Turkish Journal of Botany
http://journals.tubitak.gov.tr/botany/
Research Article
Turk J Bot
(2020) 44: 493-508
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doi:10.3906/bot-1912-23

Relation between soil salinity and species composition of halophytic plant communities: A baseline data inventory for wetland monitoring

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Received: 19.12.2019 • **Accepted/Published Online:** 15.07.2020 • **Final Version:** 23.09.2020

Abstract: Our study sets forth the outcomes of an interdisciplinary project conducted in order to fill the information gap on the management of a wetland ecosystem, in the case of a protected area on the south-eastern coast of Turkey. The hypothesis of the study is that the pattern of species composition reflects soil salinity level and some species can act as relevant indicators. The study aimed to discover a relationship between soil salinity and vegetation composition and establish some indicators useful for monitoring. For this aim, the temporal and spatial changes of soil salinity were monitored and the distribution of coastal habitats and associated plant communities were described. Twenty-three plant communities were described according to the species compositions of the vegetation. Soil salinity was found to be a driving factor controlling the spatial distribution of the plant taxa. The dominant species of the study area are *Halocnemum strobilaceum*, *Arthrocnemum fruticosum*, *Spergularia marina*, *Plantago coronopus*, and *Atriplex portulacoides*. The peak average annual salinity value, 1535 mS/m, was measured in a pure stand of *H. strobilaceum*. A high significant positive correlation was determined between plant species richness and life form richness. Strong evidence was detected for species richness, which declines at higher salinity habitats and there is also some evidence that species turnover is greater among the 52 sampling quadrates. Eleven distinct habitats were determined.

Key words: Halophytes, soil salinity, Tuz Gölü lagoon, wetland, coastal zone management, monitoring

1. Introduction

Soil salinity, which triggered the collapse of the Mesopotamian and Harrapan civilizations, is still one of the major threats to soil productivity (Tanji, 2002) and is causing enormous yield losses in global agriculture. Kafi and Khan (2008) stated that a decrease of about 1%–2% of agricultural soils every year is contrary to the increasing world population. This global trend is more drastic in arid and semiarid regions due to soil salinity. Zhang et al. (2014) reported that variation in soil salinity was mainly affected by human influence, such as irrigation practices, as well as natural factors. Climate conditions, topography, and groundwater are the prevailing natural factors. Spatio-temporal variability is a fundamental problem in combating salinization in the arid regions of south-eastern Asia. The high-temperature and low-rainfall regime that characterize these regions promote high salinity. Salinity can be classified into two groups as primary and secondary. Primary salinity develops in coastal areas, wetlands, and depression zones by natural driving forces such as soil parent materials, topography, and hydrology, whereas secondary salinity occurs in cultivated lands due to excess or inappropriate irrigation of the arid and semiarid lands. Secondary salinization affects almost 80 million hectares of land in the semiarid and arid regions of the world (Lymbery et al., 2003; Abrol et al., 1988). Several costly methods were employed in vain in rehabilitating primary saline areas permanently persistent to human intervention. However, adapting to primary salinity via halophyte management revealed promising results both for nature conservation and income generation to the local population (Wallender and Tanji, 2011).

The halophytes can improve conditions of saline soils as they are well adapted in the saline environment due to their special anatomical and morphological features as well as their physiology (Hasanuzzaman et al., 2014; Shrivastava and Kumar, 2015). Therefore, the relationship between soil characteristics and halophytic plant communities has received great attention in the literature. Salinity and flooding tolerance in halophytes

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and the relationship between salt accumulation and water content of halophytic plant species were studied by several specialists (Flowers et al., 1986; Aronson, 1989; Flowers and Colmer, 2008; Colmer and Voesenek, 2009). Despite their recognition for hundreds of years, the definition of halophytes still remains ambiguous (Flowers and Colmer, 2008). Numerous definitions for halophytes are available in the literature (Grigore et al., 2010). Flowers et al. (1986) defined halophytes as plants growing under naturally saline conditions that adapted to live in a saline environment, seawater, a salt-water marsh, or a salt-desert. For terrestrial plants, this means a minimum salt concentration of about 100 mM in the soil solution. Similarly, Flowers and Colmer (2008) stated that halophytes are plants that adapted to complete their life cycles in salinities about that of seawater and survive to reproduce in environments where the salt concentration is around 200 mM NaCl or more. Other authors underlined the obligate character of halophytes and described them as species for which saltmarsh is a major, and in many cases only, habitat (Adam, 1990), or species that occur in naturally saline conditions only (Aronson and Le Floc, 1996). Aronson (1989) composed a list of halophytes containing 1560 species in 550 genera and 117 families (Arora et al., 2013). Gleen and O'Leary (1984) reported that halophytes are rare plant forms that arose separately in unrelated families during the diversification of angiosperms. It was reported that the majority of salt marsh species are perennial and in fact, relatively few species of annual herbs have become adapted to the true salt marsh habitat (Ranwell, 1972).

Grigore (2012) provides an invaluable review of the variety of definitions, classifications, and taxonomy of halophytes. One of those proposed by Bucur et al. (1957) suggests a triple classification: euhalophytes, neohalophytes, and nonhalophytes. Euhalophytes were defined as plants strictly adapted to salinity that are exclusively preferential and grow only in salinized environments, while neohalophytes are able to adapt to salinity, but live both on nonsalinized and salinized media. Plants that are nontolerant to high concentrations of salinity were classified as nonhalophytes. Euhalophytes were mentioned as typical, true, absolute, or obligate halophytes as well as salt plants in the literature. Several classifications are available for halophytes, primarily developed by Waisel (1972), consisting of four different classes according to climate and habitats, namely as the xero-halophytes in deserts and arid environments, hygrohalophytes in estuaries, salt marshes, wet soils, submerged hydrohalophytes (subtidal growth) and aero-halophytes associated with salt spray and salt dust conditions (Schaefer, 1988).

Abulfatih et al. (2002) described seven common halophytic communities in Qatar according to two basic gradients: land morphology and distance from the coast. Habitat features and floristic composition of halophytic communities were surveyed, and halophytes were grouped into two groups as inland and coastal halophytes. Naz et al. (2010) determined five distinct habitats in the Cholistan desert and reported that community structure and spatial distribution of the species was mainly dependent on the salinity gradient. The more salt-tolerant species of *Sporobolus ioclados* (Trin.), *Aeluropus lagopoides* (L.) Trin. ex Thw., *Haloxylon recurvum* Bunge ex Boiss., and *Suaeda fruticosa* (L.) Forssk. were dominant in highly saline habitats, whereas moderately saline sites supported less tolerant plant species. Another study revealed that the salt tolerance of certain halophytic plants may differ in terms of the soil ionization gradient. Barth (2008) reported that the most noticeable difference between the *Halocnemum* M.Bieb. and *Halopeplis* Bunge ex Ung.-Sternb stands were the higher concentration of SO_4^{2-} at the *Halocnemum* sites (1700 mg/L compared to 570 mg/L), while Ca^{+2} concentrations at both stands were similar (330 mg/L and 421 mg/L, respectively). Asri and Ghorbanli (1997) studied the halophilous plant communities of salt marshes around the Orumieh lake and described the soil and habitat characteristics of the area, subsequently defining the vegetation types and recognizing the six different classes of Halocnemetea strobilacei, Thero-Salicornietea, Tamaricetea, Juncetea maritime, Agrostietea stoloniferae, and Phragmitetea. *Halocnemum*, which belongs to the Amaranthaceae subfamily Salicornioideae, is a widespread halophyte genus distributed along the range from South Europe and North Africa to Asia and Mongolia. Al-Mailem et al. (2010) reported that halotolerant bacteria that are able to grow in environments with a wide range of salinity have been isolated from *Halocnemum strobilaceum* Pall. Whereas the genera *Halocnemum* was monotypic and represented by *Halocnemum strobilaceum* M.Bieb., a second species of this former circumscription was described as the *Halocnemum yurdakulolii* Yaprak in the Göksu Delta, Turkey, in 2004 (Yaprak and Kadereit, 2008).

