Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology
Official Journal of the Societa Botanica Italiana

ISSN: 1126-3504 (Print) 1724-5575 (Online) Journal homepage: http://www.tandfonline.com/loi/tplb20

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To cite this article: Mohamed Abdelaal, Mauro Fois & Giuseppe Fenu (2017): The influence of natural and anthropogenic factors on the floristic features of the northern coast Nile Delta in Egypt, Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, DOI: 10.1080/11263504.2017.1302999

To link to this article: http://dx.doi.org/10.1080/11263504.2017.1302999

Plant Biosystems, 2017
http://dx.doi.org/10.1080/11263504.2017.1302999

The influence of natural and anthropogenic factors on the floristic features of the northern coast Nile Delta in Egypt

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Abstract

The Egyptian Mediterranean sand dunes are being lost due to recent excessive unplanned anthropogenic interventions that caused a modification in floristic composition. The present study provides a description of the floristic inventory and plant clusters in coastal dunes in relation to natural and human factors. Floristic sampling was carried out in nine transects along Nile Delta coast, a total of 55 plots were randomly placed and data on natural and anthropogenic factors were measured for each plot. Agglomerative Hierarchical Cluster allowed to identify four plant clusters: (A) *Elymus farctus-Silene succulenta*, (B) *Echinops spinosus-Moltkiopsis ciliata*, (C): *Stipagrostis lanata-Echium angustifolium* and (D): *Lycium schweinfurthii-Asparagus stipularis*. Fish farming, ceramic industry, trampling, agriculture, urbanization, magnesium, total nitrogen, potassium, calcium and organic matter were identified as the most significant key factors for the definition of plant clusters by Canonical Correspondence Analysis. Variance partitioning confirmed that 40% of the variance was explained by both natural and anthropogenic factors. In particular, anthropogenic factors explained only 9% while natural variables 2% of the total variance, whereas the combined shared effect was 29%. The information in this study enables us to establish an effective conservation strategy to prevent further declines in plant diversity along coastal dunes.

Keywords: *Mediterranean Basin, human disturbance, coastal flora, biological indicators, sand dunes, psammophilous plants*

Introduction

Coastal dunes are recognized as one of the most important ecosystems in the world, branded by extreme ecological diversity in terms of plant diversity and landscape heterogeneity (Acosta et al. 2009; Ciccarelli 2014; Agir et al. 2015; Pinna et al. 2015a). Moreover, coastal dunes offered human beings with crucial services such as raw materials, coastal shield, water catchment, wildlife preservation, tourism and carbon sequestration among others (Mendoza-González et al. 2012; Malavasi et al. 2016).

In sand dunes systems, the environmental gradient along seashore-inland determines the disposal of different plant communities which are the result of biotic and abiotic influences (Acosta et al. 2009; Fenu et al. 2012, 2013b; Ciccarelli 2014). However, all of these exceptional features of coastal dunes make them particularly fragile and stressful ecosystems in response to both natural and anthropogenic factors (Fenu et al. 2013a, 2013b). In fact, during the last century, the Mediterranean coastal dunes systems appear to undergo a reduction percentage of about 70% within Europe (Brown & McLachlan 2010; Pinna et al. 2015a) and, unfortunately, in Egypt this process appears to be even more intensive than European coasts, up to reach decreases higher than 75% (Ahmed et al. 2014).

According to several authors (e.g. El Banna 2004; Honrado et al. 2010; Fenu et al. 2012, 2013a), some natural factors related to soil and climatic traits as well as human-induced activities, or a combination of these factors, are the main controlling drivers for distribution of plant communities in dune ecosystems. Natural factors comprise both climatic (e.g. temperature, rainfall and wind speed) and soil-related factors (e.g. EC, pH, organic matter, nutrients; Maun 2009; Fenu et al. 2012, 2013a). In addition, the impacts released by unplanned human activities, such as urbanization, agriculture, pollution, industrialization, fish farming, trampling, touristic pressures, over-cutting and uprooting, over-collecting, overgrazing, military camping and colonization of alien plant species, may have a significant negative influence on the coastal

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ecosystems in all the Mediterranean countries (Honrado et al. 2010; Pinna et al. 2105b; Fois et al. 2016). In particular, human disturbance can reduce plant cover, diversity and productivity; in general, this is more evident in rare and threatened species. According to Ciccarelli (2014), the disappearance of embryonic dune habitats was correlated with erosion, whereas vegetation destruction and soil compaction are the major adverse effects of human trampling. Some wind-related factors viz. sand movement and salt spray are considered the main factors in determining the composition and distribution of coastal plant communities (Fenu et al. 2013a).

