Soil Survey Based on Sampling Scheme Adjusted to Local Heterogeneity

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Introduction

Hortobágy in NE Hungary is the largest contiguous salt-affected landscape in Central Europe. Because of its relatively low fertility it is characterized by extensive land use, mainly cattle and sheep grazing. Many elements of the formerly more diverse biome, which extincted from the majority of the intensively used Great Hungarian Plain, survived here. To save these elements as well as the traditional land use, Hungary's first national park was established on part of the Hortobágy two decades ago.

The soil and vegetation of Hortobágy has been intensively studied (cf. MAGYAR, 1928; SZABOLCS, 1989; BODROGKÖZY, 1965: RAJKAI et al., 1988; TÓTH and RAJKAI, 1994). The salt-affected landscape is highly sensitive to changes in the climatic and hydrological conditions both in space and time. As was mentioned above, the formation of the landscape, specifically of the soil, is the resultant of several, partly local, factors like groundwater composition and depth, high evaporation and relief. Consequently, the landscape is extremely heterogeneous and may change rapidly with the changing climate. In order to follow and predict the changes a thorough soil and vegetation survey was carried out. At the same time, because of the extreme heterogeneity, a novel approach to vegetation and soil mapping has been developed and tested.

As stated by 'SIGMOND (1927b) *"The greatest difficulty, in surveying salty or alkali soils for mapping, consists in the very fact that the distribution of the water-soluble salts is widely variable both in their horizontal, as well as in their vertical sections. ...it seems to me more reliable and easier to accommodate the sampling of the soil according to the native vegetation or the cropped culture plants and their cropping conditions."* In his time RAPAICS (1927), TREITZ (1927), BALLENEGGER (1929) and others used these principles widely, and MAGYAR (1928) established a correlation between the ranges of salinity and sodicity distinguished in 'Sigmond's classification of Hungarian salt-affected soils and the plant associations of solonetzic landscapes. Starting from these foundations BODROGKÖZY (1965) created a system correlating plant categories (down to the level of subassociations) with the genetic soil categories (down to the level of variants) of the Hungarian solonetz grasslands. A quantitative description of the variability of the soils and vegetation was given by RAJKAI et al. (1988). The correlation between vegetation and soil is strong enough to be formalized and used for the prediction of soil pH, soil salt content and soil sodium concentration in mapping (TÓTH & RAJKAI, 1994).

'SIGMOND and MAGYAR (1928) elaborated a parallel soil and vegetation classification system for salt-affected areas, in which classes with differing salt content and soda content were distinguished within two large groups, one consisting of wet alkali biotopes and one of dry ones. These conditions are shown later on in Figure 2 and Table 2. (In Table 2 the logic of the increase and then decrease of salt content and pH and the parallel deficiency of available soil moisture is expressed.) The most adverse conditions, i.e. the driest (because of the often solodized A horizon and the high clay content in the Natric B horizon) and most saline, alkali conditions, are found in the middle of the catena. The relative location, i.e. the relative elevation of the biotopes (the soil and vegetation), shows a systematic correlation with the ecological conditions. In the study this correlation has been used to create a new variable, the "catena position", i.e. the relative elevation-class of the spots relative to the geomorphologically deepest spots, the marshes. The catena position was determined based on the vegetation category distinguished *in situ*.

The traditional survey method is based on delineations of soil patches which are then characterized by soil type names and by the associated expected values and ranges for the variables of interest. This method needs detailed *a priori* stratification of the sample site, small numbers of sampling points, usually profiles, thorough profile description and analyses, and a series of *a posteriori* judgements on the delineations (WEBSTER & OLIVER, 1990).

Recently, geostatistical methods have been applied for mapping, utilizing spatial stationary assumptions for the variables of interest (WEBSTER, 1985). Applying geostatistics requires more samples from strictly known locations and provides better estimations of the numerical variables than the traditional survey method, but can hardly proceed the categorical variables such as soil type, although there are efforts to expand the field of application.

The vegetation, which indicates soil properties, can be utilized in soil surveys either by field observation or by remote sensing. However, vegetation is rarely applied for soil mapping in Europe as soil surveys usually focus on intensively used landscapes where the land use disguises the effect of soil on vegetation. For the same reason, remotely sensed data only serve as a basic map, i.e. for basic stratification.

As was described above, the vegetation and soil types of the salt-affected landscape can be arranged along a catena. Thus the primary target variable of the mapping was the catena position which integrates our knowledge about both the vegetation and the soil. It was assumed that, knowing the catena position of a site, the values of characteristic soil properties could be predicted.

According to previous field experience (RAJKAI et al., 1988; TÓTH et al., 1991), and to the application of airborne photographs (TÓTH & KERTÉSZ, 1993) and satellite images (KERTÉSZ et al., 1994), the vegetation and soil pattern of the salt-affected landscape of Hortobágy can hardly be assumed stationary since most of the soil and vegetation types occur in small patches from several square metres up to large patches of several or several dozen hectares; at the same time there are abrupt boundaries as well as gradual trends between the patches. Thus the pilot area of 5 by 5 km could not be stratified as required for traditional soil mapping; the regular sampling design suggested by geostatistics was also rejected.

