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Medium-term vegetation dynamics and their association with edaphic conditions in two Hungarian saline grassland communities

Tibor Tóth

Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest, Hungary

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Correspondence
Tibor Tóth, T.P. 290, Joint Research Centre, 210 20 Ispra (VA), Italy.
Email: tibor.toth@jrc.ec.europa.eu

Present address: Tibor Tóth, European Commission, DG Joint Research Center, Institute for Environment and Sustainability, Rural, Water and Ecosystem Resources Unit, Ispra, Italy.

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Abstract

Medium-term (5.5 years) changes in the cover of major species in "*Artemisia saline puszta*" (*Ass*) and "*Pannonic Puccinellia limosa hollow*" (*PPlh*) grassland communities in the Kiskunság region, Hungary, were monitored and analyzed in relation to abiotic factors (e.g. air temperature, precipitation, soil moisture, salinity and alkalinity). Soil salinity varied considerably, indicating leaching and desalinization of surface layers as the most typical process occurring in the region. Yearly average covers of *Artemisia santonicum* and *Plantago maritima* were negatively and positively related to surface soil salinity, respectively, in accordance with their salt tolerance. Multiple regression analysis showed soil pH and salinity to be the most important factors determining yearly average cover of plants at *Ass*. Increasing pH increased the cover of *A. santonicum* and *P. maritima*, but decreased the cover of *Podospermum canum*. Increasing salinity decreased the cover of *A. santonicum* and *P. canum*. At *PPlh*, pH of groundwater had a positive effect and the lakewater level had a negative effect on the cover of *Puccinellia limosa*. The results provide information on the ongoing changes in the soil properties and the resulting changes in plant composition in these Hungarian salt-affected grasslands.

Introduction

Grasslands are important and threatened habitats in Europe. The extension of croplands and afforestation are common forms of new land use, and these changes have a fatal effect on grassland biota. Hungary has large areas covered by grasslands (12% of total area), and among those some of the most typical and endemic ones occur between the Rivers Danube and Tisza, in the Kiskunság region (Molnár *et al.* 2008), partly protected in the Kiskunság National Park. These salt-affected grasslands, which provide habitats for a large number of rare and protected animals, are vulnerable to cycles of salinization and desalinization resulting from changes in the water regime of the soil and subsoil (Fitzpatrick *et al.* 2003). It is known that salinity and water regimes of the salt-affected grasslands vary not only seasonally (annual cycle) but also in the medium- and long-term; for example, grasslands in the Kiskunság region have undergone long-term changes for more than 80 years through the drainage of the wide marshlands along the River Danube (Iványosi Szabó 1993). The motivation for studying such grasslands was given by Pennings and Callaway (1992): "Salt marshes are attractive to community ecologists because they are relatively simple systems that contain strong gradients in physical stress (notably waterlogging of soils and soil salinity)". However, little has been studied about the changes in botanical composition of the grassland vegetation in relation to varying soil and water conditions, although such information is useful for the management of grasslands (e.g., prevention of complete desalinization of salt-affected habitats Bagi and Molnár 2003).

In this study, I monitored medium-term (5.5 years) changes in the coverage of major plant species, soil and water properties and meteorological conditions in two plant communities typical to the salt-affected grasslands in the Kiskunság region. The objective of the study was to explore how the grassland vegetation is associated with abiotic factors (e.g., soil salinity, soil alkalinity, sodicity, moisture content, air temperature and precipitation) in the medium term.

