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Soil-plant Relations in Inland Natural and Anthropogenic Saline Habitats

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ABSTRACT

Three types of saline habitats were investigated in central Poland: natural saline grasslands, anthropogenic saline meadows next to the waste ponds of two soda factories and halophytic vegetation along brine pipelines. In total 76 phytosociological relevés and soil samples (0-25 cm) in each plot were taken. After discriminant analysis (CVA) including all measured soil properties high pH values were identified as significant for pipeline habitats, high EC_e values together with high Ca^{2+} concentrations (and the highest Ca^{2+}/Na^{+} ratio) for the waste pond areas and finally relatively high K^{+} concentrations as characteristic for natural stands. Canonical Correspondence Analysis (CCA) of all species and environmental data demonstrated that in species-environment relations model EC_e linked to waste pond areas, K^{+} characteristic for natural habitats and N_{tot} together with organic matter were significant. Vegetation of the natural habitats differed significantly from the vegetation of waste pond and pipeline areas. More species were frequent in the natural habitats, both halophytes and glycophytes, than in the waste ponds and brine pipelines. There were no significant differences in vegetation between waste ponds and pipelines stands. For the two anthropogenic habitats, the presence of obligatory halophytes *Salicornia europaea*, *Aster tripolium*, *Atriplex prostrata* and *Spergularia marina* was typical. Considering community distribution the results of discriminant analysis identified natural stands as significantly different from the two other categories with more frequent *Scirpus maritimus* community and a *Glaux maritima-Potentilla anserina-Agrostis stolonifera* and *Triglochin maritima* communities. *Salicornia europaea*, *Puccinellia distans-Salicornia europaea*, *Puccinellia distans* and *Atriplex prostrata* communities were typical for anthropogenic stands. Differences between the two anthropogenic habitats were not reflected well by differences in species and community distribution.

Keywords: CCA, discriminant analysis, halophytes, inland salt-marshes, salt-affected soils, soil salinity

INTRODUCTION

In Poland, as in other Central European countries with a humid climate, two types of inland saline habitats are present. Natural areas of inland salt-marsh vegetation are connected with salt springs and saline ground water in contact with Zechstein rock-salt deposits uplifted in the form of salt domes (Wilkoń-Michalska 1963; Bank and Spitzenberg 2001; Piernik *et al.* 2007). Anthropogenic saline habitats occur in the surroundings of salt, soda and potassium industry (Wilkoń-Michalska 1963; Westhus *et al.* 1997; Hulisz 2007). These two types of habitat may differ in soil properties and therefore in vegetation pattern. Due to the location of the transitional climatic zone and the specificity of the sources of salinity, Poland is a country where the soil salinity does not cause significant environmental hazards.

Polish salt-affected soils are formed under the impact of seawater, highly mineralized springs, and liquid and semi-liquid industrial waste. The saline soils are mainly meadow organic (Histosols) and mineral-organic (Gleysols) characterized by particular sensitivity to changes in water relations and by the lack of visible salinity features in their morphology. For this reason soil salinity in Poland can be considered as secondary in relation to other soil forming processes (Hulisz 2007). Because of the lack of visible features in the morphology of salt-affected soils, the use of halophytic plants as indicators of soil physical and chemical properties is potentially very useful, especially under the field conditions. Furthermore, it also facilitates fast classification of these soils (Charzyński *et al.* 2005).

The vegetation-soil relations between halophytic species and their communities either on coastal or inland salt marshes have been investigated within several region around the world (Chapman 1960; Ungar 1974; Adam 1990; Burhill and Kenkel 1991; Cantero *et al.* 1998a, 1998b; Álvarez Rogel *et al.* 2000; Piernik 2005; Li *et al.* 2008; Naz *et al.* 2010). The most important factor controlling species distribution, especially on inland environment, was salinity level, so that halophytes can be used as indicators of soil salinity (Tóth *et al.* 1994, 1995, 1997; Piernik 2003). However, different sets of soil properties could influence the pattern of species and communities distribution (Piernik *et al.* 1996; Álvarez Rogel *et al*. 2000, 2001; Piernik 2005). The pattern can be linked with different types of land use and habitats.

The present study aims to compare the soil conditions in natural and industrial saline areas and to identify the main factors in vegetation-environment relationship according to these two types of sites. Because of the different chemical properties of water caused soil salinization in the study areas, differences in vegetation composition could be expected.

MATERIALS AND METHODS

The study area

The research was done in the Kujawy region in Central Poland, between 52-53° N and 18-20° E (**Fig. 1**). Three types of habitats were investigated: 1. natural saline grasslands in the villages Jacewo, Turzany and Słonawy and meadows in the valley of river Zgłowiączka, 2. anthropogenic saline meadows next to the waste ponds of two soda factories in town Inowrocław and Janikowo and 3. halophytic vegetation along brine pipelines connecting salt