The family Chenopodiaceae, which comprises numerous halophile taxa, contributes essentially to the flora and vegetation of the Old World arid belt (Freitag, 1991). According to the recent classification, many halophile taxa are classified in the subfamilies of Salicornioideae, Salsoloideae, and Suaedoideae. They include several bi- or pluregional hygrohalophytic species classified under the genera of *Salicornia* L., *Sarcocornia* (Scott), *Halopeplis*, *Arthrocnemum* Moc., *Halocnemum*, *Microcnemum* Ung.-Sternb, *Salsola* L., and *Suaeda* Forssk. ex J.F. Gmel.

The species diversity of Salicornioideae is the highest in Australia. However, the highest generic diversity is found in Eurasia and North Africa, where 26 species belonging to 9 genera occur in tidal mud or sand flats and coastal salt marshes. Those habitats are generally rich in clay, nutrients, and organic matter. Coastal and inland habitat complexes represent intricate mosaics, particularly in coastal salt marshes of isolated seas with nontidal temporarily flooded areas similar to the habitats in the Mediterranean (Kadereit et al., 2006). Romagna et al. (2002) and Masip (2001) provide information on saline habitats and halophytes of the Po delta and the Ebro delta, respectively, while Seçmen and Leblebici (1978), Gehu and Uslu (1989), Gehu et al. (1989), and Karaömerlioğlu (2007) give syn-taxonomic characteristics of vegetation along the Turkish Black Sea and the Mediterranean coasts. The vegetation of inland saline habitats of Central Anatolia received great attention as well as coastal habitats of the Mediterranean (Yurdakulol, 1974; Yurdakulol and Ercoşkun, 1990; Yurdakulol et al., 1996).

Salt marshes along the Turkish Mediterranean coast form ecologically important habitat chains. The country is rich in wetlands, ranking first in this respect among Middle Eastern and European countries. Almost 75 wetlands, including both coastal and inland, are larger than 100 hectares in Turkey. One of those ecologically important sites, namely Çukurova, was well investigated in terms of floristic and phytosociological aspects. Described syntaxa were classified under Asteretea tripolii Westhoff & Beeftink in Westhoff, van Leeuwen & Adriani (1962), Arthrocnemetea fruticosi Tüxen & Oberdorfer (1958), and Saginetea maritimae West et al. (1961) em. Géhu et Biondi (1986) by Çakan et al. (2005). Although sufficient information on coastal marshes and plant zonation is available in the relevant literature (Chapman, 1960; Adam, 1990), the change of species composition of halophytic plant communities along the salinity gradient received relatively little attention on the local scale. In this respect, this paper attempts to discover soil–plant relationships and an indicative role of species and vegetation in the monitoring of a protected lagoon wetland ecosystem, and fill the information gap in the management of coastal protected areas.

2. Materials and methods

2.1. Materials

2.1.1. Study site

The study site (Tuz Gölü Lagoon and surrounding habitats), an alluvial plain and a wildlife reserve (3.974 ha) managed by the Turkish Ministry of Agriculture and Forestry, is located at the southwestern end of Çukurova (Figure 1). This biodiversity hotspot is a key migratory stop-over site for waders and waterfowl in the Mediterranean Basin. It was reported that 240 bird species and 601 vascular plant taxa were observed along this coastal area of five lagoons with sixty threatened plant taxa and endemics. Çakan et al. (2005) and Yılmaz et al. (2010) also documented that 18 endemic or threatened plant taxa occur along the coastal habitats of the Tuz Gölü Lagoon and that the ecological values of these wetland ecosystems are threatened by several anthropogenic impacts, particularly agricultural activities.

2.1.2. Equipment and software

A handheld device, EM-38 sensor, was used for measuring soil salinity. MVSP 3.1 A MultiVariate Statistical Package was employed to evaluate the relation between recorded plant taxa and soil salinity and how species richness and

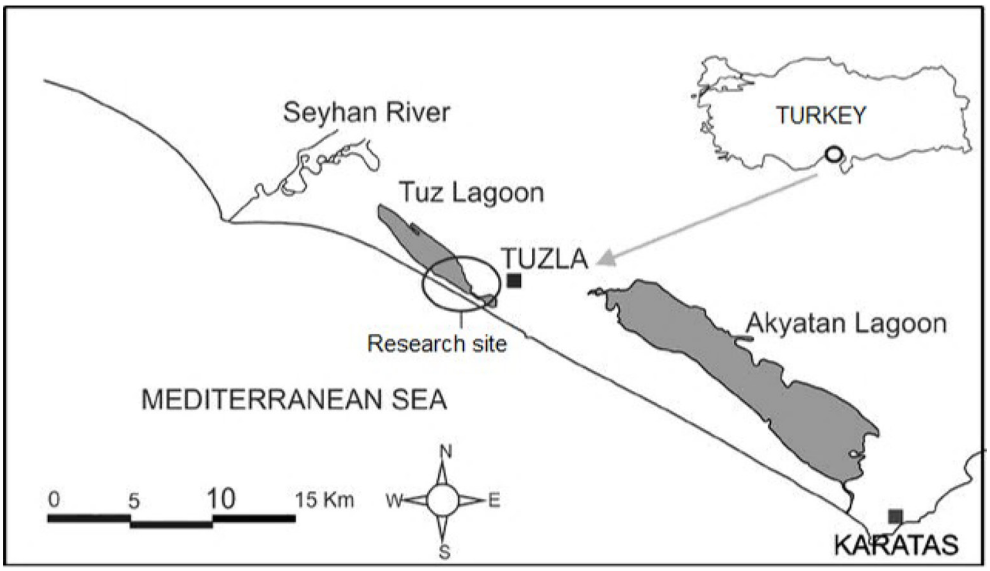

Figure 1. Location of the study site.

plant life from the spectra of plant communities were affected by soil salinity.

2.2. Methods

2.2.1. Fieldwork and data collection

Several classification approaches, such as the general ecological character and distribution of an area, quality and quantity of the salt intake in a basin, growth response to salinity, and the salinity level of the habitats, may be considered for dividing the halophytes into subgroups (Albert, 1975). The approach concerning the salinity of the soils of the habitat primarily accounted for achieving a comparative evaluation along the gradients of salt buildup in the study area. The main source of data on soil salinity and vegetation presented in this paper was collected during two years (2010–2011) of fieldwork. In this context, soil salinity was recorded at 76 permanent measuring points located along transects perpendicular to the coast and their positions were given in Figure 2. The salinity was monitored by replicated measurements along these gradient points. Measurements were taken six times, from March 2010 to March 2011. The monitoring campaign was performed with in situ field surveys and soil sampling was not conducted. The device was used to position the midpoints of the EM-38 magnets at a height of 10 cm above the ground when readings were taken.

Quadrate sampling was performed to describe the species composition of the habitats in which salinity measurements were taken. Since soil salinity changes along the distance gradient from the lagoon to inland areas, 52 sampling quadrates overlapping the salinity measurement points were selected for vegetation analysis. Transect layout and the placement of quadrats on West and East transects are shown in Figure 2. The coverage and abundance values of each plant taxa occurring in sampling quadrates were visually estimated following Braun-Blanquet (1964). Occurrence values were calculated on the basis of presence/absence data. The system proposed by Raunkiaer (1937) was followed for the classification of the plant life forms of the plant taxa. Measuring points and recorded salinity values were correlated with the occurrence of plant species and communities.

