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Ten years primary succession on a newly created landfill at a lagoon of the Mediterranean Sea (Lake Burullus RAMSAR site)

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ABSTRACT

This study was carried out on the transported bed soil dredged from the outlet of Lake Burullus to the Mediterranean Sea and deposited nearby, forming by this way new land that underwent a primary plant succession. The multi-methodological approach comprised floristic inventories, vegetation sampling and soil composition analyses of the study site in order to detect the crucial parameters controlling the plant resettlement on recently deposited soil as related to time, local micro-topography and substrate characteristics. Floristic composition was assessed for the first 10 years of primary succession (2001–2010) on 18 stands of the area, distributed on basement, slope stands and plateau of the landfill, respectively. Vegetation surveys were the basis of multivariate analyses of the vegetation and soil data using TWINSPAN, DCA and CCA. Relationships between the edaphic gradients, floristic composition and species diversity were assessed.

Forty-one species were identified (22 annuals and 19 perennials) after ten years development compared with 7 species at the first year. After application of TWINSPAN and DCA on the data of the first year of establishment, two simple vegetation groups were recognized and named after their dominant species, *Senecio glaucus* and *Bassia indica*. In comparison, the multivariate analysis of the last year (i.e. after 10 years of succession) led to identify 4 more advanced vegetation groups: *Senecio glaucus–Cakile maritima–Zygophyllum album*, *Bassia indica–Mesembryanthemum nodiflorum*, *Arthrocnemum macrostachyum* and *Phragmites australis–Limbarda crithmoides*. These plant communities are comparable to the other communities in the same region, showing the tendency to establish the climax vegetation of Mediterranean coastal areas. The notable edaphic variables that affect the succession of the vegetation groups in the study area were moisture, salinity, organic matter, minerals (Ca, Na, K, Cl, SO_4), soil texture and human disturbance.

Introduction

Wetlands are of ecological importance due to their hydrological attributes, their role as ecotones between terrestrial and aquatic ecosystems, and their high productivity. They are sources, sinks and transformers of numerous chemical, biological and genetic materials, and provide valuable habitats for marine resp. coastal animals. One of these wetlands is Lake Burullus along the deltaic Mediterranean coast of Egypt which is one of the RAMSAR sites and was declared by the Egyptian Government as a natural protectorate in 1998 (Shaltout and Al-Sodany, 2008). The outlet that connects the Mediterranean Sea with Lake Burullus is a natural water pass. Its length approximates 750 m, width at the narrowest point is about 50 m, and water depth varies between 50 cm and more than 200 cm. This outlet crosses the marine bar at the narrowest point, where the soil surface is flat and devoid from sand dunes (Fig. 1). This outlet was subjected to bigger maintenance works in October 2000 by dredging the sediments from its basin. The soil masses were put afterwards as a landfill along the shore. Vegetation arose and developed over this new substrate (i.e. plant succession has been starting).

As vegetation dynamics develop following a chronosequence, we will expect a simple vegetation composition during the early years which moves toward more advanced successional stages with time. Matthews and Whittaker (1987) and Anderson et al. (2000) showed that factor complexes like exposure, moisture, terrain and time control such a vegetation succession. As yet, no studies have dealt with substrate characteristics and time controlling such

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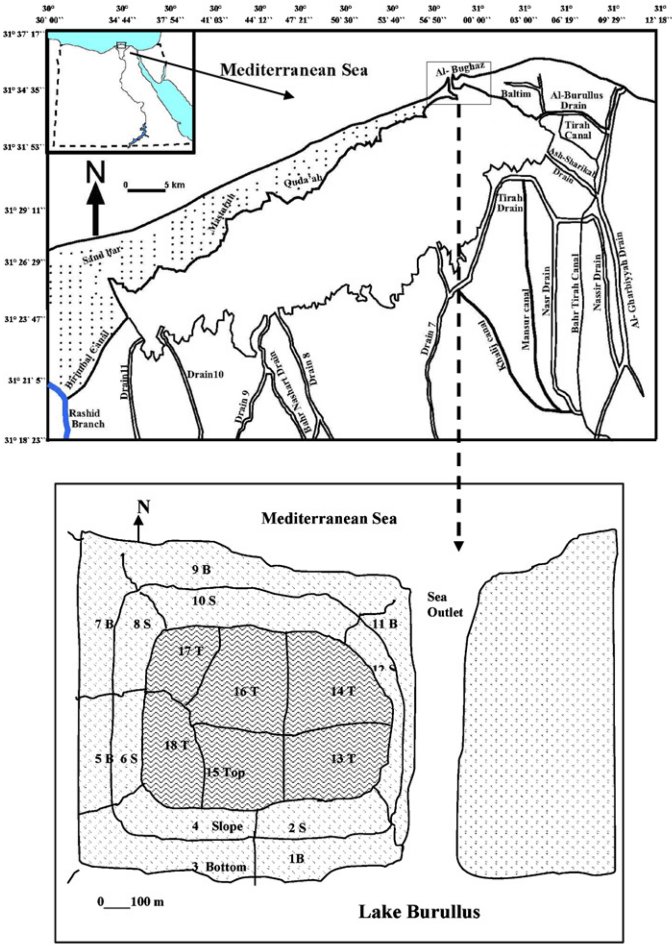

Fig. 1. Map of Lake Burullus showing the sea outlet and the distribution of the 18 study stands in the study area.

processes in the newly created Burullus wetland and the consequences on plant growth. In order to explain a plant succession on a new substrate some authors suggested a micro-site approach, taking into account small-scale differences in microclimate, disturbance levels, water supply, grain size and chemical quality of the substrate, and soil development (e.g. Burga, 1999; Burga et al., 2010; El-Sheikh, 2005; Tintner and Klug, 2011). The present study aims at elucidating the crucial factors governing plant establishment on the new substrate area, such as time, micro-relief and edaphic factors, using a multi-method approach including: 1 – floristic relevés along a chronosequence covering 10 years (2001–2010); 2 – description of vegetation structure, and 3 – soil analyses. We tried to establish and characterize a generalized model explaining the patterns of the seral plant succession observed on the new substrate.