In coastal dunes, any direct or indirect measures of biodiversity are useful bioindicators for their conservation status assessment. Hence, many methods have been proposed for such goal as vegetation composition, diversity, characteristic plant communities, landscape cover and human impacts (e.g. Vallés et al. 2011; Fenu et al. 2012, 2013a; Ciccarelli 2014; Pinna et al. 2015a).

In Egypt, coastal dunes along Nile Delta harbour a wealth of natural resources that provide many ecosystem services, particularly fertile agriculture soils, mineral resources, recreation places and fish farms opportunities (Zahran et al. 1990). Therefore, these areas have been overexploited since the last century and several pressures on biodiversity are concentrated in coastal dunes. Most of the threats to biodiversity are caused by a recent unplanned land-use change. In particular, human activities have caused the fragmentation of dune systems by developing agriculture, fish farming and aquacultures, urbanizations, ceramic industries and the expansion of the international coastal highway (Zahran & Willis 2009). Moreover, climate changes, a foreseeable rise of sea level, salt water incursion, and beach erosion are threatening factors in these coastal areas (El Banna & Frihy 2009).

Although many earlier studies have focused on the floristic composition in coastal sand formations in Egypt (e.g. Zahran et al. 1990; Galal & Fawzy 2007; Shaltout et al. 2010), no information is available on the relationships between environmental factors (i.e. natural and anthropogenic variables) and vegetation composition and structure.

Therefore, the specific objectives of this study were: (1) to update the floristic information about the dunes system along Nile Delta coast, (2) to define the prevailing plant clusters in this environment and (3) to analyse how these are influenced by natural and anthropogenic factors.

Materials and methods

Study area

This study was conducted in the Mediterranean coastal dunes of Nile Delta (northern Egypt). It extends for ca.136 km from the eastern side (Damietta) to western side (Rosetta) covering an area of ca. 18,000 km^2, occupying an overall area of ca. 200 km^2 (Figure 1).

Currently, the coastal dunes are mainly distributed in four representative sites from east to west: Zaiaan, Qalabshu, Baltim and remnants in Rosetta. The first two sites are belonging to El-Dakahlia province, while the other two sites are located in Kafr El-Sheikh and El-Behira provinces, respectively (Figure 1). In particular, the coastal dunes in Qalabshu site are considered the less impacted in comparison with other sites and, in fact, they capture a wilder dune vegetation succession. In addition to sand dunes, the coastal zone along Nile Delta is characterized by other natural habitats such as sand flats and salt marshes.

Geologically, the Egyptian Mediterranean dunes originated from fine detritus developed from weathering processes in Ethiopian plateau and transferred by the Nile River to the Mediterranean Sea; this sediment is sporadically deposited nearby the mouths of Nile distributaries (Galal & Fawzy 2007).

Climatically, the Nile Delta is included in the coastal belt of the arid province with mild winters and hot summers (Shaltout et al. 2010). The annual temperature ranges between about 19 to 24°C and rainfall fluctuates between 9 and 15 mm per year.

Floristic sampling

Nine transects, orthogonal to the coastline, were placed in the coastal dunes during October–November, 2014 and April–June, 2015 (two in Zaiaan, three in Qalabshu, two in Baltim and two in Rosetta). The length and number of transects varied depending on dune morphology and width. Fifty-five plots of 10 × 10 m each, based on minimal area (Moravec 1973) were randomly sampled in the study sites. The number of sampling plots was based on the ecological and floristic variability. In each plot, a list of plant species was compiled and the cover percentage of each species was visually estimated. The taxonomic treatment of plant species follows the updated checklist of Boulos (2009). A synoptic appendix of plant species with their families, life span, life forms and chorotypes was implemented.

Estimation of natural and anthropogenic factors

The natural factors considered in this study include climatic and soil factors. The data of the mean values of the annual air temperature (At; °C), rainfall (R; mm), and wind speed (Ws; m/s) for 10 years (2005–2014) were provided by the Climatological Normals of Egypt (unpublished data, personal communication).

