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RESEARCH

Plant diversity of the pads of electric towers along the deltaic Mediterranean coast of Egypt

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Background: Comparing with the several types of infrastructures, linear infrastructures are known to facilitate the spread of undesirable species in ecosystems. Recently, some new man-made habitats (e.g., gravel pads of the high-voltage towers, solid wastes and sewage habitats) were established along the Deltaic Mediterranean coast of Egypt as a result of the construction of the E-W coastal international highway. The current study evaluates the floristic composition associated with the pads of high-voltage towers that had been constructed for stabilizing the power line towers in the North Nile Delta. Plant cover was measured for 22 randomly stand.
Results: Eighty-four species were recorded, of which 35 are perennials (41.6%), 2 biennials (2.3%) and 47 annuals (56.0%) belonging to 23 families. The largest families were Asteraceae (16 species), Poaceae (15 species), Chenopodiaceae (12 species), and Fabaceae (7 species). Ten aliens (10.7%) out of the 84 species were recorded. Therophytes have the highest percentage (58%), followed by hemicryptophytes (14%), chamaephytes (11%). Six vegetation groups were recognized in the study area after the application of two way indicator species analysis (TWINSPAN), *Arthrocnemum macrostachyum*, *Phragmites australis*, and *Mesembryanthemum nodiflorum* have the highest presence percentage. Both of *Salsola cyclophylla* and *Solanum villosum* were recorded for the first time in North Nile Delta. Natural habitat had the highest α-diversity, but the lowest β-diversity (4.9, 15.4), while gravel pads had the reverse (2.7, 30.8). Some species which are native to the desert habitats (e.g., *Rumex pictus*, *Salsola kali*, and *Carthamus tenuis*) were able to invade the North Nile Delta.
Conclusions: Habitat of gravel pads is an expressing form about the intense of disturbance in Deltaic Mediterranean coast of Egypt. More of efforts should be carried out to avoid more human disturbances that creating as ruderal habitats which open the gate to invasive species in the flora of North Nile Delta.

Keywords: disturbance, detrended correspondence analysis, gravel pads habitat, North Nile Delta, ruderal habitat, two way indicator species analysis

Introduction

The Mediterranean region is characterized by its high plant richness (Myers et al. 2000), where about 10% of the world's vascular plants exist (Radford et al. 2011). Coastal areas are typically rich in natural resources, which provide excellent opportunities for economic activities; particularly resource-based economic activities such as agriculture, fisheries, tourism, oil and gas extraction, and maritime transportation, which all tend to be concentrated in these areas. Furthermore, coastal locations serve as important gathering points for a high number of immigrants, with rising need for housing, energy, products, and services (Balmford et al. 2002; Costanza et al. 1998).

The coastal zones of Egypt suffer from a number of serious problems including: unplanned development, land subsidence, excessive erosion rates, water logging, salt water intrusion, soil salinization and as well as several anthropogenic activities especially unplanned construction of villages and ecosystem degradation (Eid and El-Marsafawy 2002; El-Raey 1997). Deltaic Mediterranean coast of Egypt is rich in many wild plant species, which seem to be economically promising. It differentiates into four habitats: sand formations, salt marshes, fertile sandy lands and reed swamps (Mashaly 1987; Shaltout et al. 1995). Deltaic areas are sensitive ecosystem toward both natural hazards and human interventions. During the last decades, Nile Delta coast has been subjecting to several threats, mainly anthropogenic, which leads to change the natural habitats and vegetation (El-Amier and Abd El-Gawad 2017). The coastal zone of the Nile Delta lodges highly populated cities (e.g., Alexandria, Baltim, Damietta, and Port Said) together with small towns and villages with major populations of fishermen and farmers. It represents the major industrial, agricultural, and economic resource of the country. The area has been subjected to intensive and extensive unplanned developmental projects to foster the economic status of the local communities that, however, negatively impacted both land use and land cover characteristics.

Nile Delta coast is experiencing a pronounced landform transformation that is mainly controlled by man-made activities which happened in response to either social or economic trends, as well as the present local market trends and the population habits or both. These changes will certainly dramatically impact the Nile Delta coast, not only by reshaping the spatial distribution of the current landforms, but also will lead to a great change in the ecosystem characteristics (e.g., sea water intrusion, shoreline erosion, modification, transformation and disappearance of some natural ecosystems: Ali and El-Magd 2016).

Ruderal habitats may vary depending on the substrates of existing roads, transported soils and compacted rocks with different sizes (Frenkel 1977). Human activities such as construction and maintenance of transmission power lines and their associated rights-of-way create suitable conditions for establishment and growth of ruderal plant species that can threaten biodiversity and other ecological services of the nearby natural ecosystems (Wagner et al. 2014). These activities may facilitate the invasion of ruderal vegetation in natural ecosystems through several ways. First, fragmentation of natural habitats and loss of native vegetation increase environmental heterogeneity that facilitates the invisibility and spread of ruderal species (Tewksbury et al. 2002). Second, seeds and propagules of several ruderal species may be transported in constructed soil of pads and foundations for overhead utility line towers and substations (Cameron et al. 1997). Third, the internal disturbance of native vegetation creates gaps with increased resources that enhance the establishment of less competitive ruderal species (Ehrenfeld 2008). Fourth, establishment and maintenance of transmission line rights-of-way and their connected service tracks closer to access roads may favor dispersal of seeds and propagules of roadsides ruderal plant species (Rubino et al. 2002; Tyser and Worley 1992). Fifth, changes in soil physical properties and enhancement of soil nutrients may contribute to the establishment of ruderal plant species which have the ability to grow and thrive in this enriched soil (Cameron et al. 1997).