Methods

Study area

Burullus Wetlands is located along the Mediterranean Deltaic coast of Egypt. It lies at a central position between the two branches of Nile River: Damietta to the east and Rosetta to the west. Its coordinates are 31° 36′ N and 30° 33′ E in north-west, 31° 36′ N and 31° 07′ E in the north-east, 31° 22′ N and 30° 33′ E in the south-west, 31° 22′ N and 31° 07′ E in the south-east. It has a total area of 460 km^2, which includes the entire area of Lake Burullus with a shoreline of about 65 km. The study area is the sea outlet that lies in the eastern part of this lake, its coordinates are: 31° 36′ N and 30° 58′ E and has an area of about 2 km^2 with an altitude of 10 m a.s.l. (Fig. 1). The investigated area was built from transported soil from the bed of the sea outlet in October 2000. The soil of this habitat is silty-clayey with organic materials from algae and marine debris. The climatic conditions of the site are warm summer (20–30 °C) and mild winter (10–20 °C). Relative humidity is between 65 and 73%, while rainfall is between 0.0 and 46.6 mm month^{-1} (Al-Sodany, 2009).

Stands selection and vegetation analysis

For the present study, we used a multi-method approach combining: 1 – floristic relevés along a chronosequence covering 10 years (2001–2010); 2 – vegetation; and 3 – soil analysis. Physiographically, the study area was distinguished into three different zones: bottom, slope and tope zones (Fig. 1). Eighteen sites were selected randomly in the various observed vegetation and landform types to cover the three zones of the latter (6 stands in each zone); the size of each stand was 50 m × 30 m. Sampling was carried out during spring season (March and April 2001, 2002, 2003, 2007 and 2010) when most species were expected to be growing. The vegetation parameters included listing of all species and their life forms and chorotypes in each stand. Nomenclature follows Boulos (1999, 2000, 2002, 2005, 2009). In each stand, species present were recorded and their densities were estimated in five randomly distributes quadrates (each 1 m × 1 m) and expressed as individuals/100 m^2. Plant cover was estimated quantitatively using the line intercept method (Canfield, 1941), with five parallel lines each 50 m long laid down in each stand. The lengths of interceptions by each species in each stand were measured in centimeter, summed up, and related to the total length of lines stretched in the particular stand (in %). Such estimates were used to calculate the relative cover of each species (p_i).

The rate of change (RC) was calculated for presence, density and cover of the recorded species according to the following equation: RC = (presence, density or cover of the last year − presence, density or cover of the first year)/presence, density or cover of the first year and expressed as a ratio of the initial record. For explaining the patterns of the plant succession observed on the new substrate, a diagrammatic vegetation map was established based on the field observations of the vegetation cover at different years.

Soil analysis

Three soil samples, down to 50 cm depth, were collected from each stand and mixed as one composite sample for each stand. They were air dried and passed through a 2 mm sieve to separate gravel and debris. Soil water extracts (1:5) were prepared for the determination of electric conductivity (EC in mS cm^{-1}) and soil reaction (pH) using conductivity and pH-meters. Chlorides were estimated by direct titration against silver nitrate using 5% potassium chromate as indicator. Bicarbonates were estimated by direct titration against HCl using 0.05% methyl orange as indicator. Sulfates were determined using the gravimetric with ignition of residue method, where sulfates were precipitated in 1% HCl solution as barium sulfate. Soil texture was analyzed using the Bouyoucos hydrometer method (Bouyoucos, 1962), whereby the percentage of sand, silt and clay were calculated. Total organic matter was determined by loss-on-ignition at 550 °C for 2 h. 2.5% (v/v) glacial acetic acid was used for the extraction of Na, K, Ca, and Mg. Atomic absorption was used for the determination of Mg. Estimation of Ca, Na and K was carried out by flame photometer. All these procedures followed the measurement protocols outlined by Allen et al. (1989).

Data analysis

Three data matrices of species cover data were created: (1) matrix of 18 stands × 7 species cover value during the first year of succession, (2) matrix 18 stands × 31 species cover values after the 10 years of succession, and (3) matrix of 18 stands × 31 species cover values and soil variables after the 10 years of succession. For comparison, multivariate analyses were applied to the three data sets. The first and the second matrices were subjected to a numerical classification using Two-way indicator species analysis, "TWINSPAN" (Hill, 1979a). TWINSPAN produces a hierarchical classification of vegetation groups (i.e. plant communities). Plant communities were named after their dominant species. The Detrended Correspondence analysis, "DCA" (Hill, 1979b) was applied to the same (first and second matrices) data sets in order to obtain an efficient graphical representation of the ecological structure of the vegetation groups identified using TWINSPAN. In order to detect correlations of the derived vegetation associations with environmental data, Canonical Correspondence Analysis, "CCA", according to Ter Braak and Smilauer (2002) was conducted with species cover, stands and soil variables after the 10 years of succession using the third matrix.

Species richness (α-diversity) of each year was calculated as the average number of species stand^{-1}. Shannon-Wiener index $\hat{H} = -\sum_{i=1}^{s} p_i \log p_i$ for the relative evenness, and Simpson index $C = \sum_{i=1}^{s} p_i^2$ for the relative concentration of dominance were calculated for each relevé on the basis of the relative cover p_i of the ith species (Magurran, 1988; Pielou, 1975). Relationships between the ordination axes on one hand, and soil variables, on the other hand, were tested using Pearson's simple linear correlation coefficient (r). The variation in the species diversity, stand traits and soil variables in relation to plant community were assessed using one way analysis of variance (SAS, 1989).

Results

Succession pattern

Colonization during the first year

Plant succession during the first year (2001) started with a pioneer population of *Bassia indica*, associated with some other low-growing halotolerant species (*Senecio glaucus*, *Cakile maritima*, *Mesembryanthemum crystallinum*, *Mesembryanthemum nodiflorum*) and few seedlings of the shrub *Arthrocnemum macrostachyum* and the halotolerant, helophytic reed *Phragmites australis*. These populations started to colonize the periphery of the study area and expanded toward its center (Table 1).

