FINAL REPORT

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OPTIMAL RESOLUTION MAPPING OF SALT-AFFECTED LANDSCAPES

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Executive Summary

The objective of the project is to develop, test and verify information criteria to characterize environmental mapping data, and to apply it in field survey, information processing and agroecological management. The proposed methodology facilitates building geographic databases with optimizing accuracy on cost-benefit functions, therefore it is applicable for baseline studies as well as for areas where detailed information is available.

First we elaborated an image tiling method guided by the local heterogeneity. Using simulated images we found that based on tiling one could design sampling schemes which are more effective than regular or random or image classification based sampling design . Then we designed and carried on a detailed field sampling on a heterogeneous solonetzic grassland including botanical description and taking soil samples. After the laboratory analyses we studied the soil-vegetation correlation and proved its applicability in estimation of both quantitative and qualitative soil properties. Based on the early results we confirmed the applicability of the theoretical findings, i.e. the mapping process can be guided by the local heterogeneity of the mapped properties.

We pointed out that the spatial pattern of the remotely sensed image used was similar to the pattern of the relevant soil properties though there was poor correlation between sampled variables and satellite imagery. Consequently, the applicability of remotely sensed data at the spatial scale of our mapping proved limited. We produced interpolated maps of soil properties and vegetation cover of the study area using geostatistical methods. Recently we are looking for opportunities to utilize information on spatial structure of images to produce vegetation and soil maps. We elaborated a wavelet decomposition method providing multi-scale pattern description which we are intend to use to produce soil and vegetation maps applying conditional simulation. The data and procedures used has been integrated in GIS.

Research Objectives

The overall aim of the project was to develop an information criterion to characterize environmental mapping data, and to apply it in field survey, information processing and management. We intended to apply our findings to map the very heterogeneous solonetzic grassland. As stated by 'Sigmond (1927) "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 their vertical sections. ... it seems to me more reliable and easier to accommodate the sampling of the soil according to the native vegetation..." (cf. Rajkai et al. 1988, Tóth and Rajkai 1994). Since the remotely sensed data reflect well the spatial structure of the vegetation and therefore provide information on the pattern of soil cover as well (Tóth et al. 1991), we intended to use satellite images as auxiliary data source for soil and vegetation mapping.

From a geographical analytical perspective much effort has been devoted to characterizing the accuracy of maps derived from remotely sensed imagery (Congalton 1988, Goodchild and Wang 1989). In general, the costs are reported to be an exponentially increasing function of the quality of the results (Aronoff 1990). From a users point of view, the accuracy of maps is described most frequently in terms of the efficiency information extraction (Swain and Davis 1978).

Numerous methods serve as segmentation preprocessors significantly reducing the number of mapping units to be classified by identifying homogeneous patches (Masson and Pieczynski 1993). In many cases, these studies rely on extensive user information and sampling independent of the segmentation procedure, while they report an increase in the classification accuracy (Cross et al. 1988, Ton et al. 1991). Hierarchical methods are also investigated, but the goodness of approximation has not been measured by linking the number of units to loss of information (i.e. accuracy) while optimizing the latter (Cross et al. 1988, Strobach 1991). The users, however, prefer maps accuracy is uniform over the entire map, and the spatial resolution correspond to the level of detail required for its use. This goal can be achieved by varying spatial resolution (Csillag et al. 1992). A generalized concept for handling attribute and spatial information, called the cartographic uncertainty relation, suggests that when attribute accuracy is fixed, spatial resolution should vary, and vice versa (Csillag and Kertész 1989, Csillag 1991).

Traditional soil and vegetation surveys provide maps for salt-affected areas with a very small number of large, predictably heterogeneous patches while methods sensitive to local pattern lead to an unacceptably large number of relatively heterogeneous mapping units and require too many reference points. Both of these approaches are disadvantageous for sampling, mapping and modeling. Our specific objective, therefore, was to develop and test a method that links the heterogeneity of mapping units with the number of mapping units. Linking these two characteristics makes it possible to optimize one of them given the other.

Methods and Results

Methods

Survey site

The Hortobágy National Park is located in the Great Hungarian Plain, between 47'45" and 47'25" NL and 20'55" and 21'20" EL. The area is very flat, the mean altitude is 89 m above sea level, but most of the area is lying between 88 and 92 m. In this basin of the river Tisza the mean January temperature is -4.5 degrees centigrade and mean July temperature is 21.5 degrees centigrade. 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 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 criteria of the image selection was to obtain the maximal spatial resolution and maximal difference between the vegetation types.