2.2.2. Statistics and software

Multivariate statistical analyses were used to determine the plant communities and their relationship along the salinity gradients. Principal component analysis (PCA) and cluster analysis (Ward's minimum variance method) were carried out to evaluate the relationship between recorded plant taxa and soil salinity. The characteristic species of the communities were grouped according to the soil salinity classification suggested by Abrol et al. (1988). Correlation analyses were employed to determine how species richness and plant life from the spectra of 23 plant communities were affected by soil salinity.

On a spatial scale, the distribution of diversity can be investigated by alpha, beta, and gamma diversity. The difference between these diversity measures stems from the way that diversity varies with the sampling scale (Shaw, 2003). Whittaker (1960, 1972) introduces alpha diversity as the diversity in individual units, beta diversity as the quantification of compositional variation of a selected sample, while gamma diversity stands for the overall diversity within a landscape. In this study, calculations related to alpha and beta diversity indexes were carried out with PC-ORD (MJM Software Design, 2019). Beta diversity, which is defined as the turnover of community composition in space and time, was employed and findings in species turnover along soil salinity gradient at two different extents were discussed.

3. Results

3.1. Soil salinity

The soils of the study area were classified as strongly saline (hypersaline) in general, as 13 plant communities, out of 23, were associated with this class. The lowest and the highest salinity values were measured to be 30 mS/m and 1700 mS/m in the foredune and salt marsh, respectively (Figure 3). The spatial distribution of soil salinity changes along the two basic gradients was related to the variation of soil microstructures and the distance from the lagoon. Salinity increases towards the lagoon and reaches peak value in the dried lagoon bed at the southern ends of the transects. As an exceptional case, salinity was found to be very low (average 70 mSm) in sandy habitats in embryonic dunes and the seafront when compared to salt marshes. Salinity was found constant with minor fluctuations via the replicated annual measurements along the gradient points. These outcomes of the annual soil salinity distribution can be recommended as baseline data for monitoring possible changes in soil salinity sampling along gradients for future studies.

3.2. Relationship between soil salinity and species composition of plant communities

The 60 plant taxa (Table 1) determined in the field embody 23 plant communities that were described according to their species compositions along with their life forms and representative species (Table 2). Those were defined under 6 distinct major communities (class) as *Sisymbrietea officinalis* Gutte & Hilbig 1975, *Euphorbio-Ammophiletea arundinaceae* J.M. et J. Géhu 1988, *Salicornietea fruticosae* Br.-Bl. & Tüxen ex A. & O. Bolos 1950 (syn: *Arthrocnemetea fruticosi* Tx. & Oberd. 1958), *Juncetea maritimi* Br.-Bl. ex Tüxen & Oberdorfer 1958, *Phragmiti australis-Caricetea elatae* Klika 1941, and *Nerio-Tamaricetea* Br.-Bl. et O. Bolós1957.

Therophytes were the dominant life form (48%) followed by chamaephytes (39%). Soil salinity was found

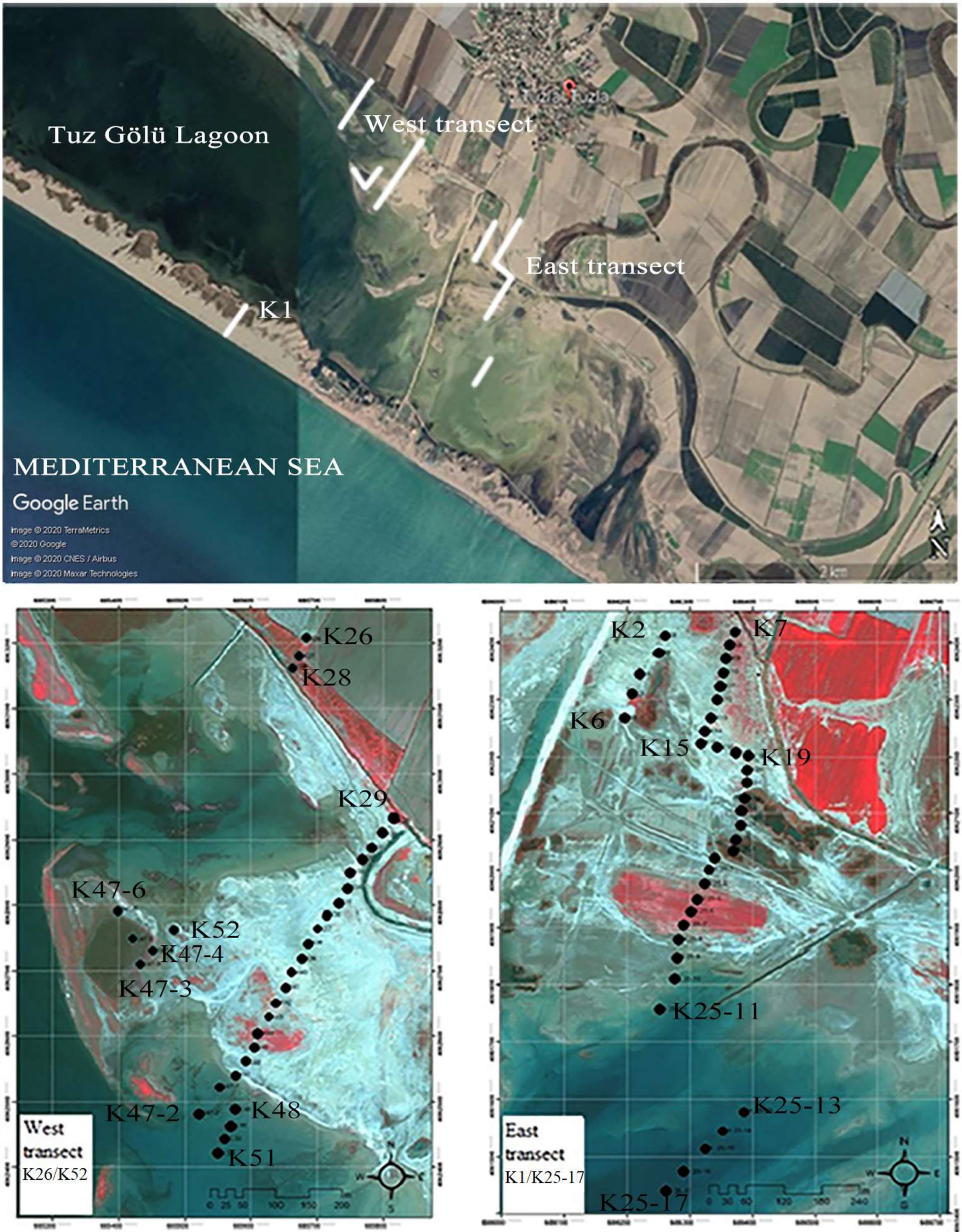

Figure 2. The position of 76 permanent measuring points located along the East and the West transects.