Materials and methods

I conducted 67 monthly measurements between June 1997 and December 2002 for two plant communities; an ''*Artemisia saline puszta*'' (*Ass*) community at Apaj (47°05′14.0″N, 19°05′54.7″E; 92 m above sea level [asl]) in a large salt-affected grassland and a ''*Pannonic Puccinellia limosa hollow*'' (*PPlh*) community beside Zabszék saline lake (46°50′34.8″N, 19°10′17.1″E; 89 m asl). In each site, I established four replicate permanent 1 m^2 quadrats inside an 11 × 11 m plot with homogeneous typical vegetation, and nondestructively estimated botanical composition based on the green plant cover. The frequently occurring species (nomenclature according to Simon (1992)) in the *Ass* community were *Festuca pseudovina* Hack. ex Wiesb., *Artemisia santonicum* L. (ssp.), *Bromus hordaceus* L. ssp *hordaceus*, *Plantago maritima* L., *Podospermum canum* C. A. Mey., *Puccinellia limosa* (Schur.) Homberg. and *Lepidium crassifolium* W. et K., with the first five as the major species in terms of coverage. The major species of *PPlh* were *P. limosa* and *Aster tripolium* ssp. *pannonicus* (Jacq.) Soó. I recorded actual green cover for *F. pseudovina* and *P. limosa*, and the area covered between the extremes of the shoots for other species, such as *A. santonicum*. Plant species not usually found and with very low cover were not included in the evaluation.

Soil samples were taken from places randomly selected on each monthly measurement occasion, at intervals of 10 cm depth to the shallow groundwater (i.e., water table) level. Groundwater was also sampled. At *PPlh*, the level of the lakewater was measured and the lakewater was sampled. The soil samples were dried and passed through a 1 mm screen, and the water samples were filtered and put into refrigeration before analysis. Gravimetric soil moisture content was measured after oven-drying at 105°C. Basic soil parameters were determined in a 1.0 : 2.5 soil : distilled water suspension after an overnight rest. Soil electrical conductivity (EC, mS cm^{-1}) and pH were determined using a conductometer and a combination glass electrode, respectively. Sodium ion activity was determined with an Na-selective electrode and a reference electrode, to produce pNa (negative logarithm of the sodium ion activity [mol L^{-1}]). For water samples, EC and pH were determined.

The meteorological data were collected at the nearby Kecskemét station of the Hungarian Meteorological Service, from which monthly mean air temperature and total precipitation were calculated. Since the distance between the two study sites is less than 30 km, the same meteorological data from the station were used for the sites.

Correlation analysis (Pearson correlation) and multiple regression analysis (stepwise variable selection) were performed to evaluate the relationships of the cover of the major plant species with abiotic factors (average air temperature, total precipitation, groundwater depth, lakewater level, groundwater and lakewater EC and pH, soil moisture content, EC [as an index of salinity], pNa [as an index of sodicity], pH [as an index of alkalinity] in each soil layer down to groundwater level). A correlation coefficient and an explanatory variable were interpreted significant at $P < 0.05$.

Results and discussion

Abiotic conditions

Compared with the long-term (1901–1950) averages of mean annual air temperature (10.3°C) and annual precipitation (506–517 mm based on data from three stations around Kecskemét, 70 km away), 1999 was a warm, humid year, 2000 was a warm, dry year, and 2002 was a warm year (Table 1, Figure 1b).

The average lakewater level at *PPlh* (Figure 1a) was 0.26 m lower than the altitude of the surface of the site. During the driest period, when the salinity of lakewater approached the concentration of seawater (data not shown), the level of lakewater was 0.55 m lower. On the other hand, the maximum level was 0.27 m above the surface of the site, when the data collection was suspended for 16 months in 1999–2000 due to waterlogging (Figure 1a) caused by extreme high precipitation (Table 1, Figure 1b).

The two study sites represented the most typical salt-affected habitats of the Kiskunság region, Hungary. The groundwater was shallower at the lakeside *PPlh* (0.95 m depth on average) than at the *Ass* site (1.62 m; Figure 1a), which agreed with the characteristic groundwater depths in Solonchak (<1 m) and Solonetz (1.5–3 m) soils, respectively. Consequently, the soil moisture was higher at *PPlh* than at *Ass* (Figure 1d).

