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THE RELEVANCE OF PHYSICAL FACTORS ON SPECIES DISTRIBUTIONS IN INLAND SALT MARSHES (ARGENTINA)

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Abstract. The objective of this paper is to describe the factors that affect vegetation pattern on continental saline lowlands around rivers. Three transects were laid perpendicular to the River Saladillo (S.E. Santa Fe, Province, Argentina). Vegetation and soil data were collected and analysed based on indirect canonical correlation, Spearman rank correlation coefficient and Pearson correlation coefficient. Three plant communities were detected: Flechillar of *Stypa hyalina*, Espartillar of *Spartina densiflora* and a Halophilous prairie. Flechillar was positively correlated with soil texture and exchangeable ions, Mg, Ca, CO_3 and P_2O_5; the Halophilous prairie with elevation, HCO_3, pH, Na and CO_3; and the Espartillar clearly with none of the examined edaphic variables. Characteristic species, in contrast to rare species, show correlation with edaphic variables for all three transects. No correlations for rare species can be related to plasticity.

Introduction

Halophytes can withstand a wide range of salinity (Jefferies and Pitman 1986) and there is general agreement that the physical factors are more important than the biotic ones for plant species distribution in marshes (Bertness and Ellison 1987). However, several authors suggest that biotic interaction may be important as well (Silander and Antonovics 1982; Bertness and Ellison 1987).

The plant communities of SE Santa Fe have been analysed by Lewis *et al.* (1985) and Collantes and Lewis (1980). They suggested that plant community distribution follows environmental (edaphic) gradients. In a previous paper (Carnevale et al. 1987) we analysed plant species distributions along environmental gradients in a marsh at the River Saladillo (Province of Santa Fe, Argentina). We found three distinct communities: the Flechillar, the Halophilous prairie, and the Espartillar. We also found that species distributions along the gradient respond to physical (edaphic) factors, but there was another response component that could be correlated with species interactions.

The objective of this paper is to discover how far different physical factors determine plant species distributions, as a first approximation to understanding the causes which mold vegetation pattern (Ernst 1978) on continental marshes of river valleys.

