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Effects of selected groundwater chemical traits on a salt marsh community

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Abstract – Electrical conductivity, exchangeable sodium ratio and water depth have negative impacts, whereas soil organic matter concentration has a positive impact on Black Sea salt marsh vegetation. The most saline soils were characterized by *Salicornia prostrata* vegetation and associated with exchangeable sodium ratio. *Alhagi pseudalhagi* and *Tamarix smrynensis* populations were associated with water depth, while *Juncus littoralis*, *Ammophila arenaria* and *E. paralias* were associated with soil organic matter. *Euphorbia paralias*, *Ammophila arenaria* and *Iris orientalis* were associated with acidity.

Key words: Black Sea, groundwater, salt marsh, vegetation, Black Sea

Introduction

Salt marsh ecosystems are known to be a highly structured environment providing a gradient of environmental conditions from extremely inundated and saline to relatively mesic (ZHANG 1996, CANTERO et al. 1998a). Coastal salt marshes vegetated by herbs, grasses, and low shrubs bordering saline water bodies are unique ecosystems universally recognized for their exceptional ecological value (MITSCH and GOSSELINK 1993). They comprise areas of land bordering the sea largely covered with vegetation and subject to periodic tidal inundation (KENNISH 2001). A small number of halophytic species that are spatially segregated in pronounced vegetation zones dominate these ecosystems (BERTNESS et al. 1992, ASRI and GHORBANLI 1997, ABD EL-GHANI 2000a, APAYDIN et al. 2009). The use of halophytes as indicators of groundwater and soil chemical traits could be an effective and useful method for scientists to inform extension agents, and end users about the state of the environment (LI WEI-QUIANG et al. 2008, SHALTOUT and AL-SODANY 2008).

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It has been reported that vegetation zonation in salt marshes is primarily related to the salinity of the groundwater (CHAPMAN 1974, ABDEL-RAZIK and ISMAIL 1990, PENNINGS and CALLAWAY 1992, JONGMAN et al. 1995, CANTERO et al. 1998a, KUTBAY and DEMIR 2001) and groundwater chemical traits are often considered to determine the possibility of restoring or rehabilitating a salt marsh.

This study is aimed to determine the role of chemical traits of groundwater on plant communities in a salt marsh located in the north of Turkey using numerical methods. For this reason, selected groundwater and soil chemical traits were used and the roles of these traits on plant communities in the study area were evaluated.

Study area

The study area is situated on the east bank of the Kızılırmak River in the northern and northeastern parts of Bafra town (41°43'10.09'' N, 35° 59' 26.32'' E), North Turkey, in the Central Black Sea Region (Fig. 1). The area is characterised by a semi-humid Mediterranean climate with the highest potential evaporation rate (140 mm) occurring during June (ENGIN and KORKMAZ 1990, APAYDIN et al. 2009).

The study area is located at Kızılırmak River delta. The Kızılırmak River delta is an exception in that coastal erosion is an environmental threat that increases inundation, thus leading to land loss. Coastal retreat in the study area is between 2.5–5.0 m per year. The sediments supplied by the Kızılırmak River feed the coastal barriers in the study area under the influence of the longshore flows with an average speed of 40–50 cm s^{-1}. The soils of the study area are formed from alluvial materials. The sediments in the area consist of Upper Pleistocene and Holocene alluviums and vary from fine sand, silt and clay in varying thickness and extents. The thickness of Quaternary deposits increases northwards. The soils are