With the help of satellite images, utilizing the correspondence between the vegetation and the soil, it is possible to make a sampling design for mapping. A formal solution is suggested for making the sampling design, with a varying density of sampling points following the varying heterogeneity of the satellite image. This means that fewer samples are taken from less heterogeneous parts of the pilot area and more samples from the more heterogeneous parts.

In spatial data processing a well-known data storage method is the quadtree (SAMET, 1990), where large homogeneous patches are represented by large squares and smaller patches by smaller squares. The squares form a hierarchical system, i.e. a tree, where each square contains four subsquares. Quadtrees are usually used for storing maps without information loss, i.e. the maps can be recovered without loss of details, but they have recently been used for representing spatial data with information loss as well (CROSS et al., 1988; STROBACH, 1991; KERTÉSZ et al., 1994). It is suggested that this varying resolution representation should be applied with controlled information loss for sampling design (CSILLAG et al., 1994).

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Materials and Methods

Survey site

The Hortobágy National Park is located in the Great Hungarian Plain, between 47'45" and 47'25" N and 20'55" and 21'20" E. The area is very flat; the mean altitude is 89 m above sea level, but most of the area lies between 88 and 92 m. In this basin of the river Tisza the mean January temperature is -4.5 °C and mean July temperature is 21.5 °C. The mean yearly precipitation is 540 mm. The parent material of the soils is stratified alluvial deposit, river sediments and transported loess.

Sampling design

The basis of the sampling design was a panchromatic SPOT satellite image with 10 m nominal resolution. The image was taken on September 28, 1990, when the pilot area was very dry. The criterion of the image selection was to obtain the maximal spatial resolution and maximal difference between the vegetation types.

The size of the image (Figure 1) is 512 by 512 pixel, so it represents an area of approx. 5120 by 5120 m. The image was then approximated by a series of quadtree-represented maps. The first map consisted of one homogeneous quadrant covering the whole image. Then it was split into four quadrants. The diver-

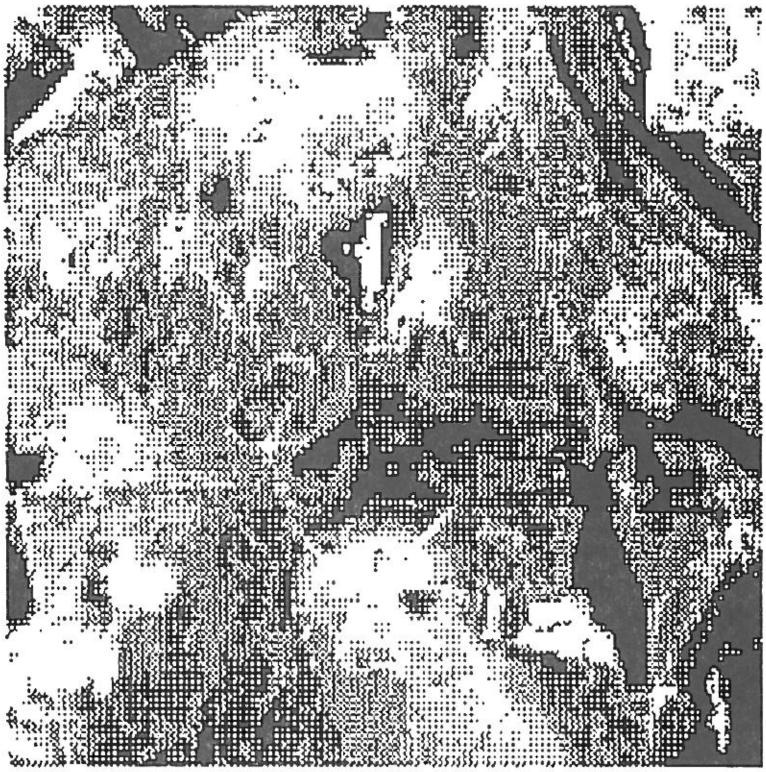

Figure 1
The panchromatic SPOT satellite image of the pilot area

gences of the quadrants from the covered part of the image were calculated, then the quadrant of the maximal divergence was split into four quadrants again. The last two steps were repeated until a predefined number of quadrants was reached.

The divergence calculated can be considered as a measure of the local heterogeneity of the image. In the more heterogeneous parts the divergence is higher; thus these parts are split while less heterogeneous parts remain intact. Consequently, an uneven pattern of quadrants is achieved, where the more heterogeneous parts of the image are represented by smaller quadrants and the less heterogeneous parts by larger ones.