The size of the image is 512 by 512 pixel, so it represents circa 5120 by 5120 m area. 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. We calculated the divergence of the quadrants from the covered part of the image. Then the quadrant of the maximal divergence was split into four quadrant again. The last two steps had been 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, 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 we assume 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 case of quadtree represented maps, each pixel has the same value, which is equal to the mean of the corresponding image pixel values. We applied a kind of f-divergence, a modified version of Kullback-divergence:

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

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 i,jth pixel of the image
map_{ij} is the value for i,jth 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. (1995).

We approximated the satellite image with a quadtree represented map of 256 quadrants. Then we located the sampling points to the centers of the quadrants of the map.

Field recordings and laboratory analyses

The field sampling was performed in June and early July 1992. At the sampling points soil samples were taken in 10 cm depth increments from the surface to 30 cm. In the field we took samples at 234 locations out of 256 designed sampling points leaving out those fallen on roads, canals, fishponds, farmhouses, etc. For interpolations and computations regarding the soil-vegetation correlation we used 214 locations leaving out some points referring arable lands and introduced forests. For computations regarding the spatial pattern of the studied variables we used samples from 196 locations leaving out some points which were placed close to each other because the local heterogeneity of the satellite image accidentally induced by a cloud.

Water saturated paste was prepared from the soil samples and left to equilibrate overnight. Next day electrical conductivity was measured with conductivity cell, pH with glass electrode and sodium ion activity with ion selective electrode, this latter expressed as pNa, i. e., the negative logarithm of the ion activity (mol L^{-1}).

Discriminant analysis was used to study how much the field categorization of vegetation can be reproduced based on the linear combinations of the soil data. The results were expressed in terms of the ratio of matching of the two categorizations.

Detection of vegetation

Plant species were recorded in 25 by 25 cm squares at the soil sampling locations. Small sampling units were used in order to minimize the chance of meeting borders of vegetation patches in the often extremely heterogeneous vegetation.
The semi-natural vegetation around the sampling points was classified in circles of 15 m radius. We determined the vegetation types approximately according to the coenotaxonomy used by Bodrogközy (1965). The determination was not quite correct in terms of coenotaxonomy because we did not take detailed coenotaxonomic records, but at the same time we recorded the transitional types and also the dominant plant species if it was not involved in the name to the detected plant association. Later we grouped the recorded, more then 60 types into 6 catena position categories.

Wavelet decomposition

At last, we shortly mention a recently developed new approach to characterize the spatial structure of satellite images (Csillag and Kabos, 1995). A quadtree-represented

image can be hierarchically decomposed by using three base functions for each quadtree leaves starting from the highest level (i.e. when the whole image is represented by one quadrant or rectangle) to the four-pixel leaves of the lowest but one level. The base functions are the north-south, east-west and chessboard difference. They are spatial difference operators and they are mutually orthogonal. The complete set of the function parameters provides an identical representation of the image. The wavelet decomposition can be considered a nested partitioning of the variance which is computed hierarchically. We intend to use this approach to simulate the properties to be mapped combining characteristics of the spatial pattern of the images with field reference data.

Results and Discussion

Performance of the sampling design

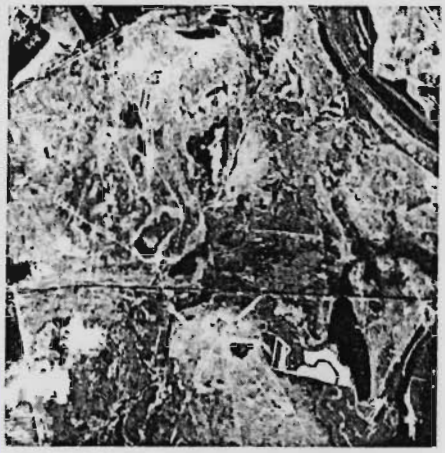
It was studied how the planned sampling density can satisfy the requirements of the traditional mapping and geostatistical evaluation (Burgess et al., 1981). The variogram of the panchromatic density of the remotely sensed image was calculated, i. e., the estimation of the variance of the difference of pairs of values as the function of distance (Webster, 1985). During the calculation not all data were used, only the data of 256 randomly selected points.

The range of the fitted spherical variogram was 619 m. This shows that points located at an average distance of 619 m from each other can be considered to be spatially independent. The sample of the 256 points represents 320 m average distance between the points, and this is suitable for map compilation. Although the requirements of spatial stationarity condition is not assumed to be met in the image and the points are not allocated in a regular or random arrangement, the variogram indicates that the selection of the number of sampling points was adequate.