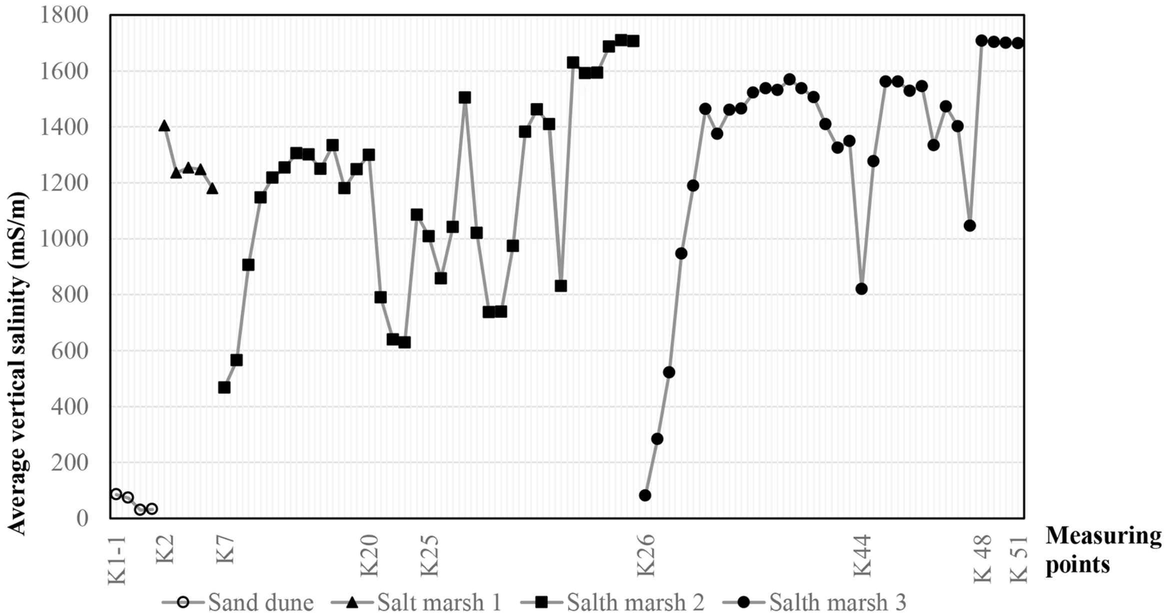

Figure 3. Spatial variation of average vertical salinity values along 76 measurement points.

to be the main driving factor controlling the spatial distribution of the plant taxa. The highest species richness value (25 species) was associated with moderate soil salinity (767 mS/m), comprising the dominant plant taxa of *Halocnemum strobilaceum*, *Arthrocnemum fruticosum*, *Spergularia marina* (L.) Griseb., *Plantago coronopus* L., and *Atriplex portulacoides* L., respectively.

The principal components analysis ordination diagram shows the position of the plant taxa along the soil salinity gradient. Black dots are indicated by average vertical salinity scores on the x-axis and associated plant taxa are shown by their abbreviation (Figure 4). *Plantago coronopus*, *Atriplex portulacoides*, *Spergularia marina*, *Arthrocnemum fruticosum*, and *Halocnemum strobilaceum*, the most salt-tolerant halophytes, are located in the rightmost part of the PCA diagram. Contrary to this tendency, a group of nonhalophytic herbs is located in the leftmost part, associated with relatively lower salinity (Figure 4).

Strong evidence was detected for the species richness, which declines at higher salinity habitats, and there is also some evidence that species turnover is greater among 52 sampling quadrates. Shannon (1948) and Simpson (1949) indexes shown in Figure 5 are covered by alpha diversity. As the beta diversity measure, Whittaker's Beta diversity was employed by using Sorensen/Bray Curtis Distance Measure and calculated as 16.3 for 52 sample units and 10.9 for 23 sample units. Standard deviations were 3.275 and 5.612, respectively.

Cluster analysis dendrogram splits characteristic species of the plant communities into 2 main clusters. The upper cluster includes euhalophytes associated with a strongly saline environment while the lower one comprises mainly neohalophytes and nonhalophytes (Figure 6).

The results of the Multiple Variable Analysis based on the Pearson correlation coefficients for each pair of variables are presented below. The P values shown in parentheses are smaller than 0.05, reflecting a linear correlation at the 5% significance level between the two variables. The second value in parentheses indicates the level of signification that those are statistically significant where the confidence level is $\alpha = 0.05$. A significant negative correlation (–0.4314; $\alpha = 0.0399$) was found between soil salinity and the number of plant species (species richness), as well as between the occurrence of the chamaephytic life forms and plant species richness (–0.4101; $\alpha = 0.0520$). A high significant positive correlation (0.8116; α = 0,0001) was determined between plant species richness and life form richness (Figure 7). As can be seen in Figure 7 (a), plant communities #3, 7, 10, and 11, which reflect euhalophytes associated with the salinity range between 1400–1500 (mS/m), are located in the uppermost part of the diagram. Species richness is very low in the abovementioned communities; the number of species varies between 1 and 4. The correlation coefficient for those variables is in line with this evaluation; a significant negative correlation between soil salinity and species richness was determined.

3.3. Habitat classification

Eleven habitats were identified by the CORINE classification based on vegetation community indicators. These eleven distinct habitat types were matched with the list of the endangered habitats stated in the annexes of the BERN Convention, where four of these were influenced by

Table 1. Recorded plant taxa, their abbreviations, life forms, and occurrence values along 52 sampling quadrates (Ph: Phanerophyte, Ch: Chamaephyte, H: Hemicryptophyte, Cr: Cryptophyte, Th: Therophyte).

Plant taxa	Abbrev.	Life form	Occurrence (%)	Plant taxa	Abbrev.	Life form	Occurrence (%)
Alhagi mannifera Desv.	Alha man	Ph	3.50	*Juncus subulatus* Forssk.	Junc sub	H	1.75
Allium curtum Boiss. & Gaill.	Alli cur	Cr	3.50	*Kickxia elatine*	Kick ela	Th	1.75
Anagallis arvensis	Anag arv	Th	7.01	*Limonium narbonense* Mill	Limo nar	H	7.01
Anagallis foemina	Anag foe	Th	7.01	*Limonium virgatum* (Willd.) Fourr.	Limo vir	H	7.01
Atriplex portulacoides	Atri por	Ch	14.03	*Lythrum hyssopifolia* L.	Lyth hys	Th	1.75
Arthrocnemum fruticosum	Arth fru	Ch	35.08	*Matricaria chamomilla*	Matr cha	Th	12.28
Aster squamatus (Spreng.) Hieron.	Aste squ	H	7.01	*Medicago litoralis* Rhode ex Loisel.	Medi lit	Th	3.50
Bolboschoenus maritimus (L.) Palla.	Bolb mar	Cr	1.75	*Melilotus indica*	Meli ind	Th	1.75
Cardopatium corymbosum (L.) Pers.	Card cor	H	3.50	*Minuartia mesogitana* (Boiss.) Hand.-Mazz.	Minu mes	Th	5.26
Centaurea calcitrapa L.	Cent cal	Th	1.75	*Ornithogalum umbellatum* L.	Orni umb	Cr	7.01
Centaurium spicatum (L.) Fritsch	Cent spi	Th	1.75	*Pallenis spinosa*	Pall spi	Th	1.75
Cerastium glomeratum	Cera glo	Th	3.50	*Pancratium maritimum* L.	Panc mar	Cr	1.75
Conyza canadensis	Cony can	Th	3.50	*Parapholis incurva* (L.) C.E.Hubb.	Para inc	Th	1.75
Cressa cretica	Cres cre	H	7.01	*Phyla nodiflora* (L.) Greene	Phyl nod	H	3.50
Cuscuta planiflora Ten.	Cusc plan	Th	3.50	*Plantago coronopus*	Plan cor	Th	15.78
Cynodon dactylon	Cyno dac	H	3.50	*Plantago crassifolia* Forssk.	Plan cras	H	3.50
Cyperus capitatus Vand.	Cype cap	Cr	1.75	*Polypogon maritimus* Willd.	Poly mar	Th	3.50
Echium angustifolium Mill.	Echi ang	Ch	1.75	*Prosopis farcta* (Banks & Sol.) J.F.Macbr.	Pros far	Ch	1.75
Eleusine indica (L.) J.Gaertn.	Eleu ind	Th	3.50	*Pulicaria dysenterica* (L.) Bernh.	Puli dys	H	1.75
Erodium laciniatum (Cav.) Willd.	Erod lac	Th	3.50	*Rumex conglomeratus* Murray	Rume cong	H	3.50
Eryngium falcatum F.Delaroche	Eryn fal	H	1.75	*Salicornia europaea* L.	Sali eur	Th	5.26
Gynandriris sisyrinchium (L.) Parl.	Gyna sis	Cr	3.50	*Salsola tragus* L.	Sals tra	Th	7.01
Halocnemum strobilaceum	Halo str	Ch	61.40	*Spergularia marina*	Sper mar	Th	31.57
Halopeplis amplexicaulis (Vahl) Ung.-Sternb. ex Ces. & al.	Halo amp	Th	10.52	*Sphenopus divaricatus* (Gouan) Rchb.	Sphe div	Th	10.52
Hedypnois rhagadioloides (L.) F.W.Schmidt	Hedy rha	Th	1.75	*Stellaria media* (L.) Vill.	Stel med	Th	1.75
Hordeum marinum Huds.	Hord mar	Th	7.01	*Tamarix tetragyna* Ehrenb.	Tama tet	Ph	5.26
Limbarda crithmoides (L.) Dumort.	Limb cri	Ch	1.75	*Trifolium campestre*	Trif cam	Th	3.50
Ipomoea imperati (Vahl) Griseb.	Ipom imp	Cr	1.75	*Trifolium lappaceum*	Trif lap	Th	10.52
Juncus acutus L.	Junc acu	H	5.26	*Urtica urens*	Urti ure	Th	3.50
Juncus buffonius L.	Junc buf	Th	10.52	*Xanthium strumarium* L.	Xant str	Th	3.50