To calculate the divergence it is assumed that both the image and its map consist of pixels. Each pixel of the image corresponds to a pixel of its map. Inside a patch of the map, i.e. quadrants in the case of quadtree-represented maps, each pixel has the same value, which is equal to the mean of the corresponding image pixel values. A kind of f-divergence, a modified version of Kullback-divergence, was applied:

$$D(image|map) = \sum_{i=1}^{I} \sum_{j=1}^{J} \left[image_{ij} / SUM\right] \log_2 \left(image_{ij} / map_{ij}\right)$$

and

$$SUM = \sum_{i=1}^{I} \sum_{j=1}^{J} image_{ij} = \sum_{i=1}^{I} \sum_{j=1}^{J} map_{ij}$$

where:

$image_{ij}$ is the value for the *i,j*th pixel of the image;

map_{ij} is the value for the *i,j*th pixel of the map

I and J are the side lengths of the image and the map in pixels

A thorough description of the approximation is given by KERTÉSZ et al. (1994).

The satellite image was approximated with a quadtree-represented map of 256 quadrants. Then the sampling points were located in the centres of the quadrants of the map.

Field sampling

The key to field surveys utilizing spatial statistics is the exact location of the sampling points in the field. First the local geodesy system determined by the rows and columns of the image applied had to be fitted to a cartographic geodesy system which was a Gauss-Krüger projection. The accuracy of the fitting was estimated to be less than 10 m, i.e. less than a pixel size. Thus the location of two orientation points could be expressed in local coordinates. For locating the sampling points, a theodolite with infrared distance meter was used. Because of the mirage, the range of the distance measurement was up to 900 m. The accuracy of the determination of the location was within 2 m based on repeated determinations with altered derivation.

In the field, samples were taken at 234 locations out of 256 designed sampling points, leaving out those which fell on roads, canals, fishponds, farmhouses, etc. For interpolations and computations regarding the soil-vegetation correlation 214 locations were used, leaving out some points referring to arable lands and introduced forests. For computations regarding the spatial pattern of the studied variables samples were used from 196 locations, leaving out some points which were placed close to each other because the local inhomogeneity of the satellite image accidentally induced by a cloud.

Detection of vegetation

The semi-natural vegetation around the sampling points was classified in circles of 15 m radius. The vegetation types were determined approximately according to the coenotaxonomy used by BODROGKÖZY (1965). The determination was not quite correct in terms of coenotaxonomy because detailed coenotaxonomic records were not made, but at the same time transitional types and dominant plant species were recorded. The vegetation types where the soil samples had been taken were also noted. Later the types recorded (more than 60) were grouped into 6 catena position categories (Figure 2).

Selection of chemical variables for study

The selection of the appropriate soil chemical variables was guided by two requirements: the variable should show close correlation with the seminatural vegetation (because the sampling scheme was based on the indication of the vegetation, and because it was intended to map ecologically important soil variables), and it should not be too tedious.

Traditionally there are 3 groups of chemical properties widely used for the characterization of salt-affected soils:

- pH value measured in soil water extracts, suspensions or pastes;
- salt content or EC measured in soil paste or in aqueous extracts with different soil:water ratios;
- exchangeable sodium and cation exchange capacity (CEC) from which exchangeable sodium percentage or ESP (exchangeable sodium/CEC * 100) is calculated.

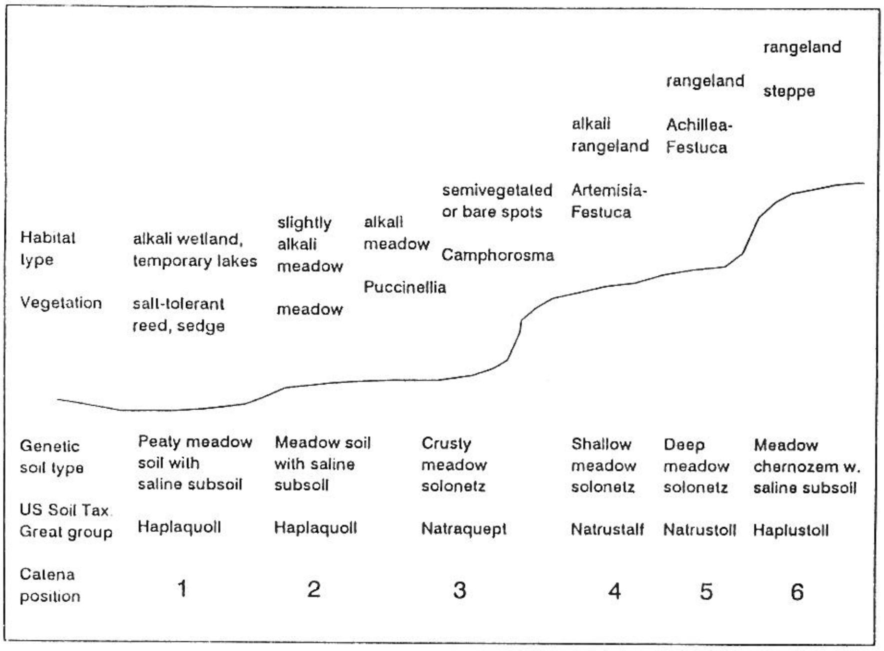

Figure 2
Scheme of catema positions

Besides the salt content or EC, the ratio of dissolved Na^+ to bivalent cations, measured in soil water extracts (SAR), and the relative amount of exchangeable sodium (ESP) are the most important parameters in the diagnosis of salt-affected (saline and alkali) soils.