On the other hand, the semivariogram of the electrical conductivity of the 0-10 cm layer showed a relatively low nugget/sill ratio (0.27) and a range similar to that of the panchromatic density calculated from random points (589 m). The other measured properties showed similar ranges (471 to 702) and low nugget ratio (0.2 to 0.47) as well. The similarity of the semivariogram parameters suggests that the spatial pattern of the vegetation (reflected by the image) and the soil properties are correlated. Nevertheless, the spatial distribution of the soil properties are "smoother" than that of the vegetation. This is the reason why they resulted in semivariograms of low nugget/sill ratio in spite of the uneven sampling arrangement.

The performance of the sampling design was checked in terms of reconstructing satellite images from the pixel values taken at the sampling points from auxiliary images. The auxiliary images were made of the original imaged adding random noise of different levels of variance and autocovariance ranges. Our suggested design proved better than regular or random schemes (Csillag et al. 1995).

The average sampling point spacing is 320 m in the pilot area in case of 256 sampling points (Figure 1) . In our sampling design the spacing ranges from 640 m to 80 m.



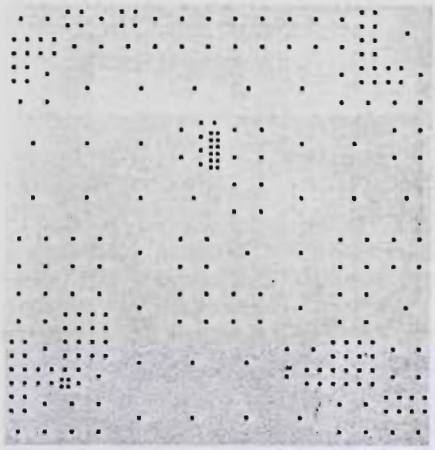


Figure 1. The SPOT panchromatic image used and the sampling design

Soil-vegetation correlation

In the study area about 60 vegetation categories were distinguished in the field and these were grouped hierarchically in three steps. Finally we got six categories representing the most characteristic soil and vegetation formations at the same time. These categories form a toposequence from the deepest depressions to the highest spots of the study area so we called them catena positions. They were labeled after the most (or only) characteristic plant associations (Figure 2).

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

The soil chemical data were used to examine whether the vegetation categories distinguished in the field match the grouping which is based on the similarities of the soil properties. This task is the opposite to that solved during the routine mapping of solonetzic soils, but it is convenient for the quantification of the power of the soil-vegetation relationship and to decide which are the easily predictable vegetation categories. This task also favors the compilation of a hierarchical system of vegetative associations based on the similarity of soil properties.
In studies carried out in smaller areas, comprising 3-4 associations (Rajkai et al., 1988 and Tóth et al., 1991) it became evident that based on soil properties the points can be classified relatively precisely by clustering and discriminant analysis. When there were 4 categories, the discriminant analysis based on the soil properties of 0-5 and 10-15 cm depths classified the categories with a precision of approximately 80%, and this result was not worse than that received by the linear combination of the cover of plant species, and very similar to the precision received during a repeated field classification one year later.

A system of the less categories was received by uniting the *loess steppe* with *Achillea-Festuca* and *Agrostis-Alopecurus* with *wetland* vegetation categories. The precision of the classification was expressed by the classification matrix of DA, which was created by comparing the original, field categorization of observations to the classification provided by the discriminant scores.