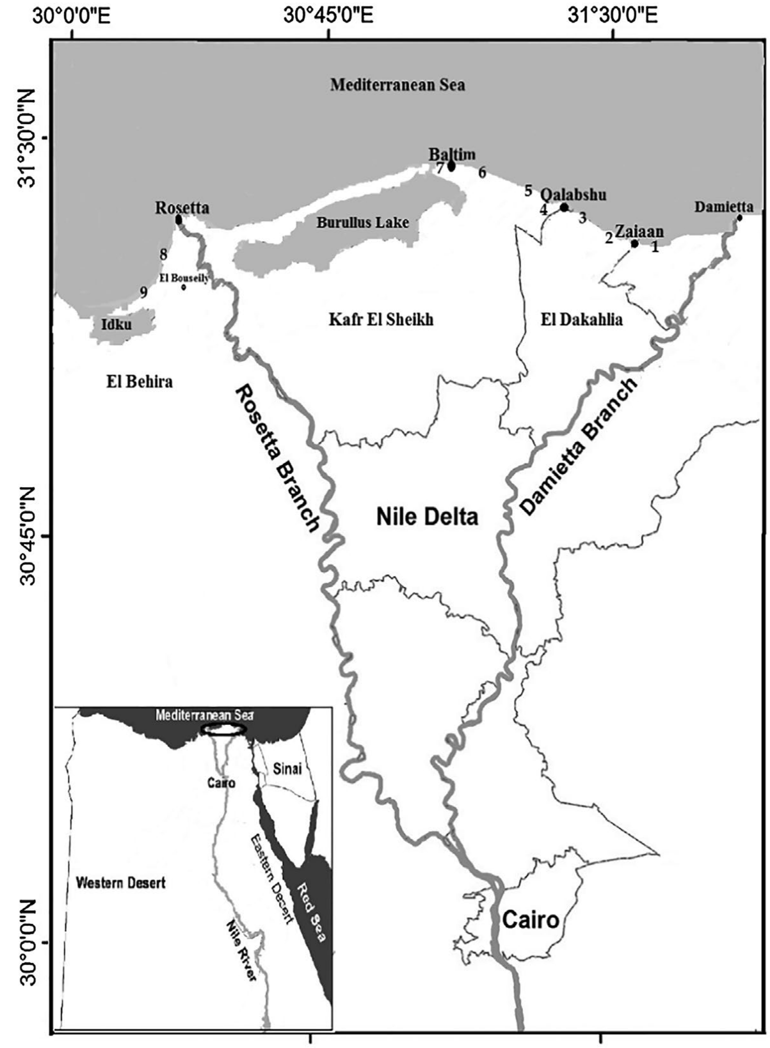

Figure 1. Location map and distribution of transects within the studied sites. Source: Mohamed Abdelaal.

Soil characteristics were directly analysed in composite soil samples collected from each plot at a depth of 0–50 cm. Soil water content percentage (Wc; %) was estimated using the drying method at 105°C for 24 h. Organic matter content (Om; %) was analysed using Walkley-Black method by digestion with acidic chromic acid and titration against 1 N $FeSO_4 \cdot 7H_2O$ solution using diphenylamine as an indicator. $CaCO_3$ (%) content was measured by an acid attack using diluted HCl and titration against 1 N NaOH (Jackson 1962). Total nitrogen (N_T, mg 100 g^{-1} soil) was assessed by Kjeldahl digestion method (Estefan et al. 2013). The automated readings of pH and electric conductivity (EC; mmhos cm^{-1}) in a soil solution of 1:5 ratio (100 g sand sample in 500 ml distilled water) were recorded by using pH-meter (Model Lutron pH 206) and conductivity meter (Model Corning, NY 14831 USA), respectively. Total phosphorus (P_T; mg 100 g^{-1} soil) was estimated by stannous chloride method (Estefan et al. 2013). Elements (K, Ca, Mg; mg 100 g^{-1} soil) were measured using Atomic Absorption Spectrometer (Perkin Elmer Model 2380). The grain size (Gs; mm) of the sand samples were obtained from the previous literature of El Banna (2004). Soil temperature (St; °C) was recorded after the Climatological Normals of Egypt.

For each plot, ten anthropogenic factors were estimated according to field observations and ranked from 0 to 4 using the following disturbance classes: 0: absent, 1: low, 2: moderate, 3: high and 4: severe. These factors include agriculture activities (Ag), urbanization (Ur), fish farms (Ff), ceramic industry (Ci), overcutting (Oc), overgrazing (Og), pollution (Po), military camping (Mc), trampling (Tr) and alien weeds (As).

Data analysis

A data matrix of 55 plots × 79 plant species was constructed to define the plant clusters by Agglomerative Hierarchical Cluster analysis (AHC) with Jaccard coefficient as a dissimilarity measure and complete linkage as a clustering algorithm (Roleček et al. 2009).