Although, urbanization and their attendant effects are obvious features in the Mediterranean wetlands, these effects remain insufficiently studied particularly in those of arid and semi-arid environments of North African countries where there is a rapid rate of uncontrolled urban development (Redeker and Kantoush 2014). Much less is known about the impact of the construction of gravel pads, which is a conspicuous landscape disturbance feature for supporting power line towers, and forming a network of linear terrestrial patches in wetlands. Spatial configuration of benched and graveled pads may facilitate the invasion and spread of ruderal plants into the intersected wetlands. In addition, the installation of these terrestrial barriers in water may induce sediment deposition and nutrient enrichment which change plant community development and create appropriate microhabitats for establishment of non-native plants in wetlands (Dubé et al. 2011; El-Bana 2015; Heneidy et al. 2021).

In last decade, North Nile Delta has been subjected to several projects in different fields such as construction of new cities and black sand company. Burullus Power Plant was constructed close the international road parallel to the Mediterranean coast, followed by huge transmission power lines network. There is a little knowledge about ruderal plants that colonize the new habitats initiated by these power plants. This study was carried out on the pads of high-voltage towers as a recent newly type of ruderal habitats in the study area. It aims to evaluate their impacts on the vegetation in Mediterranean Deltaic coast in terms of floristic composition, life forms, chorotypes and plant communities. It also aims to assess the environmental factors that affect the prevailing plant communities.

Study area

The study area lies along the Deltaic Mediterranean coast of Egypt forming a belt extending in E-W direction for about 135 km between two the Nile branches (Rosetta and Damietta) and in N-S direction of about 8–15 km from the seashore (Fig. 1). This region is characterized by a morphological structure basically different from that to the west of Abu-Qir (Mareotis coast) and the east of Port-Said (Sinai coast). Sand dunes are the main geomorphic feature in the greatest part of the Deltaic coast, which has loose textured soils, thus they are considered as natural reservoirs of fresh water. Also, this coast is characterized by salt marshes and three Northern shallow brackish lakes: Manzalla in the east with an area of ca.1,000 km^2, Burullus in the middle (452 km^2) and Idku in the west (36 km^2), which are joined to the Mediterranean by narrow gaps in the sandy bars (Ramdani et al. 2001). Both the western and eastern section of Egyptian Mediterranean coast depend mainly on rainfall as the main source of water, while the Deltaic coast has five water sources (winter rainfall, River Nile water, sea water, northern lakes, and underground water).

Climatologically (Ayyad and Le Floc'h 1983; UNESCO 1977; Zahran et al. 1985), the Mediterranean coastal region

Fig. 1 Deltaic Mediterranean Coast of Egypt indicating the sampled pads of high-voltage towers (red).

of Egypt belongs to the dry arid climatic zone of Koppen's classification system (as quoted by Trewartha and Horn 1980), the arid mesothermal province of Thornthwaite (1948) and Mediterranean arid bioclimatic zone of Emberger (1955). The region lies in Meigs's warm coastal desert (Meigs 1973): summer's warmest month with mean temperature of < 30°C, and winter's coldest month with mean temperature of > 10°C. Though occasional rainstorms occur in winter, most of days are sunny and mild.

This coast is recognized into different habitats, some of them are natural such as inland sand sheets, sand dunes, coastal dunes, saline sand deposits, salt marshes, sand sheets and brackish shallow lakes; while others are man-made habitats such as water courses (canals and drains), roads, railways, abandoned and cultivated fields (Shaltout et al. 2010). Recently, some new man-made habitats were established in the northern part of Nile Delta due to the construction of the coastal international highway such as gravel pads of the high-voltage towers, solid wastes and sewage habitats.

Materials and Methods

Sampling process

Twenty-two stands on gravel pads of high-voltage towers under transmission power line (each stand represent a pad one and tours) were selected randomly as a type of ruderal habitat to represent the vegetation physiognomy along such new man-made habitat. The average distance between each stand and the other ranged from 0.5–5 km (Fig. 1). During this study, additional 24 sampled stands were selected in the natural habitat in the vicinity of the sampled pads to compare between the plant diversity of the recorded species in both habitats. The field work was carried out during January–December 2021. The area of each stand was (20 × 20 m) which represents the minimal area for the vegetation cover in this region. In each stand, the following data were recorded: 1- GPS Coordinates (Garmin 12XL), 2- list of the present species, and 3- visual estimates of the total cover and cover percentage of each species according to Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974). Nomenclature of the recorded species was according to Täckholm (1974), Boulos (1999–2005, 2009). Voucher specimens were deposited at the Herbaria of Faculty of Science, at Tanta and Kafr-Elsheikh Universities. Alien species were determined based on the recent updating of the alien species in the Egyptian flora (see El-Beheiry et al. 2020; Shaltout 2020).

Vegetation measurements

Species life form was identified following the scheme of (Raunkiær 1937). National distributions of the recorded species were determined according to (Täckholm 1974); while their global distributions (Table 1) (White and Léonard 1990) were determined from Zohary (1966, 1987), Feinbrun-Dothan (1978, 1986) and Boulos (1999–2005). Species richness (Alpha-diversity) of the vegetation groups (VGs) was calculated as the average number of species per stand, while species turnover (beta-diversity) was calculated as the ratio between the total species recorded in a certain vegetation group and its alpha-diversity. Shannon–Weaver index ($H = -\Sigma\, p_i \log p_i$) for the relative species evenness, and Simpson index ($C = \Sigma\, p_i^2$) for the relative concentration of dominance were estimated based on the relative cover (p_i) of species (Pielou 1975; Whittaker and Levin 1977).