The pH of saline and alkali soils is basically determined by the sodium saturation of the colloids, the salt content of the soil solution, the ionic composition of the solution and the partial pressure of CO_2 (FILEP, 1988).

At present, it is possible to formulate theoretical equations which describe the relation between the above-mentioned chemical properties and the ratio of Na^+ to bivalent cations either in the soil solution or in the exchange complex (DUDLEY, 1994; USSL, 1954). Owing to the difficulties arising in the determination of exchange coefficients these relationships are often approximated by curve fitting procedures (USSL, 1954; CHANG et al., 1956; ROBBINS & MEYER, 1990; ROBBINS, 1993).

The use of theoretical formulae that relate SAR, ESR or ESP to salt content, sodium content and pH is complicated by difficulties in determining the value of pCO_2 and individual dissociation constants (SZABOLCS, 1989; DARAB, 1981).

There is a consensus regarding the basic form of that relationship, such as formulated by GUPTA et al. (1981) on the interrelationship of ESR, the partial pressure of CO_2 (pCO_2), Na concentration, pH and ionic strength (I)

$$\log ESR = 0.51 * I + pH + 0.5 * \log pCO_2 + \log Na + 5.236$$

The assumption in the present study was that it is possible to determine a stochastic relationship between measured soluble sodium, pH and electrical conductivity data and ESP, ESR or SAR. Such a relationship should be considered valid only locally and used for the estimation of ESP, ESR or SAR under limited circumstances.

The data of some published works were reevaluated to compute the multiple regression equation of soluble sodium concentration, pH and electrical conductivity data (predictor variables) and ESP, ESR or SAR (predicted variables) using the logarithmic values of the chemical components studied. The soils originated from Europe (KUST, 1985; TÓTH, 1989), Asia (GUPTA et al., 1981) and Northern America (REID et al., 1993; HECK & MERMUT, 1992) and the values of multiple R for the cases reviewed ranged from 0.85 to 0.99 and indicated that it is possible to use pH, sodium concentration and salt content values to predict the ratio of sodium to calcium plus magnesium in the exchange complex or soil solution. In samples from differing depths and horizons sodium concentration, salt content and occasionally pH were important variables in predicting the ratio of sodium to calcium + magnesium. In samples collected close to the surface the sodium content is usually the only important parameter which is useful for the prediction of the ratio of sodium to calcium + magnesium, presumably because of the pedogenic homogenization of soil properties.

Among the soil samples collected in the study area, those selected represent the high variation of soils in Northern Hortobágy, for the full catena of soils and vegetation. These samples were collected in the solonetzic catena (hydromorphic soils, solonetzes, solonetzic soils and chernozems), from horizons A to B, and depths 0 to 30 cm.

The SAR of Hortobágy soil samples was calculated from Na, Ca and Mg concentrations determined in the saturation extract; EC (mS/cm), pNa (the negative logarithm of the Na ion activity, mol/litre) and pH were all measured in a saturation paste, using appropriate conductivity cells, ion selective electrodes and pH electrodes, respectively.

The basic parameters of Hortobágy soil samples are as follows:

Variable	Mean	Std dev.	Minimum	Maximum	N
SAR	10.65	8.82	0.72	37.8	30
EC	0.98	0.66	0.22	2.48	30
pH	6.80	0.99	5.20	8.75	30
pNa	2.06	0.57	1.42	3.81	30

The relationship between the SAR and other parameters of the Hortobágy samples was the following.

$$\ln SAR = 4.718 - 0.163 * \ln EC + 0.048 * pH - 1.510 * pNa$$

$$R = 0.81$$

Based on the above results we decided to use saturation paste to measure pH, EC and sodium ion activity, ommitting the cumbersome determination of either ESP or SAR, because of the difficulty involved in obtaining a saturation extract from the heavy soils studied and in determining exchangeable sodium and CEC (for ESP), where the error of analysis is high. Consequently the pH, EC and sodium ion activity measured in the saturated paste were selected as chemical variables for characterizing the salinization and alkalinization status of the sampled spots.

Since RAJKAI et al. (1986) showed that in Northern Hortobágy layers 10 cm thick were only correlated with the studied vegetation properties to a depth of 40 cm, it was decided to take 10 cm thick samples to a depth of 30 cm.

Vegetation-soil correlation

Regression and discriminant analysis were used for studying the correlation between the soil and vegetation properties. In the case of regression the independent variable was the catena position, which was considered as an interval variable instead of as a rank variable. This means that the number denoting the catena position is considered to be an index referring to the vegetation and soil status of the sample points.

The electric conductivity values were log-transformed because their distribution was right-skewed. In this way all the chemical measurements, i.e. pH, pNa and lnEC, were consistently log-transformed, and this transformation was also required to predict SAR values from the measured parameters. A series of regressions were calculated where the dependent variables were the above three chemical measurements from the three depths (0-10, 10-20, 20-30 cm) and their averages by depth. Beyond the univariate linear regression multivariate linear regressions were also calculated using quadratic and sine terms. The strength of the correlation was expressed by the multiple correlation coefficient R.