Seral communities during the 10 years

Forty one vascular plant species were recorded during the period from the first year (2001) to the last year (2010) of succession (Table 1). The number of plant species increased from 7 in the first year to 31 species during the last year of observation. The seven species found at start of the succession were continuously recorded from first year till the last year, other eight species appeared in the second year (2002), six of them continued to be present till the last year of succession (*Sarcocornia fruticosa*, *Suaeda pruinosa*, *Zygophyllum album*, *Polypogon monspeliensis*, *Salsola kali* and *Spergularia marina*). Three species appeared in the third year 2003 (*Suaeda monoica*, *Cynodon dactylon* and *Spergularia diandra*), and at the end of study, 2010, nine additional species were present (*Cynanchum acutum*, *Silybum marianum*, *Beta vulgaris*, *Brassica tournefortii*, *Chenopodium album*, *Cichorium endivia* subsp. *divaricatum*, *Rumex dentatus*, *Sonchus oleraceus* and *Trifolium resupinatum*).

The rate of change in species richness through the 10 years indicated that some species approximated an J-shaped or positive rate of change (i.e. the presence percentage of plants increased with the time). This was the case with *Senecio glaucus*, *Mesembryanthemum crystallinum*, *Polypogon monspeliensis*, and *Phalaris paradoxa*. Others approximated an inverse J-shaped or negative rate of change (i.e. decreasing with time), viz. *Salsola kali*, *Suaeda aegyptiaca* and *Spergularia marina* (Fig. 2). On the other hand, some species showed a bimodal change, i.e., increased during the first two years (2001 and 2002), decreased after that during the third year 2003 and increased again from the 7th year (2007) till the end of the study (e.g. *Bassia indica*, *Cakile maritima*, and *Mesembryanthemum nodiflorum*).

Regarding the life form spectra, therophytes had the highest contribution (22 species), followed by subshrubs and perennial herbs (16 species) and shrubs (3 species). Therophytes increased gradually from 5 species in the first year to 20 at the last year, and the perennial species had a distinct increase from the first to the seventh year (2–13 species), but were represented in the last year by only 11 species. Considering the global floristic distribution, most of the species belonged to the Mediterranean element (25 species), followed by Irano-Turanian (21 species) and Saharo-Arabian plants (19 species). On the other hand, pluri-regionals (22 species including 7 cosmopolitans) had the highest contribution, followed by bi-regionals (14 species) and mono-regionals (5 species). The cosmopolitans are: *Phragmites australis*, *Cynodon dactylon*, *Polypogon monspeliensis*, *Chenopodium murale*, *Chenopodium album*, *Salsola kali* and *Sonchus oleraceus* (Tables 1 and 2). The species diversity indices (species richness, turnover and relative evenness) increased gradually from the first year to the last year, while the relative concentration of dominance had the highest value in the first year (0.14) and the lowest of (0.06) in the last year (Table 2).

Vegetation analysis

The first-year plant communities

Multivariate analysis revealed seven very simple subgroups at the level 3 and allied into two simple communities at level one after the application of the TWINSPAN on the matrix of 7 species in 18 stands: I: *Senecio glaucus* and II: *Bassia indica*. Application of the DCA program confirmed the separation of these groups (Fig. 3). Seedlings of *Senecio glaucus* community colonized the bottom stands and extended toward the slope zone of the study area, while the *Bassia indica* community started colonization from the bottom and extended widely into the top zone. Seedlings of *Phragmites australis* colonized the slope zone, while *Arthrocnemum macrostachyum* inhabited the wet bottom zone.

The last year plant communities

Application of TWINSPAN on the last year data (31 species in 18 stands) led to identification of six subgroups at level 3, which are allied to four plant communities at level two (Fig. 3): (I) *Senecio glaucus*–*Cakile maritima*–*Zygophyllum album*, (II) *Bassia indica*–*Mesembryanthemum nodiflorum*, (III) *Arthrocnemum macrostachyum* and (IV) *Phragmites australis*–*Limbarda crithmoides*. Cluster I colonized the top zone, cluster II the dry bottom zone, cluster III the slope zone and cluster IV the wet bottom zone. Application of DCA and CCA confirmed the separation between these communities and pointed also to the most effective environmental gradients (Fig. 3).

Relationships between soil and plant communities in the last year

Correlation coefficients between the environmental factors and CCA axes (Fig. 4, Table 3) indicated that separation along the first

Table 1

Average density (individual 100 m^{-2}), cover (m 100 m^{-1} – see Methods) and rate of change (RC: as a ratio of the initial record) of the recorded species during ten years (2001–2010). The chorotypes are: COSM: Cosmopolitan, ES: Euro-Siberian, IT: Irano-Turanian, ME: Mediterranean, SA: Saharo-Arabian, SU: Sudanian and TR: Tropical.