Table 1 Yearly mean air temperature and total precipitation

Year	Air temperature (°C)	Precipitation (mm)
1997	10.45	481
1998	10.98	596
1999	11.21	830
2000	11.71	332
2001	10.70	594
2002	11.79	464

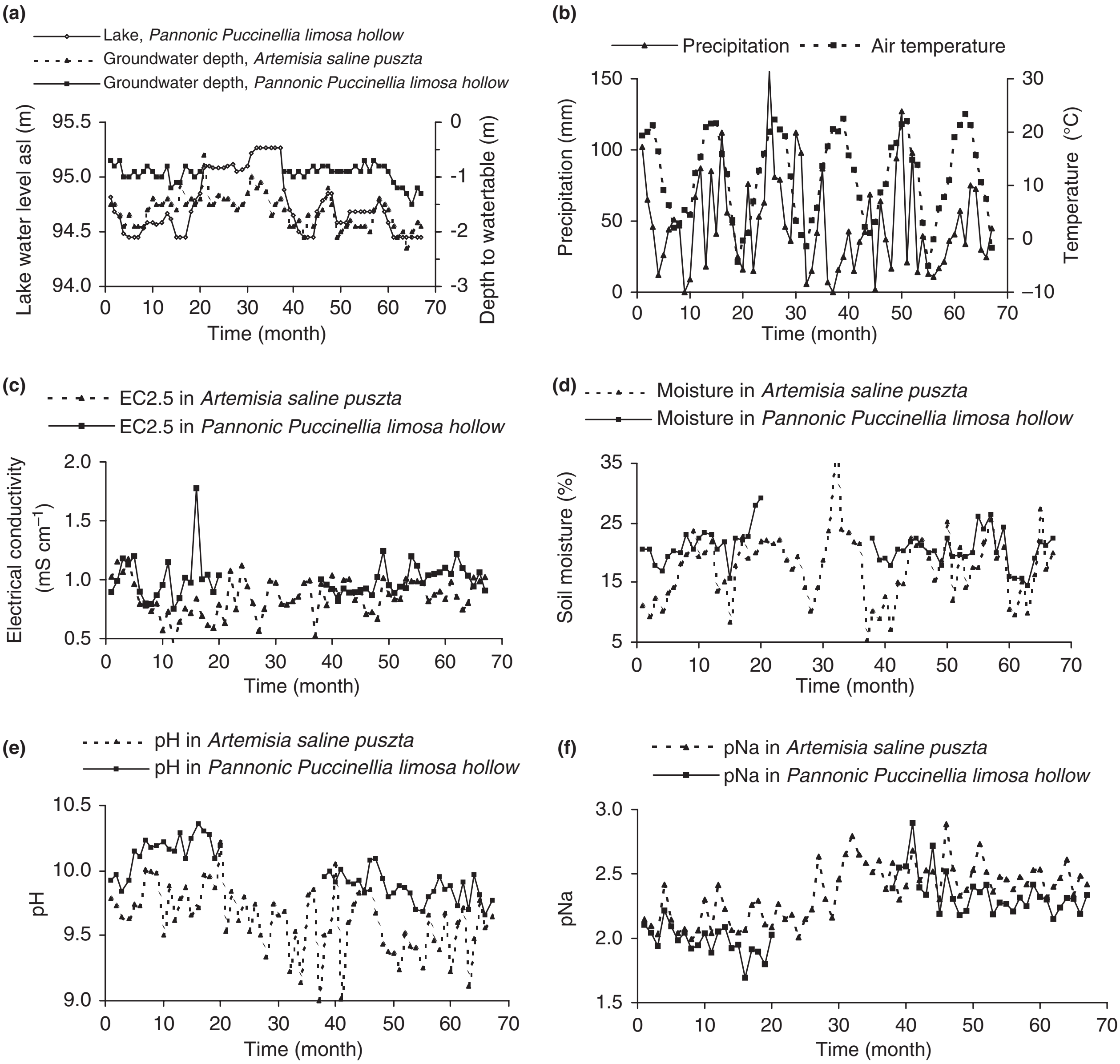

Figure 1 Variations in monthly abiotic properties at *Artemisia saline puszta* (*Ass*) and *Pannonic Puccinellia limosa hollow* (*PPlh*): (a) lakewater level and groundwater depth; (b) precipitation and air temperature; (c) electrical conductivity (EC 2.5) in the 0–40 cm soil layer; (d) moisture in the 0–40 cm soil layer; (e) pH in the 0–40 cm soil layer; (f) pNa in the 0–40 cm soil layer. Months 1 (June)–7 (December), 8–19, 20–31, 32–43, 44–55 and 56–67 correspond to the years 1997, 1998, 1999, 2000, 2001 and 2002, respectively.

The soil salinity (EC) in the 0–40 cm layer tended to be higher at *PPlh* than at *Ass* (Figure 1c). A marked difference between the two sites was found in the vertical distribution of soil salinity (data not shown), that is, the salinity increased with soil depth (from 0–10 cm to 30–40 cm layers) at *Ass*, whereas the reverse took place at *PPlh*. The salinity in the top layer was three times higher at *PPlh* (5.3 mS cm^{-1}) than at *Ass* (1.8 mS cm^{-1}). Furthermore, at *Ass*, there was an increasing tendency in the salinity in the 20–30 cm and 30–40 cm layers across the study period (data not shown). Because the salinity difference between the top and bottom layers shows the degree of leaching in the profile, the results indicate the progress of soil transformation from Solonchak (highest salinity at the soil surface) into Solonetz (higher salinity in deeper layers) at the *Ass* site. This is further evidenced by the significantly