Table 2. Species composition of 23 plant communities, dominant life forms, and corresponding average salinity values recorded at the measuring points (for abbreviations, see Table 1).

Measure points	Plant species	Major Plant community		Average vertical salinity (mS/m)	Dominant life form (%)	Life form richness (number)	Plant species richness (number)
K1-1, K1-2	Xant str, Anag foe, Aste squ, Rume cong, Urti ure, Cony can, Trif lap, Junc buf, Meli lit, Cyno dac, Eleu ind, Phyl nud, Cusc pla, Alh man	1	Sisymbrietea officinalis	70	64% Th	4	14
K1-3	Panc mar, Cype cap, Ipom imp, Echi ang	2	Euphorbio-Ammophiletea arundinaceae	30	75% Cr	2	4
K36, K47-3	Arth fru	3	Salicornetea fruticosae	1458	100 Ch	1	1
K 25-2, K 25-3, K29	Arth fru, Halo str	4		935	100% Ch	1	2
K2, K3, K24	Arth fru, Halo str, Atri por, Halo amp, Hord mar	5		1249	60% Ch	2	5
K7, K8, K9, K21, K25-4	Arth fru, Halo str, Plan cor, Matr cha, Sphe div, Sper mar, Atri por, Sals tra, Limo nar, Trif cam, Cent spi	6		692	64% Th	3	12
K47-5	Arth fru, Junc sub	7		1497	50% Ch	2	2
K44, K 47-6	Arth fru, Arti por, Sper mar, Halo str, Orni umb, Card cor, Puli dys, Trif cam, Erod lac, Limo nar, Limo vir, Cent cal, Minu mes, Anag arv, Cera glo, Eryn fal, Pall spi, Cres cre, Para inc, Alli cor, Meli ind, Plan cor, Gyna sis, Stel med, Hedy rha	8		926	52% Th	4	25
K28	Atri por	9		521	100% Ch	1	1
K12, K13, K14, K15, K25-3, K30, K32, K33, K35, K36, K37, K40, K41, K46, K47-4	Halo str, Cres cre, Halo amp, Arth fru	10		1447	50% Ch	3	4
K 25-9, K25-10, K25-11	Halo str, Halo amp, Sali eur	11		1410	70% Th	2	3
K 25-8	Halo str, Plan cor	12		1242	50% Ch	2	2
K 25-7	Hord mar, Plan cor, Junc buf, Cres cre, Trif lap	13		833	80% Th	2	5
K 25-5, K25-6	Plan cor, Anag foe, Anag arv, Sper mar, Junc buf, Matr cha, Pros far, Poly mar, Trif lap, Lytr hys, Kick ela	14		670	91 %Th	2	11
K4, K16	Sper mar, Arth fru, Hord mar	15		1223	70% Th	2	3
K10, K11,K42	Halo str, Sper mar, Halo amp	16		1191	70% Th	2	3
K43, K45	Sper mar, Halo str, Orni umb, Arth fru, Limo vir	17		1279	40% Ch	4	5
K17, K19	Sper mar, Minu mes	18		1186	100% Th	1	2
K27	Junc acu, Atri por, Limb chr	19	Juncetea maritimi	284	66% Ch	2	3
K22	Junc acu, Atri por, Tama tet, Aste squ, Plan cra, Arth fru, Limo nar	20		606	57% H	3	7
K5	Junc buf, Hord mar, Sphe div	21		1226	100% Th	1	3
K 25-1	Bolb mar	22	Phragmiti australis-Caricetea elatae	858	100% Cr	1	1
K25	Tama tet, Halo str, Arth fru	23	Nerio-Tamaricetea	1069	70% Ch	2	3

anthropogenic impacts (Table 3). These are: Chaste tree thickets (F9.312), Shifting coastal dunes (B1.3), Brackish coastal lagoons (X03), and *Ranunculus* communities in shallow water (C1.3411). Chaste tree thickets that occur along dune strips in the study site are the most endangered habitats, converted to agricultural fields by the local farmers. Destruction of indigenous vegetation due to intensive agricultural activities resulted in severe degradation on both dune scrubs and the lagoon. Mobilized dunes in the post degradation stage tend to move toward the lagoon

