | Coastal + | 11.11 |
| Amaranthus lividus L. | Amaranthaceae | Th | PAL | Coastal + | 2.22 |
| Anagallis arvensis L. var. arvensis | Primulaceae | Th | COSM | Coastal + | 11.11 |
| Anchusa humilis (Desf) I.M.Johnst. | Boraginaceae | Th | ME+SA-SI | Coastal + | 2.22 |
| Atriplex hortensis (Pers.) F. Muell. Ex.Benth. | Primulaceae | Th | COSM | Coastal + | 4.44 |
| Astragalus peregrinus Vahl | Fabaceae | Th | SA-SI | Coastal + | 2.22 |
| Bassia indica (Wight) Scott. | Chenopodiaceae | Th | IR-TR+S-Z | Coastal + | 33.33 |
| Bassia muricata (L.) Asch. | Chenopodiaceae | Th | IR-TR+SA-SI | Coastal + | 4.44 |
| Beta vulgaris var. cicla L. | Chenopodiaceae | Th | ME+IR-TR+ER-SR | Coastal + | 20 |
| Bidens pilosa L. | Asteraceae | Th | PAL | Coastal + | 24.44 |
| Bromus diandrus Roth | Poaceae | Th | ME | Coastal + | 17.78 |
| Calilie maritima Scop. subsp. aegyptiaca (Willd.) | Brassicaceae | Th | ME+ER-SR | Coastal + | 35.56 |
| Nyman | | | | | |
| Calendula arvensis L. | Asteraceae | Th | ME+IR-TR+SA-SI | Coastal + | 2.22 |

(Contd...)
### Appendix 1: (Continued)