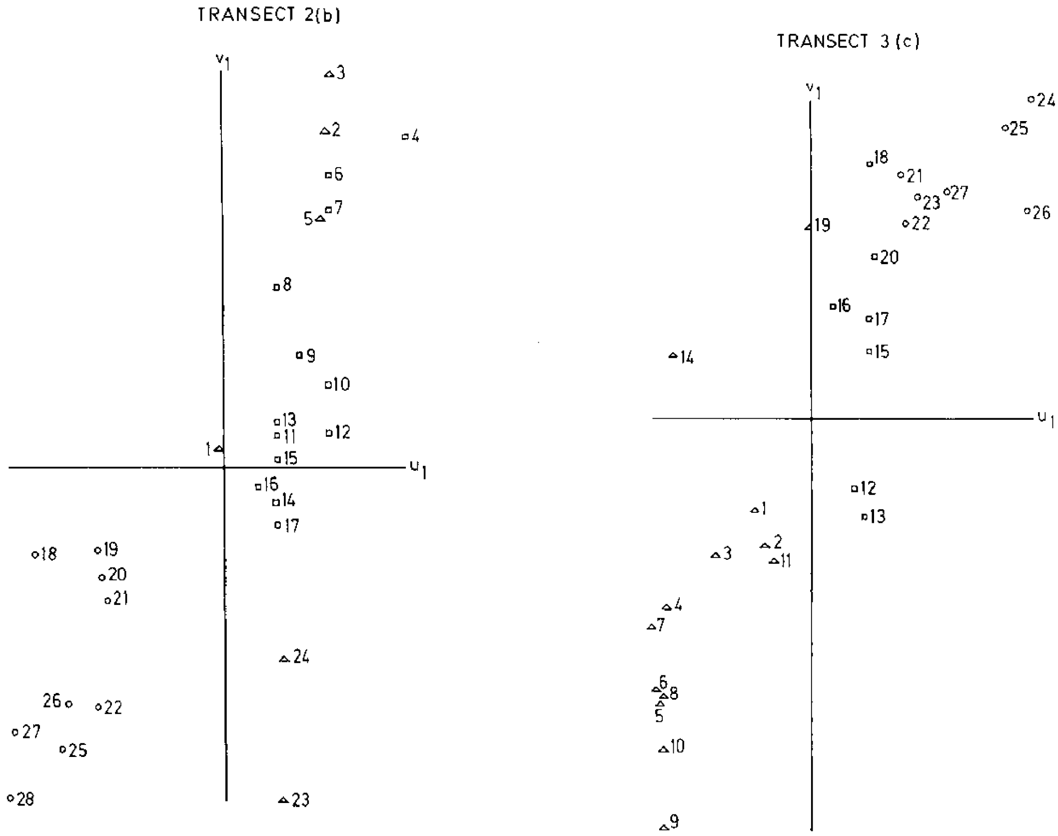
Material and methods

Three transects, 650, 675 and 850 m long, were laid across the River Saladillo valley near Chabás and Sandford. Vegetation and soil data were obtained from 26, 28 and 27 plots over the transects in the same way as in Carnevale *et al.* (1987). In all, 29 soil variables were analysed and 66, 55 and 65 species were recorded. Soil and vegetation data were analysed by PCA (Principal Component Analysis) using SPAD programs (Lebart and Morineau 1982). Then for each transect, vegetation and soil data were correlated in indirect canonical analysis (Lagonegro and Feoli 1985) using CANCOR (Orlóci and Kenkel 1985). The Spearman rank correlation coefficient (Siegel 1980) and Pearson correlation coefficient (Snedecor and Cochran 1979) were also calculated.

Results

The three plant communities that we already mentioned appear in all transects (see Appendix 1), and always there is *Phyla canescens, Stipa hyalina* and *Paspalum vaginatum* in the Flechillar, *Paspalum vaginatum* in the Halophilous prairie and *Spartina densiflora* in the Espartillar. Different variants of the Halophilous prairie occur in the different transects and differences exists in companion species of *Spartina densiflora* in the espartillares. The transects were analysed separately. Canonical correlations are shown in Figure 1 (a, b and c). The principal component values of species and soil variables for calculating canonical variables are in Appendix 2.

The Flechillar is highly correlated with organic matter (0.87), clay (0.73), exchangeable Mg (0.76) and total exchangeable bases (0.69) on transect 1 (Fig. 1a); with silt, fine sand, and to a lesser degree, CO_3, total and exchangeable Ca, total exchangeable bases and clay on transect 2 (Fig. 1b); and with exchangeable Mg (0.92), total Ca (0.90), total exchangeable bases (0.85), total Mg (0.83), exchangeable Ca (0.79), P_2O_5 (0.68), clay (0.63), organic matter (0.55), medium sand (0.76) and silt (0.62) on transect 3 (Fig. 1c). On transect 1 (Fig. 1a) the Halophilous prairie is associated with pH, both water extraction and paste (−0.80), HCO_3 (−0.82), CO_3 (−0.68), Na percentage (−0.77), and elevation (−0.86); and the



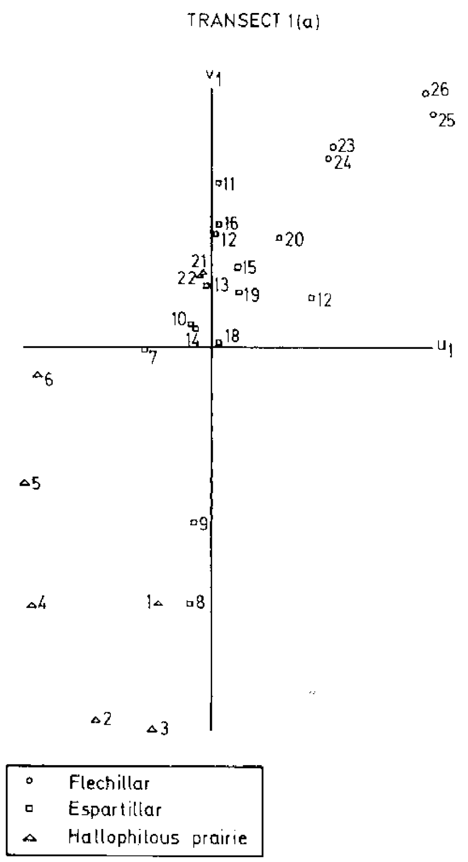


Fig. 1. Joint scatter of the dominant canonical variates from the vegetation (u_1) set of principal components and soil-variable (v_1) set of principal components on Transects 1, 2 and 3. Symbols: ○ Flechillar. □ Espartillar. △ Halophilous prairie.

Espartillar with organic matter, clay, exchangeable Mg and total exchangeable bases. On transect 2 and 3 (Fig. 1b and c) the relationship of Halophilous pairie and Espartillar is not clear.

On transect 2 the Halophilous prairie is associated with the negative values of y3 (Fig. 2a), *i.e.*, exchangeable Mg (—0.68), clay (—0.62), pH in paste (—0.48), exchangeable Na (—0.46), and pH in water extraction (—0.38); and the Espartillar with negative values of y2 (Fig. 2b), *i.e.*, Na percentage, pH in water and paste, medium sand, elevation and HCO_3. On transect 3, the Halophilous prairie is negatively related to y1 (Fig. 3a), *i.e.*, pH in paste and water (—0.92; —0.91), elevation (—0.91), $CaCO_3$ (—0.85), HCO_3 (—0.84), Na percentage (—0.82), and CO_3 percentage; and the Espartillar with positive values of y1 (Fig. 3a); *i.e.*, exchangeable Mg (0.92), total Ca (0.90), total exchangeable bases (0.85), total Mg (0.83), exchangeable Ca (0.79), P_2O_5 (0.68), clay (0.63), and organic matter (0.55), as shown in Fig. 3.