Soil analysis

Three soil samples were collected from profiles (0–50 cm) of each sampled stand and mixed as one composite sample. Soil texture (percentages of sand, silt, and clay) was determined by Bouyoucos hydrometer. Total organic matter (O.M.) was determined based on loss-on-ignition at 450°C (Wilke 2005), and total $CaCO_3$ was estimated by the use of Collin's calcimeter (Wright 1939). Soil-water extracts (1:5) were prepared for the estimation of electrical conductivity (EC in mS cm^{-1}) using electric conductivity meter and soil reaction (pH) using pH-meter (Jenway 3020; Cole-Parmer, Staffordshire, UK) (Allen 1989). Bicarbonates (HCO_3), sulphates (SO_4) and chlorides (Cl) were analyzed according to Dewis and Freitas (1970) and Ayers and Westcot (1985). Soil extracts of 5 g soil samples were prepared using 2.5% v/v glacial acetic acid for estimating K, Ca, Na, and Mg. Na and K were analyzed using a flame photometer (Corning 410 BWB; Sherwood Scientific Ltd., Cambridge, UK).

Table 1 Global distribution (floristic categories) according to White and Léonard (1990)

Floristic category	Code	Description
Saharo-Sindian	SA	Flat and arid areas of North Africa, the Arabian Peninsula, southern Iran and the deserts of Pakistan and west India. Saint Catherine in Sinai and Genu and Homag in southern Iran.
Sudano-Zambezians	SZ	Savanna and grassland vegetation with occasional dry forests and thickets, and patches of edaphically controlled swampy vegetation, in a wide zone in Subsaharan Africa around the Guineo-Congolian region.
Irano-Turanian	IT	Central Asia and West Asiatic areas and Mediterranean floristic region (western and eastern parts of the Mediterranean Basin).
Euro-Siberian	ES	Extends from Iceland around most of Europe via Siberia to Kamchatka.
Mediterranean	ME	Includes the Mediterranean Sea and seven Member States, either partially (France, Portugal, Italy, and Spain) or completely (Greece, Malta, and Cyprus).
Palaeotropical	PAL	The tropical areas of Africa, Asia, and Oceania (excluding Australia and New Zealand).
Pantropical	PAN	Covers tropical regions of both hemispheres.
Cosmopolitan	COSM	Extends across all or most of the world.
Australian	AUST	New Guinea, Australia, New Zealand, and Oceania.

Data from the article of White and Léonard (Lubrecht & Cramer Ltd.; 1990. p. 229-46).

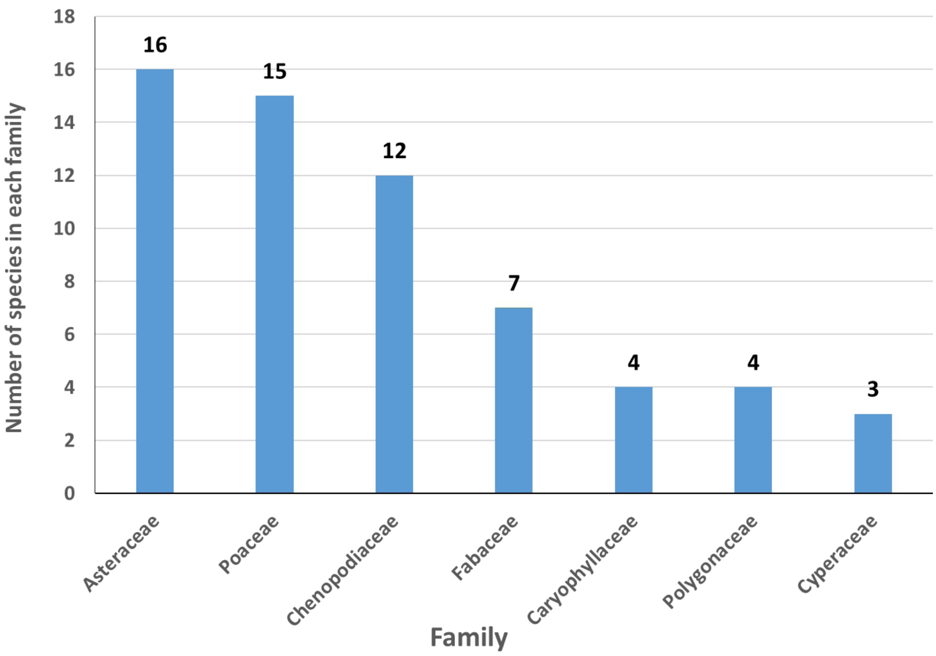

Fig. 2 Plant families of ≥ 2 recorded species.

Data analysis

Two way indicator species analysis (TWINSPAN) and detrended correspondence analysis (DCA; DECORANA) were applied to the matrix of 84 species in 22 stands (Hill 1979a, b). Presence percentage for each species in each vegetation group was calculated as the number of stands for each species divided into total number of stands. The DCA axes and environmental variables were correlated after the ordination procedure. The direct ordination was performed using canonical correspondence analysis (CANOCO) program for windows version (4.5); which is a constrained ordination technique, where results are simultaneously trained based on species abundance and environmental variables (Kent and Coker 1992). The variation in the soil characters in relation to VGs was assessed using one-way analysis of variance (ANOVA) according to SPSS program v. 21 (IBM Co., Armonk, NY, USA).