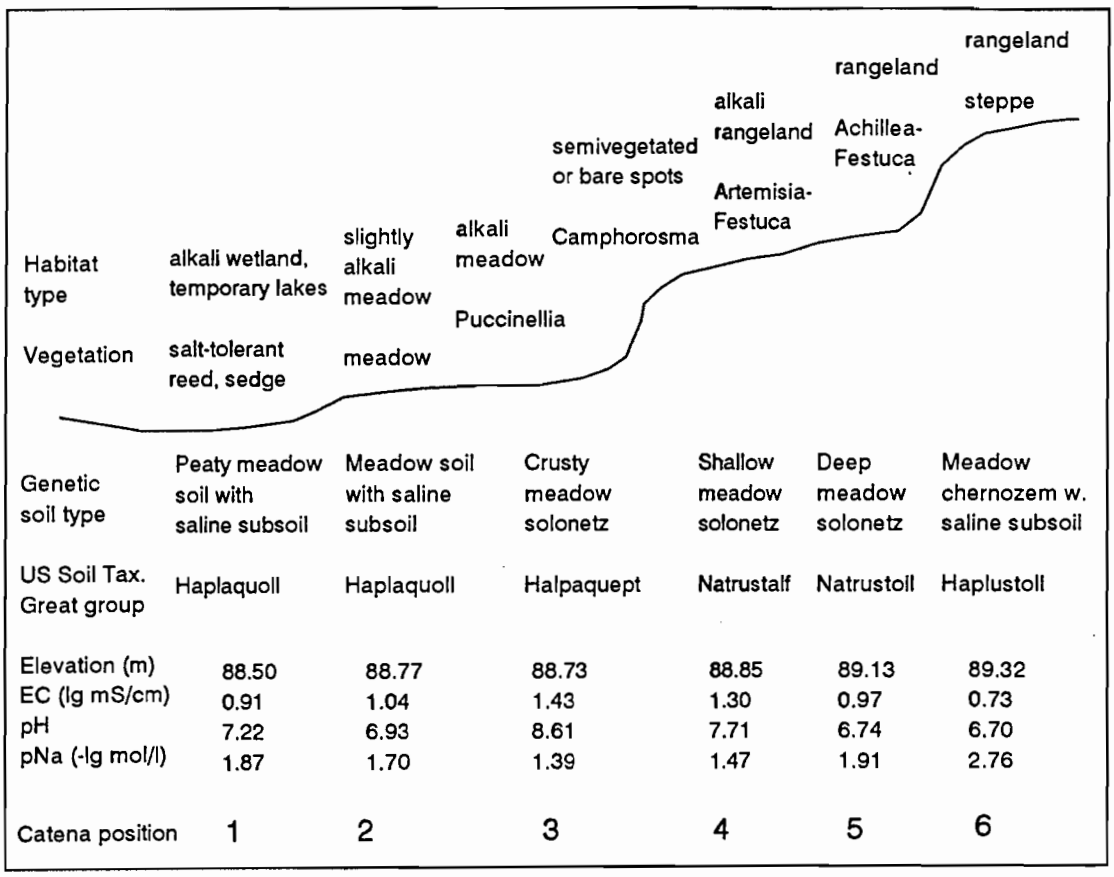


Figure 2. The scheme of the soil and vegetation toposequence of the solonetzic grassland

The values of electrical conductivity, pH and sodium activity in the increase by the depth in all vegetative categories. The highest pH, electrical conductivity and sodium activity were found under the *Artemisia-Festuca* vegetative category. The values of the soil properties of *Achillea-Festuca* category and the *loess steppe* were very similar and only the EC and pNa of the 20-30 cm layer distinguishes them. The soil properties of *Agrostis-Alopecurus* and the *Achillea-Festuca* vegetative categories are very similar in the 20-30 cm depth, but the first has higher average electrical conductivity and pH in the 0-10 cm layer. Comparing the *wetland* vegetative category with the *loess steppe* and *Achillea-Festuca* vegetative categories the *wetland* category had larger electrical conductivity in the 0-10 cm layer than the two other. According to the significance of the F, except for the saturation percentage of the 0-10 and 10-20 cm depth, it was proved that the means in the vegetation categories are not the same since the significance level was less than 0.0005.

The discriminant analysis showed that the match of the observed vegetation categories and those predicted based on the soil properties was 63%. The most important

variable in the prediction was the pNa, the negative logarithm of sodium ion activity of the 0-10 cm layer and the electrical conductivity of the 20-30 cm layer. When the number of categories was reduced to three the match became 75%.

From the classification matrix it is possible to infer the homogeneity of the vegetation categories in terms of the predictability by the soil data. In the case of the xeromorphic *loess steppe* and *Achillea-Festuca* vegetative categories most of the misclassifications fell into the other category which indicates that the soil properties of these vegetation types do not differ much. The category of hydromorphic associations, the *Agrostis-Alopecurus* category, was rather heterogeneous. This was manifested at several levels of grouping, because the most detailed categories are rather complex, therefore when classified with discriminant analysis these categories are decomposed.

The chemical properties of the salt-affected soils studied can classify substantially the vegetation categories. However, besides these, there are other important factors that affect the solonetzic rangeland of Hortobágy, such as the water regime of the soil. Other authors ('Sigmond, 1927, Magyar 1928 and Petrova, 1988) have previously written that the classification of the vegetation should consider the gradients of these two ecological conditions, i.e., of the salt concentration and moisture supply. This reasoning lead the way to the traditional classification of dry and humid associations of the solonetz soils of Central and Eastern Europe. Between the members of the two groups of associations (dry and humid) there are overlaps in the water regime and also in the values of the chemical properties, therefore these properties do not classify precisely the categories.