For each identified cluster, species richness was calculated as the average number of species per sampled plot. The Shannon's evenness index (E) was estimated from the formula:

$$E = H'/\ln S \quad (1)$$

where S is the total number of species and H' is the Shannon–Wiener's niche width index (Van Valen 1965). It assigns low niche width values to specialists and higher values to generalists and was calculated as follows:

$$H' = -\sum_{n=1}^{n} \log_e p_i \sum_{n=1}^{n} \log_e p_i \quad (2)$$

where p_i is the cover value of the i^{th} species. Thus, the relative concentration of dominance was assessed using Simpson's index (Pielou 1975):

$$C = \sum p_i^2. \quad (3)$$

The non-parametric Kruskal–Wallis one-way analysis of variance was applied to test the significant differences in cover percentage, diversity indices, natural and anthropogenic variables among plant clusters.

Hence, the six plant species with the highest Shannon–Wiener's niche width values were used to construct a Pearson correlation network of interspecific relationship. This method illustrates the level of niche overlap among plant species based on their co-occurrence in distinct plots (Zhang 2013). Pearson correlations ranges from 0 to 1, where 0 indicates that no niches are shared and 1 indicates complete overlap.

Relationships among characteristic plant species in the study area and natural and anthropogenic factors were investigated using Canonical Correspondence Analysis (CCA; Ter Braak 1986). In our analysis, to reduce the effects of rare plant species and natural and anthropogenic factors, only characteristic plants with mean cover >1.5% and significant variables (permutation test = 1000, $F = 0.596$, $p < 0.01$) were used (Ag, Tr, Ur, Ci, Ff, Gs, Ca, K, Mg and N_T).

Finally, variance partitioning (Borcard et al. 1992) was performed to determine the relative influence of natural and anthropogenic factors and their combined effects. AHC, CCA, and Kruskal–Wallis one-way analysis were performed by XLSTAT (2016), while species niche overlap and variance partitioning were performed in R environment (version: 3.1.1; R Development Core Team 2014), using the "spaa" (Zhang 2013) and vegan (Oksanen et al. 2015) packages.

Results

Floristic inventory

The floristic checklist of middle Egyptian Mediterranean dunes includes 79 species belonging to 24 families and 68 genera (Appendix 1 in supplemental data). Annual plants (44 species) were more represented than perennials (35 species). The Poaceae family was the most represented (24.0%), followed by Asteraceae (17.7%) and Chenopodiaceae (10.1%).

As regards the biological forms, the greatest percentage of therophytes (55.7%) was followed by hemicryptophytes (15.2%), geophytes (12.6%) and chamaephytes (10.1%). Only one parasitic species (*Cistanche phelypaea*) was recorded.

In terms of chorology, the floristic composition was mainly made up of Mediterranean (69.6%) and Saharo-Sindian species (43.0%). The Mediterranean element comprises pure Mediterranean (monoregional with 20.2%), biregional (32.9%) and pluriregional species (16.5%). No endemic species were accounted. Within the Saharo-Sindian element, monoregional plant species were represented by 7.6%, biregional by 22.8% and pluriregional by 12.7%. Also, the floristic spectrum comprises eight cosmopolitans, two palaeotropical and one neotropical species. Eight alien weeds represent 10.1% of the total number of species. Among these weeds, *Chenopodium murale* and *Melilotus indicus* were the most frequent.

Plant clusters

Agglomerative hierarchical cluster based on dissimilarity index allowed to identify four plant clusters (Figure 2) named according to their respective most representative species (by cover percentage): (A) *Elymus farctus*-*Silene succulenta* (17 plots and 24 species), (B) *Echinops spinosus*-*Moltkiopsis ciliata* (nine plots and 33 species), (C): *Stipagrostis lanata*-*Echium angustifolium* (eight plots and 27 species) and (D): *Lycium schweinfurthii*-*Asparagus stipularis* (21 plots and 67 species) (Figure 2 and Appendix 2 in supplemental data). *Rumex pictus* resulted as the most dominant annual species in all clusters. The peak number of alien weeds was observed in cluster D (five species) followed by cluster B (four species) and cluster C (two species), whereas no alien weeds were present in cluster A.