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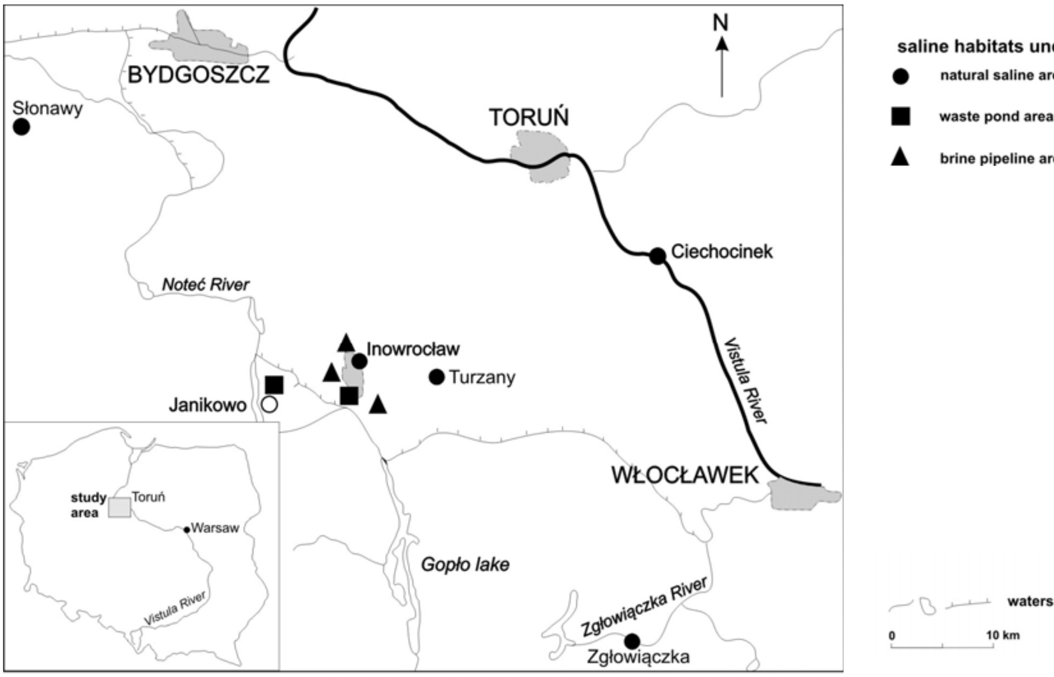

Fig. 1 Location of the study area.

mains with soda factories and pipelines dumping saline waste of soda production to the adjacent rivers.

Data collection

In total 76 phytosociological relevés were taken. The Braun–Blanquet method was used (Braun-Blanquet 1964; Westhoff and van der Maarel 1978). The size of each relevé was about 10 m^2 to reflect soil conditions. Nomenclature follows Flora Europaea (Tutin *et al.* 1964-1980).

In the middle of each plot, one soil sample was taken from the root zone (0-25 cm) for chemical analyses. The following properties were determined: actual soil moisture content (% in weight) by oven-drying method, organic matter content (OM) on the basis of the loss on ignition in 550°C and total nitrogen content (N_{tot}) by Kjeldahl method. Soil saturation extracts were analyzed for: electrical conductivity (EC_e), reaction (pH_e) and ion content (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-) (van Reeuvijk 2002).

Data analysis

Soil salinity was characterized for each habitat. The dominant ions were described and sodium absorption ratio (SAR) was calculated. Spearman rank correlations (Zar 1999) between main ions (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-) were obtained to compare salinity types in each habitat. Discriminant analysis was used to identify the main differences between these habitats (Canonical Variates Analysis - CVA, CANOCO package; ter Braak and Šmilauer 2002). Forward selection and Monte Carlo permutation test (499 unconstrained permutations) were applied to assess statistical importance of a particular soil property in differentiation of the types of investigates sites (Økland 1990; ter Braak and Šmilauer 2002).

The pattern of plant - soil relations was analysed by Canonical correspondence analysis (CCA; ter Braak and Šmilauer 2002). The cover/abundance values obtained with the Braun-Blanquet scale were transformed into the ordinal scale values (van der Maarel 1979) in the following way: r → 1, + → 2, 1 → 3, 2 → 5, 3 → 7, 4 → 8, 5 → 9. In ordination all 76 phytosociological relevés were used and 16 environmental variables: actual soil moisture, organic matter (OM), total nitrogen content (N_{tot}), electrical conductivity (EC_e), reaction (pH_e), ion concentrations Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, Ca^{2+}/Na^+ ratio and the type of habitat as nominal variable (waste ponds, pipelines, natural areas). Organic matter and total nitrogen content were included as they could modify salt tolerance of plant species (Hodson *et al.* 1985; Kiehl *et al.* 1997). Forward selection and Monte Carlo permutation test were applied to assess relative importance and statistical significance of each variable in the pattern of plant distribution (CANOCO; ter Braak and Šmilauer 2002). Plant communities-environment relations analysis were based on the classification of vegetation in the investigated area (Piernik 2005) and the above 16 environmental variables. CVA analysis, forward selection and Monte Carlo permutation test (CANOCO; ter Braak and Šmilauer 2002) were applied.

RESULTS

Soil conditions

The main characteristics of the studied soils are given in **Table 1**. The soil surface horizons were characterized by a very wide range of organic matter (0.87-57.1%) and total nitrogen content (0.03-2.16%). pH values measured in saturation extract (pH_e) were between 3.8 and 9.0. Strong acidification of one sample probably resulted from oxidation of sulphides under the laboratory conditions. The highest pH_e values were found in surface horizons of soil located at places where the brine pipeline had failed.