Results

Floristic composition

The recorded species in the study area, their geographical distributions, life forms, habits, biogeographical regions, VGs and their relative constancy values (P%) are listed in Table S1 and Fig. S1. Eighty-four species: 35 perennials (41.6%), 2 biennials (2.4%) and 47 annuals (56.0%) belonging to 23 families were recorded. The largest families were Asteraceae (16 species = 19%), Poaceae (15 species = 17.8%), Chenopodiaceae (12 species = 14.2%), and Fabaceae (7 species = 8.3%). These four families represent about 59.3% of the total recorded species forming most of the floristic structure in the study area.

Ten alien species (10.7%) were recorded among the total species (Fig. 2). Regarding the life forms, therophytes have the highest percentage (58%), followed by hemicryptophytes (14%), chamaephytes (11%), geophyte-helophytes (11%), and phanerophytes (5%) (Fig. 3). Thirty-three native-weeds and 10 aliens were associated with 41 natural species. The alien species are: *Acacia saligna, Atriplex semibaccata*, *Cynanchum acutum*, *Foeniculum vulgare*, *Heliotropium curassavicum*, *Nicotiana glauca*, *Symphyottrichum squamatum*, *Apium graveolens*, *Bassia indica*, and *Eleusine indica*. Nine species are restricted to the gravel pads and not recorded in the natural habitats (*Acacia saligna*, *Salsola cyclophylla*, *Astragalus tribuloides*, *Chenopodium ambrosioides*, *Herniaria hemistemon*, *Lotus peregrinus*, *Solanum villosum*, *Spergularia diandra*, and *Sphenopus divaricatus*).

National and global distribution

Regarding the national phytogeographical distribution (Fig. 4), 89.3% of the recorded species belong to the Mediterranean (75 species), followed by the Nile (63 species = 75%) and desert (62 species = 73.8%) regions. The global bio-geographical distribution indicated that the bi-regional

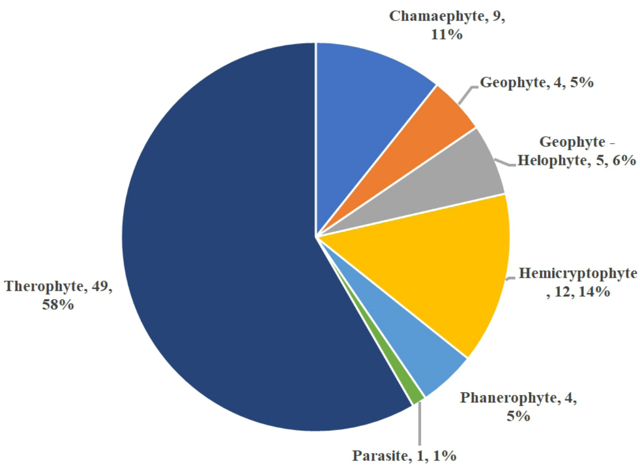

Fig. 3 Raunkier life-form spectrum of the recorded species.

(34 species = 40.5%) were the highest, followed by the pluri-regional (21 species = 25%) and mono-regional elements (20 species = 23.8%) elements. Eight cosmopolitan species (9.5%) were recoded, while there was no endemic species. In general, Mediterranean elements had the highest contribution (57 species), followed by Saharo-Arabian (34 species and Irano-Turanian (30 species). On the other hand, Paleotropic and Sudano-Zambezian elements had the lowest contribution (3 and 6 species, respectively).

Multivariate analysis

Application of the TWINSPAN classification technique on the cover estimates of the 84 species recorded in 22 stands of gravel pads led to the recognition of 9 VGs (communities) at the 6th level of classification, but 6 groups at the 4th level. These six groups are named after the species of highest presence percentage as follows: I- *Reicharadia tingitana*, II- *Arthrocnemum macrostachyum*, III- *Zygophyllum album*, IV- *Cynodon dactylon*, V- *Carthamus tenuis*, and VI- *Alhagi graecorum* groups (Table 2, Fig. 5A). Consequently, application of the DCA ordination technique on the same set of data indicates a reasonable segregation among these groups along ordination axes 1 and 2 (Fig. 5B). On the other hand, *Cynodon dactylon* (VG IV) had the highest α-diversity (0.45) followed by *Zygophyllum album* (VG III) (0.37), while *Alhagi graecorum* (VG VI) had the highest β-diversity followed by *Cynodon dactylon* (VG IV) and *Zygophyllum album* (VG III) (Table 3). Nine species associated only with the gravel pads: *Acacia saligna*, *Salsola cyclophylla, Astragalus tribuloides*, *Chenopodium ambrosioides*, *Herniaria hemistemon*, *Lotus peregrinus*, *Solanum villosum*, *Spergularia diandra*, and *Sphenopus divaricatus*. Natural habitat had the highest α-diversity (4.9), while the gravel pads had the highest β-diversity (30.8), Shannon–Weaver index (1.9) and H-max (1.9). Both of them had the same value of Simpson index (0.01) (Table 4).