Species	Chorotype	Density					RC	cover					RC
		2001	2002	2003	2007	2010		2001	2002	2003	2007	2010	
Shrubs													
Atriplex halimus L.	ME + SA				10.5	15.5					3.0	0.1	
Suaeda monoica Forssk. ex J.F. Gmel	SU			30.8						1.8			
Tamarix nilotica (Ehrenb.) Bunge	SA + SU			5.5						2.0	0.7	0.1	
Subshrubs-Perennial herbs													
Arthrocnemum macrostachyum (Moric.) K. Koch	ME + SA	3.0	733.8	730.2	282.0	323.4	106.8	0.1	4.3	6.6	18.1	5.8	57.0
Atriplex leucoclada Boiss.	SA + IT				40.7	530.8					1.1	1.0	
Halocnemum strobilaceum (Pall.) M.Bieb.	ME + SA + IT		127.8	6.8					5.9	0.4			
Limbarda crithmoides (L.) Dumort.	SA				117.3	50.67					3.5	0.7	
Lolium perenne L.	ME + ES + IT			5.5	5.5	100.7				2.0	0.1	0.2	
Sarcocornia fruticosa (L.) A.J. Scott	SA		4500.5	10.5	460.5	250.5	0.1		17.0	0.2	6.4	0.5	0.0
Suaeda aegyptiaca (Hasselq.) Zohary	SA		20.6	11.8	120.5		0.0		1.3	0.5	1.0		0.0
Suaeda pruinosa Lange	ME + SA		70.0	130.8	130.8	67.33	1.0		10.2	2.3		0.2	0.0
Symphyotrichum squmatum (Spreng.) Nesom	TR										10.1		
Zygophyllum album L.f.	ME + SA		81.3	25.6	382.9	158.9	2.0		3.1	13.4	9.0	1.6	0.5
Cynodon dactylon (L.) Pers.	COSM			10.5						1.0			
Phragmites australis (Cav.) Trin. ex Steud.	COSM	3.0	887.2	1323.4	3130.2	2231	742.7	0.1	9.2	7.2	4.9	5.3	52.0
Polygonum equisetiforme & Sm.	ME + IT				10.5						1.0		
Cynanchum acutum L.	ME + IT					75.5						6.5	
Launaea nudicaulis (L.) Hook.f.	SA + IT + SU			5.3	5.5					0.7	0.1		
Silybum marianum (L.) Gaertn.	ME + ES + IT					400.7						1.5	
Therophytes													
Bassia indica (Wight) A.J. Scott	IT + SU	30.0	68.6	212.3	1042.9	2799.5	92.3	0.2	7.8	9.4	23.1	9.3	45.5
Beta vulgaris L.	ME + ES + IT					25.5						0.5	
Brassica tournefortii Gouan	ME + SA + IT					50.7						0.6	
Cakile maritima Scop.	ME + IT	2.0	907.9	1631.6	238.4	698.7	348.4	0.1	7.7	13.6	2.2	6.3	62.0
Chenopodium album L.	COSM					930.8						6.1	
Chenopodium murale L.	COSM				1200.5	214.2					1.4	1.3	
Cichorium endivia subsp. *divaricatum* (Sch.) P.D. Sell	ME + IT					25.5						0.5	
Ifloga spicata (Forssk.) Sch. Bip	ME + SA				50.5						1.0		
Malva parviflora L.	ME + IT					367.3						2.3	
Melilotus indicus (L.) All.	ME + SA + IT			2.5		75.5						0.1	
Mesembryanthemum crystallinum L.	ME + ES	11.0	32.0	39.3	618.0	728.2	65.2	0.2	3.3	2.2	1.9	10.7	52.5
Mesembryanthemum nodiflorum L.	ME + ES + SA	20.0	34.3	80.0	205.8	3678	182.9	0.2	0.3	2.4	1.5	17.4	86.0
Phalaris paradoxa L.	ME + IT + EU			10.5	5.5	167.3	14.9			0.3	0.1	1.1	2.7
Polypogon monspeliensis (L.) Desf.	COSM		47.4	14.3	40.7	7938	167.5		0.7	2.6	1.1	9.8	14.0
Rumex dentatus L.	ME + ES + IT					25.5						1.0	
Salsola kali L.	COSM		33.9	97.5	100.5	84.17	2.5		6.6	13.6	2.0	1.0	0.2
Senecio glaucus L.	ME + SA + IT	15.0	109.4	142.5	1144.9	4783	317.9	0.1	1.9	1.4	5.9	29.6	295.0
Sonchus oleraceus L.	COSM					113.3						1.2	
Spergularia diandra (Guss.) Boiss.	ME + SA + IT			244.0						6.0			
Spergularia marina (L.) Griseb.	ME + SA + IT		54.6	1184.8	74.0	100.5	1.8		0.6	3.6	0.1	4.0	6.7
Sphenopus divaricatus (Gouan) Rchb.	ME + SA + IT				154.0	67.33					0.6	0.1	
Trifolium resupinatum L.	ME + ES + IT					313.3						0.8	