Both electrical conductivity and soluble ion content of saturation extract reflected the specific character of the salinity source. The highest EC_e values, over 100 $dS \cdot m^{-1}$, were measured in soils polluted by soda waste (2.30-118 $dS \cdot m^{-1}$). The soil salinity levels of natural saline and brine pipeline areas were respectively between 1.58-38.5 and 1.91-39.7 $dS \cdot m^{-1}$ (**Table 1**). Sodium adsorption ratio (SAR) values in studied soils ranged from 0.4 to 100. The highest sodium level was stated in natural saline soils.

The quantitative differentiation of soil salinity was also confirmed by Spearman's rank correlation test (**Table 2**). All study soils demonstrated a highly significant correlation between Cl^- and Na^+ (r values 0.88-0.96, $p<0.001$). In addition, the presence of the following ions was characterized by equally high correlation coefficients ($p<0.001$) pairwise: Mg-SO_4 (0.73), Ca-SO_4 (0.71) and K-HCO_3 (0.69) for natural salt-affected soils, Ca-Cl (0.73) and Mg-Cl (0.66) for soils affected by the soda waste.

Discriminant analysis (CVA) of all measured soil parameters and Monte Carlo permutation test showed that high pH values were identified as significant for pipeline area habitats, high electrical conductivity of saturation extract, high Ca^{2+} concentrations and the highest Ca^{2+}/Na^+ ratio for the waste pond areas and finally relatively high K^+ concen-

Table 1 Soil characteristics of the studied habitat types.

Habitat type	Actual moisture [%]	OM [%]	N_{tot} [%]	pH_e	EC_e [$dS \cdot m^{-1}$]	Dominant cations and anions	SAR
Natural saline areas (n=27)	8.6 - 242	1.89 - 40.7	0.04 - 1.63	5.9 - 8.5	1.58 - 38.5	$Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ and $Cl^- > SO_4^{2-} > HCO_3^-$	2 - 100
Waste pond areas (n=33)	15.2 - 426	0.87 - 57.1	0.04 - 2.16	3.8 - 8.3	2.30 - 118	$Ca^{2+} > Na^+ > Mg^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO_3^-$	0.4 - 44
Brine pipeline areas (n=14)	9.2 - 318	1.02 - 36.6	0.03 - 1.36	6.7 - 9.0	1.91 - 39.7	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > SO_4^{2-} > HCO_3^-$	2 - 87

Table 2 Spearman's rank correlation between ions and EC_e values.

	HCO_3^-	Cl^-	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}	Na^+
Natural saline areas							
Cl^-	0.05						
SO_4^{2-}	0.11	0.53**					
K^+	0.69***	-0.20	0.06				
Ca^{2+}	-0.15	0.47	0.73***	-0.003			
Mg^{2+}	0.06	0.34	0.71***	0.38	0.83***		
Na^+	0.11	0.96***	0.53**	-0.21	0.35	0.24	
EC_e	-0.04	0.94***	0.66***	-0.18	0.58***	0.49*	0.90***
Waste pond areas							
Cl^-	-0.04						
SO_4^{2-}	0.22	-0.29					
K^+	-0.09	0.43***	-0.003				
Ca^{2+}	0.13	0.73***	0.15	0.43*			
Mg^{2+}	-0.28	0.66***	-0.18	0.44**	0.35**		
Na^+	-0.003	0.96***	-0.35***	0.44**	0.69**	0.62***	
EC_e	-0.05	0.82***	-0.46**	0.24	0.66**	0.39*	0.82**
Brine pipeline areas							
Cl^-	-0.28						
SO_4^{2-}	-0.59*	-0.04					
K^+	-0.16	0.48	0.14				
Ca^{2+}	-0.68**	-0.66*	0.26	0.22			
Mg^{2+}	-0.02	0.50	-0.24	0.68**	0.29		
Na^+	0.07	0.88***	-0.26	0.50	0.30	0.48	
EC_e	-0.47	0.87***	0.16	0.48	-0.56*	0.36	0.76**

*p<0.05, **p<0.01, ***p<0.001

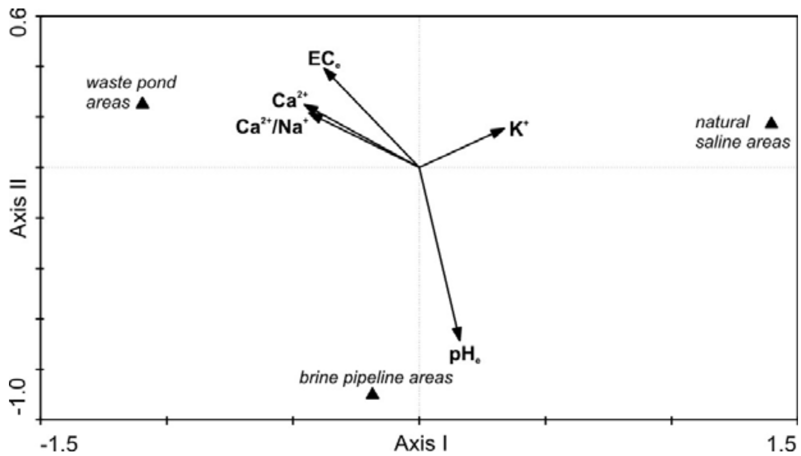

Fig. 2 Differentiation of investigated habitats along significant soil properties. CVA – discriminant analysis. Detailed results in the corresponding **Table 3**.

trations as characteristic for natural stands (**Fig. 2, Table 3**). Forward selection of explanatory variables demonstrated that Ca^{2+} 13.5%, K^+ 7.0%, pH 6.5%, Ca^{2+}/Na^+ ratio 5.5% and EC_e 3.5% mostly contributed to the total variance of the environmental data (**Table 3**). In total these variables explained 36% of variance.