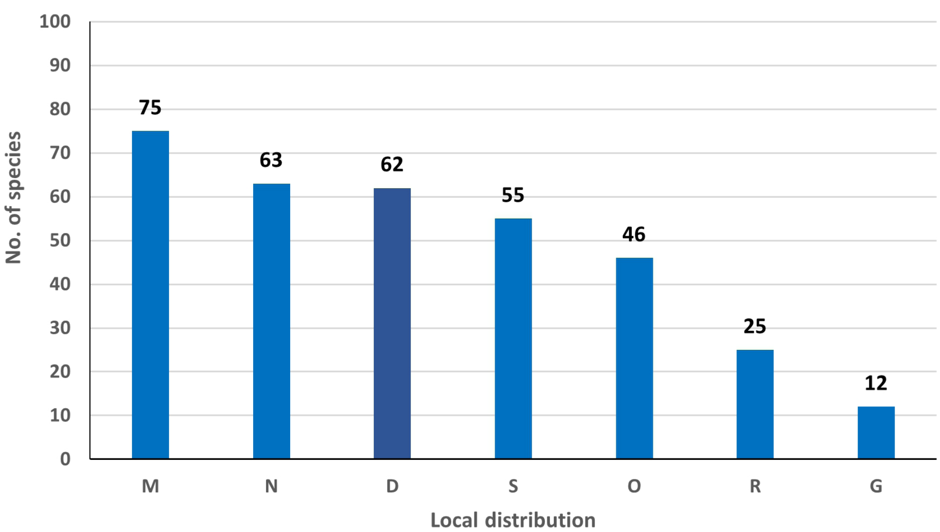

Fig. 4 National distributions of the recorded species in the present study. S: South Sinai; M: Mediterranean coast; N: Nile region; O: oases; D: desert; R: Red Sea coast; G: Gebel Elba. Values above the bars are the numbers of species in each region.

Table 2 Characteristics of 6 vegetation groups (I–VI) identified after the application of two way indicator species analysis (TWINSPAN) on 22 stands including recorded species

VG	No. of stands	% of stands	First dominant species	P%	Second dominant species	P%
I	1	5	*Reicharadia tingitana* (L.) Roth	100	*Polygonum equisetiforme* Sm.	100
II	4	18	*Arthrocnemum macrostachyum* (Moric.)	100	*Phragmites australis* (Cuv.) Trin. ex Steud.	50
III	6	27	*Zygophyllum album* L.	83	*Arthrocnemum macrostachyum* (Moric.) K.	83
IV	5	23	*Cynodon dactylon* (L.) Pers.	80	*Carthamus tenuis* (Boiss & Blanche) Bornm.	80
V	4	18	*Carthamus tenuis* (Boiss & Blanche) Bor.	75	*Conyza bonariensis* (L.) Cronquist	75
VI	2	9	*Alhagi graecorum* Boiss.	100	*Parapholis incurva* (L.) C.E. Hubb.	100

VG: vegetation group.

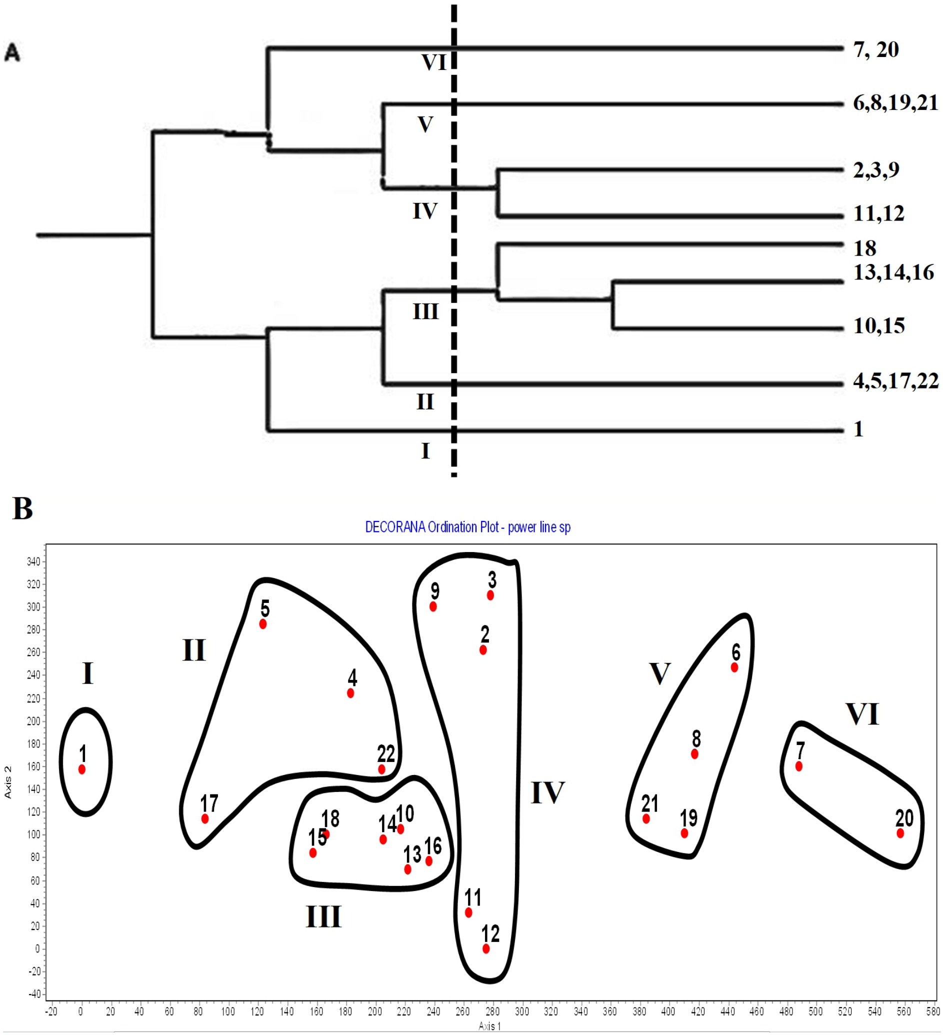

Fig. 5 (A) Dendrogram of the 6 vegetation groups (VGs) derived after application of two way indicator species analysis (TWINSPAN) classification technique. (B) Cluster segregation of the 6 VGs along axes 1 and 2 using detrended correspondence analysis (DCA; DECORANA). The 6 groups are named after the characteristic species as follows; I: *Reicharadia tingitana*, II: *Arthrocnemum macrostachyum*, III: *Zygophyllum album*, IV: *Cynodon dactylon*, V: *Carthamus tenuis*, and VI: *Alhagi graecorum*.