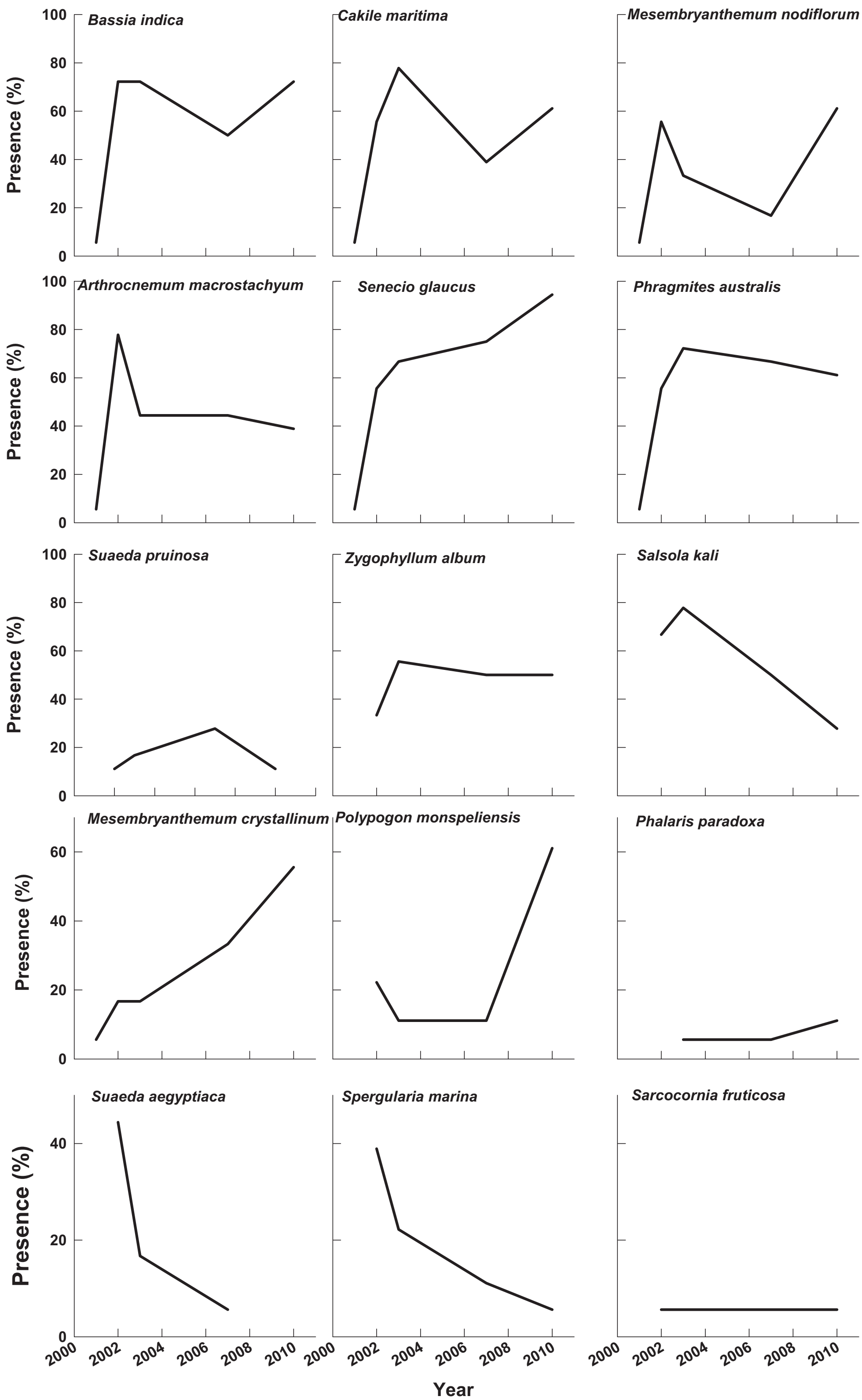

Fig. 2. Variation in the presence percentage of 15 species in the observed stands in the study area at Lake Burullus during 2001–2010.

axis is positively influenced by silt, organic matter, salinity, moisture and minerals, and negatively by pH and clay. On the other hand, sand contents are correlated negatively with the second axis. The therophytic species of community I (*Senecio glaucus*, *Cakile maritima*, *Zygophyllum album*, *Salsola kali*, *Brassica tournefortii*, *Silybum marianum*, *Chenopodium murale*) correlated negatively with pH and clay along axis one (species that inhabit the top stands of the study area). The halophytic species of communities II, III and IV (*Phragmites australis*, *Limbarda crithmoides*, *Sarcocornia fruticosa*, *Suaeda aegyptiaca*, *Arthrocnemum macrostachyum*, *Symphyotrichum squamatum*) correlated positively with silt, organic matter, salinity, moisture and minerals along axis one (species that inhabit the

Table 2
Floristic and diversity variables in the study area during the 10 years investigation period. Maximum and minimum values in bold.

Variable	Period				
	2001	2002	2003	2007	2010
Shrubs (n)	0	0	2	1	1
Subshrubs – Perennial herbs (n)	**2**	7	10	**12**	10
Total perennial species (n)	**2**	7	12	**13**	11
Total annual species (n)	**5**	8	11	11	**20**
Total species (n)	**7**	15	23	24	**31**
Species richness (n stand^{-1})	**2.3**	6.2	7.0	5.2	**8.2**
Species turnover (RC)	**0.7**	1.5	2.4	2.5	**3.2**
Species relative evenness [Shannon-Wiener index ($\hat{H}$)]	**0.9**	1.1	1.2	1.2	**1.3**
Species concentration of dominance [Simpson index (C)]	**0.14**	0.09	0.08	0.07	**0.06**

Table 3
Inter-set correlations of environmental variables with axes CCA of the last year. Significant values are bold.

N	NAME	AX1	AX2
1	Sand %	−0.23	**−0.32***
2	Silt %	**0.72*****	0.22
3	Clay %	**−0.82*****	**0.32***
4	Org. matter %	**0.82*****	**0.32***
5	pH	**−0.58****	−0.27*
6	EC mS/cm	**0.76*****	−0.07
7	Moisture %	**0.53****	−0.12
8	HCO_3 m eq/L	−0.23	0.16
9	Cl m eq/L	**0.63*****	−0.08
10	SO_4 m eq/L	**0.75*****	−0.19
11	Ca m eq/L	**0.69*****	0.01
12	Na m eq/L	**0.73*****	−0.11
13	K m eq/L	**0.79*****	−0.03
14	Mg m eq/L	**0.41***	−0.25

* ≤0.05.
** ≤0.01.
*** ≤0.001.

bottom and slope zones near the sea shoreline). *Mesembryanthemum crystallinum*, *M. nodiflorum*, *Suaeda pruinosa* and *Atriplex halimus* correlated negatively with sand along the axis 2. On the other hand, ruderal species (*Beta vulgaris*, *Rumex dentatus*, *Launaea nudicaulis*, *Spergularia diandra* and *Spergularia marina*) inhabit the slope and bottom zones away from the sea shoreline or do not show a clear distribution pattern (Fig. 5).

Seral changes of the edaphic variables

According to t-test application, the soil of the first year had significant higher values of silt, organic matter, salinity, moisture, chloride, sulfates, Ca, Mg, Na and K; while in the last year it had significant higher values of sand, clay, pH and bicarbonates (Table 4).

Discussion

Seral changes in floristic composition

During the first year of the present study, the vegetation development started from simple scattered annuals at the peripheral naked wetted soil, associated with few seedlings of halophytic perennials. At the initial stage (0.5–1.0 yr), only short-lived annuals (*Bassia indica*, *Senecio glaucus*, *Cakile maritima*, *Mesembryanthemum crystallinum* and *Mesembryanthemum nodiflorum*) started to colonize the periphery of the study area and extended toward its center. At the end of the first year, the seedlings of the halophytic perennial *Arthrocnemum macrostachyum* and the helophytic reed *Phragmites australis* (Gorai et al., 2010) grew few meters apart from the periphery. This stage could be influenced by many factors: dryness of the soil after it became removed from the outlet, high organic matter from the debris of the aquatic biota, and presence of a seed bank from the neighbor area. Thus, pioneer annuals, in the studied case strongly halophilic ones, and few perennial species firstly appeared, as it occurs typically at the beginning of primary successions (Burga et al., 2010; Erfanzadeh et al., 2010). After two years, the study area was suitable already for a low-shrub woody stage dominated by *Sarcocornia fruticosa*, *Suaeda pruinosa*, *Zygophyllum album* and *Halocnemum strobilaceum*. During the third year, the area was more favorable for an early high-shrub, partly woody, stage dominated by *Suaeda monoica*, *Atriplex* spp. and *Tamarix nilotica*. This change occurred fast and is similar to that found by Halwagy (1963) in his study on the vegetation succession in a Nile Island in Sudan, and the study of El-Sheikh (2005) on plant succession of the abandoned fields in Egypt.