Relations between properties of habitats and vegetation

The general pattern of all species and environmental data analyzed by CCA are presented in **Fig. 3**. The Monte Carlo permutation test demonstrated that EC_e values were linked with waste pond areas, great K^+ concentration was characteristic for natural habitats and great total nitrogen accompanying great organic matter content were significant in a species-environment relations model (**Fig. 3, Table 4**). Vegetation of the natural habitats differed significantly from the vegetation of waste-pond and brine-pipeline areas (p = 0.002). All significant variables explained 17.9% of the total variation in the data set. The most important variable in the pattern of species distribution was locality in natural saline areas (6.3% variance explained, **Table 4**), next N_{tot} (3.5%), EC_e (3.2%), OM (2.6%) and K^+ (2.2%). More species were frequent in the natural areas than in the areas of anthropogenic salinization; as well the halophytes *Glaux maritima*, *Festuca arundinacea*, *Trifolium fragiferum*, *Melilotus dentata*, *Carex distans*, *Scirpus maritimus* and *Scirpus lacustris*, as glycophytic meadow species *Festuca rubra*, *Poa angustifolia*, *Alopecurus geniculatus*, *Poa trivialis*, *Leontodon autumnalis*, *Lotus corniculatus*, *Plantago major* ssp. *intermedia*, *Juncus compressus* and *Potentilla anserina* (**Fig. 3**). There were no significant differences in vegetation composition between waste pond and brine pipeline stands.

Table 3 Results of discriminant analysis (CVA, forward selection and Monte Carlo permutation test) showing importance of environmental factors in the discrimination of three types of habitats: natural saline, waste pond and brine pipeline areas. See **Fig. 2**. Abbreviations: OM – organic matter, N_{tot} – total nitrogen.

Variable	% variation explained	p	F
Ca^{2+}	13.5	0.002	11.2
K^+	7.0	0.006	6.63
pH_e	6.5	0.010	5.64
Ca^{2+}/Na^+	5.5	0.006	5.43
EC_e	3.5	0.038	3.67
Mg^{2+}	2.5	0.056	2.93
Na^+	3.0	0.055	3.28
OM	3.0	0.060	3.22
N_{tot}	1.0	0.314	1.22
SO_4^{2-}	1.0	0.338	1.05
HCO_3^-	0.5	0.360	0.89
actual moisture	0.5	0.724	0.31
Cl^-	0.0	0.896	0.10

Table 4 CCA of species environment relations – result of forward selection and Monte Carlo permutation test. Mg^{2+} content and brine pipeline areas were automatically excluded as colinearity was detected. See **Fig. 3**. Abbreviations: OM – organic matter, N_{tot} – total nitrogen.

Variable	% variation explained	p	F
natural areas	6.3	0.002	4.80
N_{tot}	3.5	0.002	2.75
EC_e	3.2	0.004	2.48
OM	2.6	0.002	2.12
K^+	2.2	0.016	1.75
actual moisture	1.6	0.064	1.45
HCO_3^-	1.4	0.264	1.18
pH_e	1.6	0.146	1.28
Ca^{2+}/Na^+	1.4	0.166	1.25
waste pond areas	1.2	0.580	0.92
SO_4^{2-}	1.0	0.758	0.81
Ca^{2+}	0.8	0.872	0.72
Na^+	0.6	0.964	0.56
Cl^-	0.8	0.894	0.64

For these two anthropogenic habitats, the presence of obligatory halophytes (Wilkoń-Michalska 1963) (i.e. *Salicornia europaea*, *Aster tripolium*, *Atriplex prostrata*, and *Spergularia marina*) was typical. *Puccinellia distans* was also more frequent in these habitats than in the natural sites. Halophytes were present on arable fields together with *Triticum vulgare*, *Hordeum vulgare*, *Avena sativa* and *Brassica napus* and accompanied very often by weeds *Echinochloa crus-galli*, *Apera spica-venti*, *Polygonum aviculare* and *Lepidium ruderale*. In all habitats, *Triglochin maritima* was characteristic in places rich in organic matter and nitrogen (**Fig. 3**).

In the investigated areas ten plant communities were described by Piernik (2005): *Salicornia europaea* community; *Puccinellia distans* - *Salicornia europaea* – *Spergularia marina* community; *Puccinellia distans* - *Spergularia marina* community; *Atriplex hastata* var. *salina* community; *Aster tripolium* community; *Puccinellia distans* community; *Elymus repens* community; *Triglochin maritima* community; *Scirpus maritimus* community and *Glaux maritima-Potentilla anserina-Agrostis stolonifera* community.

Considering the community distribution, the results of discriminant (CVA) analysis identified natural stands as significantly different from the two other anthropogenic habitats (**Table 5**). The CVA ordination diagram presents the means of each group along a gradient of environmental variables (**Fig. 4**). The distance between the means represents Mahalanobis distance (ter Braak and Šmilauer 2002). In the natural saline areas the most frequent were *Scirpus maritimus* community, *Glaux maritima-Potentilla anserina-Agrostis stolonifera* and *Triglochin maritima* community. *Salicornia europaea*, *Puccinellia distans-Salicornia europaea*, *Puccinellia distans* and *Atriplex prostrata* communities were typical for anthropogenic stands. Differences in soil conditions between waste pond and pipeline areas were not reflected well by differences in community distribution.

