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Soil Determinants for Distribution of *Halocnemum strobilaceum* Bieb. (Chenopodiaceae) Around Lake Tuz, Turkey

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Abstract: In this study we aimed to reveal the ranges and effectiveness of soil parameters on the distribution of *H. strobilaceum*. *Halocnemum strobilaceum* Bieb. is a widespread species in saline habitats and the distribution pattern of this halophytic species around Lake Tuz in Central Anatolia was examined according to the soil characteristics. pH, electrical conductivity, soil humidity, salt percentage, soluble Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} values, total cations, cation exchange capacity, sodium adsorption ratio, exchangeable Na^{+}, K^{+}, Ca^{2+} and Mg^{2+} values were the examined soil properties. The most effective soil parameters for flowering period were found as Na, SO_4, total cations, SAR and EC and for seed bearing period as EC, Mg, total cations, Cl, Na, SO_4 and salt (%) content of the soil.

Key words: *Halocnemum strobilaceum*, Lake Tuz, soil parameters, Turkey

INTRODUCTION

In Turkey, 2-2.5 ha of the soils is saline or salt effected (Munsuz *et al*., 2001) but the ecological studies on saline soils and halophytes are limited. For the utilization of saline ecosystems, their soil, vegetation and floristic characteristics and also the relationships between them should be understood in detail. The changes in each components of a natural ecosystem, especially plants and soil, lead to changes in whole system gradually. For these reasons, the importance of separation and classification of plant communities in the ecosystems, their limitations as well as their relations with other components of ecosystem become more clear (Jafari *et al*., 2003).

Saline habitats exhibit moisture and soil salinity fluctuations throughout the year, this is one of the factors determining the distribution of plants. The most important factors determining the plant distribution in saline habitats are soil salinity, water availability and competition (Ungar, 1987; Pujol *et al*., 2000). There is a zonation among halophytic communities in coastal and inland salt marshes (Chapman, 1974). Around Lake Tuz, there is an obvious plant zonation according to the changes in soil salt content and type. *H. strobilaceum* occupies in almost pure stands in the coastal and inland salt steppes and marshes and occasionally occur with other species (Pujol, 2000; Damin, 1981). It is a monotypic perennial species, very frequent from South Europe through Asia to Mongolia and North Africa between 0-1000 m (Jalas and Suominen, 1980; Freitag, 1991).

Different studies have revealed that although competition influences the growth and distribution of the plants, soil characteristics are of high importance in distribution of halophytic plants (Jafari *et al*., 2003). Although it was known that the *H. strobilaceum* is a halophytic species it can spread at the areas with relatively low saline soils around Lake Tuz. With this study it was aimed to find out the soil parameters and their ranges that were effective on the distribution of *H. strobilaceum*.

Lake Tuz is the second largest lake in Turkey and is situated at 38°25'-39°10' N and 35°5'-33°48' E and at the altitude of c.910 m. It was declared as a Specially Protected Area in 2000 because of its high biodiversity and the endemism ratio. Lake Tuz is on the route of migrating birds and provides nesting and breeding area for them. Lake Tuz is a closed saline lake of hypersaline-alkaline with the depth of 1 m. It is fed almost entirely by ground water inflows and rain flows in winter and more than half of the lake area dried out in summer season. The salinity of the lake was measured as 83% at the eastern part of the lake in 1991 (Kashima, 2002).

MATERIALS AND METHODS

Brief description of the study area: The study area is under the influence of semi-arid very cold Mediterranean climate (Emberger, 1932). The annual total precipitation of the area changes between 326 and 387 mm. The ranges of mean, mean minimum and maximum temperatures are as

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follows respectively; 10.2-12.1, -6- -3.8, 29.8-30.7°C. The precipitation regime of the area is SpWFSu and belongs to the East Mediterranean precipitation regime type 2.