Discriminant analysis was used to study the correspondence between vegetation types and measured soil properties. The logic of discriminant analysis is that the grouping is found by the ranges of linear combinations of the dependent numerical variables which have the maximum correspondence with a predefined grouping, i.e. the ranges (or values) of the independent variable. In the present case, the predefined grouping was the catena position and the dependent variables were the pH, pNa and lnEC of the three depths.

Interpolation

Unlike traditional mapping where the soil patches are drawn to be homogeneous, geostatistical methods were used where the target variables are estimated in non-sampled locations with interpolation. While in the sampling design the spatial distribution of the studied variables was not assumed to be stationary, kriging and cokriging were used for interpolation, requiring the assumption of stationarity (cf. WEBSTER, 1985). Kriging and cokriging are robust against certain deviations of models from stationary ones, but in this case kriging and cokriging can be considered suboptimal in terms of minimizing the estimation variance.

The catena position was interpolated using this variable as an interval index. As co-variable, the elevation derived from the contour map was applied. Isotropic spheric variograms and crossvariograms were used with ordinary cokriging in an 80 by 80 m grid.

The variogram calculation and interpolations were performed using Geo-EAS and GeoPack programmes. The variogram models were fit weighted by the numbers of pairs. The derivation of elevation from the contour map was carried out using ARC/Info. The maps were drawn with IDRISI programmes.

Results and Discussion

Sampling design

The satellite image with the sampling design is shown in Figure 3. The performance of the sampling design was checked by reconstructing the satellite image from the pixel values at the sampling points. The suggested design proved better than regular or random schemes (CSILLAG et al., 1994).

The average sampling point spacing is 320 m in the pilot area in the case of 256 sampling points. In the present sampling design the spacing ranges from 640 m to 80 m. Table 1 shows the distribution of catena positions by sampling spacing.

The Artemisia-Festuca and Achillea-Festuca catena positions represent less heterogeneous parts of the sample site while wetland catena position samples come from more heterogeneous parts. This result coincides with field experience. The number of Camphorosma and Puccinellia samples were too small to provide a reliable estimation of their distribution by spacing. In fact, these types can often be found in smaller patches than the pixel size of the image used, so their spatial pattern did not directly affect the sampling design.

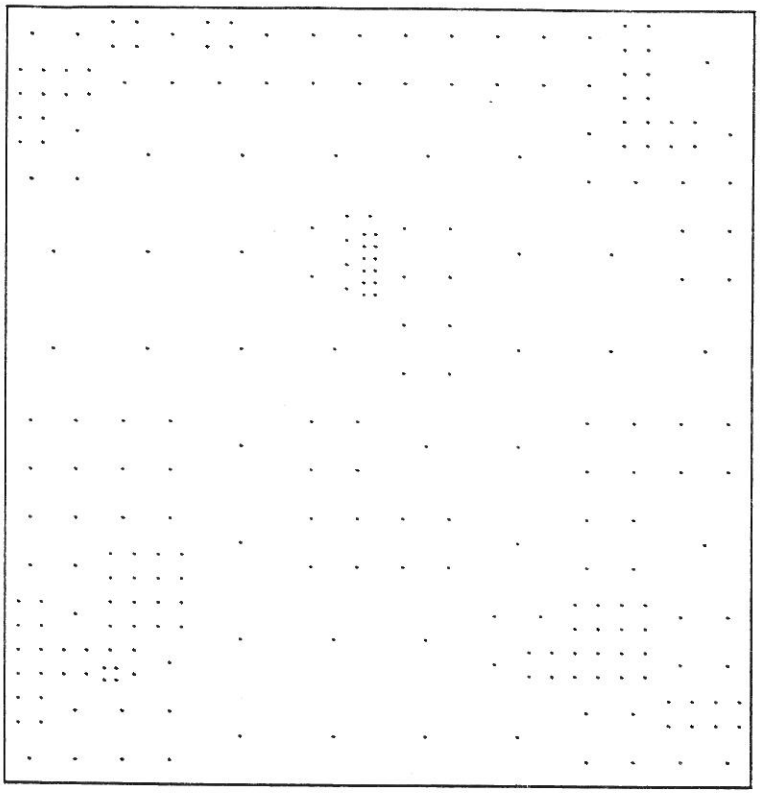

Figure 3
Sampling scheme

Table 1
Distribution of catena positions by sampling spacing

Spacing	N	Wetland	Meadow	Cam-Puc	Art-Fes	Ach-Fes	Steppe	Area (ha)
640 m	29	1	3	1	14	9	1	1187.8
320 m	85	3	22	2	23	18	17	870.4
160 m	68	11	7	1	21	3	25	174.1
80 m	14	10		2	1	1		9.0
Total	196	25	32	6	59	31	43	2241.3
Area (ha)		106.2	366.1	65.3	863.4	561.3	279.0	2241.3

The area was computed by summation of quadrants of the given side length

Table 2

The means and standard deviations of the studied soil parameters by catena position classes