Table 5 Results of discriminant analysis (CVA, forward selection and Monte Carlo permutation test) showing importance of environmental factors in the discrimination of communities. K^+ content and brine pipeline areas were automatically excluded as colinearity was detected. See **Fig. 4**. Abbreviations: OM – organic matter, N_{tot} – total nitrogen.

Variable	% variation explained	p	F
EC_e	6.4	0.002	4.88
natural areas	4.7	0.002	3.70
OM	3.2	0.012	2.60
N_{tot}	2.9	0.018	2.34
SO_4^{2-}	2.9	0.016	2.48
actual moisture	2.4	0.030	2.06
Na^+	2.0	0.078	1.71
Ca^{2+}/Na^+	1.8	0.138	1.50
Mg^{2+}	1.1	0.434	0.97
Ca^{2+}	1.1	0.442	1.00
waste pond areas	1.0	0.576	0.82
Cl^-	0.7	0.816	0.58
HCO_3^-	0.6	0.852	0.51
pH_e	0.7	0.888	0.52

DISCUSSION

Three different origins of soil salinity were observed in the investigated sites. The area next to waste ponds of soda factory was affected by waste of soda ash production. The waste consisted of sediment containing mainly: $CaCO_3$, $CaSO_4$, $Ca(OH)_2$, $Fe(OH)_3$, silicates, aluminosilicates and oversedimentary liquid, which is a solution of KCl, NaCl, NH_4OH, Na_2SO_4, NaOH, $MgCl_2$, $CaCl_2$ (Abramski and Sobolewski 1977). As a result of inappropriate sealing of bottoms of the waste ponds contaminated solutions infiltrate into the soil, causing soil alkalization and salinization (Cieśla *et al.* 1981; Czerwiński *et al.* 1984; Hulisz 2003). Therefore the highest salinity, the highest Ca^{2+} concentration Ca^{2+}/Na^+ ratio and the lowest SAR values were typical for soils affected by waste from soda production. Areas affected by waste from brine pipelines were contaminated mostly by NaCl solution coming from a salt mine to the soda factory as a substrate for soda production. After a pipeline failure, the effect of brine contamination was to result in excess exchangeable sodium in the soil and in consequence in a significantly higher pH_e than in the natural soil. The relative balance between calcium and sodium ion content in saturated extract of soils polluted by brine depended on whether the soil was reclaimed (treatment of phosphogypsum) or not.

The salinity of natural places was associated with the presence of several salts: chiefly NaCl and $CaCl_2$, but also $MgSO_4$, $CaSO_4$ and $KHCO_3$, and differed significantly from the others habitats by greater K^+ content. The very wide range of sodium adsorption ratio (SAR) values was typical for natural salt-affected soils in Poland and may also reflect properties not directly related to salinity such as mineral composition, organic matter content, carbonates (Hulisz 2007).

Natural saline and brine pipeline areas had a very similar range of soil salinity expressed as EC_e. However, the samples from pipeline areas were taken in some cases several months after the brine pipeline failures. In that period, due to an endopercolative water regime in Polish soils, the