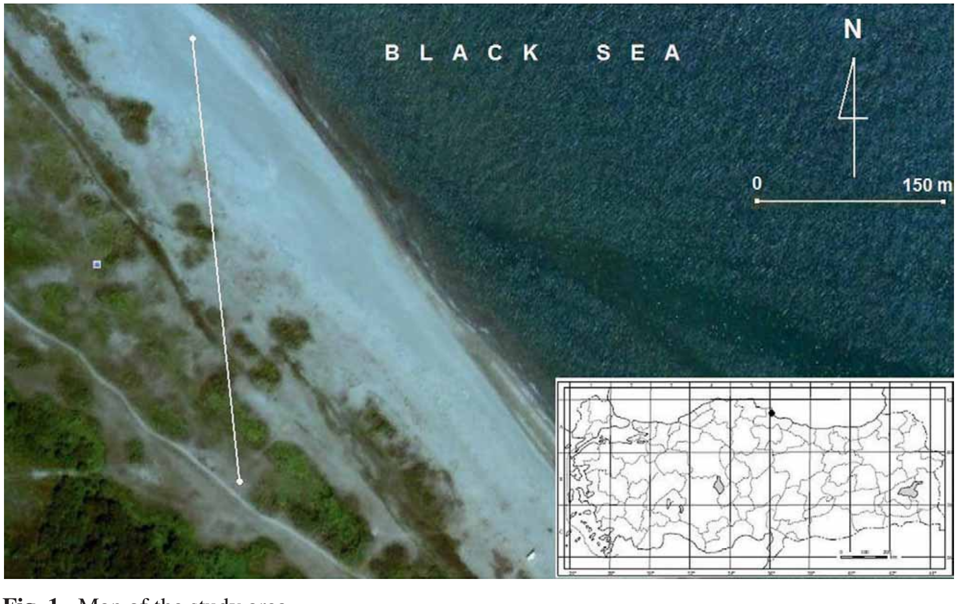

Fig. 1. Map of the study area

fine-textured with moderate hydraulic conductivity. Sublayers of these soils are massive in structure (ALPAR 2009, DEMIR et al. 2009). Soil pH and electrical conductivity are rather high and soils are alkaline (ARSLAN et al. 2007). Additionally, groundwater in the study area has high electrical conductivity (DEMIR et al. 2009).

Coastal dunes occur along the shoreline and they extend about 30–40 m from the shoreline and coastal dunes are characterised by *Ammophila arenaria* subsp. *arundinacea*, *Euphorbia paralias* and *Tamarix smrynensis* communities. Coastal sand dunes are replaced by salt pans and these salt pans are characterised by *Salicornia prostrata* communities. At the edge of these communities *Alhagi pseudalhagi* communities occur. About 200 m from the shoreline *Juncus littoralis* C. A. Meyer and *Juncus acutus* communities occur. About 270 m from the shoreline inland dunes are characterised by *Iris orientalis* Miller communities (Fig. 2).

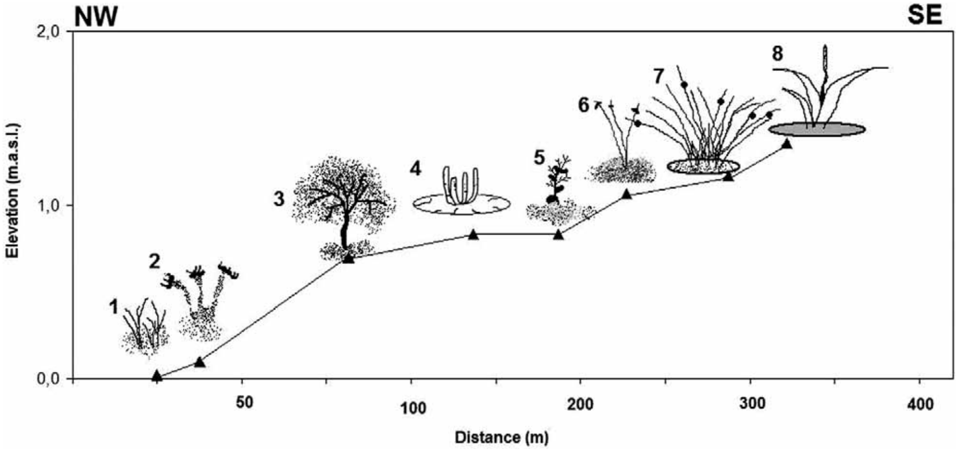

Fig. 2. The transect showing plant zonation in the study area. 1. *Ammophila arenaria,* 2. *Euphorbia paralias,* 3. *Tamarix smrynensis,* 4. *Salicornia prostrata* subsp. *prostrata,* 5. *Alhagi pseudalhagi,* 6. *Juncus littoralis,* 7. *Juncus acutus,* 8. *Iris orientalis*

We use taxonomic nomenclature according to DAVIS (1965–1985) and DAVIS et al. (1988) and BRUMMITT and POWELL (1992).