Plots 8 and 9 on transect 1 are far separated from all other Espartillar plots; their levels of Sulphate and Chloride are extremely high. Also, plots 14 and 19 on

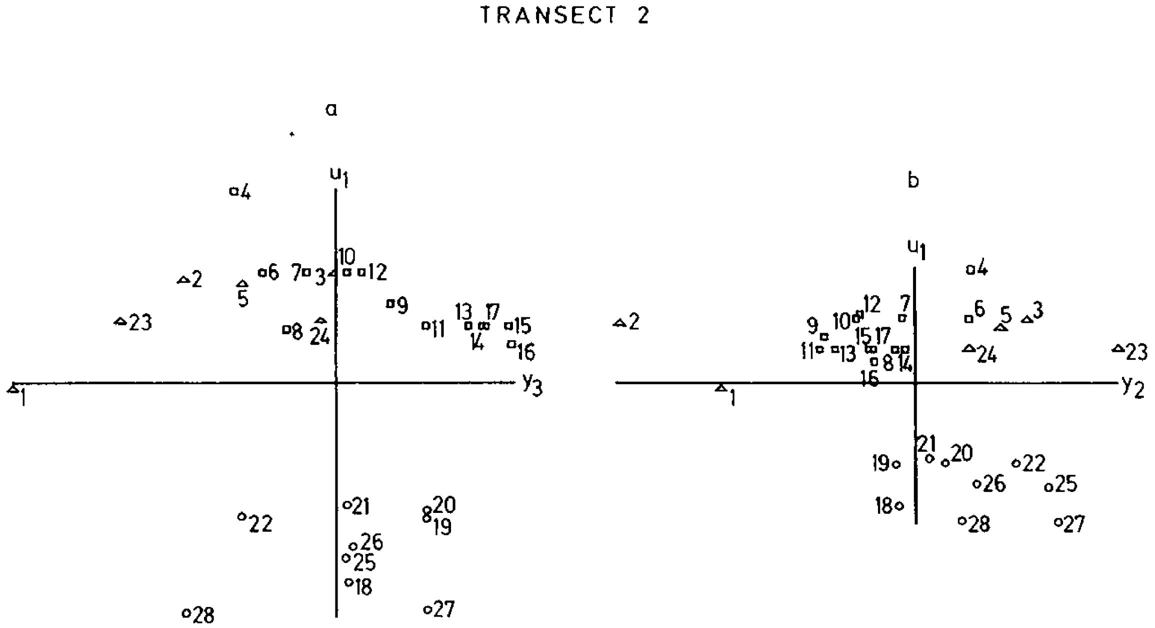


Fig. 2. Joint scatter of the dominant canonical variate from the vegetation (u_1) set of principal components and the 2nd and 3rd soil-variable principal components on Transect 2. Symbols: ○ Flechillar. □ Espartillar. △ Halophilous prairie.

transect 3 are anomalous, although both are Halophilous prairies, the former has *Stipa hyalina* and *Phyla canescens* which are Flechillar species and the latter has *Salicornia ambigua* and *Rumex pulcher* which are common in the Espartillar.

Table 1 shows a matrix of high correlation coincidences for species, common to the three transects, and soil variables. There is a higher number of coincidences in high correlations between species of transects 1 and 3 and soil variables than between species of transect 2 and the same soil variables. Also, there is an evident similarity between the communities physiognomy of transects 1 and 3, except for the Flechillar, as it shown by their Euclidean distances (Table 2).

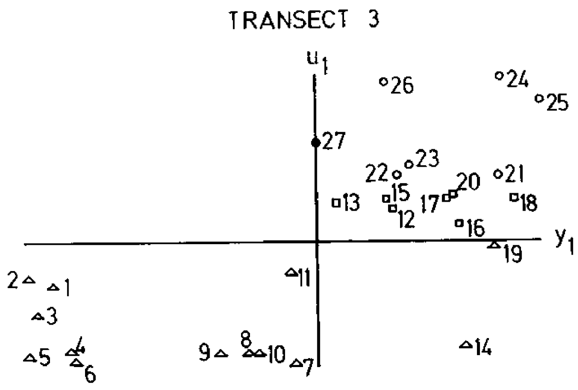


Fig. 3. Joint scatter of the dominant canonical variate from the vegetation (u_1) set of principal components and the 1st soil-variable principal component on Transect 3. Symbols: ○ Flechillar. □ Espartillar. △ Halophilous prairie.