In a subsequent step we tried to use the catena positions as predictor variables of soil pH, salt content and sodium concentration. We calculated regression equations in which the dependent (predicted) variable was one of the studied soil chemical properties and independent (predictor) variables were the transformed values of the quantified catena position.

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 count for the asymmetry of the two sides of the curve, as was written previously to account for the lower soil sodium content and the higher end (steppe) of the catena.

The precision of predicting the soil chemical properties can be inferred from the value of 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 received in this paper with EC and pNa values (0.76-0.82). The precision of predicting pH values with the catena position is low.

The pattern of the catena positions

The distributions of the catena positions by the sample spacing guided by the local heterogeneity of the satellite image applied is not homogeneous. 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 our field experience. The number of *Camphorosma* and *Puccinellia* samples are two 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 affect directly the sampling design.

Interpolation of catena position index

In this section we use the term catena position index in order to emphasize that we considered catena position data interval variable when we interpolated them. The cross-semivariogram of catena position index with the elevation shows strong spatial structure in spite of that the linear correlation between them is small because their relation 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 our interpolation where the distribution of detected catena position index is far from normality. The difference between the two distributions was too big to accept the result. Thus we reclassified the interpolated data producing categories for map drawing with the area distribution represented by the detected catena position data.

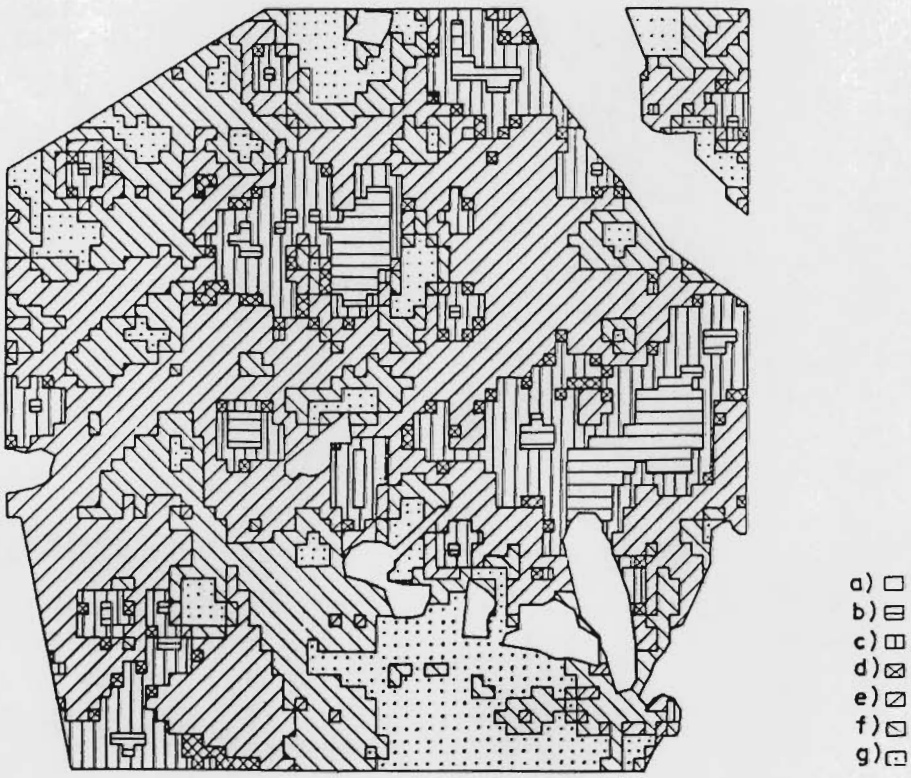


Figure 3. Map of catena positions cokriged with elevation
a) Non-classified; b) wetland; c) meadow; d) Camphorosma-Puccinellia; e) Artemisia-Festuca; f) Achillea-Festuca; g) loess steppe

The resultant map (Figure 3) consists of 4096 pixels of 80 by 80 m size. The map corresponds well with our field experience. The drawn categories denote the most probable local catena positions except the *Camphorosma-Puccinellia* category. In the map this category occurs in small patches between the Artemisia-Festuca and meadow categories. In fact, this type occurs in the same position in the field but in much smaller patches and much frequently, as it was mentioned earlier. We would better say that this catena position can occur in the *Artemisia-Festuca* and meadow categories with certain frequency but at 80 by 80 m resolution there is no pixel where this could be the most probable catena position.