| Species | Family | Life form | Chorotype | Phytogeographical regions | P% |
|---------|--------|-----------|-----------|---------------------------|----|
| Capsella bursa-pastoris (L.) Medik. | Brassicaceae | Th | COSM | - | + | 2.22 |
| Carduus getulus P. | Asteraceae | Th | SA-SI | + | - | 2.22 |
| Carduus pycnocephalus L. | Asteraceae | Th | ME | + | - | 6.67 |
| Carthamus tenuis (Boiss & Blanche) Bornm | Asteraeae | Th | ME | + | - | 2.22 |
| Chenopodium mural L. | Chenopodiaceae | Th | COSM | + | + | 4.44 |
| Conyza aegyptiaca (L.) Dryand | Asteraceae | Th | ME | + | + | 13.33 |
| Conyza bonariensis (L.) Cronquist, Bull. | Asteraceae | Th | ME | + | + | 4.44 |
| Crambopsis dichotoma (L.) Sm. | Brassicaceae | Th | COSM | + | + | 2.22 |
| Cutandia memphitica (Spreng.) Benth. | Poaceae | Th | ME + IR-TR + SA-SI | + | - | 2.22 |
| Echinocloa colonella (L.) Link | Poaceae | Th | PAN | - | + | 4.44 |
| Eclipta alba L. | Asteraceae | Th | NEO | - | + | 2.22 |
| Emex spinosa (L.) Campd. | Polygonaceae | Th | ME + SA-SI | + | + | 4.44 |
| Erodium laciniatum (Cav.) Willd. | Geraniaceae | Th | ME | + | - | 4.44 |
| Euphorbia peplus L. | Euphorbiaceae | Th | ME + IR-TR + ER-SR | + | + | 15.56 |
| Euphorbia helioscopia L. | Euphorbiaceae | Th | ME + IR-TR + SA-SI | + | + | 4.44 |
| Euphorbia heterophylla L. | Euphorbiaceae | Th | PAN | - | + | 4.44 |
| Euphorbia prostrata Alton, Hort. Kew, ed. | Euphorbiaceae | Th | PAN | - | + | 2.22 |
| Hordeum marinum Huds. | Poaceae | Th | ME + IR-TR | + | - | 24.44 |
| Ifloga spicata (Forsk.) Sch. Bip. | Asteraceae | Th | SA-SI | + | + | 2.22 |
| Juncus rigidus L. | Juncaceae | G, He | ME + IR-TR + ER-SR | - | + | 6.67 |
| Lobularia arabica (Boiss.) Muschl. | Brassicaceae | Th | SA-SI | + | - | 2.22 |
| Lotus halophilus Boiss. & Spruner | Fabaceae | Th | ME + SA-SI | + | - | 6.67 |
| Malva parviflora L. | Malvaceae | Th | ME + IR-TR | + | + | 37.78 |
| Medicago sativum L. | Fabaceae | Th | COSM | - | + | 2.22 |
| Melilotus indicus (L.) All. | Fabaceae | Th | ME + IR-TR + SA-SI | + | + | 15.56 |
| Mesembryanthemum crystallinum L. | Aizoaceae | Th | ME + ER-SR | - | + | 31.11 |
| Mesembryanthemum nodiflorum L. | Aizoaceae | Th | ME + SA-SI + ER-SR | + | + | 15.56 |
| Phalaris minor Retz. | Poaceae | Th | ME + IR-TR | + | - | 22.22 |
| Plantago lagopus L. | Plantaginaceae | Th | ME + IR-TR | + | - | 2.22 |
| Plantago squarrosa Murray | Plantaginaceae | Th | ME | + | - | 2.22 |
| Poa annua L. | Poaceae | Th | COSM | + | + | 13.33 |
| Portulaca oleracea L. | Portulaca | Th | IR-TR + SA-SI | + | + | 13.33 |
| Polygonon monspeliensis (L.) Desf. | Poaceae | Th | COSM | + | + | 13.33 |
| Polygonon viridis (Gouan) Breistr. | Poaceae | H | ME + IR-TR | + | + | 22.22 |
| Pseudognaphalium luteo-album (L.) Hiliard& B.L. Burtt. | Asteraceae | Th | COSM | - | + | 2.22 |
| Reichardia tingitana (L.) Roth | Astereaeae | Th | ME + IR-TR | + | - | 17.78 |
| Rumex dentatus L. | Polygonaceae | Th | ME + IR-TR + ER-SR | - | + | 15.56 |
| Rumex pultus Forsk. | Polygonaceae | Th | ME + SA-SI | + | - | 22.22 |
| Salsola kali L. | Chenopodiaceae | Th | COSM | - | + | 20 |
| Senecio aegyptiatus L. | Asteraceae | Th | ME + IR-TR + ER-SR | - | + | 2.22 |
| Senecio glaucus L. | Asteraceae | Th | ME + IR-TR + SA-SI | + | + | 37.78 |
| Setaria verticillata (L.) P. Beauv. | Astereaeae | Th | COSM | - | + | 2.22 |
| Sielene vivianii Steud. | Caryophyllaceae | Th | SA-SI | - | + | 2.22 |
| Sisymbrium irio L. | Brassicaceae | Th | ME + IR-TR + ER-SR | + | + | 6.67 |
| Solanum nigrum L. | Solanaceae | Th | COSM | + | + | 22.22 |
| Sonchus oleraceus L. | Astereaeae | Th | COSM | + | + | 35.56 |
| Stellaria palida (Dumort.) Murb. | Caryophyllaceae | Th | ME + ER-SR | + | + | 6.67 |
| Suada maritima (L) Dumort. | Chenopodiaceae | Th | COSM | - | + | 4.44 |
| Urospermum piciproides (L.) F.W.Schmidt | Astereaeae | Th | ME + IR-TR | + | + | 6.67 |
| Urtica urens L. | Urticaceae | Th | ME + IR-TR + ER-SR | + | + | 11.11 |
| Vicia sativa L. | Fabaceae | Th | ME + IR-TR + ER-SR | + | + | 8.89 |

P = Presence, Nph = Phanerophytes, H = Hemicryptophytes, Ch = Chamaephytes, Th = Theophytes, G = Geophytes, He = Helophytes, P = Parasites, SA-SI = Saharo-Sindian, S-Z = Sudano-Zambezian, IR-TR = Irano-Turanian, ER-SR = Euro-Siberian, ME = Mediterranean, NEO = Neotropical, PAL = Palaeotropical, PAN = Pantropical, COSM = Cosmopolitan, AUST = Australian