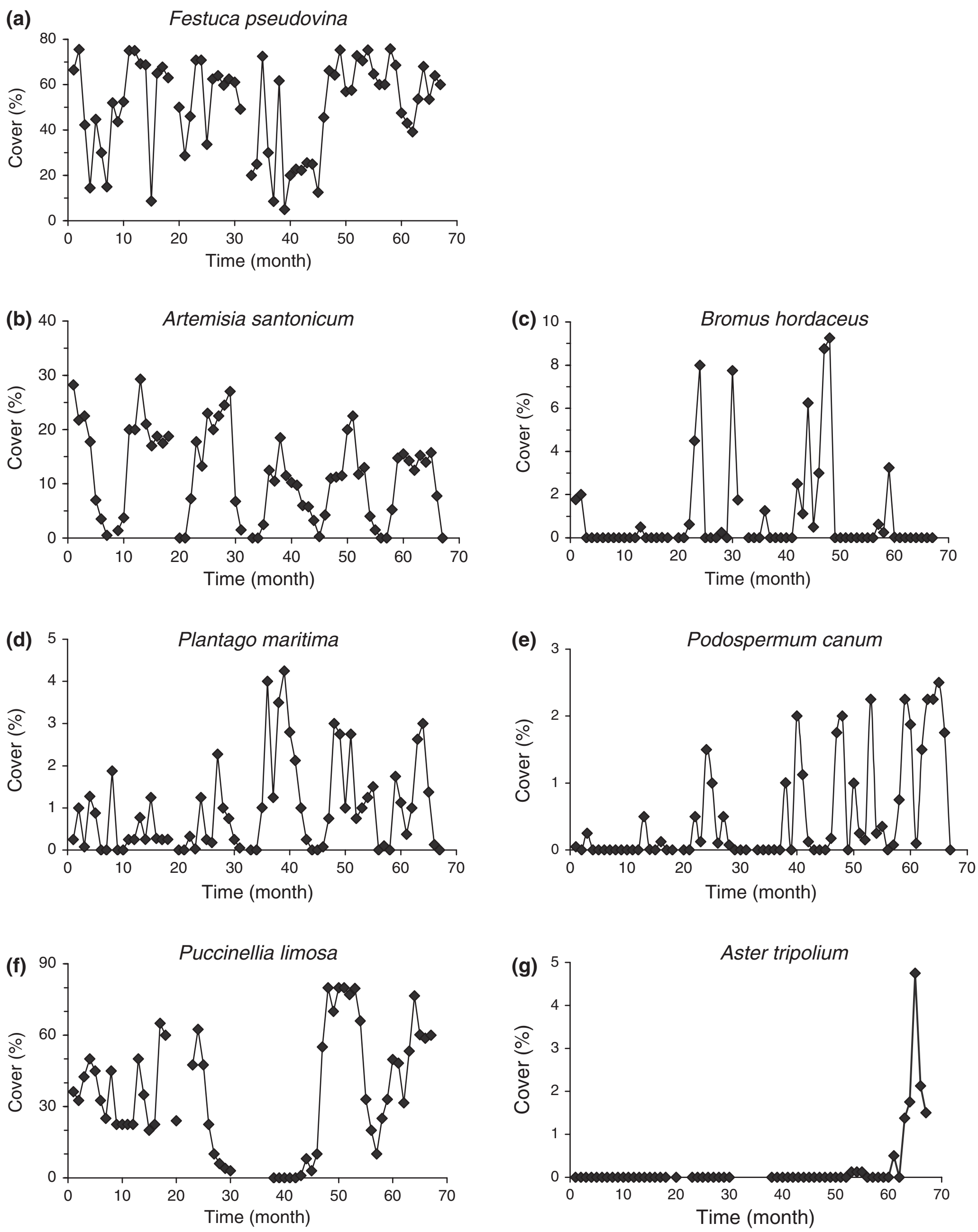

Figure 2 Variations in monthly green cover percentage of (a) *F. pseudovina*, (b) *A. santonicum*, (c) *B. hordaceus*, (d) *P. maritima* and (e) *P. canum* at *Artemisia saline puszta*, and (f) *P. limosa* and (g) *A. tripolium* at *Pannonic Puccinellia limosa hollow*.

increasing trend in pNa value in the 0–40 cm layer during the study (Figure 1f). The drop in groundwater level resulted in deeper leaching by the precipitation and caused desalinization of earlier Solonchak soils, as it was documented by Harmati (2000) during 34 years of observations in a nearby area.

The average soil pH in the 0–40 cm layer was higher at the lakeside *PPlh* site (10.0) than at *Ass* (9.6; Figure 1e). The decreasing tendency for pH (Figure 1e) and increasing tendency for pNa (Figure 1f) in the 0–40 cm soil at *PPlh* across the study period may be related to the waterlogging of the site. The rising lakewater level provided leaching water with low salinity, sodicity and alkalinity, and consequently the soil pH and Na concentration decreased.

For water quality (data not shown), lakewater pH showed a positive linear relationship with EC (data not shown), since the dilution of the lakewater by precipitation resulted in the lower dominance of carbonates (Dvihally 1960; Tóth *et al.* 2003). The salinity of groundwater was only slightly higher at *Ass* (4 mS cm^{-1}) than at *PPlh* (3.2 mS cm^{-1}) probably due to the lesser diluting effect of atmospheric water. During the study period, extreme low salinity values were observed in one winter and were related to shallow groundwater and the diluting effect of atmospheric precipitation. Opposite to the soil, the pH of groundwater was higher at *Ass* (8.7) than at *PPlh* (8.2), since it fluctuated in the more saline layers at the *Ass* site (Solonetz) and the less saline layers at the *PPlh* site (Solonchak).

Plant cover

Across the study period, there was a decreasing tendency in the cover of *A. santonicum* (Figure 2b), whereas the reverse trend was observed for *P. maritima* (Figure 2d) and *P. canum* (Figure 2e). The cover of *A. santonicum* (Figure 2b) and *P. maritima* (Figure 2d) showed a clear annual periodicity, whereas the other species lacked a clear annual cycle. The total vegetation cover was higher at *Ass* than at *PPlh*, as shown by the cover of the major component species. The higher species number and total vegetation cover at *Ass* is taken to reflect that lower salinity and alkalinity of the surface layer of Solonetz soil at this site allowed growth of relatively low salt-tolerant plants as well as salt-tolerant plants.