The number of plant species increased from 7 in the first year to 31 species after 10 years. From 2 to 7 years, annuals and perennials were increasing with the same proportion. High seed density in the early successional stages can be attributed to a high seed input

Table 4
t-Test for soil analysis comparison between the first and last year. SD: standard deviation. Maximum values in bold.

Variable	First year		Last year		t-Value	Prop.
	Mean	SD	Mean	SD		
Sand %	78.6	1.1	**83.3**	**2.2**	9.2	0.0001
Silt %	**18.8**	1.0	12.0	3.2	9.0	0.0001
Clay %	2.6	0.5	**4.8**	2.3	3.9	0.0001
OM %	**4.8**	0.5	1.8	1.0	12.7	0.0001
pH	8.2	0.9	**8.8**	0.3	8.3	0.0001
EC mS/cm	**55.6**	12.0	11.5	10.7	17.6	0.0001
Moisture %	**41.7**	2.5	33.6	5.6	6.1	0.0001
HCO_3 m eq/L	1.3	0.4	**2.8**	0.8	8.3	0.0001
Cl m eq/L	**760**	15.3	88.3	109.7	26.0	0.0001
SO_4 m eq/L	**118.1**	2.5	61.6	62.3	3.8	0.0001
Ca m eq/L	**85.2**	1.9	25.2	25.7	9.9	0.0001
Na m eq/L	**702**	5.7	102.2	105.3	24.2	0.0001
K m eq/L	**8.3**	0.5	1.7	0.9	30.0	0.0001
Mg m eq/L	**207.6**	12.1	31.8	35.2	21.2	0.0001

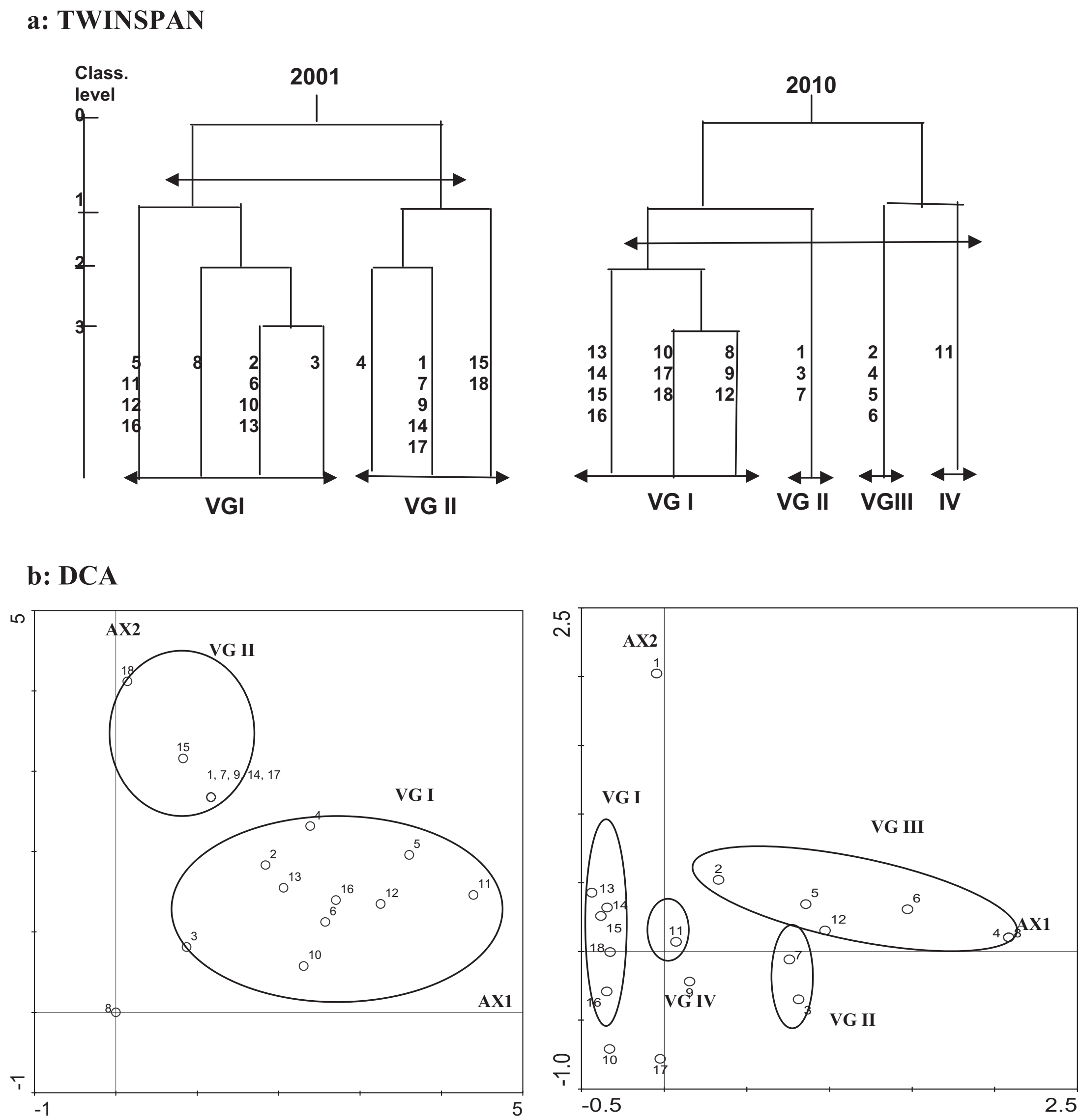

Fig. 3. Relationship between the two plant communities of the first and last year after the application of TWINSPAN and DCA. The vegetation groups of the first year are named based on the most prominent taxa are: I: *Senecio glaucus*, II: *Bassia indica.* The vegetation groups of the last year are: I: *Senecio glaucus–Cakile maritima–Zygophyllum album*, II: *Bassia indica–Mesembryanthemum nodiflorum*, III: *Arthrocnemum macrostachyum*, and IV: *Phragmites australis–Limbarda crithmoides*.