The localities where the *H. strobilaceum* specimens collected are as follows; Kulu N 38° 56.247' E 033° 18. 943' (1st zone), Cihanbeyli N 38° 45.112' E 033° 04.566' (1st and 2nd zone), Sereflikochisar N 38° 52.441' E 033° 25.547' (1st, 2nd and 3rd zone), Aksaray N 38° 39.069' E 033° 41.083 (1st and 2nd zone). The geological units of the surrounding area of the lake are mainly composed of paleozoic metamorphic schists, Mesozoic limestone and ophiolite, neogene sedimentary rock and tertiary and quaternary volcanic sediments from mountains Erciyes, Hasan and other volcanoes (Ketin, 1963). Hydrologically it is a closed basin, except for some karstic sinkholes.

Field studies and soil analysis: The soil samples and plant specimens were collected and the distribution of *H. strobilaceum* around Lake Tuz was defined between 2003 and 2004. During the winter period because of frost and snow cover soil samples were omitted. The flowering and seed bearing periods of *H. strobilaceum* were determined. The distribution pattern of plants around Lake Tuz is very homogeneous therefore the selected regions represent its ecology. During the selection of the localities, the authors tried to find the most isolated parts with less anthropogenic influences on the distribution of *H. strobilaceum*. For this reason, 8 localities were selected for soil sampling where *H. strobilaceum* was spread. Although Lake Tuz is a specially protected area, human impact on the ecosystem is very clear. This area is one of the most important salt works of Turkey, there is also agricultural and cattle breeding activities. According to the field surveys 3 zones were determined, the closest one was named as 1st zone and then 2nd and 3rd. Four of the localities were from the 1st zone, 3 of them from the 2nd and 1 of them from the 3rd zone.

The cover abundance scale of *H. strobilaceum* around Lake Tuz were determined according to Braun-Blanquet (1932).

Soil samples were taken from 0-20 cm depth, air dried and passed through 2 mm sieve before laboratory analysis. The analysis conducted to determine the soil characteristics were; saturation with water, electrical conductivity (EC), pH of saturated paste and saturation extract, soluble anions and cations (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, CO_3^{2-} and SO_4^{2-}), exchangeable anions and cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), cation exchange capacity (CEC) and humidity.

Saturation paste was prepared from 200 g 2 mm sieved soils. Soil moisture was determined by weighing of 4 g soil before and after overnight waiting in oven. The saturation paste extracted under partial vacuum at 2-4 atm pressure used for the determination of dissolved salts and soil pH. Electrical Conductivity (EC) and pH were determined by using Electrical Conductivity meter and pH meter, respectively (Richards, 1954). The soluble sodium and potassium by flame photometer soluble calcium and magnesium amounts were also determined. Carbonate and bicarbonate contents of the soil samples were determined by titration with H_2SO_4. For the determination of chloride soil samples were titrated with $AgNO_3$. The sulphate amounts of the soil samples were determined mathematically by subtraction of total anions from total cations. The exchangeable sodium, potassium, calcium, magnesium amount were determined according to Richards (1954). The boron content of the soil samples was determined spectrophotometrically (indicate the instrument). The cation exchange capacity was determined according to the sodium acetate method (Bower *et al*., 1952). All the soil analysis and measurements were triplicated and the average values were used in the statistical analysis.

Statistical analysis: The soil analysis results were evaluated with SPSS 13 and the Principal Component Analysis was used to determine the most effective factors at flowering and seed bearing periods.

RESULTS AND DISCUSSION

During the field surveys, 3 zones were observed around the Lake Tuz according to the salt concentration of the soil. Within these zones *H. strobilaceum* is the dominant plant species at the first zone which is the closest one to the lake. At the first zone *H. strobilaceum* is either the only species or present together with *Salicornia europaea* L. sl. At the second and third zones, the population density of *H. strobilaceum* decreased. According to the vegetation analysis the abundance-cover ratios of *H. strobilaceum* at these 8 locations can be show from Table 1.