Impact, Relevance and Technology Transfer

The findings can be used in the following manner

<1> The development of the sampling algorithm gives a possibility to optimize the available resources, that is a fixed cost for the sampling of a heterogeneous area.

<2> The methodology introduced into the mapping of salt-affected landscapes with the help of vegetation gives possibility to choose the variables which can be predicted with the best precision and to quantify the precision of the predictions made on the base of vegetation.

The project bought a workstation, several PCs and a few laboratory equipment. Also several computer software and some other equipment have been purchased. These can be used in the forthcoming works related to salinization and mapping.

During the works in the project several researchers got a thorough knowledge of the processes of salinization and alkalinization, and in consequence have shifted their area of research towards studies in these field. The researchers who participated in the program had an opportunity to learn contemporary geodesic techniques, satellite image processing and GIS operations. The project required considerable development in computer skills (UNIX, networking, etc.) too, which will be utilized in the future.

The project helped to invite some of the best experts in the field to Hungary, to consult with them several times during the yearly and final workshops. The project made it possible to participate in foreign events and the contacts established during these events can be a foundation for further cooperation.

Project Activities/Outputs

Collaboration, Consultations

Á. Kummert, PI, spent one month in Syracuse, NY, 10 Jan to 10 Feb 1992, were they completed a joint paper with F. Csillag.

A project meeting was held 16-18 November 1992 in Balmazújváros, Hungary with participation of R. Webster, F. Csillag, M. van Meirvenne, J. Pannier, Á. Kummert, S. Kabos, M. Kertész. T. Tóth, K. Rajkai, J. Szabó, and L. Pásztor.

M. Kertész traveled to Syracuse, N.Y. in March 1993 for a month to consult with F. Csillag.

M. Kertész traveled to Gent, Belgium, 22 Oct. - 3 Nov. 1993 to Prof. Marc van Meirvenne, University of Gent, to study GIS operations.

The second annual project meeting was held 9 - 10 Nov. 1993 in HAS RISSAC, Budapest, with participation of

M. Kertész traveled to Toronto, Ontario, in March 1994 for consulting with the collaborator F. Csillag at the University of Toronto.

F. Csillag traveled to Budapest for 2 weeks in November 1994 to consult with the Hungarian staff.

M. Kertész traveled to Toronto, Ontario, in March 1995 for consulting with the collaborator F. Csillag at the University of Toronto.

The final project meeting was held 5-8 May 1995 in HAS RISSAC, Budapest, with participation of Á. Kummert, F. Csillag, R. Webster, M. van Meirvenne, M. Kertész, L. Pásztor, T. Tóth, K. Rajkai, S. Kabos, as well as S. Arunin, J. Battle-Sales, Ye. I. Pankova, V. A. Pavlov, J. L. Richardson and D. L. Suarez

Travel

Á. Kummert participated in EGIS'92 conference in Munich, Germany, 23-26 March 1992, with oral presentation.

F. Csillag participated in AAG annual conference in San Diego, CA, 18-22 April 1992, with oral presentation.

L. Pásztor participated in Alps-Adria Workshop on GIS in Keszthely, Hungary, 11-12 June 1992, with oral presentation.

M. Kertész participated in Pedometrics-92 conference in Wageningen, the Netherlands, 1-3 Sept. 1992, with a poster.

F. Csillag participated in Pedometrics-92 conference in Wageningen, the Netherlands, 1-3 Sept. 1992, with oral presentation.

Á. Kummert, S. Kabos and M. Kertész participated in CAIP'93 Conference in Budapest in 13-15 September 1993 with oral and poster presentations.

L. Pásztor participated in COSIT'93, Elba, Italy, 19-22 September 1993, with a poster.

T. Tóth participated in the 12th Latin American Soil Science Congress in Salamanca, Spain, 23-26 September 1993 with an oral presentation.

F. Csillag participated in the AutoCarto-11, Minneapolis, Minnesota November 1993 with an oral presentation.

S. Kabos traveled to The Netherlands 15-22 Feb. 1994, to study spatial statistics at the Mathematical Department, Univ. of Agriculture, Wageningen, The Netherlands.

F. Csillag participated at the Annual Meeting of the Association of American Geographers as co-organizer of session on "Error and scale in geographic information processing and simulation".

M. Kertész and T. Tóth participated in the 15th International Soil Science Congress, Acapulco, Mexico, July 1994, with a poster.