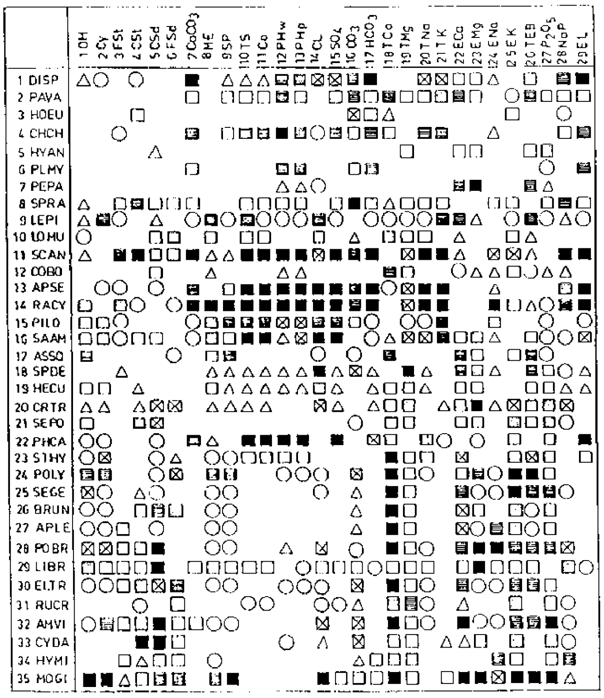
The Spearman rank correlation coefficients between characteristic and common species for all communities and edaphic variables are alike for all transects. These species are always correlated with less than 50% of soil variables ($p > 0.95$) (Table 3). There are no correlations between rare species and edaphic variables on either transects in terms of the Pearson correlation coefficient.

Discussion

If the results from the three transects are compared, it can be seen that there are some differences in canonical correlations between vegetation and soil variables due to local differences in both types of variables. However, in spite of these local differences, the results are consistent among themselves.

The Flechillar of the three transects has *Stipa hyalina* and *Phyla canescens* like any other stand of the same community within the region, but while in transects 1 and 2 *Phyla canescens* is dominant, accompanied by *Stypa hyalina* and *Paspalum vaginatum*, in the third transect, the dominant is *Stypa hyalina* accompanied by *Phyla canescens* and *Paspalum vaginatum; Paspalum dilatatum* is an important species as well. Also, in all cases, this community is significantly correlated with soil texture, *i.e.*, the proportion of clay, silt and fine sand, as well as with echangeable ions, Mg and Ca, CO_3, and P_2O_5.

Table 1. Matrix of correlation coincidences for species common to the three transects and soil variables.



○ Transect 1 (121 correlations); △ transect 2 (87 correlations); □ transect 3 (146 correlations) ⊠ transects 1 and 2 (43 coincidences); ⊡ transects 1 and 3 (83 coincidences); ⊟ transects 2 and 3 (47 coincidences) ■ transects 1, 2 and 3 (83 coincidences).

1 - Organic matter OM; 2 - Clay Cy; 3 - Silt (20 u) F St; 4 - Silt (50 u) C St; 5 Coarse and CSd; 6 - Fine sand FSd; 7 - Calcium Carbonate Ca CO_1; 8 - Moisture equivalent ME; 9 - Saturation percentage SP; 10 - Total salts TS; 11 - Conductivity Co; 12 - Water extract Pilw; 13 - Soil paste Plip; 14 - Chloride Cl; 15 - Sulfate SO_4; 16 - Carbonate CO_3; 17 - Bicarbonate HCO_3; 18 - Total calcium TCa; 19 - Total magnesium TMg; 20 - Total sodium TNa; 21 - Total potassium TK; 22 - Exchangeable calcium ECa; 23 - Exchangeable magnesium EMg; 24 - Exchangeable sodium ENa; 25 - Exchangeable potassium EK; 26 - Total exchangeable bases TEB; 27 - Posphate P_2O_5; 28 - Sodium percentage NaP; 29 - Elevation.

Table 2. Euclidean distances.

Halophilous prairie of transect 1 and transect 2 = 378.21
Halophilous prairie of transect 1 and transect 3 = 304.56
Halophilous prairie of transect 2 and transect 3 = 351.60
Espartillar of transect 1 and transect 2 = 495.84
Espartillar of transect 1 and transect 3 = 178.66
Espartillar of transect 2 and transect 3 = 431.78
Flechillar of transect 1 and transect 2 = 332.57
Flechillar of transect 1 and transect 3 = 1745.25
Flechillar of transect 2 and transect 3 = 2433.43

Table 3. Species common to the three transects and their correlation (expressed as percentages) with physical factors.