Materials and methods

The research transect was 350 m long from sand dunes in the north-east to the water level below the salt marsh in the south-west (Fig. 1). Ground water samples were taken along the transect populated by the *Ammophila arenaria* subsp. *arundinacea*, *Euphorbia paralias* and *Tamarix smrynensis* communities (Fig. 2).

The cover of species (in %) was estimated in 4 square meters (2 m × 2 m) for each community according to the Braun–Blanquet scale, as proposed by VAN DER MAAREL (1979), using standard relevé methods (MUELLER-DUMBOIS and ELLENBERG, 1974). Groundwater samples were collected during July 2000 with a sample bottle after soil cores were with the use of a 7 cm diameter soil auger to a depth of 80 cm because mean root depth was about 80 cm for the studied species and four water samples were taken per community. The groundwater level was determined at the sampling time by sinking a hole and allowing the interstitial water to refill it. Groundwater samples were taken by boreholes which, as specified by Soil Survey Staff guidelines, were sunk at each sampling point (FAULKNER et al. 1989, SÁNCHEZ et al. 1998, ÁLVAREZ-ROGEL et al. 2007, BORNMAN et al. 2008). All materials that might come in contact with the groundwater were rigorously cleaned with high purity reagents (HCl and HNO_3) and pure water (CREASEY and FLEGAL 1999).

Soil samples were taken from 4 m × 4 m (16 m^2) plots with a soil auger and soil samples were air-dried, crushed and sieved using a 2 mm mesh. The groundwater samples were analysed for:

1) electrical conductivity using a Jenway analyser,
2) Acidity using a Beckman pH meter (BLACK 1968),
3) K^+, Ca^{2+} and Mg^{2+} using a Perkin Elmer Atomic Absorption Spectrophotometer (HANLON 1998),
4) SO_4^{2-} and Cl^- (meq L^{-1}) concentrations were determined by turbidimetric and gravimetric methods, respectively (ALLEN et al. 1986, KILINC et al. 2006),
5) exchangeable sodium ratio and sodium adsorption ratio were calculated according to HUSSEIN and RABENHORST (2001).
6) HCO_3^- concentration was determined by titration with sulphuric acid (ÁLVAREZ-ROGEL et al. 2006).
7) organic matter was determined according to the Walkley--Black method (KILINC et al. 2006).

To examine the relationships between plant communities and groundwater variables, canonical correspondence analysis (CCA) was applied (JONGMAN et al. 1995) using ECOM version 1.33 (HENDERSON and SEABY 2001). The cover-abundance symbols of the Braun-Blanquet scale (r, +, 1, 2, 3, 4 and 5) were replaced by 1, 2, 3, 4, 5, 7, 8 values according to VAN DER MAAREL (1979) and FOCHT and PILLAR (2003).

Results

Chloride concentrations of groundwater and soil were rather high and sodium adsorption ratio and exchangeable sodium percentage values were also found to be high (Tab. 1).

Tab. 1. Mean ± standard deviation values of studied groundwater (GW) and soil traits.

Trait	pH	ESP	EC	SAR	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	OM
GW	7.44±0.25	–	7.71±5.41	35.44±10.30	1.90±1.63	25.13±17.86	61.41±21.22	24.31±10.35	167.94±34.08	2.02±1.52	–
Soil	7.46±0.33	23.69±8.10	8.32±3.40	–	1.40±0.40	15.38±3.95	56.32±10.25	22.91±1.69	46.36±4.35	1.70±0.53	2.22±0.70

EC – electrical conductivity; ESP – exchangeable sodium percentage; SAR– sodium absorption ratio; OM – organic matter.