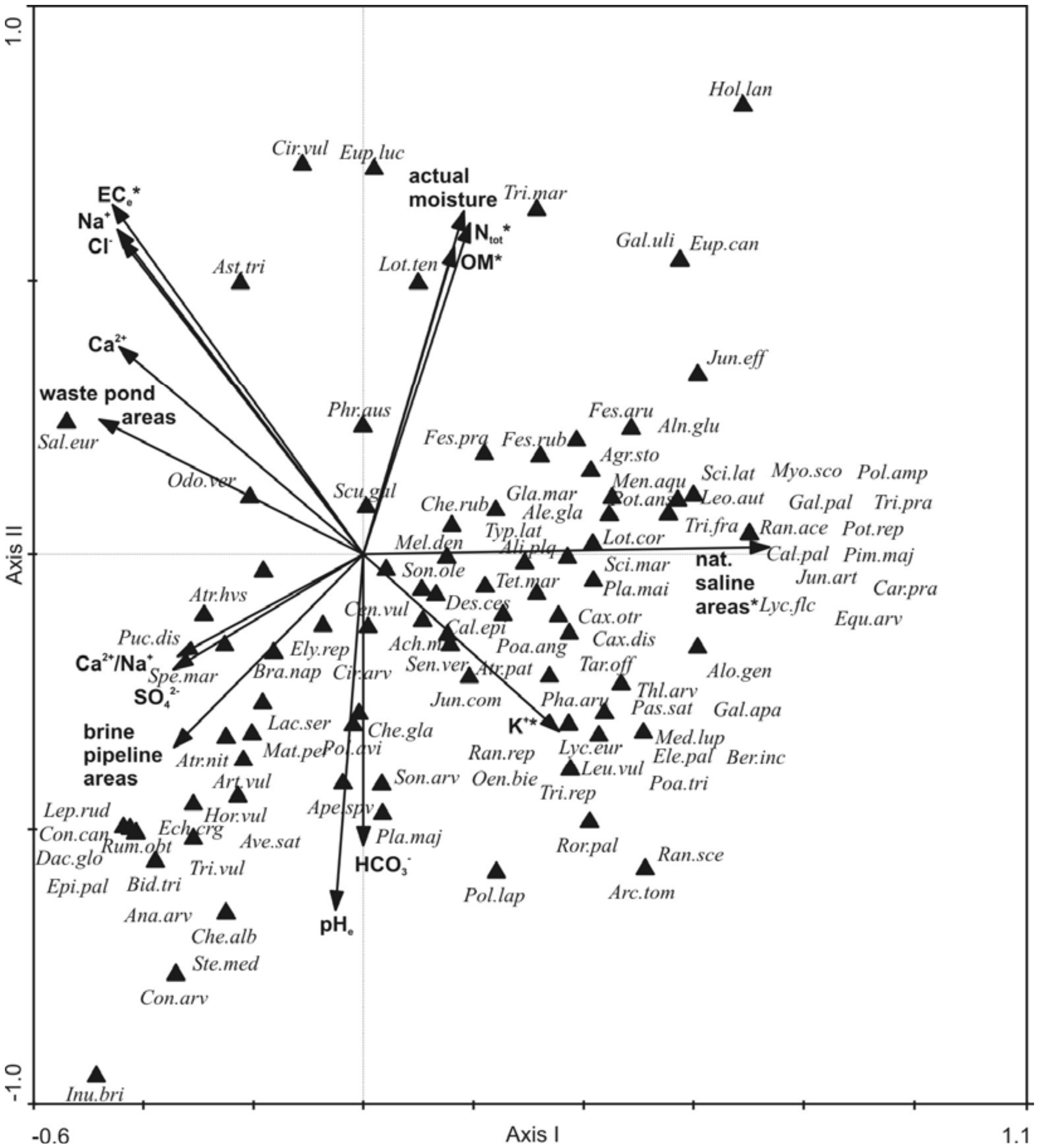

Fig. 3 Ordination CCA diagram of plant species - environment relations. Significant variables (saturated extract, 0-25 cm level) selected by Monte Carlo permutation test at p<0.05: N_{tot}* – total nitrogen, EC_e* – electrical conductivity, OM* – organic matter, K^+* – potassium content and habitat type: nat. saline areas* – natural saline areas. Species abbreviations: Sal eur - *Salicornia europaea*, Spe mar - *Spergularia marina*, Atr hvs - *Atriplex hastata var. salina*, Ast tri - *Aster tripolium*, Gla mar - *Glaux maritima*, Tri mar - *Triglochin maritima*, Puc dis - *Puccinellia distans*, Lot ten - *Lotus tenuis*, Mel den - *Melilotus dentata*, Tet mar - *Tetragonolobus maritimus*, Tri fra - *Trifolium fragiferum*, Sci lat - *Scirpus lacustris ssp. tabernaemontani*, Sci mar - *Scirpus maritimus*, Cax dis - *Carex distans*, Cax otr - *Carex otrubae*, Fes aru - *Festuca arundinacea*, Inu bri - *Inula britannica*, Agr sto - *Agrostis stolonifera*, Pot ans - *Potentilla anserina*, Pla maj - *Plantago major*, Pla mai - *Plantago major ssp. intermedia*, Lep rud - *Lepidium ruderale*, Che gla - *Chenopodium glaucum*, Che rub - *Chenopodium rubrum*, Atr pat - *Atriplex patula*, Phr aus - *Phragmites australis*, Jun com - *Juncus compressus*, Leo aut - *Leontodon autumnalis*, Son arv - *Sonchus arvensis*, Ely rep - *Elymus repens*, Ele pal - *Eeleocharis palustris*, Ach mil - *Achillea millefolium*, Son ole - *Sonchus oleraceus*, Poa ang - *Poa angustifolia*, Gna pal - *Filaginella uliginosa*, Atr nit - *Atriplex nitens*, Cel vul - *Cerastium fontanum ssp. triviale*, Cir arv - *Cirsium arvense*, Cen rhe - *Centaurea rhenana*, Con can - *Conyza canadensis*, Fes pra - *Festuca pratensis*, Mat per - *Matricaria perforata*, Pol avi - *Polygonum aviculare*, Scu gal - *Scutellaria galericulata*, Sen ver - *Senecio vernalis*, Ale gla - *Rhianthus angustifolius*, Fes rub - *Festuca rubra*, Tar