CODE	SPECIES	PERCENTAGES		
		T1	T2	T3
DISP	Distichlis spicata	44.83	48.27	41.38
SPDE	Spartina densiflora	24.14	58.62	24.14
STHY	Stipa hyalina	27.59	27.59	37.93
SEGE	Setaria geniculata	48.27	17.24	20.69
RUCR	Rumex crispus	31.03	13.79	17.24
(characterics species)				
PAVA	Paspalum vaginatum	20.69	31.45	65.51
HOEU	Hordeum euclaston	6.90	6.90	10.34
CHCH	Chaetotropis chilensis	44.83	6.90	51.72
HYAN	Hymenoxis anthemoides	0	6.90	17.24
PLMY	Plantago myosurus	17.24	0	20.69
PEPA	Petunia parviflora	13.79	13.79	10.34
SPRA	Spergularia ramosa	10.34	13.79	68.96
LEPI	Lepidium sp.	72.41	13.79	24.14
LOMU	Lollium multiflorum	3.45	20.69	34.48
SCAM	Scirpus americanus	62.07	75.86	55.17
COBO	Coniza bonariensis	10.34	24.14	13.79
APSE	Apium sellowianum	62.07	41.38	51.72
RACY	Ranunculus cymbalaria	72.41	65.52	62.07
PILO	Picrosia longifolia	51.72	10.34	37.93
SAAM	Salicornia ambigua	48.27	44.83	48.27
ASSQ	Aster squamatus	31.03	0	27.59
HECU	Heliotropium curassavicum	0	44.83	34.48
CRTR	Cressa truxilensis	24.14	82.76	37.93
SEPO	Sesuvium portulacastrum	10.34	13.79	31.03
PHCA	Phyla canescens	48.27	41.38	44.83
POLY	Polygonum sp.	58.62	20.69	37.93
BRUN	Bromus unioloides	27.59	20.69	27.59
APLE	Apium leptophyllum	34.48	13.79	20.69
POBR	Polygonum brasiliense	55.17	37.93	37.93
LIBR	Limonium brasiliense	27.59	13.79	86.21
ELTR	Eleusyne tristachya	58.62	13.79	31.03
AMVI	Ammi viznaga	55.17	31.03	41.38
CYDA	Cynodon dactylon	17.24	34.48	27.59
HIMI	Hipochoeris microcephala	10.34	10.34	34.48
MOGI	Modiolastrum gillesii	48.27	48.27	65.52

The Halophilous prairie is correlated with elevation, HCO_3, pH (paste), and percentage Na and CO_3 in transects 1 and 3, while in transect 2, it is significantly correlated only with pH among the mentioned variables. In all cases *Paspalum vaginatum* is the dominant or co-dominant species of the community, but in transect 1 and 3 *Distichlis spicata* is abundant as well as *Phyla canescens* in the latter, while in transect 2 *Ranunculus cymbalaria* is important. These suggest that the Halophilous prairie is more humid on transect 2 than on the other transects (Cabrera 1967).

The Espartillar is not correlated with any of the soil variables. Both, in transect 1 and 3, it is correlated with the same variables as the Flechillar, while in transect 2 it is correlated with the same variables as the Halophilous prairie. The Espartillar is always in the lowest segment of the elevation gradient (Carnevale *et al.* 1987), and therefore, it is periodically flooded. In transect 2, as it was pointed out above, the Halophilous prairie could be more humid than in the other transects. Flooding or periodical water excess may explain the behaviour of the Espartillar in relation to soil variables in any transect and the Halophilous prairie in transect 2. However, soil moisture and water table fluctuations were not measured, only inferted from water accumulation above the soil surface.

There seems to be good agreement between the soil variables and vegetation distribution. Transplantation experiments show that some of the species, with closely related ones in the New England shore marshes, grow better in environments different from where they naturally occur. This fact is linked to interspecific competition (Bertness and Ellison 1987). Nevertheless, although correlations do not imply causality, in two out of the three transects coincidences between species and soil factors were more similar where the same factors were correlated to the same species. So, it can be concluded that physical factors determine species distribution at least in the extreme segments of their gradients but where there is flooding, all other measured edaphic factors become less important. Under these conditions, *Spartina* becomes dominant. However, in transitional environments, certain species of very different growth form are excluded. Interestingly, the Feoli and Orlóci (1987) species dispersion profiles segregate response to soil factors from response to other variables (Carnevale *et al.* 1987). There is some inferential evidence that these "other" variables may be interactions among species.

According to interpretation of the Pearson correlation coefficient, rare species are not correlated with the measured soil variables. Although halophytes generally have a high plasticity level (Jefferies and Pitman 1986), rare species seem to be even more plastic. A high plasticity level constrains specialization within communities and may be inversely correlated with competitive ability (Pickett and Bazzaz 1978). The plastic species, the generalists, contrast with the characteristic species, the specialists, confined to competitive refugia which make them rare within the communities.

However, species like *Paspalum vaginatum* has low correlations with physical factors in transects 1 and 2 and a high correlation in transect 3, and although it is a characteristic of Halophilous prairies, it appears in other communities as well. This independent distribution may be correlated with varying local plasticity. It should be investigated if there are different genotypes of this species along the environmental gradient.

As a final remark it can be said that although species distribution is determined by physical factors in certain segments of their gradients, in other segments, other factors such as species interactions and species plasticity or genetic variation may be important.

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REFERENCES

Bertness, M. and A. Ellison. 1987. Determinants of pattern in a New England Salt Marsh Plant Community. Ecological Monographs 57: 129-147.

Braun-Blanquet, J. 1979. Fitosociologia. II. Blume Ediciones. Madrid.