Pearson correlations between species and environment scores in canonical axis 1 and 2 were highly significant and explained 76 % and 77 % of the cumulative variance, respectively (Tab. 2). A Monte Carlo permutation test (999 permutations) confirmed the significance of the first two axes ($p< 0.001$).

Tab. 2. Eigen values and species-groundwater chemical traits correlation coefficients.

	Canonical Axis 1	Canonical Axis 2
Canonical Eigenvalue	0.422	0.379
% Variance explained	5.877	5.284
Cumulative % variance	5.877	11.16
Pearson correlation species/environment scores	0.756	0.774

From the intra-set correlations of the soil factors with the first two axes of the CCA, electrical conductivity, exchangeable sodium ratio, water depth and organic matter concentration were the most significant parameters in axis 1 and all of these parameters were negatively correlated except for the soil organic matter concentration which was positively correlated. Along axis 2, only soil pH was negatively correlated and none of the other parameters were significant (Tab. 3).

According to the CCA analysis *S. prostrata* was associated with exchangeable sodium ratio, while *A. pseudalhagi* and *T. smrynensis* were associated with water depth. *J. littoralis*, *A. arenaria* and *E. paralias* were associated with soil organic matter. Along axis 2 *E. paralias*, *A. arenaria* and *I. orientalis* were associated with soil pH (Fig. 3).

The results from the detrended correspondence analysis (DCA) were similar to the results of the CCA analysis in that the species were arranged according to groundwater salinity along axis 1. Species grouped along a groundwater salinity gradient with *S. prostrata* grouping separately on the right of axis 1 followed by *J. acutus* and then rest of the species along the left of axis 1. DCA axis 2 represents the distance from the sea and sand-dune species like *E. paralias, A. arenaria* and *J. littoralis* grouped along the bottom of axis 2 (Fig. 4).

Tab. 3. Intraset correlation coefficients of soil and groundwater. Statistically significant correlations ($p<0.05$) are marked in bold.

	Can. Axis 1	Can. Axis 2
pH	0.345	**–0.523**
EC	**–0.817**	0.131
ESR	**–0.644**	–0.145
OM	**0.677**	–0.011
WD	**–0.579**	–0.394
SAR	–0.151	0.039
K^+	–0.069	0.210
Ca^{2+}	–0.005	0.424
Mg^{2+}	0.254	0.375
HCO_3^-	0.055	–0.282
Cl^-	0.308	0.236
SO_4^{2-}	0.001	0.245