off - *Taraxacum officinale*, Ape spv - *Apera spica-venti*, Aln glu - *Alnus glutinosa*, Jun eff - *Juncus effusus*, Odo ver - *Odontites verna ssp. serotina*, Eup luc - *Euphorbia lucida*, Alo geni - *Alopecurus geniculatus*, poa tri - *Poa trivialis*, Pol lap - *Polygonum lapathifolium ssp. lapathifolium*, Ror pal - *Rorippa islandica*, Ran sce - *Ranunculus sceleratus*, Arc tom - *Arctium tomentosum*, Med lup - *Medicago lupulina*, Tri rep - *Trifolium repens*, Oen bie - *Oenothera biennis*, Ran rep - *Ranunculus repens*, Leu vul - *Leucanthemum vulgare*, Lyc eur - *Lycopus europaeus*, Art vul - *Artemisia vulgaris*, Pha aru - *Phalaris arundinacea*, Thl arv - *Thlaspi arvense*, Gal apa - *Galium aparine*, Lac ser - *Lactuca serriola*, Ber inc - *Berteroa incana*, Des ces - *Deschampsia cespitosa*, Pas sat - *Pastinaca sativa*, Ana arv - *Anagallis arvensis*, Bid tri - *Bidens tripartita*, Ech crg - *Echinochloa crus-galli*, Epi pal - *Epilobium palustre*, Che alb - *Chenopodium album*, Ste med - *Stellaria media*, Ave sat - *Avena sativa*, Hor vul - *Hordeum vulgare*, Dac glo - *Dactylis glomerata*, Rum obt - *Rumex obtusifolius*, Tri vul - *Triticum aestivum*, Cal epi - *Calamagrostis epigejos*, Cen vul - *Centaurium littorale*, Bra nap - *Brassica napus*, Lot cor - *Lotus corniculatus*, Con arv - *Convolvulus arvensis*, Hol lan - *Holcus lanatus*, Gal uli - *Galium uliginosum*, Eup can - *Eupatorium cannabinum*, Typ lat - *Typha latifolia*, Ali plg - *Alisma plantago-aquatica*, Tri pra - *Trifolium pratense*, Cal pal - *Caltha palustris*, Myo sco - *Myosotis scorpioides*, Jun art - *Juncus articulatus*, Pot rep - *Potentilla reptans*, Gal pal - *Galium palustre*, Lyc flc -*Lychnis flos-cuculi*, Pim maj - *Pimpinella major*, Pol amp - *Polygonum amphibium*, Car pra - *Cardamine pratensis*, Men aqu - *Mentha aquatica*, Equ arv - *Equisetum arvense*, Ran ace - *Ranunculus acris*, Cir vul - *Cirsium vulgare*.