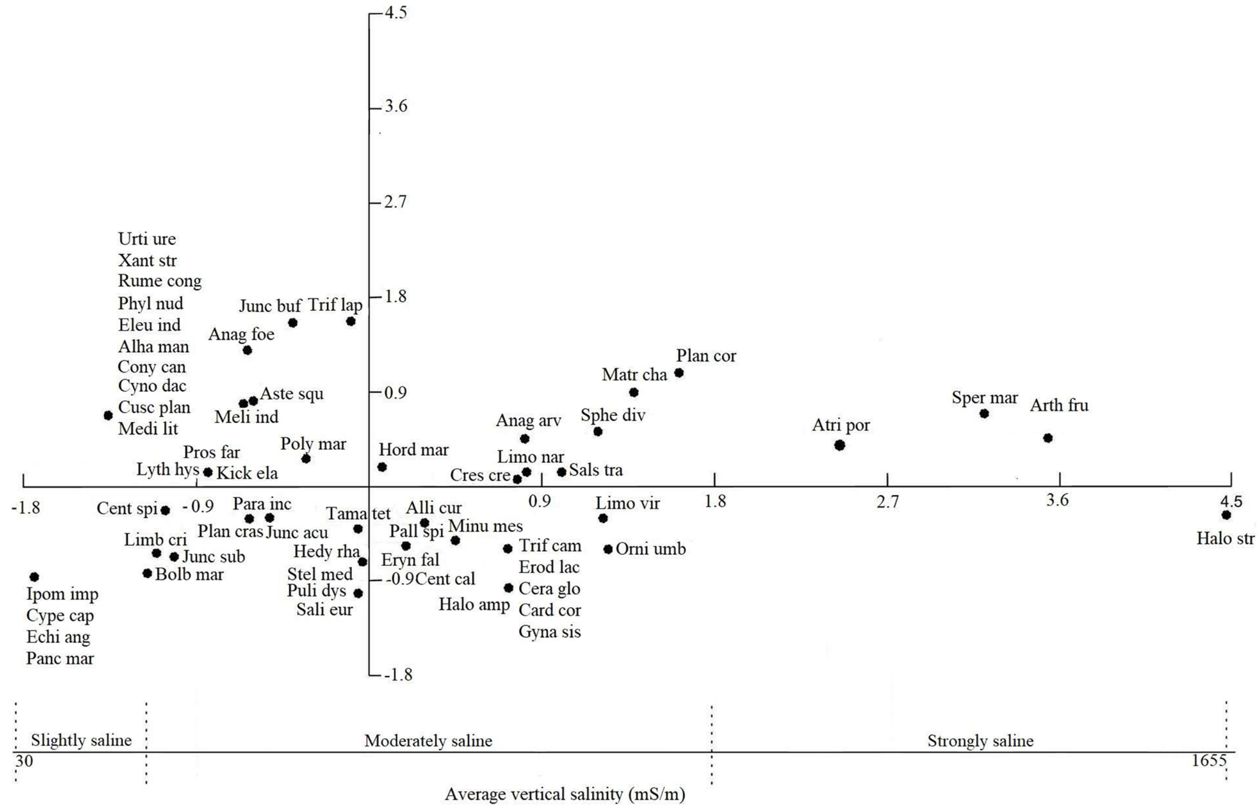

Figure 4. The principal components analysis ordination of the 60 plant taxa along the soil salinity gradient (for abbreviations, see Table 1).

by aeolian transport. Sand transport is accelerated by the contribution of shifting dunes since the barrier effect of former dune strips disappeared. This process is also hazardous to the shallow freshwater ponds that appear at the scattered depression locations.

4. Discussion

The spatial distribution of the individual species, determined in the salt marshes of the study site, was affected by the soil salinity of the habitats. Naz et al. (2010) reported similar findings for halophytic species in Cholistan. We found that the species composition of the plant communities depended on the level of salinity tolerance of the individual species and *Halocnemum strobilaceum* was determined to be the most tolerant species to soil salinity. The peak average annual salinity value, 1535 mS/m, was measured at point # K47-4, where a pure stand of *H. strobilaceum* was detected. In comparison with the values measured at points # K47-4 and # K47-3, it is obvious that the salinity value (1535 mS/m) recorded in the pure stand of *H. strobilaceum* is higher than that value (1457 mS/m) recorded in the pure stand of *A. fruticosum*. Both species are considered as euhalophytes according to the classification proposed by Bucur et al. (1957). In contrast, species with low tolerance to salinity were recorded among the widely distributed therophytic weeds. Bilalis et al. (2014) reported that the lowest weed density and biomass were associated with saline conditions. Buhler (2003) stated that limited information was available on the salt tolerance of weeds, and a clear explanation on the interaction of soil characteristics and the occurrence of specific weed species needs further studies. However, we found a clear bias when evaluating the occurrence of common weeds and their association with specific salinity values. *Cynodon dactylon* (L) Pers., *Xanthium spinosum* L., *Urtica urens* L., and *Conyza canadensis* (L.) Cronquist., which are the common weeds of the region, occur in the sampling plots where the lowest average salinity value (70 mS/m) was measured. A group of weeds associated with relatively higher average salinity range (609–926 mS/m: average 767 mS/m) include *Plantago coronopus*, *Matricaria chamomilla*, *Trifolium lappaceum* L., *T. campestre* Schreb., *Anagallis arvensis* L., *A. foemina* Miller, *Melilotus indica* (L.) All., *Cerastium glomeratum* Thuill, *Kickxia elatine* (L.) Dumort, *Pallenis spinosa* (L.) Cass., and *Stellaria media* (L.) Vill. Those taxa are contemplated to be neohalophytes as suggested by Bucur et al. (1957). The highest species richness value (25 species) is associated with the moderate

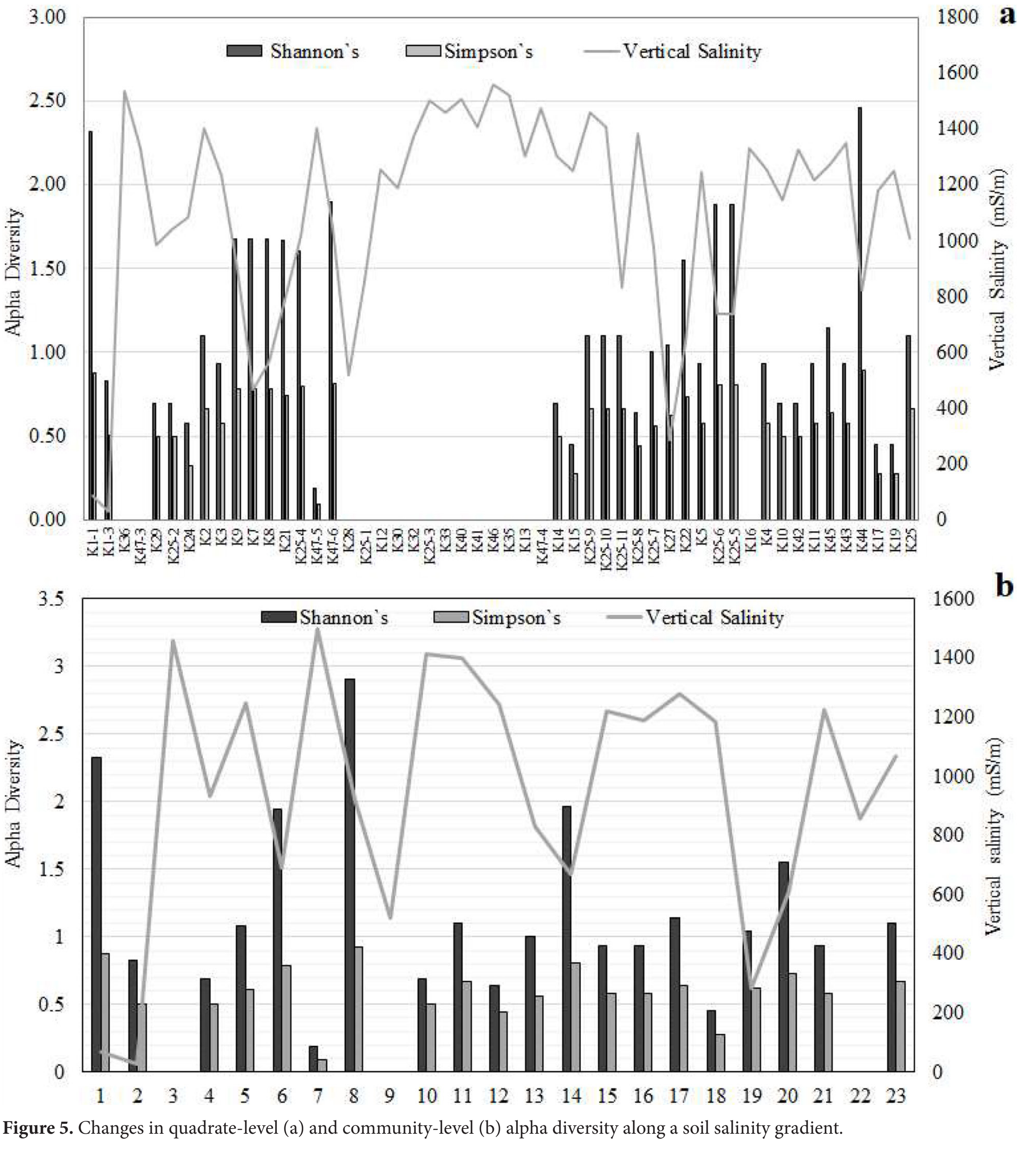

Figure 5. Changes in quadrate-level (a) and community-level (b) alpha diversity along a soil salinity gradient.