Soil analysis

Soil analysis indicated that the silt, sand, saturation percentage (SP), EC, sulphate, and sodium contents varied significantly in relation to the 6 VGs ($p < 0.05$). Soils of group II (*Arthrocnemum macrostachyum*) had the highest content of silt, clay, SP, O.M., pH, EC, SO_4^{-2}, and Na^+; but the lowest of sand (Table 5). Soils of group III (*Zygophyllum album*) had the highest of sand, HCO_3^-, Cl, Ca^{+2}, and Mg^{+2}; but the lowest of silt, clay, and SP. Group IV (*Cynodon dactylon*) had the lowest of EC, while group VI (*Alhagi graecorum*) had the highest of O.M. and Ca^+. Soils of group V (*Carthamus tenuis*) had the highest of K^+, but the lowest of bicarbonates and chlorides; while those of group I (*Reicharadia tingitana*) had the lowest of EC, sulphates, Mg^{+2}, and Na^+. CANOCO ordination plot indicates that the O.M., EC, sulphates and sodium are the factors that mainly affect the distribution of the recorded species in the habitat of gravel pads (Fig. 6).

Table 3 Characteristics of the 6 vegetation groups derived after the application of two way indicator species analysis (TWINSPAN) classification technique

Species	Vegetation group						Total	
	I	II	III	IV	V	VI	Actual	%
Diversity								
Total species	4	15	32	39	30	18	84	-
α-diversity	0.05	0.2	0.37	0.45	0.36	0.21		-
β-diversity	80	75	83.8	84	38.3	85.7		-
Natural species	1	10	15	19	16	5	41	48.8
Native weeds	3	5	12	14	12	12	33	39.3
Alien species		1	5	6	3	1	10	11.9
Life forms								
Phanerophytes		3	2	1	1		4	4.8
Hemicryptophytes		4	5	5	6	4	13	14.3
Chamaephytes		2	5	5	1		9	10.7
Geophyte-helophytes	1		2	3	4	4	8	9.5
Parasites			1				1	1.2
Therophytes	3	6	17	25	18	10	49	58.3
Floristic category								
Mono-regional		3	7	9	9	4	20	23.8
Bi-regional	4	6	15	16	11	5	34	40.5
Pluri-regional		2	7	10	7	6	21	25.0
Cosmopolitan		1	3	4	3	3	8	9.5
Saharo-Sindian	1	7	11	18	11	3	34	40.5
Mediterranean	4	9	18	28	20	12	57	67.9
Irano-Turanian	3	4	9	14	10	8	30	35.7
Euro-Siberian		3	3	7	3	4	15	17.9
Sudano-Zambezian		5	5	3	2		6	7.1
Palaeotropical			1	1	2		3	3.6
Pantropical		2	3	3		2	8	8.3

Values are presented as number only.
–: not available.

Table 4 Diversity indices of gravel pads and natural habitat

Diversity index	Gravel pads	Natural habitat
Total species	84	75
α-diversity	2.70	4.90
Standard deviation	2.60	3.60
β-diversity	30.8	15.40
Shannon–Weaver index	1.90	1.88
Simpson index	0.01	0.01
H-max	1.90	1.40

Values are presented as number only.

Discussion

The floristic change is often caused by changes induced by human's beings. Ecological factors causing the decline of species in urban biotopes include: reduction in the variety of habitats, soil movements and construction, lowering of the ground water table and other alternations to the water balance, changes in use (e.g., from kitchen to ornamental garden), abandoning periodic working of soil, soil compaction, intensive care with frequent mowing and weeding (Al-Sodany 2009; Korneck and Sukopp 1988; Scholz 1960).

This study indicated that the majority of plant species within the pad plots belong to Asteraceae, Poaceae, and Fabaceae. These families represent the main bulk of the ruderal plant species in Egypt (Abd El-Ghani et al. 2011) and in the disturbed road networks of Mediterranean climate regions (Di Castri et al. 1990). These families were the most represented in the weed flora of the agro-ecosystems of Nile valley (Abd El-Ghani et al. 2013), Nile Delta (Shaltout et al. 2010) including North Nile Delta (Al-Sodany 2006, 2009). Also, this result agrees with the evidence that both Poaceae and Asteraceae has the highest contribution to the recorded species. The tendency of families to beget alien invasive species can be explained by their biological features. Asteraceae is one of the most evolutionary advanced plant families (Cronquist 1981), where its members possess many features that are advantageous for invasion (e.g., high reproductive rate, large proportion of self-pollinated species, self-dispersal and vegetative spread, specialized dispersal structures such as pappus and hooked seeds, and high level of apomixis which account for their superior ability to invade adventive areas: Pyšek 1997, 1998). Similarly, successful dispersal mechanisms in Poaceae may explain why it is one of the most commonly invaded families (Cronquist 1981). Many of the species of both families are synanthropic species occurring in the adjacent cultivated lands as weeds, where they spread along

Table 5 Mean ± standard deviation of the soil characteristics of the 6 vegetation groups generated after the application of two way indicator species analysis (TWINSPAN) on the floristic composition of the 22 sampled stands of the recorded species