salts has been largely washed out the profile. When measurements were taken soon after a failure, the electrical conductivity of saturation extract exceeded 190 $dS \cdot m^{-1}$ (Hulisz 2003). In natural saline soils in the Polish coastal zone significantly lower EC_e values were noted: from 1 to 43 $dS \cdot m^{-1}$ (Pracz 1989).

These differences in soil conditions partly resulted in differences in vegetation composition. Although soils in the

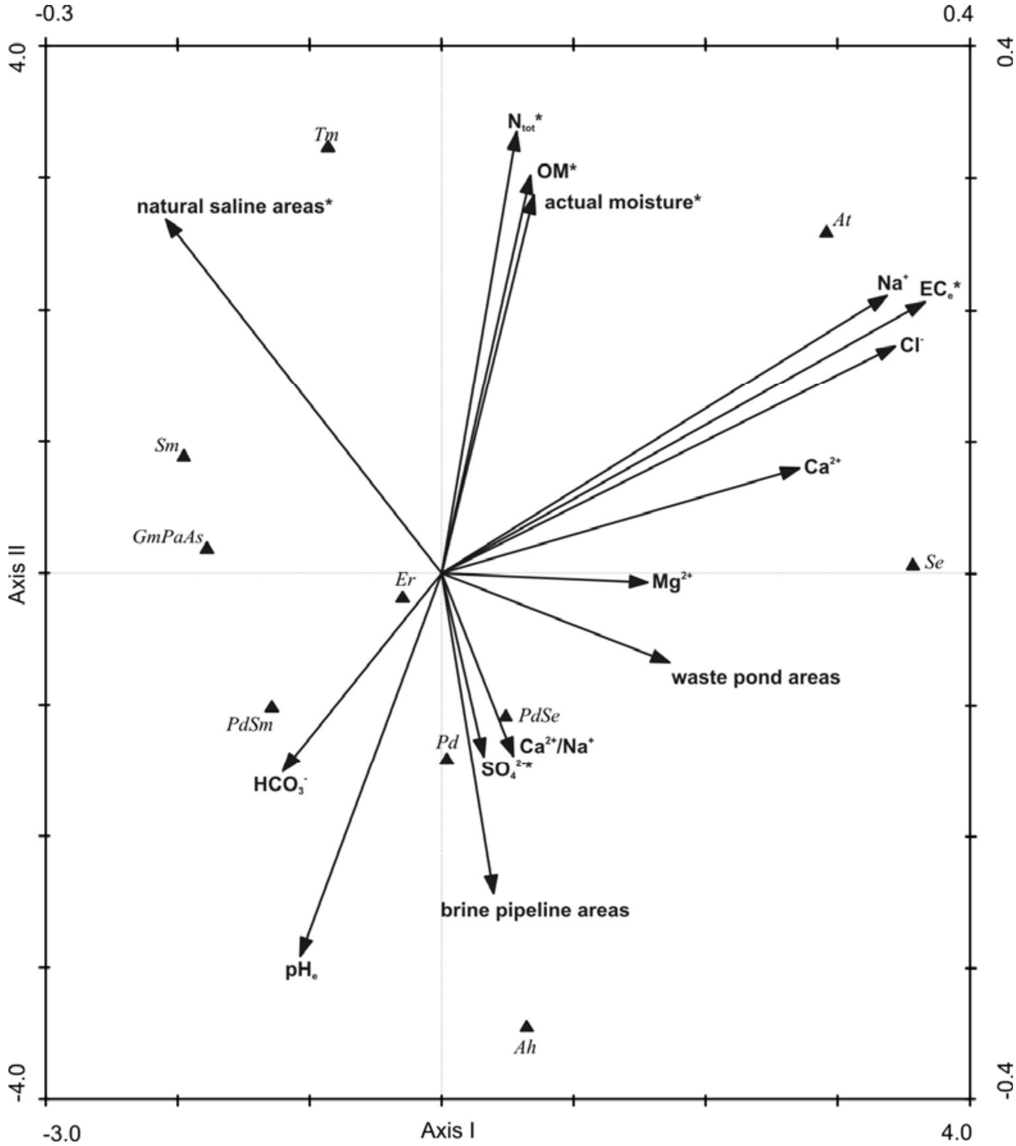

**Fig. 4 Differentiation of plant communities along environmental properties (CVA – discriminant analysis). *** $p<0.05$, Abbreviations: OM – organic matter, N_{tot} – total nitrogen, Se – *Salicornia europaea* community, PdSe – *Puccinellia distans – Salicornia europaea - Spergularia marina* community, PdSm - *Puccinellia distans – Spergularia marina* community, Ah – *Atriplex prostrata* community, At – *Aster tripolium* community, Pd – *Puccinellia distans* community, Er – *Elymus repens* community, Tm – *Triglochin maritima* community, Sm – *Scirpus maritimus* community, GmPaAs – *Glaux maritima-Potentilla anserina-Agrostis stolonifera* community.

vicinity of pipelines were alkaline, a significant difference in vegetation distribution was not found between the areas of waste ponds and pipelines. Besides, the factors typical for soils of any investigated areas – N_{tot} and organic matter content – were also significant in the pattern of vegetation. On the other hand in the pattern of plant species distribution the most important was high K^+ content, typical for the natural saline soils and high salinity level expressed as EC_e,, typical for waste pond areas. High salinity limited the number of species especially in waste pond areas. There were obligatory halophytes *Salicornia europea* and *Aster tripolium* which have disappeared nowadays from their former natural stands in Poland (Nienartowicz and Piernik 2004a, 2004b). Results of the investigations done on inland salt marshes in Argentina (Cantero *et al.* 1998a) demonstrated that EC was the most important factor among ground water parameters. Results of the investigation carried out on inland salt marshes in Canada (Burchil and Kenkel 1991) proved that the total sum of easily soluble salts was the most significant factor in vegetation-environment relations. In case of Polish soils this parameter was not considered in the statistical analysis as it was multi-correlated with EC_e and other parameters. Research on inland salt marshes of Spain (Álvarez Rogel *et al.* 2000) pointed out that ionic ratios: K^+/Na^+, Ca^{2+}/Mg^{2+}, Ca^{2+}/Na^+ largely explained the soil-vegetation relationships. In the presented study, the Ca^{2+}/Na^+ ratio significantly affected the differences in soil conditions and separated the waste pond areas from the other habitats, but it was not important in the species pattern and community distribution. Hydrogen ion concentration (pH) has been suggested as an important factor determining the distribution of halophytes in south eastern Spain by Ortiz *et al.* (1995). However, this factor did not affect significantly the distribution of plant and communities in the investigated habitats, though it was significantly related to soil properties in the brine pipeline areas.

The distribution of plant communities was determined by the same main factors as in case of plant species – EC_e, N_{tot}, organic matter, and in addition moisture and SO_4^{2-} content. The communities of obligatory halophytes *Salicornia europaea* and *Aster tripolium* were limited to the most saline sites in the vicinity of waste ponds. *Triglochin maritima* community was typical for organic soils as well in natural as anthropogenic habitats.

Vegetation distribution could be modified by other factors than soil properties. Especially important may include mowing and grazing (Wilkoń-Michalska 1970; Bakker 1989), competition (Bertness and Shumway 1993; Ungar

1998). However, in case of such strong environmental differences between the three investigated types of sites they seem to be of minor importance.

Knowledge about vegetation of anthropogenic saline habitats could help in the restoration of these areas and in the introduction of saline meadows in the degraded lands (Schmeisky and Podlacha 2000; Wilkoń-Michalska and Sokół 1968).

CONCLUDING REMARKS

1. After discriminant analysis (CVA) including all measured soil properties high pH was identified as significant for pipeline habitats, high EC_e together with high Ca^{2+} concentrations (and the highest Ca^{2+}/Na^+ ratio) for the waste pond areas and finally relatively high K^+ concentrations as characteristic for natural stands.
2. CCA analysis, Monte Carlo permutation test and forward selection of all species and environmental data demonstrated that significant in species-environment relations model were EC_e linked to waste pond habitats, K^+ characteristic for natural habitats and N_{tot} together with organic matter. There were no significant differences in vegetation pattern between waste pond and pipeline areas.
3. The results of discriminant analysis (CVA) considering communities distribution identified natural stands as significantly different from two other categories. There were more frequent *Scirpus maritimus* community, *Glaux maritima - Potentilla anserina-Agrostis stolonifera* and *Triglochin maritima* community. *Salicornia europaea*, *Puccinellia distans - Salicornia europaea*, *Puccinellia distans* and *Atriplex prostrata* communities were typical for anthropogenic stands.
4. Differences in soil conditions between waste pond and pipeline areas were not reflected well by differences in species and community distribution.

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