T. Tóth participated in the fifth International Rangeland Congress in Salt Lake City, 20-24 July, 1995, with two poster presentations.

Training

M. Kertész, 1 week at Dept. of Soil Science, Gent University, Gent, Belgium, 26 Nov. - 1 Dec. 1991.

Á. Kummert, S. Kabos, M. Kertész, T. Tóth, K. Rajkai, J. Szabó, L. Pásztor, 1 week UNIX (AIX) training at IBM Hungary Ltd, Budapest, Hungary, 16-20 Dec. 1991.

S. Kabos. 3 months at Staring Center, Wageningen, the Netherlands, 8 Jan - 25 March 1992.

L. Pásztor, 1 month at Remote Sensing Center of FÖMI, Budapest, Hungary, April 1992.

Á. Kummert, 5 days training in the use of SPANS in Salzburg University, Austria, 1-4 November 1992.

M. Kertész and L. Pásztor, 2 days training in AIX system management held by IBM Hungary Ltd, 9-10 November 1992.

Á. Kummert, 1 week training course of GIS - GRASS held by USDA Soil Conservation Service, Fort Worth, TX, 12-16 April 1993.

Publications

Research papers in refereed journals

Csillag, F. and S. Kabos. 1995. Hierarchical decomposition of variance with applications in environmental mapping based on satellite images. Mathematical Geology, 28 (in press)

Csillag, F., M. Kertész and Á. Kummert. 1995. Sampling and mapping two-dimensional surfaces adjusted to the local variability of ancillary data. International Journal of Geographical Information Systems. (in press)

Csillag, F., Á, Kummert and M. Kertész. 1992. Resolution, accuracy and attributes: Approaches for environmental geographical information systems. Computers, Environment and Urban Systems 16, 289-297.

Kertész, M., F. Csillag and Á. Kummert. 1995. Optimal tiling of heterogeneous images. International Journal of Remote Sensing 16, 1397-1415.

Tóth, T., M. Kertész. 1996. Application of soil-vegetation correlation to optimal resolution mapping of solonetzic grassland. Arid Soil Research and Rehabilitation 10, 1-13.

Other publications

Csillag, F. 1992. Dirty quadtrees: Decomposition of variability as a quality descriptor in a soil database. Proc. AAG Annual Meeting 18-22 April, San Diego, CA.

Kertész, M., Á. Kummert and F. Csillag. 1993. From Pyramids To Quadtrees: Approximation Of Heterogeneous Surfaces By Fixing Complexity. in: D. Chetverikov and W. Kropatsch (eds.). Computer Analysis of Images and Pattern. 5th International Conference, Budapest, Hungary. Springer-Verlag. pp. 49-57.

Kertész, M. and T. Tóth. 1994. Soil survey based on sampling scheme adjusted to local heterogeneity. Agrokémia és Talajtan. 43:113-132.

Kummert, Á., F. Csillag and M. Kertész. 1992. Dirty quadtrees: Decomposition of variability as a quality descriptor in a soil database. Proc. of EGIS'92, 23-26 March 1992 Munich, Germany, pp. 722-731.

Kummert, Á. and S. Kabos. 1993. Calculation and Estimation of Sample Statistics of Binary Images Using Various Data Representations. in: D. Chetverikov and W. Kropatsch (eds.). Computer Analysis of Images and Pattern. 5th International Conference, Budapest, Hungary. Springer-Verlag. pp. 58-64.

Van Meirvenne, M., P. De Groote, M. Kertész, T. Tóth, G. Hofman. 1995. Multivariate geostatistical inventory of sodicity hazard in the Hungarian Puszta. Intl. Symp. Remote sensing and GIS. Ouagadougou, Burkina Faso. pp. 11.

Tóth, T. and M. Kertész. 1993. Utilización de la relación entre la vegetación y suelo en una pradera seminatural solonétzica para la mapificación con resolución optimalizada. El Estudio del Suelo y de su Degradación en Relación con la Desertificación. Sociedad Española de la Ciencia del Suelo, Tomo III. pp. 1425-1432.

Tóth, T., L. Pásztor, M. Kertész and F. Csillag. 1992. Reflectance as indicator of soil salinity/alkalinity status at different scales in the Hortobágy region (A relation based approach of salinization/alkalization processes by remote sensing). Proc. Alps-Adria Workshop on GIS 11-12 June 1992, Keszthely, Hungary.