Catena Position	Case	Height	lnEC			pH			pNa		
			0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1 Wetland	28	88.58	-0.23	-0.22	-0.15	6.60	6.78	7.13	2.12	2.09	1.99
s.d.		0.34	0.21	0.25	0.24	0.99	1.06	0.94	0.42	0.46	0.37
2 Meadow	36	88.89	-0.11	0.02	0.12	6.27	6.97	7.43	1.88	1.77	1.71
s.d.		0.45	0.18	0.24	0.24	0.77	0.83	0.92	0.31	0.39	0.35
3 Cam-Puc	7	88.74	0.24	0.38	0.46	8.06	8.74	9.04	1.47	1.38	1.34
s.d.		0.51	0.22	0.22	0.25	0.41	0.57	0.72	0.21	0.22	0.20
4 Art-Fes	68	88.86	0.08	0.29	0.43	6.97	7.82	8.44	1.63	1.47	1.35
s.d.		0.36	0.24	0.23	0.22	0.65	0.71	0.65	0.24	0.28	0.18
5 Ach-Fes	32	89.15	-0.33	-0.04	0.16	0.97	6.79	7.22	2.29	1.86	1.75
s.d.		0.47	0.23	0.32	0.16	0.73	0.83	1.04	0.49	0.49	0.58
6 Steppe	43	89.66	-0.39	-0.38	-0.34	6.70	6.84	6.98	3.07	2.88	2.90
s.d.		0.67	0.17	0.15	0.18	0.92	0.79	0.76	0.53	0.57	0.67
Total	214	89.03	-0.14	-0.00	0.11	6.64	7.22	7.65	2.12	1.94	1.86
s.d.		0.58	0.29	0.35	0.38	0.89	0.97	1.05	0.66	0.67	0.71

Vegetation-soil correlation

The means and standard deviations of the most important chemical properties determined in the saturation paste are shown in Table 2.

The increase in pH, sodium ion activity and EC from the low and high ends of the catena towards the Camphorosma-Puccinellia category is clearly visible. The Wetland category showed higher salt content than the Steppe category, since in the steppe the salts are leached by infiltrating precipitation, whereas in the wetlands these salts are accumulated, but at the same time are diluted by the accumulated surface and subsurface waters.

Discriminant analysis shows the separability of the different catena positions in terms of linear combinations of chemical measurements (Table 3).

Table 3

Classification results of the discriminant analysis performed with the soil chemical variables

Catema position		**Wet-land**	**Mea-dow**	**Cam-Puc**	**Art-Fes**	**Ach-Fes**	**Steppe**
	Cases	**44**	**27**	**23**	**45**	**40**	**35**
1 Wetland	28	23	4			1	
2 Meadow	36	6	16	2	6	5	1
3 Cam-Puc	7			7			
4 Art-Fes	68	5	4	13	35	11	
5 Ach-Fes	32	3		1	4	21	3
6 Steppe	43	7	3			2	31

Cam-Puc: Camphorosma Puccinellia; Art-Fes: Artemisia Festuca; Ach-Fes: Achillea Festuca; Precision of classification: 62%;

Discriminant analysis indicated that the highest correlation with the standardized discriminant functions was shown by the sodium ion activity values measured in the saturation pastes and the electric conductivity values.

Table 3 shows that the most alkali classes are the easiest to classify, i.e. the dispersion of the values of chemical properties is the smallest inside the Camphorosma Puccinellia category. This was also proved by the means and s.d. values in Table 2. The poorest possibility of classification was shown by the Meadow class, since, according to the classification of MAGYAR (1928) and 'SIGMOND (1927a), it included vegetation categories of different salt content and alkalinity status. The overall precision of classification is favourable and shows that, although the ranges of the studied soil properties overlap, the relationship between the classes and soil properties can be used for prediction.

In a subsequent step an attempt was made to use the catena positions as predictor variables of soil pH, salt content and sodium concentration. Regression equations were calculated in which the dependent (predicted) variable was one of the studied soil chemical properties and the independent (predictor) variables were the transformed values of the quantified catena position. The different versions of data transformations and inclusions in the regression analysis are shown in Table 4, with the indication of the multivariate R values only.

Table 4

Correlation coefficients (R) of the regression equations used for prediction of soil chemical properties

Variable		Regression type		
		Linear	Quadratic	Quadratic with sine
pNa	avg	0.40	0.81	0.82
	0-10	0.46	0.80	0.80
	10-20	0.35	0.77	0.79
	20-30	0.36	0.77	0.79
pH	avg	0.02	0.40	0.55
	0-10	0.01	0.12	0.49
	10-20	0.01	0.42	0.54
	20-30	0.06	0.53	0.62
lnEC	avg	0.18	0.74	0.76
	0-10	0.24	0.61	0.68
	10-20	0.15	0.72	0.74
	20-30	0.14	0.76	0.76

The inclusion of quadratic and sine terms increased the precision of the predictions to an acceptable level. The sine transformation was necessary to change the symmetrical line of the regression equation to account for the asymmetry of the two sides of the curve (Figure 4), as was mentioned previously, to account for the lower soil sodium content at the higher end (steppe) of the catena.