The ranges of soil parameters examined at the areas where *H. strobilaceum* is distributed are presented in Table 2. The maximum, minimum and mean values of the soil parameters of 9 months from the localities where

Table 1: Abundance-cover values of *H. strobilaceum*

Abundance-cover scale	Locality
4	Kulu 1st zone
5	Cihanbeyli 1st zone
1	Cihanbeyli 2nd zone
5	Sereflikochisar 1st zone
2	Sereflikochisar 2nd zone
1	Sereflikochisar 3rd zone
4	Aksaray 1st zone
2	Aksaray 2nd zone

Table 2: Monthly ranges of soil parameters

		March	April	May	June	July	August	September	October	November
Salt (%)	Min	0.06	0.16	0.07	0.15	0.04	0.26	0.14	0.12	0.35
	Max	9.31	6.81	11.48	17.63	7.08	4.63	5.19	10.18	16.61
	Mean	3.83	3.40	4.00	5.02	2.60	2.67	2.89	3.26	5.62
Humidity (%)	Min	0.34	0.15	0.21	0.24	0.22	0.27	0.16	0.15	0.16
	Max	2.62	2.47	3.22	2.90	4.56	5.69	4.98	5.72	5.69
	Mean	1.28	1.05	1.28	1.33	1.49	2.23	1.71	1.68	1.97
pH_{mud}	Min	7.74	7.93	8.08	7.85	7.91	7.97	7.74	7.73	7.85
	Max	9.04	8.84	8.83	8.77	8.54	8.41	8.47	8.59	8.62
	Mean	8.17	8.28	8.21	8.27	8.21	8.23	8.10	8.05	8.28
pH_{exc}	Min	7.35	7.68	7.51	7.58	7.65	7.15	6.72	7.08	7.58
	Max	8.95	8.73	8.76	8.67	8.73	8.43	8.46	8.47	8.46
	Mean	7.97	8.01	7.90	8.09	8.20	7.91	7.57	7.78	8.09
Saturation (%)	Min	32.66	28.70	27.76	30.31	27.79	28.27	38.22	27.70	27.71
	Max	99.09	117.75	101.80	98.99	96.06	116.16	118.36	90.29	132.51
	Mean	61.30	65.05	61.49	65.74	52.74	74.60	65.68	51.98	64.78
EC (dS m^{-1})	Min	2.94	8.81	4.21	7.68	2.40	8.81	5.87	4.31	19.58
	Max	162.51	146.85	176.22	195.80	124.80	97.90	90.08	176.22	195.80
	Mean	89.07	72.34	81.66	105.10	60.73	61.49	65.84	83.67	116.87
Soluble (me L^{-1})										
Na^+	Min	24.50	87.00	33.00	68.00	14.00	37.00	15.00	28.00	178.00
	Max	1440.00	1320.00	1650.00	3307.50	1050.00	1010.00	860.00	1450.00	1850.00
	Mean	798.69	664.00	718.63	1011.63	507.75	390.88	468.50	697.91	1079.75
K^+	Min	3.50	5.00	6.00	0.38	3.00	6.00	0.37	3.25	7.00
	Max	34.00	31.00	30.00	122.00	18.00	24.00	134.00	72.00	48.00
	Mean	16.31	14.75	13.75	16.36	9.75	10.63	26.30	22.53	26.75
Ca^{2+}	Min	1.53	1.94	2.04	6.83	0.92	4.08	5.61	3.67	3.06
	Max	79.56	35.7	66.22	43.86	44.17	61.20	66.30	93.84	81.60
	Mean	31.43	17.56	30.32	26.18	22.71	24.91	32.31	33.23	35.13