Presentation and poster abstracts

Davidson, A. and F. Csillag. 1994. Integrating remotely sensed and field data in a GIS for mapping salinity status of natural grassland. 6th Canadian GIS Conference/Symp. Intl. Soc. Photogrammetry and Remote Sensing.

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Project productivity

The project basically accomplished the proposed goals. We have elaborated and tested a new approach in sampling and mapping heterogeneous soil and vegetation cover using satellite images. However, one specific goal was not completed, namely, we could not integrate the and the Hungarian Soil Information System in our study. The resolution of the first proved too small for our purposes. When we wrote the proposal we thought that the Hungarian Soil Information System would be available for the proposed study area too, but meanwhile its elaboration has been suspended.

Future work

We shall use the algorithm and the accompanying sampling scheme in more extended regions in Hungary. During this work there will be three kind of improvements planned in the technique:
<1> the selection of the best timing of the used satellite image, and use multi-temporal satellite data;
<2> the multiple use of satellite detector channels together with digital terrain models and/or other remotely sensed images, such as combining visible and near-visible with radar etc.;
<3> producing maps by simulation combining wavelet decomposition parameters and field reference data.

We intend to use the algorithm in mapping in developing countries. We consider India as potential cooperator, but the final selection will be defined by the financial assistance. In India we intend to use the sampling algorithm during the mapping of large arable areas.

We plan to apply our findings in frame of long-term ecological research for mapping and modeling heterogeneous endangered ecosystems in cooperation with researchers of US LTER network and with other teams.

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Optimal resolution of salt-affected landscapes
Report of project's final meeting

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The final meeting of project no 12.058E, funded by the U S Agency for International Development, took place in the Research Institute of Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences (RISSAC) in Budapest from 4 to 6 May 1995. Its purpose was to summarize final results and conclusions from the project for a small group of specialists drawn form the international community of soil science.

Programme

The first day was devoted to formal presentations. The programme was as follows.

I. Szabolcs (RISSAC). The mapping of salt-affected soil.

R. Webster (Rothamsted). Predictive soil survey: where have we reached?

M. Kertész (RISSAC). Introduction to the project and sampling design.

T. Tóth (RISSAC). Correlations between solonetz soil and vegetation.

F. Csillag (University of Toronto). Using remotely sensed images for soil and vegetation of alkaline grassland.

M. Van Meirvenne (University of Gent). Factorial kriging in soil mapping.

The programme thus covered Hungary's contribution to understanding the genesis and mapping of such soil, of which it has more than any other country in Europe; progress in predictive soil survey, showing how modern statistical technology had developed and illustrating two of the most promising techniques for spatial prediction and mapping salt concentration; and an introduction to the project itself. Results from the project included the quadtree technique for representing an image of the ground economically and how this led to efficient sampling; the relations between soil, landscape and vegetation in the Hortobágy National Park, and how soil and

vegetation might be predicted from landscape position; the value of remote sensing, especially concerning the spatial resolution for such intricate terrain; and geostatistical prediction free of the 'nugget effect'.

On 5 May T. Tóth led participants to the Hortobágy Park to see the situation in the field. The timing was well-chosen. The different associations of vegetation were very evident, and the relations between the vegetation and the soil were demonstrated for those who had not seen the terrain before. Equally evident was the complexity of the spatial pattern and the nature of the mapping problem.

The final session of the meeting took place on 6 May in the Institute in Budapest. Its main aim was to plan future research on managing salty land in the sandy region between the River Tisza (which flows across the central Plain) and the Danube. Participants used the opportunity to discuss past achievements in addition and to suggest means for understanding the dynamics of the soil and hydrology in the Hortobágy Park.

Achievement

The principal line of research, namely mapping intricately patterned terrain, has been pursued to a reasonable theoretical conclusion. The quadtree decomposition appears to work well, and information on the soil and vegetation is recoverable where the Kullback divergence measure is large enough. The investigators have papers in press on this topic.

The relation between vegetation and soil, which has been appreciated qualitatively and intuitively for a long time, has been expressed quantitatively in a way that can lead to statistical prediction. This has been extended by M. Van Meirvenne to include a spatial component, even though the spatial patterns are not stationary.

The broad aims have been achieved, and the team has gained experience in and mastered much statistical technique en route. Staff have used the opportunity offered by the grant to travel abroad, to attend conferences, to attract foreign scientists, and generally to get to know what is happening in their fields of study.

In summary, I believe that the grant has been used wisely and profitably for the purpose for which it was intended.

R. Webster
Harpenden, May 1995