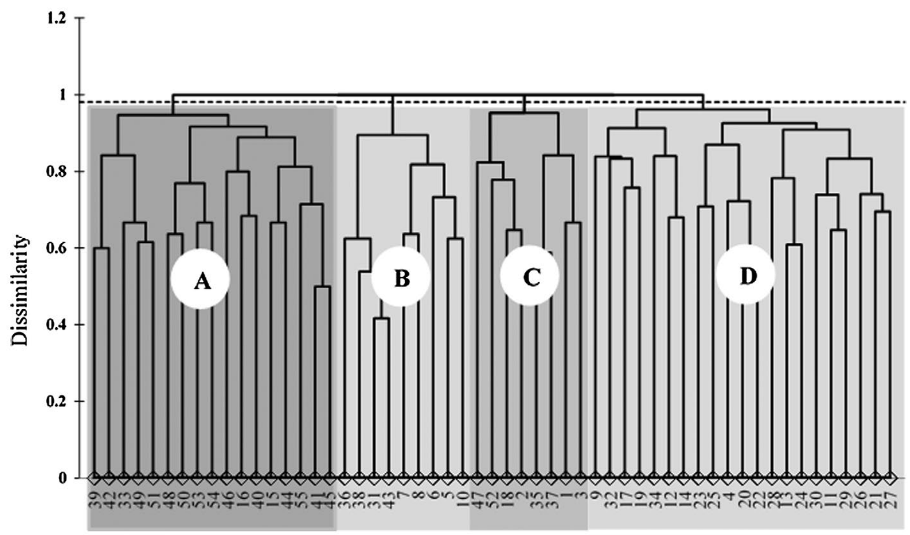

Figure 2. Agglomerative hierarchical cluster (AHC) using average Jaccard dissimilarity. Numbers indicate the number of plot, whereas letters A, B, C and D are coded for the plant clusters.

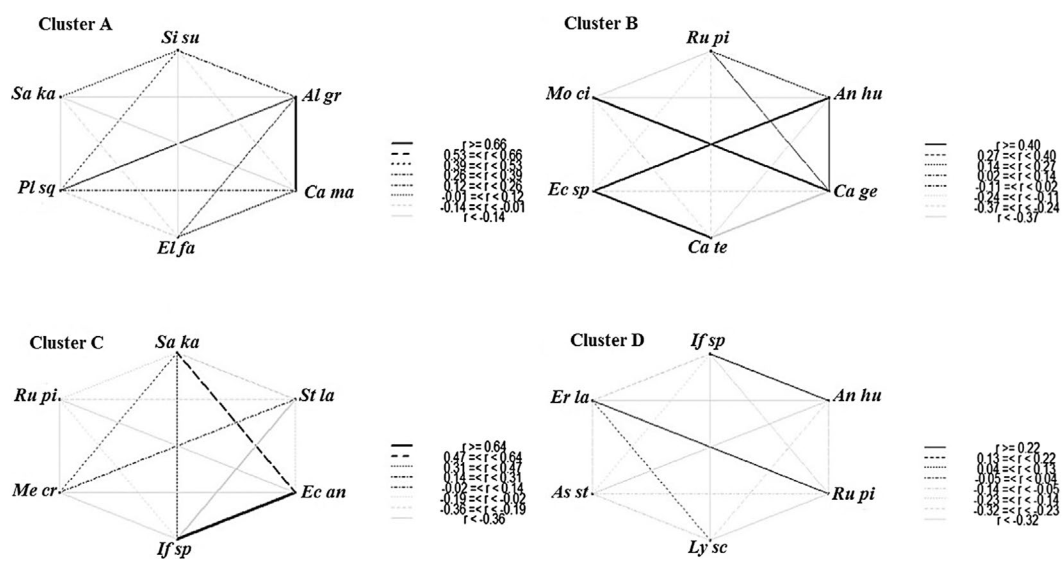

Figure 3. Species niche overlap in the plant clusters.

The *Elymus farctus*-*Silene succulenta* cluster resulted significantly different ($p < 0.05$) from the other clusters in terms of mean cover percentage and species richness and *Lycium schweinfurthii*-*Asparagus stipularis* cluster significantly differed from the other clusters only in terms of Shannon's index. No significant differences were recorded between *Echinops spinosus*-*Moltkiopsis ciliata* and *Stipagrostis lanata*-*Echium angustifolium* clusters (Appendix 2 in supplemental data).

The six species with the highest Shannon-Wiener's niche width index were recorded in each cluster (Appendix 2 in supplemental data) and the inter-specific network relationship explained the level of niche overlap among species (Figure 3). In cluster A, the first dominant perennial *Elymus farctus* resulted with the largest niche width (2.30) followed by *Silene succulenta* (2.28). In cluster B, the maximum niche width was shown by *Echinops spinosus* (1.72) followed by *Rumex pictus* (1.42). *Stipagrostis lanata* (1.64) and *Rumex pictus* (1.61) resulted with the maximum niche width in cluster C. *Lycium schweinfurthii* and *Asparagus stipularis* had the highest niche width in cluster D with values of 2.30 and 2.21, respectively.