Bagi (1988, 1989) reported occurrence and spread of *Gypsophila muralis* L. and *B. hordaceus* with the development of Solonetz from Solonchak soil at the *Ass* site. However, there was no occurrence of *G. muralis* and no increase in *B. hordaceus* (Figure 2c) during the study. In a sodic grassland in Tiszántúl region, Précsényi (1975) found variation in the biomass ratio of *A. santonicum* and *F. pseudovina* among three samplings in a year. However, the cover ratio calculated for the same species did not show significant variation among the five consecutive years in the present study. The reason for such inconsistency needs further research.

Table 2 Correlation coefficients of yearly average cover of *Artemisia santonicum* and *Plantago maritima* with soil properties over 5 years

Soil property	*Artemisia santonicum*	*Plantago maritima*
Salinity 0–10 cm	−0.917	0.882
pH 0–10 cm	0.927	–
pH 10–20 cm	0.995	−0.894
pNa 0–10 cm	−0.954	–
pNa 10–20 cm	−0.986	0.933

All correlations are significant at $P < 0.05$ ($n = 5$).

Association between plant cover and abiotic conditions

The cover of *A. santonicum* and *P. maritima*, two of the five major species at the *Ass* site, was significantly associated with soil salinity, pH and pNa, showing opposite relationships to the abiotic factors (Table 2). The negative and positive correlations of *A. santonicum* and *P. maritima* with salinity are taken to reflect their low and high salt tolerance, respectively. Although none of the major species at the *PPlh* site, *P. limosa* and *A. tripolium*, showed significant correlations with abiotic parameters, there was a significant relationship between the cover of *P. limosa* and salinity of the surface layer when data from the year 2000 (null cover due to waterlogging) was excluded ($n = 4$):

$$\text{Cover of } P.\,limosa = \exp[0.033 + 2.321 \times (\text{EC2.5 in } 0-10 \text{ cm layer})]$$
$$R2 = 0.935, P < 0.05$$

Multiple regression analysis showed soil pH and salinity to be the most important factors determining yearly average cover of plants at the *Ass* site (Table 3). Increasing pH

Table 3 First two variables incorporated into a regression equation predicting yearly average cover of main species in two plant communities

Community	Species	First variable	Second variable
Artemisia saline puszta	*F. pseudovina*	–	–
	A. santonicum	pH 10–20 cm (+)	EC 10–20 cm (–)
	B. hordaceus	–	–
	P. maritima	pNa 10–20 cm (+)	pH 30–40 cm (+)
	P. canum	pH 30–40 cm (–)	EC 20–30 cm (–)
Pannonic Puccinellia limosa hollow	*P. limosa*	pH of ground water (+)	Lakewater level (–)
	A. tripolium	–	–

Based on the stepwise variable selection algorithm ($n = 5$).
The effect (+, positive; –, negative) is shown in parentheses.
→ indicates incorporation of no variables, and thus failure of stepwise regression.
→ EC, electrical conductivity; pNa, negative logarithm of sodium ion activity.

increased the cover of *A. santonicum* and *P. maritima*, but decreased the cover of *P. canum*. Increasing salinity decreased the cover of *A. santonicum* and *P. canum*. At the *PPlh* site, pH of groundwater had a positive effect and the lakewater level had a negative effect on the cover of *P. limosa*. These results indicate the importance of soil alkalinity. Compared with other saline marshlands in the world, Hungarian sites have highly alkaline soils. At both sites, pH of groundwater or soil was selected as the first or second predictor. Sági and Erdei (2002) demonstrated the special adaptation of *A. tripolium* to this environment. At the *PPlh* site, water characteristics were selected instead of soil characteristics. This finding complements the previously mentioned statement of Bagi and Molnár (2003), that only short periods of waterlogging are tolerated by this vegetation.

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