Cabrera, A.H. 1963, 1965a, b, 1967, 1968, 1970. Flora de la Provincia de Buenos Aires, 6 Vol. Colección Científica del I.N.T.A., Buenos Aires.

Carnevale, N.J., P.S. Torres, S.I. Boccanelli and J.P. Lewis. 1987. Halophilous communities and species distribution along environmental gradients in Southeastern Santa Fe Province, Argentina. Coenoses 2: 49-60.

Collantes, M.B. and J.P. Lewis. 1980. Ordenamiento de la scomunidades herbáceas del Departamento Rosario. (Provincia de Santa FE, Argentina). Ecosur 7: 171-174.

Ernst, W. 1978. Discrepancy between ecological and physiological optima of plant species. A reinterpretation. Oecol. Plant. 13: 175-188.

Jefferies, R.L. and M.G. Pitman. 1986. Perspectives of the biology of halophytes in natural habitats in relation to forage production. Reclamation and Revegetation Research 5: 227-243.

Lagonegro, M. and E. Feoli. 1985. Analisi multivariata di dati. Università di Trieste, Italy.

Lebart, L. and A. Morineau. 1982. SPAD. Cesia. París.

Lewis, J.P., M.B. Collantes, E.F. Pire, N.J. Carnevale, S.I. Boccanelli, S.L. Stofella and D.E. Prado. 1985. Floristic groups and communities of southeastern Santa Fe, Argentina. Vegetatio 60: 67-90.

Orlóci, L. and N. Kenkel. 1985. Introduction to data analysis. Statistical Ecology Monographs. Vol. 1. International Cooperative Publishing House. Fairland, Maryland.

Pickett, S.T.A. and F.A. Bazzaz. 1978. Organization of an assemblage of early succesional species on a soil moisture gradient. Ecology 59: 1248-1255.

Schlichting, C.D. 1986. The evolution of phenotypic plasticity in plants. Ann. Rev. Ecol. Syst. 17: 667-693.

Siegel, S. 1980. Estadística no paramétrica. Editorial Trillas, México.

Silander, J.A. and J. Antonovics. 1982. Analysis of interspecific interactions in a coastal plant community - a perturbation approach. Nature 298: 557-560.

Snedecor, G.W. and W.G. Cochran. 1979. Métodos estadísticos. Companía Editorial Continental S.A., México.

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Appendix 1.

Species composition of communities by transect.

Halophilous prairie

	T1	T2	T3
Paspalum vaginatum	65.62	79.17	70.19
Phyla canescens	9.37	5.83	2.88
Distichlis spicata	9.07	4.58	17.89
Apium sellowianum	6.27	0.03	2.91
Cynodon dactylon	4.37		
Plantago myosurus	3.16	1.72	1.21
Chaetotropis chilensis	2.51	0.03	5.60
Picrosia longifolia	2.21	0.02	0.79
Stipa hyalina	1.25		0.38
Salicornia ambigua	0.70	0.85	1.18
Carex sororia	0.64		
Coniza bonariensis	0.62		0.01
Apium leptophyllum	0.62	0.02	
Hordeum euclaston	0.07		0.39
Hipochoeris microcephala	0.07	0.05	
Spergularia ramosa	0.06		0.01
Hymenoxis anthemoides	0.05	0.02	0.01
Lollium multiflorum	0.05	0.02	0.02
Heliotropium curassavicum	0.04	0.02	0.01
Rumex crispus	0.02	0.02	
Sesuvium portulacastrum	0.02	0.03	
Ranunculus cymbalaria	0.02	9.18	8.28
Cirsium vulgare	0.02		
Aster squamatus	0.02	0.02	0.01
Limonium brasiliense	0.02		
Sporobolus pyramidatus	0.01	0.83	
Spergularia platensis	0.01		
Scirpus americanus	0.01	0.85	2.88
Trifolium repens	0.01		
Melilotus sp.	0.01		0.01
Spartina densiflora	0.01		
Petunia parviflora	0.01		0.01
Juncus balticus	0.01		
Cyperus reflexus	0.01		
Cyperus cayenensis	0.01		
Bromus unioloides	0.01	0.02	
Anthemis cotula	0.01		
Gratiola peruviana		0.85	
Small rose		0.85	
Triglochlin striata		0.83	1.93
Dichondra microcalyx		0.83	
Sonchus asper		0.02	
Medicago lupulina		0.02	
Ammi viznaga		0.02	
Matricaria chamomila		0.02	
Solidago chilensis		0.02	
Spartina argentinensis			5.19
Cyperus laevigatus			2.88
Rumex pulcher			0.40
Lepidium sp.			0.40
Polypogon monspeliensis			0.01
Chenopodium macrospermum			0.01
Cressa truxilensis			0.01
Verbena gracilenscens			0.01
Juncus sp.			0.01
Polygonum sp.			0.01
Setaria geniculata			0.01