by pioneer species (e.g. *Mesembryanthemum*, *Sarcocornia*, *Suaeda*, *Spergularia* and *Cakile maritima*). Such pioneer species are known to produce high amount of seeds (Davy et al., 2001; Erfanzadeh et al., 2010; Wolters and Bakker, 2002; Zaplata et al., 2011). In the last year (2010) the proportion of the perennial species seemed to be partially stable, while that of the therophytes was still increased. Dominance of therophytes in the first year seems to be a response to substrate condition, where the succession started on harsh, naked and moist-saline soil (El-Sheikh, 2005; Erfanzadeh et al., 2010; Shaltout and Al-Sodany, 2008; Shaltout and Galal, 2006). The concentration of annuals in the last year still exceeded that of the perennials due to exposure of some of stands to local disturbances by degradation and surface soil (and plant) removal. Thus, these stands could be occupied again by short-lived annuals (Collins et al., 2001; El-Sheikh, 2005; Erfanzadeh et al., 2010). In addition, the lower salinity in substrate in the last year than in the first year (reduction from 55.6 to 11.5 mS/cm) gave chance to many glycophytic annual herbs, grasses and forbs for colonizing (Rubio-Casal et al., 2003).

The rate in change of species presence through the 10 years indicates that *Mesembryanthemum crystallinum*, *Polypogon monspeliensis* and *Phalaris paradoxa* increased with time. On the other hand, some annual halophytic species (*Salsola kali*, *Spergularia marina* and *Suaeda aegyptiaca*) had a distinctly negative rate of change. This may indicate that in the latter cases the recruitment of individuals was rare with the progression of succession process, probably due to aridity, low salinity, low levels of organic matter, and the interspecific competition with perennials which clearly dominates at the late successional stage (El-Sheikh, 2005). For most of the halophytic annuals which dominate during the early successional stages it is known that they have a very transient seed bank or are almost with no new seed input. These halophytic species were still dominant after 5 years of succession and then decreased in their presence after 10 years. Salinity can promote seed dormancy (Tobe et al., 2000) and give seeds a higher chance to penetrate deeply into the soil (or be buried deeper through sediment accretion) with time. But, as the seeds penetrate in deeper soil layers, they probably lose part of their viability. Espinar et al.

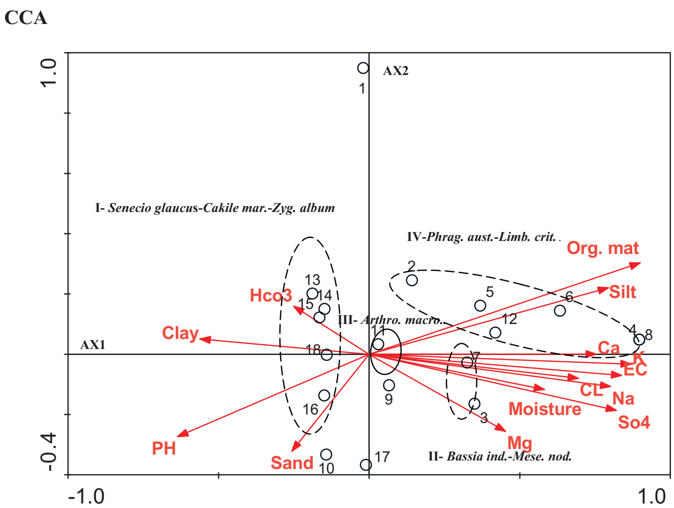

Fig. 4. Two-dimensional sorting of the four plant communities of the last (10th) observation year by the application of TWINSPAN and CCA and overlay of the environmental variables represented by arrows.

(2005) showed that seeds of some salt marsh species suffer a rapid loss of viability when buried.

Species richness and diversity indices in the present study tended to increase rapidly from the first year of establishment to the last year of monitoring. Species dominance had an inverse trend because the abundance (i.e. cover) of single or few species was larger in the earlier stage and then decreased by increase of the species number. The early succession course also resulted in lower evenness than it was the situation at the late successional stages, indicating a remarkable role of mono-dominant stands in early successional stages and subsequent development toward stands with a more equal distribution of species abundances (Pysek et al., 2004). At the start of succession in typical plots most of the cover was accounted for by one or two species (e.g. *Mesembryanthemum* spp., *Arthrocnemum macrostachyum* and *Bassia indica*) that can apparently make the best use of available resources, because of their high competitive capacities under environmental stress (El-Sheikh et al., 2010; Shaltout and Mady, 1996). Interspecific competition became increased at the medium and later stages of succession.

Mediterranean species were the most represented chorotype in the present study, being characterized as

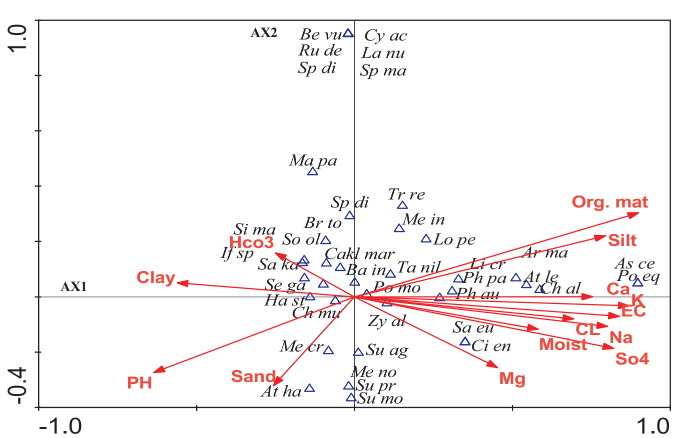

Fig. 5. CCA biplot with environmental variables (arrows) of the last year and species (represented by two to three first letters from genus and species names; for complete names of species see Table 1).