The precision with which soil chemical properties are predicted can be inferred from the value of the correlation coefficient. The R values found between predictor and predicted variables in good predictions by TÓTH and RAJKAI (1994) (0.6-0.7), TÓTH et al., 1994 (0.61-0.75) and VAUCLIN et al. (1983) (0.6-0.83) are similar to those obtained in this paper with EC and pNa values (0.76-0.82). The precision of predicting pH values from the catena position is low.

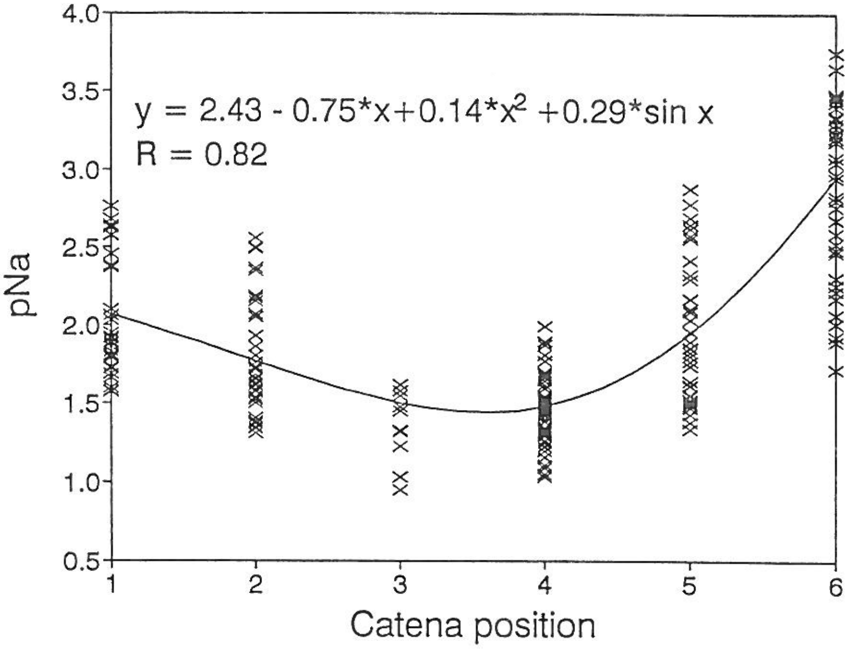

Figure 4

The curve of the regression equation predicting average pNa from the Catena position values

Interpolation of catena position index

In this section the term catena position index is used in order to emphasize that the catena position data were considered to be interval variables. The cross-semivariogram of the catena position index with the elevation (Figure 5) shows a strong spatial structure in spite of the fact that the linear correlation between them is small, because the relation between them is not entirely linear.

The distribution of the interpolated data calculated by cokriging is usually "more normal" than the input data, and this was the case in the present interpolation, where the distribution of detected catena position indices was far from normal. The difference between the two distributions was too great to accept the result. Thus, the interpolated data were reclassified (Figure 6), producing categories for map drawing with the same area distribution as was represented by the detected catena position data (Table 1).

The resultant map consists of 4096 pixels 80 by 80 m in size. The map corresponds well with field experience. The drawn categories denote the most probable local catena positions, except for the Camphorosma-Puccinellia (3)