Mg^{2+}	Min	1.80	3.95	2.16	5.52	6.23	4.47	4.46	9.22	10.98
	Max	206.20	192.30	196.06	196.70	276.74	306.30	216.36	348.64	228.90
	Mean	90.83	65.71	106.32	68.50	113.28	124.83	103.26	131.24	115.45
Cl^-	Min	25.00	0.90	35.00	75.00	10.00	47.50	20.00	37.35	175.00
	Max	1000.00	1050.00	1000.00	3350.00	1250.00	562.50	1000.00	1750.00	2000.00
	Mean	481.25	356.36	511.25	990.63	565.63	317.50	540.63	859.04	959.38
SO_4^{2-}	Min	3.93	36.05	6.12	1.10	0.75	0.33	5.89	2.88	20.43
	Max	1209.97	720.09	958.25	548.30	253.62	714.08	352.16	75.84	925.15
	Mean	452.05	400.64	351.51	136.29	84.50	216.99	86.20	22.91	293.87
HCO_3^-	Min	0.42	0.36	1.04	1.46	0.88	0.73	1.51	0.52	0.78
	Max	7.28	7.28	13.52	14.56	5.15	7.64	6.14	6.24	6.55
	Mean	3.61	4.73	5.62	4.90	2.98	3.99	3.54	2.79	3.55
CEC (me/100 g)	Min	7.50	6.58	7.52	8.77	7.54	7.52	7.54	6.27	5.95
	Max	36.26	32.05	35.44	29.81	42.84	29.45	26.90	37.18	35.05
	Mean	19.92	17.65	17.77	17.35	20.07	18.73	16.37	19.89	19.22
SAR	Min	18.99	15.89	22.77	23.22	6.49	17.90	6.68	10.86	5.95
	Max	135.43	140.02	150.16	348.16	86.12	192.42	144.33	112.46	35.05
	Mean	99.25	89.14	79.94	141.63	54.81	54.30	59.98	69.51	19.22
Total cations	Min	31.33	98.89	43.20	80.73	26.27	51.55	58.70	44.55	202.10
	Max	1715.00	1572.00	1893.50	3488.60	1382.19	1077.10	1068.50	1791.50	2128.00
	Mean	937.25	762.02	868.51	1122.67	653.86	551.24	630.36	884.91	1257.08
Exchangeable (%)										
Na^+	Min	1.78	2.01	3.28	3.33	16.80	3.75	18.63	16.60	10.34
	Max	57.89	34.30	14.43	24.33	30.34	33.37	38.56	43.40	43.74
	Mean	22.68	12.41	8.63	11.04	25.49	19.42	26.66	26.78	24.68
K^+	Min	0.70	0.18	1.12	5.74	1.01	1.90	0.63	2.26	1.38
	Max	22.30	28.36	19.97	25.61	20.32	38.10	22.08	22.32	23.76
	Mean	8.28	11.98	8.71	16.85	9.71	13.77	11.30	10.87	16.47
Ca^{2+}	Min	23.33	19.10	16.61	35.88	18.38	24.16	23.59	29.14	22.40
	Max	59.74	59.09	77.63	53.36	57.78	50.72	54.86	45.71	90.99
	Mean	36.29	38.76	43.34	43.11	39.45	37.10	36.51	36.65	43.58
Mg^{2+}	Min	8.03	17.55	6.17	18.28	12.91	9.32	8.42	12.18	11.99
	Max	41.77	39.22	43.09	44.68	34.65	48.92	33.76	30.09	36.79
	Mean	27.39	29.83	33.50	27.62	22.80	26.32	21.43	21.84	27.33
B (ppm)	Min	7.45	7.28	10.20	4.18	1.69	7.52	0.17	7.40	11.33
	Max	60.33	44.73	63.27	53.94	60.85	29.45	20.27	41.95	54.34
	Mean	26.52	29.52	28.75	27.00	25.35	18.73	10.69	19.26	25.68