Espartillar

	T1	T2	T3
Spartina densiflora	48.57	68.27	51.78
Phyla canescens	6.78		2.51
Salicornia ambigua	5.92	3.29	2.54
Coniza bonariensis	3.78	0.04	0.01
Paspalum vaginatum	1.97	7.12	3.23
Limonium brasiliense	1.81	0.01	0.01
Plantago myosurus	1.48	0.04	0.01
Hymenoxis anthemoides	1.12	0.42	0.75
Verbena gracilescens	1.11		1.46
Distichlis spicata	1.08	0.38	2.50
Apium sellowianum	0.78	0.41	
Heliotropium curassavicum	0.77	0.03	3.26
Rumex pulcher	0.74		10.71
Cressa truxilensis	0.71	0.01	0.04
Aster squamatus	0.41	0.03	0.01
Sporobolus pyramidatus	0.36	0.01	
Teucrium cubescens	0.36		
Stipa philippii	0.36		
Chaetotropis chilensis	0.07	0.02	
Sesuvium portulacastrum	0.03	0.02	0.03
Picrosia longifolia	0.03	0.44	0.03
Melilotus sp.	0.03		
Petunia parviflora	0.03	1.19	2.86
Senecio pinnatus	0.03		
Hordeum euclaston	0.02	0.01	
Hipochoeris microcephala	0.02	0.01	
Rumex crispus	0.02		
Lepidium sp.	0.02	0.01	0.06
Cirsium vulgare	0.01		0.01
Samolus valerandii	0.01		
Carex sororia	0.01		
Melica macra	0.01		
Sida rhombifolia	0.01		
Polypogon monspeliensis	0.01		0.03
Medicago sp.	0.01		
Spergularia ramosa	0.01		
Lollium multiflorum	0.01		
Chenopodium almum	0.01		
Salpichroa sp.	0.01		
Melilotus officinalis	0.01		
Deyeuxia viridiflavescens	0.01		
Solanum sp.	0.01		
Dichondra microcalyx	0.01		
Stipa papposa	0.01		
Euphorbia serpens		1.75	0.06
Ranunculus cymbalaria		0.01	
Polygonum brasiliense		0.01	0.01
Anthemis cotula		0.01	
Spartina argentinensis			0.01
Senecio grisebachii			0.01
Stipa hyalina			0.01
Setaria geniculata			0.01
Bromus unioloides			0.01
Apium leptophyllum			0.01
Trifolium sp.			0.01
Nicotiana longifollia			0.01

Flechillar

	T1	T2	T3
Phyla canescens	43.75	40.28	38.21
Stipa hyalina	28.75	14.45	43.57
Paspalum vaginatum	10.00	8.33	10.37
Cynodon dactylon	4.37	6.11	5.01
Plantago myosurus	2.50	0.08	0.04
Hipochoeris microcephala	1.32	0.05	0.03
Apium leptophyllum	1.32	0.07	0.04
Bromus unioloides	1.32	1.98	0.04
Aster squamatus	1.30	0.07	
Carex sororia	1.30		5.01
Anthemis cotula	1.27	0.58	
Spergularia villosa	1.27	0.01	
Spergularia ramosa	1.25	0.60	
Dichondra microcalyx	1.25	2.50	
Trifolium sp.	1.25		0.03
Lollium multiflorum	0.07	0.59	2.20
Limonium brasiliense	0.07	0.59	
Juncus balticus	0.05		0.03
Setaria geniculata	0.05	0.59	0.74
Modiolastrum gillesii	0.05	0.02	0.71
Hordeum euclaston	0.02	5.87	0.73
Rumex crispus	0.02	0.03	0.08
Coniza bonariensis	0.02		0.77
Sida rhombifolia	0.02		
Eleusyne tristachya	0.02	1.97	0.04
Polygonum sp.	0.02	0.03	0.01
Sonchus oleraceus	0.02	0.01	
Sonchus asper	0.02		
Medicago hispida	0.02		
Polygonum brasiliense	0.02	0.01	0.01
Ammi viznaga	0.02	0.01	0.03
Sporobolus pyramidatus		7.24	
Distichlis spicata		0.57	0.74
Chaetotropis chilensis		0.57	
Hymenoxis anthemoides		0.07	0.01
Lepidium sp.		0.04	
Petunia parviflora		0.03	
Salicornia ambigua		0.02	0.01
Euphorbia serpens		0.02	0.03
Sporobolus indicus		0.02	
Small rose		0.02	
Trifolium repens		0.02	
Sesuvium portulacastrum		0.01	0.01
Apium sellowianum		0.01	0.01
Heliotropium curassavicum		0.01	
Triglochlin striata		0.01	
Picrosia longifolia		0.01	0.01
Spartina densiflora		0.01	
Solidago chilensis		0.01	
Senecio pinnatus		0.01	
Brassica hirschfeldia		0.01	
Carduus acanthoides		0.01	0.03
Undetermined vegetative		0.01	
Anoda cristata		0.01	
Paspalum dilatatum			37.86
Alternanthera philoxeroides			2.50
Stipa brachichaeta			2.50
Sida leprosa			2.14
Hirschfeldia sp.			1.43
Ambrosia tenuifolia			0.71
Cressa truxilensis			0.07
Verbena gracilescens			0.04
Carex bonariensis			0.04
Teucrium cubescens			0.01
Anthemis sp.			0.01
Physalis viscosa			0.01
Medicago lupulia			0.01
Melilotus officinalis			0.01

Appendix 2. Canonical function and components by transect and variables.