saline soils in the study site due to the contribution of the synanthropic flora, distributed mainly by agriculture and grazing. Correlation analysis showed a negative relationship between species richness and salinity, i.e., the decrease of species richness with increasing salinity under natural conditions. Lymbery et al. (2003) reported similar results on the significance of the relations of species composition to soil salinity and plant species richness, together with diversity decrease with increasing salinity levels. Pétillon et al. (2009) reported that frequent inundations hampered plant species turnover because of the low number of species that can tolerate those environmental conditions in the salt marsh ecosystem. These results are in line with the findings described in the present study. The results of the current study reveal that spatial species turnover is relatively higher at the locations

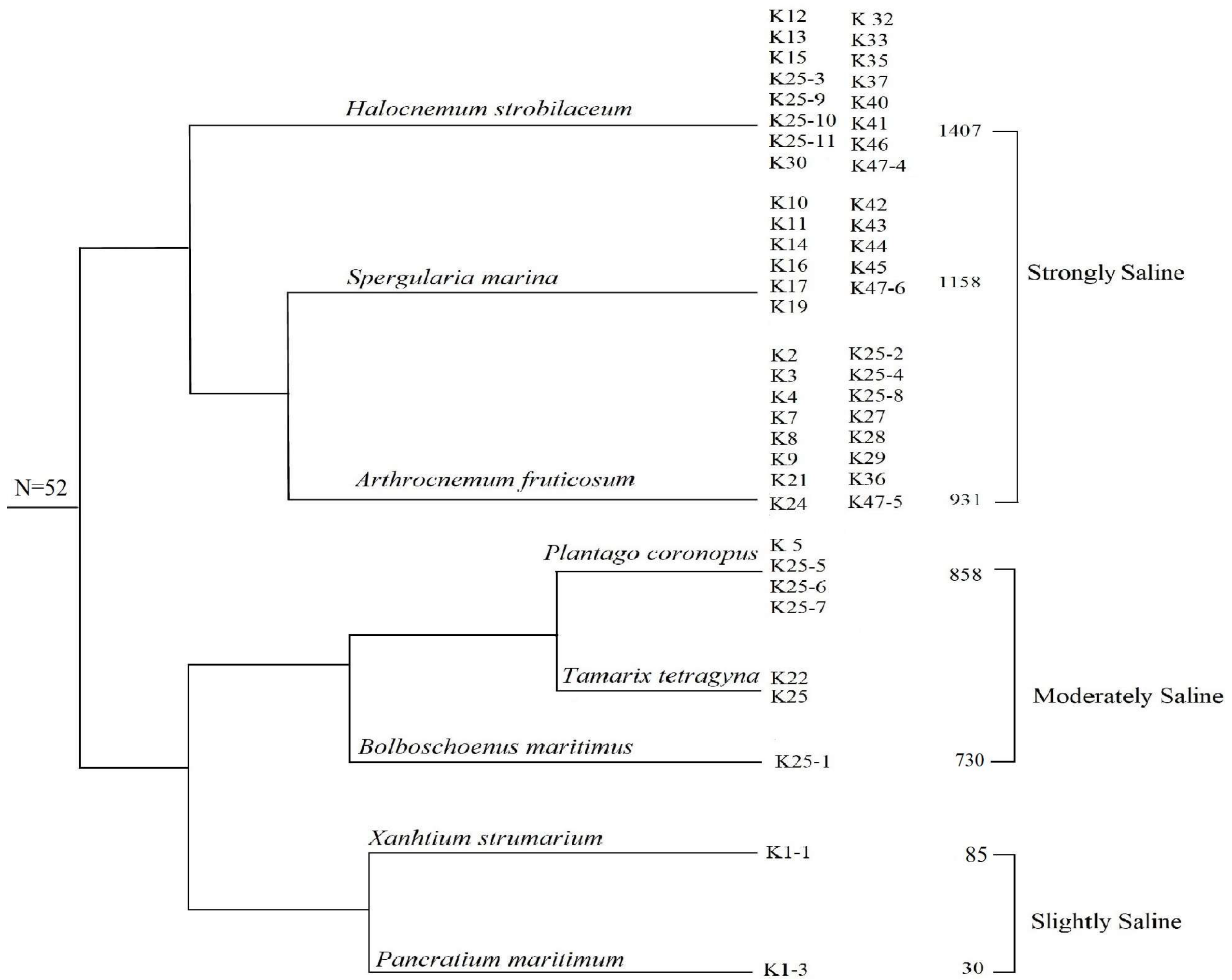

Figure 6. Cluster analysis dendrogram of characteristic species of the plant communities associated with the measuring points and the corresponding soil salinity classes.

with slight or moderate salinity while it is lower at strongly saline locations inundated by seawater.

The outcome of this study sets forth a guiding methodology for monitoring possible changes in coastal wetlands. In addition to the obtained soil salinity data, habitat characteristics, species composition of plant communities, and their spatial distribution can be used as baseline data for the management of the wetland ecosystems. According to Duarte et al. (2013), the distribution of halophytic plant species in the European estuaries and their phytoextraction ability makes them suitable biomonitors for the assessment of ecological quality, particularly for monitoring metal contamination. Typical salt-tolerant plants like *Arthrocnemum fruticosum* L., *Halimione portulacoides* L., *Triglochin maritima* L., *Scirpus maritimus* L., and *Juncus maritimus* Lam. were reported as tolerant to mercury contamination (Pereira et al., 2009). In this context, *Suaeda maritima*, a hygrohalophytic species, is stated to be a bioindicator for metal contamination. Bedell et al. (2014) stated that Plantago coronopus is a halophytic species suitable for the extraction of toxic material of dredged marine sediments thanks to its capacity to bioaccumulate metal pollutants (Cu and Zn) in its roots and aerial parts.

5. Conclusion

The hazard of salinization due to the possible saltwater intrusion into the groundwater system of the Çukurova Plain is a critical issue. Tezcan et al. (2007) stated that groundwater extraction in the coastal area causes seawater intrusion in late summer; however, during the rainy period, the groundwater is refreshed by the water recharged from the Taurus Mountains. The most significant impacts are the expected decrease in the recharge from the mountains and an increase in consumption because of the limitations of surface water resources. Extensive utilization