Soil variable	Vegetation group						Total	F-value
	I	II	III	IV	V	VI		
Physical properties								
Sand	94.7 ± 4.0	82.0[a] ± 14.9	97.5[a] ± 1.0	95.2 ± 2.3	96.5 ± 1.0	95.5 ± 0.7	94.3 ± 6.9	3.6*
Silt	3.3 ± 2.3	6.7[a] ± 3.5	1.5[a] ± 0.9	3.2 ± 1.8	2.1 ± 0.6	2.0 ± 0.0	2.9 ± 2.3	3.8*
Clay (%)	2.5 ± 2.1	11.3[a] ± 11.8	1.0[a] ± 0.3	1.8 ± 0.8	1.4 ± 0.5	2.5 ± 0.7	2.9 ± 5.1	2.8
SP	20.3 ± 2.3	34.7[a] ± 17.7	18.5[a] ± 1.4	19.8 ± 1.9	19.3 ± 1.9	21.0 ± 1.4	21.5 ± 7.6	3.1*
O.M.	2.2 ± 2.3	4.7[a] ± 4.1	3.9 ± 2.4	2.5 ± 1.6	0.9 ± 0.4	0.9[a] ± 0.8	2.7 ± 2.4	1.7
pH	7.4 ± 0.1	7.9[a] ± 0.6	7.6 ± 0.1	7.4[a] ± 0.3	7.7 ± 0.5	7.6 ± 0.1	7.6 ± 0.3	1.3
EC (mS m^{-1})	0.3[a] ± 0.2	5.3[a] ± 4.1	3.6 ± 2.1	1.8 ± 1.7	0.7 ± 0.1	0.7 ± 0.0	2.2 ± 2.5	3.3*
Chemical properties								
HCO_3^-	0.5 ± 0.3	0.5 ± 0.1	0.8[a] ± 0.4	0.5 ± 0.3	0.5[a] ± 0.2	0.6 ± 0.1	0.6 ± 0.3	1.3
Cl^-	0.8 ± 0.5	4.9 ± 6.8	10.0[a] ± 7.5	3.5 ± 4.4	0.6[a] ± 0.5	1.0 ± 0.6	4.3 ± 5.9	2.4
SO_4^{-2} (meq 100 gm^{-1})	0.3[a] ± 0.2	21.9[a] ± 21.1	7.7 ± 3.7	5.3 ± 4.1	2.3 ± 0.6	2.1 ± 0.6	6.6 ± 9.5	3.1*
Ca^{+2}	1.4 ± 1.1	1.7 ± 1.8	5.0[a] ± 2.7	2.9 ± 3.4	0.9 ± 0.5	0.7[a] ± 0.2	2.5 ± 2.6	2.2
Mg^{+2}	0.1 ± 0.1	0.7 ± 0.1	1.0[a] ± 0.8	0.4 ± 0.3	0.7 ± 0.4	0.5 ± 0.0	0.6 ± 0.5	1.7
Na^+	0.1 ± 0.0	24.7[a] ± 20.9	12.3 ± 9.1	5.9 ± 5.1	1.8 ± 0.5	2.2 ± 0.2	8.2 ± 11.2	3.4*
K^+	0.1 ± 0.0	0.1 ± 0.1	0.2 ± 0.0	0.1 ± 0.1	0.3 ± 0.4	0.2 ± 0.0	0.2 ± 0.2	1.0

SP: saturation percentage; O.M.: organic matter; EC: electrical conductivity.
[a]Maximum and minimum values.
F value were significant at $^*p \le 0.05$.

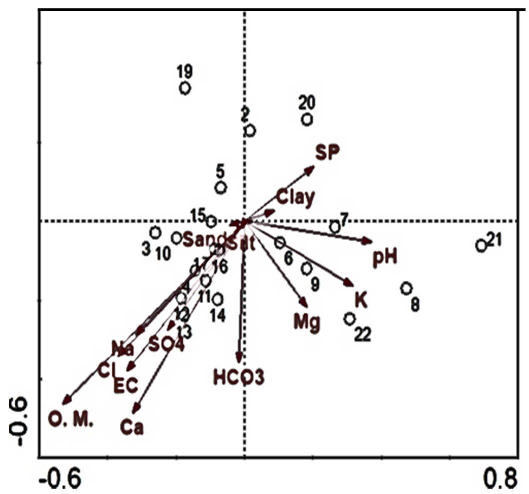

Fig. 6 Canonical correspondence analysis (CANOCO) ordination plot for the edaphic variables and the 22 sampled stands (1–22). O.M.: organic matter; SP: saturation percentage; K: potassium; Mg: magnesium; Ca: calcium; EC: electrical conductivity; Na: sodium; HCO_3: bicarbonate; SO_4: sulphates.

roads and disturbed grounds, and colonized new man-made habitats, and assume a weedy character (Lausi and Nimis 1985).

Deltaic Mediterranean coast of Egypt can be divided ecologically into four man habitats: salt marsh, sand formation, reed swamp and fertile lands (Zahran et al. 1990). The present study distinguished the gravel pads as novelty habitat in the study area, this may be attributed to the fact that the construction and use of tracks, roads, canals, railway and airports as a human activities have involved many changes, some of them are direct effect including the destruction of the existing habitats and the provision of new ones which have special characteristics (Lousley 1970).