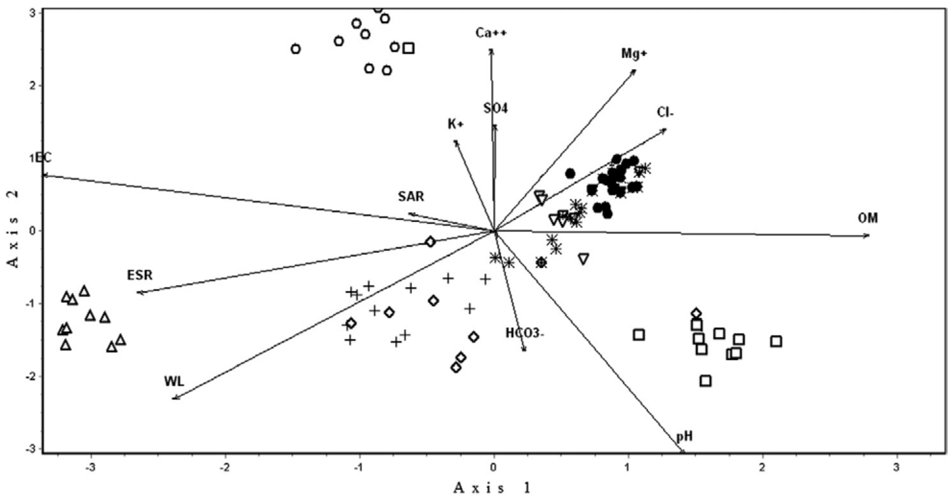

Fig. 3. The relationship among soil and groundwater traits and species by CCA. Δ *Salicornia prostrata,* ◊ *Tamarix smrynensis,* ○ *Juncus acutus,* □ *Iris orientalis,* + *Alhagi pseudoalhagi,* ▽ *Juncus littoralis,* ● *Euphorbia paralias,* ✳ *Ammophila arenaria*

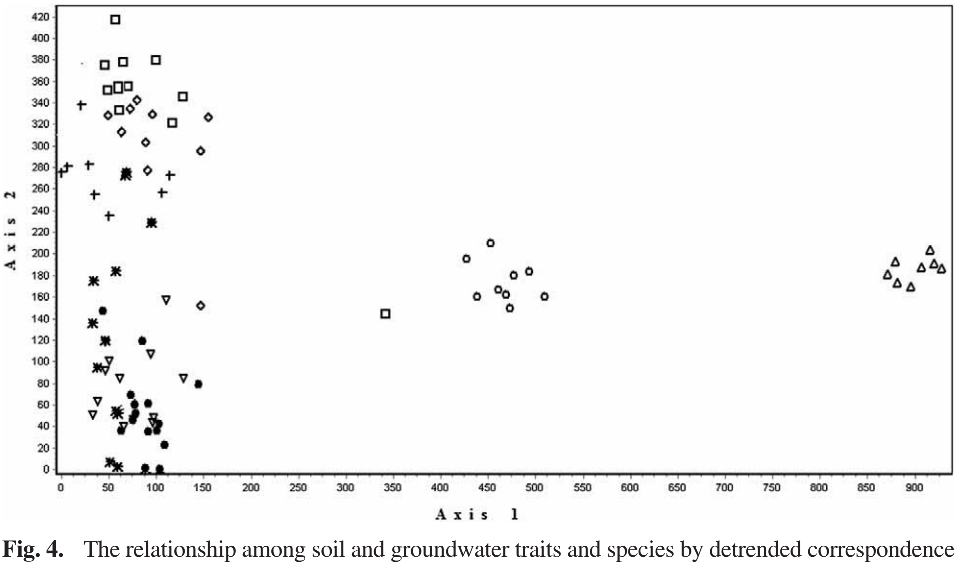

Fig. 4. The relationship among soil and groundwater traits and species by detrended correspondence analysis (DCA). Δ *Salicornia prostrata,* ◊ *Tamarix smrynensis,* ○ *Juncus acutus,* □ *Iris orientalis,* + *Alhagi pseudoalhagi,* ▽ *Juncus littoralis,* ● *Euphorbia paralias,* ✳ *Ammophila arenaria.*

Discussion

Correlations between species and environmental scores indicated a strong association between communities and measured soil parameters, as has been already reported (JONGMAN et al. 1995, ABD EL-GHANI and AMER 2003). Salinity (electrical conductivity and exchangeable sodium ratio), water depth and organic matter concentrations were found to be most significant environmental variables affecting salt marsh zonation. Groundwater salinity and depth (CANTERO et al. 1998b, MASHALY 2001, BORNMAN et al. 2002) and soil salinity (JI et al. 2009) have been identified as the most important factors in shaping vegetation patterns in other salt marsh ecosystems. Sodic soils are widespread in the study area because sodium adsorption ratio values >13 (AMEZKETA and DE LERSUNDI 2008)

Salicornia prostrata was associated with the most saline soils in the studied coastal salt marsh. This species forms monospecific stands along coastal salt marshes and inhabits salt-pan areas. These salt-pan areas are characterised by extreme conditions and *Salicornia* (Chenopodiaceae) species are regarded as fugitive species of these hypersaline bare patches and salt pans, because of their inability to compete with the dominant perennials (BERTNESS et al. 1992). It has been found that communities of halophytes were definitely better indicators of soil salinity than individual species and *Salicornia* occurred on extremely saline soils (PIERNIK 2003).