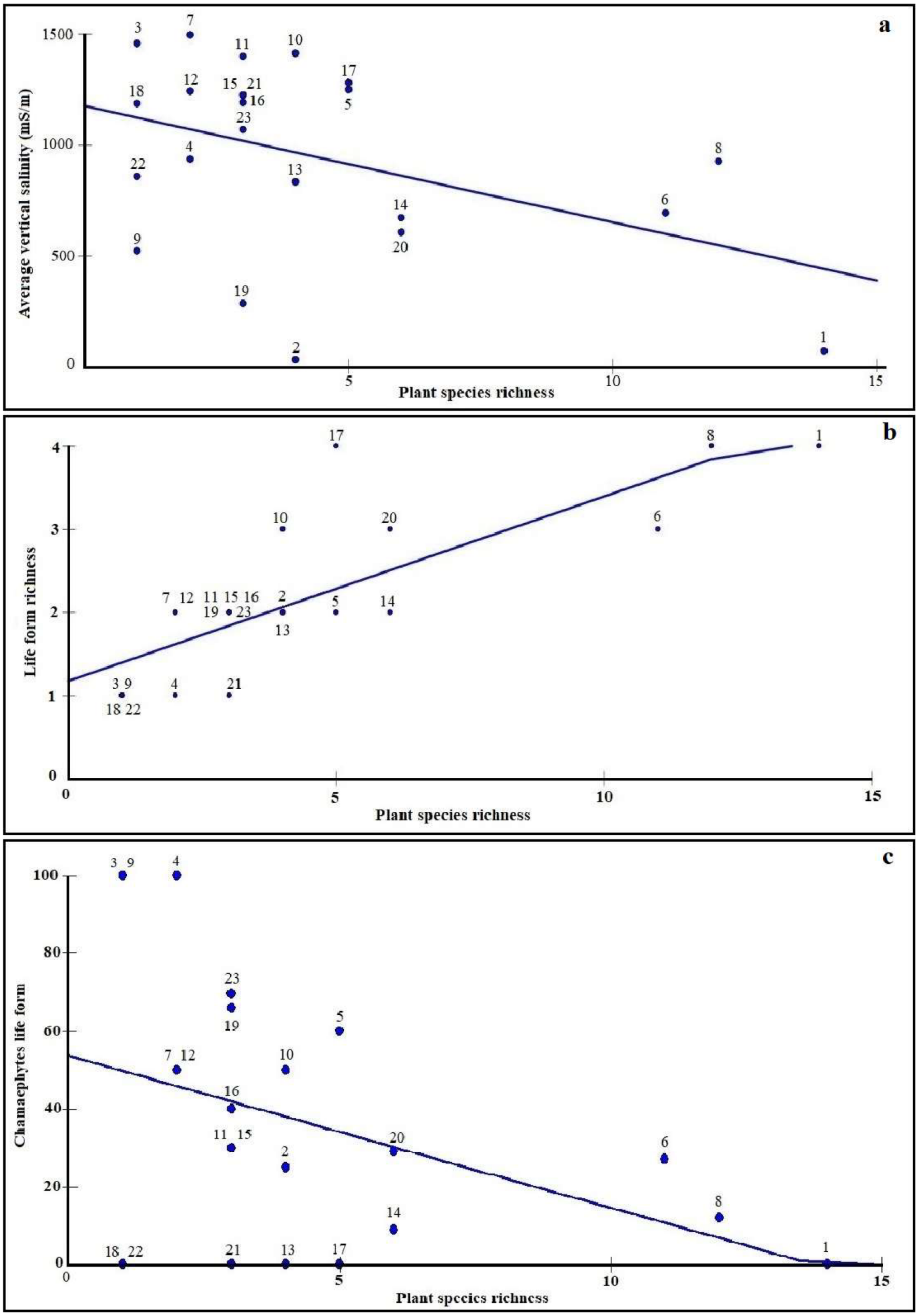

Figure 7. Relationships between the absolute numbers of plant species (species richness) and soil salinity (mS/m) (a), life form richness (absolute numbers of life forms) (b), and occurrence of a chamaephytic life form (c), taken over 23 plant communities.

of groundwater resources on the coastal landscape may cause severe problems for the hydrological system at the research site. The watermelon fields, which are irrigated by deep wells, are concentrated around the Tuz Gölü lagoon (Tezcan et al., 2007). It has been stated that if groundwater consumption increases at a rate of 50% in warmer climatic

Table 3. Habitat types of the study site and corresponding measuring points.

CORINE Habitat code and type	EUNIS Habitat code and type	Measuring point codes
1 Coastal and halophytic communities		
14 Mud flats and sand flats		K20, K25-12, K25-13, K25-14, K25-15, K25-16, K25-17, K26, K31, K34, K38, K39, K47, K47-1, K47-2, K48, K49, K50, K5, K1-4
15 Salt marshes, salt steppes and gypsum scrubs		
15.5 Mediterranean salt meadows *Juncetalia maritimi*		
15.51 Mediterranean tall rush saltmarshes *Juncion maritimi: Juncus acutus*		K27
15.58 Fine leaved rush beds *Arthrocnemetalia fruticosi. Juncus subulatus*		K47-5
15.61 Mediterranenan salt scrubs *Arthrocnemion fruticosi*		
15.612 Scrubby glasswort thickets *Arthrocnemum fruticosum*		K4, K5, K7, K8, K9, K10, K17, K20, K21, K28, K47-3, K47-6
15.617 Halocnemum scrub *Halocnemum strobilaceum, Arthrocnemum glaucum*		K2, K3, K6, K11, K12, K13, K14, K15, K16, K19, K24, K25-2 K25-3, K25-4, K25-8, K25-9, K25-10, K25-11, K29, K30, K31, K32, K33, K34, K35, K36, K38, K39, K40, K41, K46, K47, K47-4
15.617 Halocnemum scrub *Halocnemum strobilaceum, Arthrocnemum glaucum*		K25-5, K25-6, K25-7, K42, K43, K44, K45
16 Coastal sand-dunes and sand beaches		
16.29 Wooded dunes (44.812 Chaste tree tickets) *Vitex agnus-castus*	F9.312 Chaste tree thickets	
16.21 Shifting dunes *Ammophillion arenariae*	B1.3 Shifting coastal dunes	K1-3
16.21 Degredation stage, Nitrophillous communities: *Xanthium strumarium, Aster squamatus, Trifolium lappaceum*		K1-1, K1-2
2 Nonmarine Waters		
23.2 Vegetated brackish and salt waters		
23.21 Tasselweed communities		
23.211 *Ruppia maritima* communities *Ruppion maritimae*	X03 Brackish coastal lagoons	
4 Forests		
44 Alluvial and very wet forests and brush		
44.8134 Hyper-saline Tamarisk stands		K22, K25
44.81343 Saline Eastern Tamarisk Stands *Tamarix tetragyna*		
5 Bogs and marshes		

Table 3. (Continued).

53 Water-fringe vegetation		
53.1 Reed beds *Phragmition australis, Scirpion maritimi*		
53.11 Common reed beds *Phragmites australis*		
53.17 Saline *Scirpus* Beds: *Scirpion maritimi Bolboschoenus maritimus*	C1.3411*Ranunculus* communities in shallow water	K25-1
53.17 Degredation stage *Scirpion maritimi Bolboschoenus maritimus*		
8 Agricultural land and artificial landscapes		
83 Orchards, groves and tree plantations		
83.3 Plantations		
83.325 Other broad-leaved tree plantations *Acacia saligna*		

conditions, the extent of seawater intrusion may reach 10 km inland by the end of the year 2080 (Yılmaz et al., 2019). Certain herbaceous halophytes, such as *Spergularia marina*, *Plantago coronopus*, and *Cressa cretica* L., may be used as biomonitors for a rapid assessment of salinization in the arable lands. Consequently, establishing permanent sampling quadrats along a transect perpendicular to the coast can help observe the possible distribution of these species. Thus, we suggest that future wetland monitoring studies based on the methodologies of this paper within the habitat patches of the EU-BERN Convention should be conducted in order to protect the endangered habitats of European estuaries.

Acknowledgments

The authors greatly appreciate the financial support by a grant from the Hungarian–Turkish Intergovernmental S&T Cooperation Program (OMFB-00581/2009, TÜBİTAK-108Y329).

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