H. strobilaceum spread were used to define the ranges of these parameters. According to Table 2 it can be understood that *H. strobilaceum* has a wide range of ecological tolerance for the mentioned soil variables.

According to the field studies the flowering and seed bearing periods range from August to October. The soil parameters of these months were used in statistical analysis for the determination of the most effective factors on development and distribution of *H. strobilaceum*. The values of flowering and seed bearing periods were evaluated with SPSS 13 by using Principal Component Analysis. For the flowering period as a result of PCA, it was found that 96.85% of the variance was explained by 5 factors which were meaningful according to eigenvalues (Table 3). The first factor explained 22.078% of the total variance. The first and second factors defined 42.815% of total variance and first, second and third factors explained 61.815% of the total variance. The soil determinants effective on the first factor were found as soluble Na^+ and SO_4^{2-}, total cations, SAR and EC. The ones that were effective on the second factor were exchangeable Ca^{2+} and K^+, exchangeable Mg^{2+} and Na^+, soluble Ca^{2+} and saturation with water. For the third factor effective on the soil variables were CEC and B (Table 4).

According to the PCA results for seed bearing period, the first factor explained 45.165% of the cumulative variance. The statistically meaningful 4 factors according to their eigenvalues explained 95.658% of cumulative variance (Table 5). First and second factors explained 60.254% of total variance. The soil variables related with first factor were EC, total cations, salt percentage and soluble Mg^{2+}, Cl^-, Na^+, Ca^{2+} and SO_4^{2-}. Cation Exchange Capacity (CEC), exchangeable K^+, humidity, saturation with water and pH_{mud} were related with the second factor. In the view of these results, it can be stated that the first factor that was effective on distribution of *H. strobilaceum* are EC, Mg^{2+}, total cations, Cl^-, Na^+, Ca^{2+}, SO_4^{2-} and salt percentage. The second factor is related with CEC, K_{exc}, humidity, saturation with water and Mg_{exc} (Table 6).

H. strobilaceum is a halophytic plant which can grow under highly saline conditions and is a weak competitor as the other halophytes. Competition is one of the limiting factors determining the distribution of halophytes at the soils where salinity is low (Bertness, 1991b; Pennings *et al*., 2004; Ungar, 1998). The presence of *H. strobilaceum* depends on soil parameters and competition. The population density of H. *strobilaceum* decreases with decreasing salinity and increasing competition. Our findings and observations support the results of Danin's (1981) on the *H. strobilaceum* individuals occupying around the small cavities where the salt accumulation exists and prevents the germination and development of other species.

Table 3: Variance (%) of each axis. Flowering (Extraction method: Principal Component Analysis)

	Rotation sums of squared loadings		
Components	Total	Variance (%)	Cumulative (%)
1	4.857	22.078	22.078
2	4.529	20.588	42.815
3	4.213	19.149	61.815
4	2.978	13.536	75.351
5	2.781	12.642	87.993

Extraction method: Principal Component Analysis

Table 4: Loading values of variations explaining each of the components for flowering period

	Components					
Variables	1	2	3	4	5	6
Na^+	**0.926**	0.016	0.086	0.190	-0.013	0.295
SO_4^{2-}	**0.903**	-0.091	-0.187	-0.015	0.340	-0.152
Total cations	**0.869**	0.222	0.210	0.320	0.098	0.198
SAR	**0.841**	-0.319	-0.189	-0.080	-0.148	0.291
EC	**0.608**	-0.007	0.373	0.100	0.421	0.548
Ca^{2+} exc	-0.107	**0.902**	-0.205	-0.305	-0.122	0.127
K^+ exc	-0.208	**-0.793**	0.236	-0.351	0.360	-0.114
Ca^{2+}	0.150	**0.792**	0.352	0.182	0.110	0.421
Mg^{2+} exc	0.573	**-0.701**	-0.030	0.254	-0.321	-0.108
Na^+ exc	-0.426	**0.671**	0.046	0.535	0.106	0.246
Saturation with H_2O	-0.133	**0.668**	0.201	0.116	0.334	-0.283
Mg^{2+}	0.341	0.519	0.418	0.496	0.295	-0.202
CEC	-0.040	-0.006	**0.983**	0.077	0.002	0.088
B	-0.040	-0.006	**0.983**	0.077	0.002	0.088
Humidity	0.156	0.427	0.728	0.414	0.122	-0.141
pH-ext	-0.263	-0.179	-0.027	**-0.820**	-0.264	-0.203
CO_3^{2-}	-0.004	-0.217	0.600	**0.753**	-0.008	-0.116
HCO_3^-	-0.335	0.164	-0.437	-0.571	-0.324	-0.478
pH-mud	0.015	0.080	-0.077	-0.172	**-0.978**	-0.037
K^+	0.273	0.318	-0.542	0.122	0.718	-0.009
Salt	0.430	0.339	0.445	0.396	0.568	0.094
Cl^-	0.407	0.364	-0.011	0.110	-0.051	**0.829**

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a Rotation converged in 11 iterations