It is known that groundwater salinity is determined by tidal influences (SÁNCHEZ et al. 1998, HUSSEIN and RABENHORST 2001, APAYDIN et al. 2009, SALAMA and BOKHARI 2009). Flooding has been classified as a determinant factor of vegetation patterns in coastal estuaries (JI et al. 2009). *Salicornia prostrata* subsp. *prostrata* is widely subject to flooding and closely associated with exchangeable sodium ratio and may therefore be used reliably to evaluate the impact of flooding in salt marshes.

Alhagi pseudalhagi and *Tamarix smrynensis* was closely associated with water depth and both species have been identified as groundwater indicating plants (ABD EL-GHANI 2000b; EL-BANA and AL-MATHNANI 2009). Soil organic matter is an important factor that regulates the distribution of *Euphorbia paralias*, *Juncus littoralis* and *Ammophila arenaria* (ABD EL-GHANI and AMER 2003, OMER 2004, ZAHRAN and WILLIS 2008). Luxuriant growth of *J.littoralis* is associated with soil organic matter concentrations making individual clumpings, reaching a height of 100 cm (ABD EL-GHANI 2000a, EL-SHEIKH and ABBADI 2004). *Juncus littoralis* was also associated with pH.

According to the DCA diagram the two different gradients are interpreted as salinity and distance from the sea. *Salicornia prostrata* occurred in the right of the DCA diagram and indicated the most saline soils. BURCHILL and KENKEL (1991) stated that the most saline areas in salt marshes are generally dominated by succulent annual species like *Salicornia*. *Salicornia* species are subject to regions characterized by downward flow, more frequent tidal recharge, and thus hypersaline soil conditions. These conditions permit the long-term persistence of fugitive species like *Salicornia* by maintaining a physically harsh hypersaline environment that is intolerable to neighbouring communities (THIBODEAU et al. 1998).

Juncus acutus and *J. littoralis* occurred in the middle and left of the diagram. *Juncus* L. species are classified as slow-growing plants with extensive below-ground reserves, and hence tend to respond slowly to changes in soil factors (PENNINGS et al. 2005, APAYDIN et al. 2009). Salinity is decreased to the left of the diagram. Coastal dune species (*Ammophila arenaria*, *Euphorbia paralias*) inhabit the lowest part, while *Iris orientalis* inhabits the upper part of the DCA diagram along the axis 2. *I. orientalis* occurred on inland dunes. These species usually adapted to less saline conditions as compared to *Salicornia* species (IHM et al. 2007).

The importance of particular factors is likely to vary geographically in salt marshes. In particular, salinity stress probably plays a much more important role in mediating plant zonation patterns at lower latitudes (PENNINGS et al. 2005). ÁLVAREZ-ROGEL et al. (2007) stated that salinity is more effective on zonation of communities than the vegetation and distance to the shoreline in a dune coastal salt marsh ecosystem. In the present study both factors (salinity and distance from the sea) were effective on plant zonation. The similarity between CCA and DCA suggests that there might be no other environmental variables missed in sampling (ABD EL-GHANI and AMER 2003).

CISNEROS et al. (1999) found that vegetation modifies the speed of infiltration and the capillary flow of salt towards surface. It has been hypothesized that the heterogeneity of groundwater and soil traits and local topography are important determinants of plant species distribution and communities over a small geographic area (BORNMAN et al. 2004; EL-BANA and AL-MATHNANI 2009). The distribution of halophytic species has already been recognised to follow environmental gradients and the correlations between distribution and edaphic factors can be considered a first step towards understanding physical niches (ONAINDIA and AMEZEGA 1999, KHAZNADAR et al. 2009).

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