The interaction of the six species with the higher niche width was plotted by a network of interspecific relationship (Figure 3). In cluster A, there was a significant association between *Alhagi graecorum* and both *Cakile maritima* and *Plantago squarossa* ($r \geq 0.66$). In cluster B, the closer relationship was established between each pair of the following species: *Anchusa humilis*-*Echinops spinosus, Carduus getulus*-*Moltkiopsis ciliata* and *Carthamus tenuis*-*Echinops spinosus* ($r \geq 0.40$). In cluster C, the highest correlation was between *Echium angustifolium* and *Ifloga spicata* ($r \geq 0.64$), followed by the association between *Echium angustifolium* and *Salsola kali* ($0.47 \leq r < 0.64$). Lastly, the maximum correlation in cluster D was observed between each pair of *Anchusa humilis*-*Ifloga spicata*, and *Erodium laciniatum*-*Rumex pictus* ($r \geq 0.22$).

Relationship between plant clusters and natural-anthropogenic variables

The natural and anthropogenic factors of the identified plant clusters are below summarized (see also Appendix 3 in supplemental data for details). Values herein reported are averages of all plots of each cluster.

Cluster A: Elymus farctus-Silene succulenta. This cluster occupies the embryonic sand dunes of ca. 15–20 m height and one km width along Nile Delta coast. The soil features had the maximum value of $CaCO_3$ (6.2%), EC (1.10 mmhos cm^{-1}), pH (8.24), potassium (35.86 mg 100 g^{-1} dry soil), calcium (6.94 mg 100 g^{-1} dry soil), magnesium (6.86 mg 100 g^{-1} dry soil), grain size (0.24 mm). This cluster is threatened by moderate degree scale of overgrazing and trampling, but high degree scale of fish farming and urbanization.

Cluster B: Echinops spinosus-Moltkiopsis ciliata. This cluster covers the first part of stabilized sand dunes of ranges ca. 4–5 m height and 300–400 m width. It occurs in coincidence of the highest levels of annual rainfall (9.65 mm) and wind speed (3.03 ms^{-1}), but low air temperature (20.28°C). It is also characterized by the maximum of water content (0.88%), organic matter (1.6%), magnesium (6.86 mg 100 g^{-1} dry soil), but the minimum of calcium carbonates (3.7%), total nitrogen (11.41 mg 100 g^{-1} dry soil), total phosphorus (0.17 mg 100 g^{-1} dry soil) and grain size (0.22 mm). The anthropogenic disturbance factors include high fish farming; moderate agriculture, urbanization, overgrazing and the presence of four alien weeds.

Cluster C: *Stipagrostis lanata*-*Echium angustifolium.* This cluster populates the partially stabilized dune belt of ca. 10–13 m height and ca.700 m width. It is distributed in soils of high temperature (17.67°C) and lower grain size (0.22 mm) compared to the other clusters. Human threats include moderate fish farming, agriculture, urbanization, overgrazing and the presence of three alien weeds.

Cluster D: *Lycium schweinfurthii*-*Asparagus stipularis.* This cluster lodges the second part of stabilized sand dunes of ca.10–12 m height and 600 m width. It occupies the soils with maximum total nitrogen and total phosphorus (34.19 and 0.24 mg 100 g^{-1} dry soil, respectively). Minimum values of rainfall (5.42 mm), wind speed (2.67 ms^{-1}), water content (0.5%), organic matter (0.8%), pH (7.74), EC (0.59 mmhos cm^{-1}) and soil temperatures (16.36°C) were characterizing this cluster. A high disturbance of agriculture activities, moderate urbanization, fish farming and overgrazing, and the presence of alien weeds were identified as the main threats.

CCA and variance partitioning

Ten variables were used in the forward selection by the permutation test for significance of CCA axes ($p < 0.05$) on CCA ordination: fish farming, ceramic industry, trampling, agriculture and urbanization, magnesium, total nitrogen, potassium, calcium and organic matter (Figure 4(a)). These factors are the significant key factors that explain the distribution of overall four clusters along the ordination model. Correlations of these variables with CCA axes 1 and 2 are reported in Table I.

Clusters location along CCA-ordination diagram indicates their distributional and compositional similarities to each other. CCA-axis 2 separates both clusters A and B from the others, while C and D are separated by CCA1. Cluster D is separated at the upper left quarter and related to total nitrogen, organic matter, ceramic industry, and agriculture activity, whereas cluster C is linked to the human trampling influence. The clusters A and B are separated by the concentration of magnesium and potassium and also by both significant influences of fish farming and urbanization activities.

The variance partitioning highlighted that, natural-anthropogenic variables explained 40% of the total variability; anthropogenic variables explained 9% of the total variance, while the natural variables explained only 2%. The total variation explained by the combined effect of the two groups of variables is 29% (Figure 4(b)).