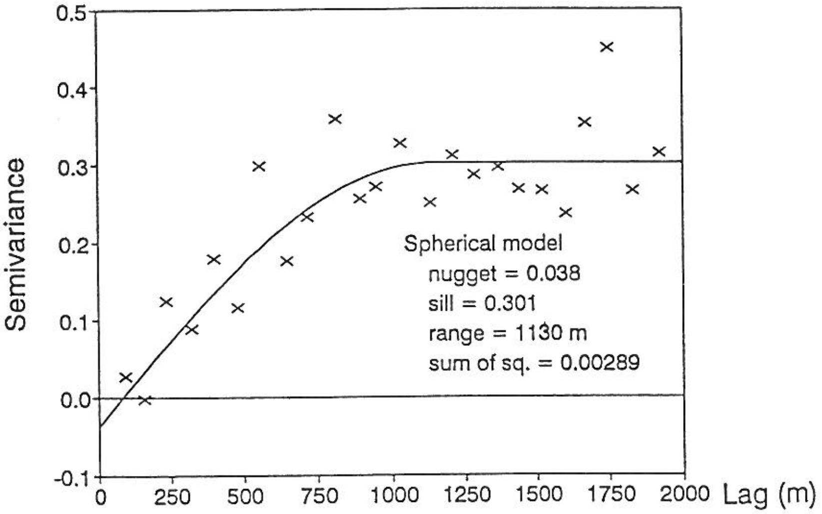

Figure 5

Cross-variogram of catena position index with elevation

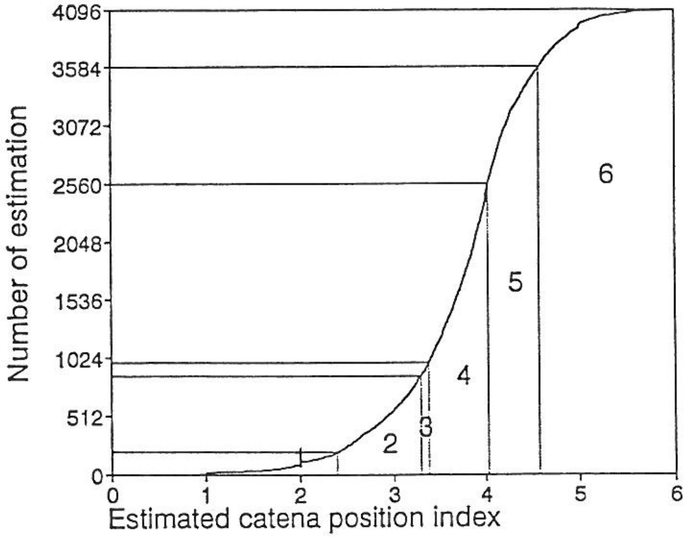

Figure 6

Frequency distribution of interpolated catena position indices and their reclassification according to the detected area distribution of catena positions. The ordinates of the horizontal lines display the detected area distribution. The vertical lines show the boundaries of the produced categories. The numbers in the graph denote the categories for map drawing

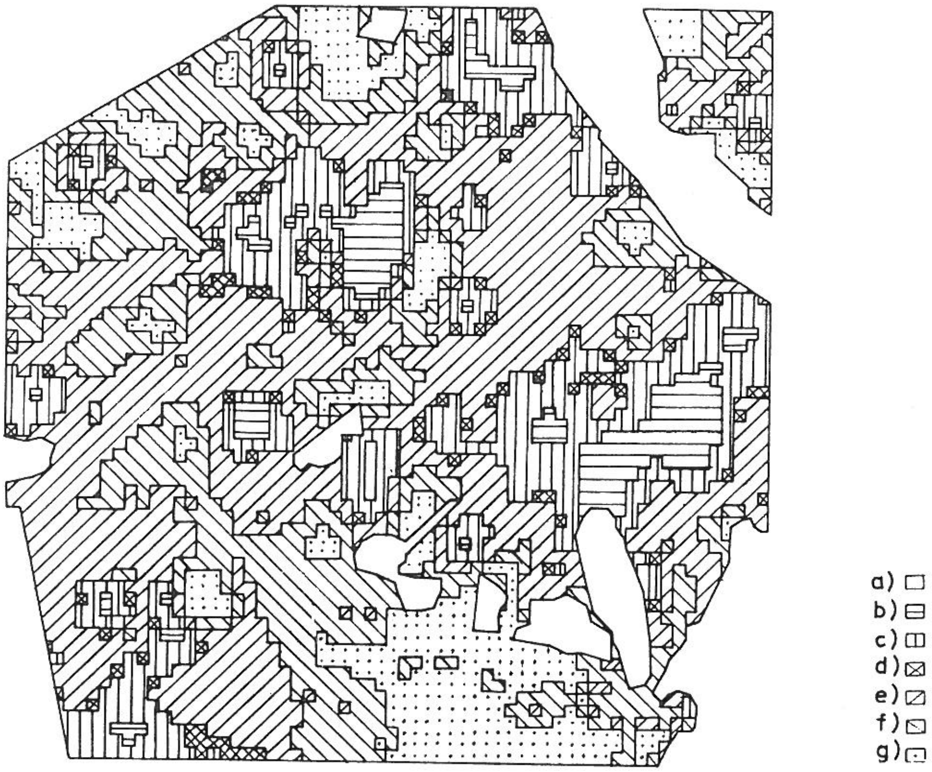

Figure 7

Map of catena position (cokriged with elevation).
a) Non-classified; b) Wetland; c) Meadow; d) Camphorosma-Puccinellia;
e) Artemisia-Festuca; f) Achillea-Festuca; g) Steppe

category. In the map (Figure 7) this category occurs in small patches between the Artemisia-Festuca (4) and meadow (2) categories. In fact, this type occurs in the same position in the field but in much smaller patches, as was mentioned earlier. It should perhaps be said that this catena position may occur in the Artemisia-Festuca and meadow categories with a certain frequency but at a resolution of 80 by 80 m there is no pixel where this is the most probable catena position.

Conclusions

The aim was to map the soil and vegetation of a salt-affected landscape in order to provide reliable information for the management of a nature conservation area. The target variable was the catena position which integrates knowledge on the soil and vegetation.

Efficient mapping requires the utilization of knowledge about relationships between the variables mapped. Spatial autocorrelations and between-attributes correlations were treated separately. Regarding the former, a formal solution is suggested taking spatial heterogeneity into consideration by designing sampling of uneven spatial density according to the satellite image of the pilot area. Regarding the latter, the determination of easily measurable chemical properties were chosen, i.e. pH, pNa and EC, utilizing their correlations with very important but tedious SAR measurements, and samples were only taken from the top 30 cm.

The close relation between natural-seminatural vegetation and soil properties can be used to estimate the latter if plant associations are identified.

It is intended to apply the probabilistic approach in the interpolation of the catena position types and in the prediction of soil properties. The use of remotely sensed images is planned not only in sampling design but in determining catena positions as well.

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