Transect 1. The following equations represent the first pair of canonical variables:

$$u_1 = -0.41\ x_1 + 0.91\ x_2$$
$$r = 0.71$$
$$v_1 = \ 0.99\ y_1 + 0.10\ y_2$$

Variables x_1, x_2 and y_1, y_2 below are principal components for species and soil factors respectively:

$x_1 = \ldots -28.78$ Paspalum vaginatum $+ \ldots + 23.57$ Spartina densiflora $+ \ldots$

$x_2 = \ldots -10.41$ Paspalum vaginatum -10.37 Spartina densiflora $+ \ldots + 16.32$ Phyla canescens $+9.62$ Stipa hyalina $+ \ldots$

$y_1 = \ldots -0.86$ elevation -0.82 bicarbonate -0.80 pH (water extract) -0.80 pH (soil paste) -0.77 sodium percentage -0.68 carbonate $+ \ldots + 0.87$ organic matter $+0.75$ exchangeable magnesium $+0.73$ clay $+0.69$ total exchangeable bases $+ \ldots$

$y_2 = \ldots -0.90$ chloride -0.89 sulfate -0.89 conductivity -0.88 total salts -0.88 total sodium -0.87 total magnesium -0.84 total potassium -0.79 exchangeable calcium -0.76 total calcium $+ \ldots + 0.66$ carbonate $+0.50$ coarse sand $+0.50$ sodium percentage $+ \ldots$

Transect 2. The following equations represent the first pair of canonical variables:

$$u_1 = 0.40\ x_1 - 0.91\ x_2$$
$$r = 0.75$$
$$v_1 = -0.91\ y_1 - 0.41\ y_2 - 0.09\ y_3$$

Variables x_1, x_2 and y_1, y_2, y_3 below are principal components for species and soil factors:

$x_1 = \ldots -22.93$ Paspalum vaginatum -9.19 Phyla canescens $+ \ldots + 34.27$ Spartina densiflora $+ \ldots$

$x_2 = \ldots -22.53$ Paspalum vaginatum -10.45 Spartina densiflora $+ \ldots + 14.94$ Phyla canescens $+8.30$ Stipa hyalina $+ \ldots$

$y_1 = \ldots -0.94$ sulfate -0.94 sodium -0.93 conductivity -0.92 total magnesium -0.91 total salts -0.88 saturation percentage -0.87 moisture equivalent -0.86 calcium carbonate -0.85 potasium -0.85 chloride $+ \ldots + 0.59$ silt (50 u) $+0.54$ fine sand

+ ...

y_2 = ... −0.88 sodium percentage −0.83 pH (water extract) −0.69 pH (soil paste) −0.67 coarse sand −0.65 elevation −0.56 bicarbonate + ... +0.83 carbonate +0.71 exchangeable calcium +0.70 total calcium +0.65 total exchangeable bases +0.64 clay + ...

y_3 = ... −0.49 total calcium −0.40 elevation + ... +0.68 exchangeable magnesium +0.62 clay +0.48 pH (soil paste) +0.46 exchangeable sodium +0.38 pH (water extract) + ...

Transect 3. The following equations represent the first pair of canonical variables:

$$u_1 = -0.98\ x_1 - 0.17\ x_2$$

$$r = 0.87$$

$$v_1 = 0.76\ y_1 + 0.65\ y_2$$

Variables x_1, x_2 and y_1, y_2 below are principal components for species and soil factors:

x_1 = ... −12.51 Stipa hyalina −12.50 Paspalum dilatatum −11.25 Phyla canescens −9.33 Spartina densiflora + ... +34.92 Paspalum vaginatum + ...

x_2 = ... −15.40 Stipa hyalina −12.33 Paspalum dilatatum −12.17 Phyla canescens −8.09 Paspalum vaginatum + ... +20.35 Spartina densiflora + ...

y_1 = ... −0.92 pH (soil paste) −0.91 pH (water extract) −0.91 elevation −0.85 calcium carbonate −0.84 bicarbonate −0.82 sodium percentage −0.74 carbonate + ... +0.92 exchangeable magnesium +0.90 total calcium +0.85 total exchangeable bases +0.83 total magnesium +0.79 exchangeable calcium +0.68 posphate +0.63 clay +0.55 organic matter + ...

y_2 = ... −0.93 moisture equivalent −0.92 chloride −0.88 saturation percentage −0.87 total potassium −0.86 total salts −0.85 conductivity −0.78 sulfate + ... +0.76 coarse sand +0.62 silt (50 u) + ...