Table 5: Variance (%) of each axis. Seed bearing (Extraction method: Principal Component Analysis)

	Rotation sums of squared loadings		
Components	Total	Variance (%)	Cumulative (%)
1	9.936	45.165	45.165
2	3.319	15.088	60.254
3	3.047	13.851	74.105
4	2.544	11.562	85.667

Extraction method: Principal Component Analysis

It was found that there were no significant differences between the recovery rate of germination and germination rate in distilled water for *H. strobilaceum* (Pujol *et al*., 2000) which support the results of our soil analysis used to define the ranges of soil parameters. According to our results, the appropriate soil conditions for the growth of *H. strobilaceum* differ extensively,

Table 6: Loading values of variations explaining each of the components for seed bearing period

Variables	Components 1	2	3	4	5
EC	**0.978**	0.059	0.034	0.024	-0.194
Mg^{2+}	**0.977**	-0.060	0.000	-0.144	-0.052
Total Cations	**0.973**	0.015	0.013	0.014	-0.227
Cl^-	**0.969**	0.013	0.014	0.025	-0.242
Na^+	**0.955**	0.018	0.007	0.064	-0.280
Ca^{2+}	**0.901**	0.363	-0.162	0.165	-0.009
SO_4^{2-}	**0.896**	0.063	-0.102	-0.281	0.232
Salt (%)	**0.874**	0.297	-0.006	0.305	-0.149
SAR	0.793	-0.035	0.043	0.026	-0.576
pH-exct.	-0.741	-0.086	0.297	-0.155	0.533
K^+	0.631	-0.184	0.435	-0.573	0.049
CEC	0.002	**0.905**	-0.223	0.257	-0.139
K^+ exc	0.127	**-0.890**	-0.231	0.280	-0.122
Humidity	0.419	**0.732**	-0.217	0.459	-0.109
Saturation with H_2O	0.564	**0.590**	-0.008	0.416	-0.377
pH-mud	-0.552	**-0.589**	0.265	0.054	0.418
Mg^{2+} exc	-0.065	0.177	**-0.968**	0.037	-0.064
HCO_3^-	-0.014	-0.003	**0.930**	-0.252	0.115
Na^+ exc	-0.397	0.337	0.641	-0.561	0.033
Ca^{2+} exc	-0.066	0.120	-0.231	**0.903**	0.061
CO_3^{2-}	-0.538	-0.170	0.149	0.208	**0.778**
B	-0.052	-0.120	0.469	-0.443	**0.534**

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a Rotation converged in 6 iterations

which is in agreement with the germination results of Pujol *et al.* (2000). Although the soil parameters are effective on the distribution of *H. strobilaceum*, it can spread into the less salty steppes around Lake Tuz if there was not a harsh competition.

The common factors effective on flowering and seed bearing periods were found as EC, Na^+, SO_4^{-} and amount of total cations. These factors reflect soil salinity and its forming components, respectively, are very effective on plant growth and adaptation, under saline conditions.

Even though there are many studies on the zonation patterns in saline habitats (Snow and Vince, 1984; Bertness and Ellison, 1987; Bertness 1991a, b; Pennings and Callaway, 1992), the forces that mediate these zonation patterns are still paradigm. As a result of these experimental studies, it was found that there is an inverse relationship between competition ability and stress tolerance, the more competitive plants occupy the least saline habitats and the more salt tolerant species occupy the most saline areas (Bertness, 1992; Pennings and Callaway, 1992; Pennings *et al.*, 2004). Plant composition and the distribution of species along the salt gradient in saline habitats depend on multivariate factors like edaphic, biotic and also the individual resistance of the plants (Pennings and Callaway, 1992; Snow and Vince, 1984; Alvarez Rogel *et al.*, 2001). The distribution of *H. strobilaceum* depends on soil salinity and competition; if the situation is not very competitive it can spread on the soils where the salinity is relatively low. The population density of *H. strobilaceum* decreases with decreasing soil salinity for the determination of the factors causes this decrease there should be some studies conducted on the interspecific competition. To find out the importance of edaphic factors in plant zonation and pattern, transplant experiments should be carried out.

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