Discussion

To our knowledge, only few studies (Zahran et al. 1990; Galal & Fawzy 2007; Shaltout et al. 2010) have focused on the analysis of floristic composition in coastal sand dunes in Egypt, and no information was available on the relationships between

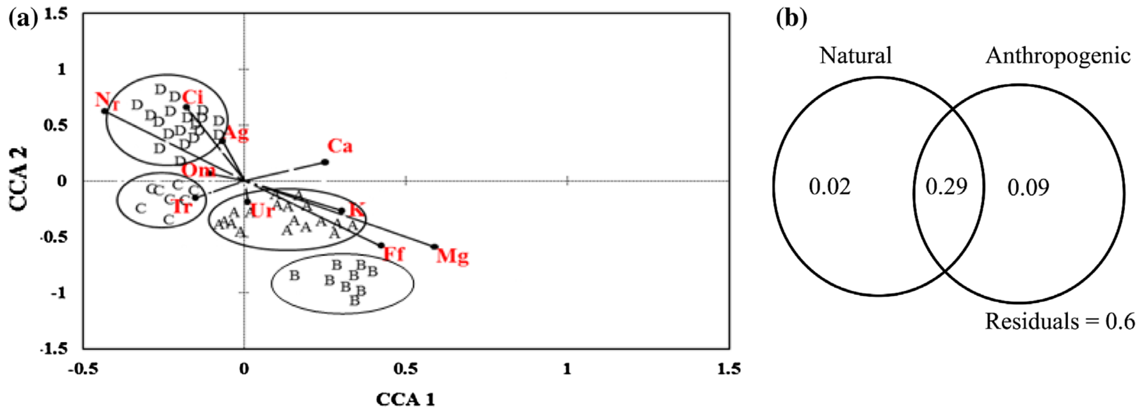

Figure 4. (a) Canonical correspondence analysis (CCA). Biplot with vegetation clusters and significant soil factors and anthropogenic factors. A, B, C and D: groups of AHC classification. NT: total nitrogen, Ci: ceramic industry, Ag: agriculture, Om: organic matter, T: Trampling, Ur: urbanization, Ff: fish farming; (b) results of variance partitioning.

Table I. Results of CCA analysis (Total inertia, 4.14).

Variables	CCA1	CCA2
Eigenvalue	0.322	0.230
Natural-anthropic variables (%)	31.262	22.351
Species variance (%)	30.86	53.61
Natural factors (soil variables)		
Mg	0.589	−0.594
N_T	−0.432	0.621
K	−0.110	0.366
Ca	0.250	0.167
Om	0.301	−0.267
Anthropogenic factors		
Ff	0.424	−0.582
Ci	−0.178	0.655
Tr	−0.150	−0.152
Ag	−0.166	0.350
Ur	0.112	−0.189

Note: N_T: Total nitrogen, Om: organic matter, Ff: fish farming, Ci: Ceramic industry, Tr: Trampling, Ag: Agriculture, Ur: Urbanization.

natural-anthropogenic factors and vegetation composition until now.

A comparison between the floristic composition recorded for this study and previous literature indicates that about 35% of the original coastal dune plant communities has been altered in the last ten years (Zahran et al. 1990; Galal & Fawzy 2007). This is also in line with the evidences found for other coastal dunes of the Mediterranean Basin where a decline in plant diversity was mainly due to agriculture practices, over collecting and other human activities (Fenu et al. 2013b; Ciccarelli 2014; Pintó et al. 2014). Otherwise, the study dunes are still harbouring 79 plant species which represent approximately 14% of the total flora recorded in the Nile Delta of Egypt (Shaltout et al. 2010).

Further analyses could better explain differences found by Ahmed et al. (2014) in floristic composition between the studied area and the northwestern coast of Egypt. Indeed, the latter includes differential plant species (e.g. *Ammophila arenaria, Euphorbia paralias, Zygophyllum album, Nigella arvensis, Juncus hybridus* and *Crucianella maritima*) which are probably limited in this locality because of differences in annual rainfall and soil sediments (Zahran & Willis 2009).

The studied dunes exhibited the recruitment of some common segetal and ruderal alien weeds (Shaltout et al. 2010). This may be attributed to the change in the land use loaded from human activities. Pinna et al. (2015b) reported that under different disturbance regime, the number of alien species is an indirect measure for the degree of human disturbance. Otherwise, our field observations confirm that, the low incidence of alien weeds does not reflect the high naturalistic interest of the study area. Segetal and ruderal weeds are less tolerant species against predominant abiotic stress in the coastal environment, and they only occupy rich soil patches (Biondi et al. 2014).