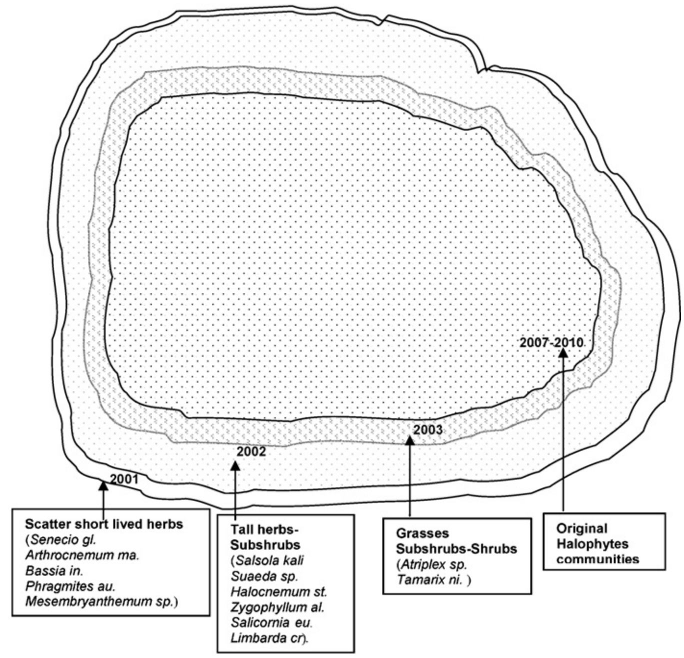

Fig. 6. Generalized model explaining the patterns of the seral plant succession observed on the new substrate.

pluriregional > bioregional > monoregional ones. Irano-Turanian elements are the second group followed by Saharo-Arabian chorotypes, while the other elements have a minor representation. Prevalence of the Mediterranean elements does occur there due to proximity to the Mediterranean coast of Nile Delta. Similar sequences of chorotypes were described by Mashaly (1987), Khedr (1999) and Shaltout and Al-Sodany (2008) in the same region. There are links to biregional distribution of Irano-Turanian and Saharo Arabian plants liked to the Mediterranean region, indicating that Egypt's location is a midpoint for these neighbor chorotypes (Zohary, 1973).

Seral change of plant community structure

The vegetation stands of the first year show a clear pattern of two simple communities which inhabit mainly the margins of wet stands (*Senecio glaucus* and *Bassia indica*). When succession progresses, four advanced, original halophytic, communities cover the whole area, as seen after 10 years of development. Two of the four communities of this last year (*Senecio glaucus–Cakile maritima–Zygophyllum album* and *Bassia indica–Mesembryanthemum nodiflorum*) inhabit the top zone of the dry sandy soil (they are comparable with groups described by Al-Sodany, 2006, along the roadside of a newly constructed highway near the study area). Obviously, many annual and perennial herbs found the opportunity to develop in later successional stages, together with the original halophytic vegetation. These, mostly annual, species, with high reproductive capacities and ecological and genetic plasticity, are adapted to the stress of disturbed stands (Bornkamm, 1986; El-Sheikh, 2005; Grime, 1979; Redzic, 2000). On the other hand, *Phragmites australis–Limbarda crithmoides* and *Arthrocnemum macrostachyum* groups, which inhabit the wet bottom and slope stands and facing the sea, represent original communities after 10 years of seral succession. Edaphically, these communities are characterized by more silty saline soil, rich in minerals, and comparable to the halophytic communities described in previous studies on Lake Burullus shores (e.g. Al-Sodany, 2006; Khedr and Lovett-Doust, 2000; Shaltout and

Table 5
Comparison between vegetation groups at first and last year.

VG	First year	Habitat	Last year	Habitat
I	*Senecio glaucus*	Bottom-slope	*Senecio glaucus–Cakile maritima–Zygophyllum album*	Top
II	*Bassia indica*	Bottom-top	*Bassia indica–Mesembryanthemum nodiflorum*	Dry bottom
III			*Arthrocnemum macrostachyum*	Slope
IV			*Phragmites australis–Limbarda crithmoides*	Wet bottom

Al-Sodany, 2008; Shaltout et al., 2005). The expected climax of this region is a halophytic scrubland, but further study is recommended to verify this hypothesis.

Seral changes of the environmental variables

Nutrient situation (organic matter, moisture, salinity, soil minerals and fertility) was greater in the early successional stage than during the later ones. This can be due to the rapid development of herbaceous communities that vigorously take up nutrients from the topsoil (El-Sheikh, 2005; Odum et al., 1984). In addition, the deposited soil of this habitat had high contents of fine materials enriched with organic matter from algae and marine debris in the earlier successional stage, which were subjected to rapid decomposition with time (Eid, 2009).

Conclusions

1. During the early successional stage on the newly created land from deposited soil dredged from the inlet bottom between Lake Burullus and the Mediterranean Sea two species-poor annual vegetation types did establish. In this stage few annual species are the colonizers, based on seed bank resources and diaspore input from the surroundings (Fig. 6, Table 5). They have a short life, but are able to recharge the seed bank and to modify the substrate before the next succession stages.
2. *Senecio glaucus*, *Bassia indica* and *Mesembryanthemum* spp. seedlings germinated first, preferably at the bottom edges. Later they extended their occurrences into the slope and top zones of the study site. Seedlings (resp. rhizomes) of the halotolerant pioneer perennials *Phragmites australis* and *Arthrocnemum macrostachyum* encroached from the bottom edges and spread further.
3. The later seral successional, more stable, communities were found after 10 years of site development. They are essentially characterized by resprouter species: grasses, perennial herbs, subshrub and shrub species. Due to increase of the local diversity, spreading colonization and substrate stabilization, many halophytic and glycophytic species finally become established rendering the vegetation-covered landfill area with time similar to the surrounding coastal areas of natural geomorphology.
4. In general, the simultaneous invasion of both early and late successional species and their successful establishment depends on the specific nutrient availability, the peculiar life cycles of the involved taxa, and the resulting interspecific competition.

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