It is worth noting that, a mixture of different floristic elements such as Cosmopoliton, Palaeotropical, Pantropical, Saharo-Arabian, Sudano-Zambezian, and Irano-Turanuian elements are represented by variable number of species in the study area. This may be attributed to human impact, history of agriculture and capability of certain floristic elements to penetrate the study area from several adjacent phytogeographical regions (Zahran and Willis 2009).

Many of the species identified in the present study (84 species) are compared to those of the previous related studies. It was found that 57% by the recorded species in the present study were recorded in the study of ruderal plant communities in Nile Delta (El-Sheikh 1996), 47% were recorded also in the study of gravel pads in the Mediterranean wetlands of Egypt (El-Bana 2015). Some species are native to the desert of Egypt and invaded the Nile Delta region. Such invasion may be associated with the transport of sand, gravel and ballast from the desert for the construction of roads and houses in the Nile Delta region. Of these species are *Rumex pictus*, *Salsola kali*, and *Carthamus tenuis*. This conclusion is supported by Shaltout et al. (1995) in his study on the post-agricultural succession in the Nile Delta, who recorded *Ifloga spicata* as a new record to this region, and related its presence to the transportation of building materials from the desert.

Therophytes (i.e., annuals) are more represented species, this could be explained in the view that the annual species are the most successful colonizers of most highly disturbed areas (e.g., disturbance by trampling of roads and fields by man, animals and vehicles, firing, grazing and disturbance by maintenance processes as laying of electronic telephone cables). This could be attributed to the fact that annuals have higher reproductive capacity, and ecological, morphological and genetic plasticity (Grime 1979; Harper 1977; Kowarik 1985).

Disturbance is an important gateway for invasive species which are usually introduced first into ruderal habitats, from where they spread to other habitats (Catford et al. 2012). The present study recorded 10 alien species (e.g., *Acacia saligna*, *Atriplex semibaccata*, and *Heliotropium curassavicum*), which represent about 4% of alien species in the Egyptian flora (Shaltout 2020). This may be attributed to the fact that several ruderal habitats situated in cities are drier than their surrounding habitats, making them more suitable for alien species, many of which originate from warm and dry regions. The growth of some alien species can also be encouraged by building activity (Kowarik 1990), which typically takes place near many ruderal habitats (e.g., constructions sites) that experience strong disturbances, resulting in the creation of empty niches that promote the expansion of alien species (Mack et al. 2000).

Ruderal habitat may facilitate the entry of plants into a new area (Frenkel 1977). This can contribute in the explanation of nine species that not recorded in the natural habitat and recorded in gravel pads habitat *(Acacia saligna*, *Salsola cyclophylla*, *Astragalus tribuloides*, *Chenopodium ambrosioides*, *Herniaria hemistemon*, *Lotus peregrinus*, *Solanum villosum*, *Spergularia diandra*, and *Sphenopus divaricatus*); two of them (*Salsola cyclophylla* and *Solanum villosum*) are the first records in North Nile Delta (Al-Sodany 1992, 2006, 2009; Mashaly et al. 2008; Shaltout and Al-Sodany 2008; Shaltout et al. 2010).

Diversity indices are related with both undisturbed and disturbed habitats. The present study indicated that the natural habitats had the highest α-diversity but the lowest β-diversity (4.9, 15.4), while the habitat of gravel pads had the lowest α-diversity but the highest β-diversity (2.7, 30.8). This can be contributed that the species richness and unique species were lowest in the highly disturbed habitat where human disturbances can result in fragmentation of natural habitats, which leads to the dropping of species richness (McKinney 2002). On the other hand, Warwick and Clarke (1993) reported that the β-diversity increased in disturbed sites compared with the natural sites deduced that increased β-diversity might be used as a diagnostic tool in disturbed areas.

CANOCO ordination plot indicates that the O.M., EC, sulphates, and sodium are the main factors that affect the distribution of the recorded species in the habitat of gravel pads. This could be interpreted in the view that this habitat is covered with layer of high resistant-electric materials such as gravels, stones, sand, and crushed rocks to prevent the formation of puddles and accumulation of water, making it suitable dry habitat for some species such as: *Echinops spinosus*, *Salsola cyclophylla*, *Atractylis carduus*, and *Bassia muricata* (Al-Sodany 2009; Boulos 1999–2005).

Conclusions

Habitat of gravel pads reflects the intense of disturbance in Deltaic Mediterranean coast. Urgent efforts should be carried out to avoid more human disturbances that creating ruderal habitats which act as open gates to invasive species in the flora of North Nile Delta (e.g., *Acacia saligna* and *Bassia indica*). Human-made habitats such as gravel pads of power line towers can be utilized for sustainable land use, employing introduced native woody trees on the connected service tracks in combination with herbaceous species on the pads under the overhead towers. This would optimize ecological benefits and values of the constructed patches. The trees can be used for firewood production. Herbaceous productivity on gravel pads can be utilized by livestock grazing.

Supplementary Information

Supplementary information accompanies this paper at https://doi.org/10.5141/jee.23.019.

Table S1 Floristic composition and presence percentage (P%) of the recorded species in both gravel pads and natural habitats in the study area. **Fig. S1** Photos of the pads of electric towers along the deltaic Mediterranean coast of Egypt.

Abbreviation

TWINSPAN: Two way indicator species analysis
VG: Vegetation group
EC: Electrical conductivity
DCA: Detrended correspondence analysis
CANOCO: Canonical correspondence analysis
SP: Saturation percentage
O.M.: Organic matter

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Author’s contributions

YAS, HB analyzed and interpreted data regarding transplant experiment. YAS, HB, KS performed statistical analysis. YAS was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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The data sets analyzed in the present paper are available upon request from the author.

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Competing interests

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