As in other Mediterranean contexts (e.g. Da Costa et al. 2007; Fenu et al. 2013b), therophytes are highly adaptable to mild winters and hot dry summers and are indicators of human disturbances. Despite the highest contribution of Mediterranean species in the floristic composition of Nile Delta coast, its dry climate does not support the establishment of typical Mediterranean vegetation (Dallman 1998). The presence of other chorological elements like Saharo-Sindian, Euro-Siberian and Irano-Turanian confirm the presence of other salty and/or anthropic habitats, and also forceful climatic changes that modify the Mediterranean ecosystem with subsequent invasion of some species from the neighbouring regions (Galal & Fawzy 2007).

Characteristic plant communities act as bioindicators for the consistency of dune ecosystems (e.g. De Luca et al. 2011; Ciccarelli 2014; Pinna et al. 2015a).

Furthermore, these bioindicators were proposed for assessing the conservation status of dune system in response to climatic conditions and human impacts.

Interestingly, *Silene succulenta*, *Echium angustifolium*, *Lycium schweinfurthii*, *Echinops spinosus*, *Elymus farctus* and *Rumex pictus* are still the dominant species in the study dunes with relatively high coverage and density. The abundance of particular plant species in a small scale area over a long time may be attributed to their capability to survive under dune harsh conditions (Shaltout et al. 2010). On the other hand, some populations that were previously common in their communities are now becoming threatened (e.g. *Pancratium maritimum*, *Thymelaea hirsuta*, *Aeluropus lagopoides*, *Asphodelus viscidulus* and *Calligonum polygonoides*). These plant species have suffered from over-collection, overcutting and uprooting for research, home medicinal uses, paper industry and local trade by inhabitants and herbalists (Shaltout et al. 2010). Moreover, the continuous expansion of the international coastal road may cause further local extinctions of native plant species.

Along the Mediterranean Basin, it is common to find that stabilized dunes have the highest plant species richness, cover and evenness, followed by semi-stabilized dunes, while the embryonic dunes have the lowest values of these indexes (Fenu et al. 2012; Ciccarelli 2014). Embryonic dunes are generally hosting a higher proportion of psammophilous plant species than stabilized dunes. Indeed, frequent sand movements of embryonic dunes permit the colonization and survival of mainly specialized plants that have the ability to withstand sand burial and substrate instability (Ahmed et al. 2014).

Through both CCA and variance partitioning, we found that anthropogenic factors explained more of the variation than natural variables. The CCA result revealed that, out of anthropic factors: fish farming, ceramic industry, trampling, agriculture and urbanization were the most important factors. Whereas, magnesium, total nitrogen, potassium, calcium and organic matter are the soil factors that were related to the distribution of clusters along CCA-axes. The rest of anthropogenic (over-collecting, over-cutting, waste disposal and alien weeds), climatic (air temperature, rainfall and wind speed) and soil-related variables (water content, pH, total phosphorus, grain size and soil temperature) did not significantly explain the vegetation patterns. Along with Egyptian dunes, organic matter and soil texture were the most determining factors according to Shaltout et al. (2010). Ciccarelli (2014) reported that erosion, trampling and paths were the most important anthropogenic factors disturbing coastal dune vegetation in Italy, whereas Fenu et al. (2012) stated that plant communities distribution on coastal systems can be explained mainly by soil factors particularly organic matter and grain size with a minor importance of wind-related variables. The significant differences in some soil properties among clusters may be attributed to the effect of micro-topography of dunes (Álvarez-Rogel et al. 2007), floristic composition, water sources, salt spray, plant-animal remains, microbes, human activities (Shaltout et al. 2010).

The ten analysed anthropogenic factors showed significant differences among the clusters as each one of them had different levels of disturbance (absent, low, moderate, high or severe) corresponding to a varying level of influence in the floristic composition of each cluster. According to their averages among clusters, we could rank the human-induced threats as follows: fish farming, urbanization, agriculture, overgrazing, trampling, over-cutting, pollution, ceramic industry, military camping and alien weeds.

In conclusion, the knowledge about the current status of vegetation, factors affecting plant diversity, spatial distribution of plant communities, and types of threats enable us to establish an effective conservation strategy to prevent further losses of plant diversity and attempt for recovery and restoration of dune vegetation. Accordingly, we hope for the development of a periodical monitoring programme of Egyptian coastal dunes vegetation and flora and for a Mediterranean cooperation for a coordinated coastal species conservation programme.

Acknowledgements

The authors would like to thank Prof Ibrahim A. Mashaly for his help during field work, his revision for plant species names and valuable advices during preliminary preparation of the work.

Disclosure statement

No potential conflict of interest was reported by the authors.

Supplemental data

Supplemental data for this article can be accessed here. [http://dx.doi.org/10.1080/11263504.2017.1302999].

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