Determining Ecotones by Decision Support Systems

Vilém Pechanec, Jan Brus, and Jan Caha

Department of Geoinformatics, Faculty of Science, Palacký University in Olomouc
Tř. Svobody 26, 771 46 Olomouc, Czech Republic
vilem.pechanec@upol.cz, jan.brus@upol.cz, jan.caha@klikni.cz

Abstract The investigation into ecotones enabled a better understanding of the causal relationships between certain landscape elements, landscape utilisation categories and ecotones. By studying ecotones, we wanted to expand understanding of patterns having an influence on the landscape condition, structure, functions, landscape elements and their relationships. The fuzzy approach was applied for better understanding and modelling of ecotones. This methodology was afterwards built in expert system. The landscape assessment process based upon an expert system allows for a multidisciplinary view of a landscape. The landscape is evaluated from several perspectives: the ecological stability, soil erosion, retention capacity and economic landscape calculations by designed expert system. These results from expert system were taken into consideration during mapping ecotones. Ecotones may serve as one of the distinctive indicators of the impact humans have on the landscape. It is therefore necessary to develop more sophisticated methods of their studying.

1 Introduction

Ecotones are significant regions of landscape heterogeneity that contain elements, patterns, and processes existing and operating at varying spatial scales [19], [14], [24]. Ecotones play a pivotal role in landscape. This can be seen from several viewpoints — environmental, biological, economic, historic, aesthetic, etc. Their most crucial task is ecological. They represent specific ecosystems in a landscape, corridors for the migration of animals or distribution of plants. They also contribute to soil protection against erosion, etc. During their existence ecotones go through developmental stages which depend primarily on the dynamics of factors in the surrounding environments. Some ecotones are temporally stable some may migrate or mutate. Spatial relationships within the surrounding environments are of great importance since ecotones are the zones where communities, populations of plants and animals meet, where they compete, create some tension and blend. In nature ecotones often function as corridors or barriers enabling or restricting the flow of mass or energy. The temporal and spatial stability of ecotones contributes to the ecological value of the ecotone community and to the greater value of a landscape.

V. Snášel, J. Pokorný, K. Richta (Eds.): Dateso 2011, pp. 206–215, ISBN 978-80-248-2391-1.

We can classify ecotones by various aspects, e.g. by structure. It is difficult to perfectly simulate the real world, due to its complexity. It has been argued that uncertainty information is a vital component in the use of spatial data for decision support [11], [1]. We are forced to model uncertainties which suggest fuzzy logic to problem solving. Many techniques have been developed for communicating uncertainty in data and models for specific visualization applications, such as remote sensing, land allocation, [3], [16], [1]. Development in the field of Geographical Information Systems (GIS) facilitates the integrating of flexible decision support functionalities to perform multicriteria evaluations to solve allocation or location problems, to perform suitability analysis, to integrate different criteria for options choice and group decisions [13], [18]. For such a specific and complex field as ecotones there is compulsory to use unique technique. Fuzzy approach can be applied to help to better mapping and modelling, due to non-sharp nature of ecotones, also their uncertainties. Fuzzy theory is practically implemented through decision-making processes in expert system. Build in expert knowledge helps to coping with vague concepts such as imprecise and uncertain values of attributes of spatial entities of ecotones. This research was mainly focused on testing possibilities of using Spatial Decision Support Systems (SDSS) for mapping ecotones.

2 Theoretical background

2.1 Fuzzy theory

Sometimes crisp information isn’t the best approximation of reality. This is the main reason for use of fuzzy set theory and fuzzy logic in GIS and decision making process. This point of view is shared by many authors [6], [8], [12], [22] and [23]. The best overview of use of fuzzy sets in modelling geographical elements and phenomena are presented in [6] and [8]. Concepts of fuzzy set theory and fuzzy logic were firstly presented by L. A. Zadeh in 1968 [25] in his article "Fuzzy sets". Compared to classical set theory where elements are evaluated like belonging or not belonging to the set, fuzzy set theory uses membership function to assess each element's membership value. Membership value is the number from interval [0, 1] where 0 means that element is not included in set. Value 1 means that element is fully included in the set, any other value from given interval means that element is a fuzzy member of the given set. The higher of the membership value predicate how much the element belongs to this set Fig.1. Within fuzzy set theory, vague and imprecise numeric values can be represented by fuzzy subsets on the basic numeric domains. There are several ways how can we define membership values for elements, for finite sets we can clearly define membership value for each element and for infinite sets (i.e. real numbers) we can define a function, named membership function, which defines membership value for each element of the set.

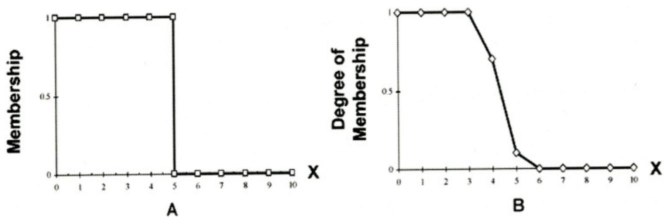

Fig. 1 Boolean versus Fuzzy sets [11]

Unlike from the crisp set theory where element either belongs to set A or B with fuzzy sets it is possible for an element to belong to both sets A, B to each with different membership value. Fuzzy logic is derived from those assumptions. Fuzzy logic is a multi-valued logic that deals with reasoning where classic binary sets are not appropriate.

3 Technical background

3.1 SDSS

In recent years, the GIS is increasingly understood as a means used to support decision-making and recognized as the basis for the Spatial Decision Support Systems (SDSS). SDSS are a specific kind of information system. There is no unambiguous and generally accepted definition because forms of technology have not been profiled yet. However, the majority of authors agree that it is a spatial expansion of Decision Support Systems (DSS), or rather the integration of GIS and DSS. SDDS are computer information systems that provide support for problems difficult to formulate and structure. They are usually considered when it is impossible to use a fully automated system. SDSS are closely related to knowledge-based and expert systems whose creation was possible due to artificial intelligence. SDSS also provide detailed displays resulting in reduced decision time and enabling a better grasp of spatial problems due to better visualization of the problem to be solved [16].

In relation to the previous paragraph, we can set apart special category of SDSS which are expert systems. They can stand alone, but in combination with GIS they integrate into a very powerful tool. We must emphasize here that the possibility of easy handling without deeper knowledge of processes and algorithms may lead to a completely incorrect interpretation of results, and thus, erroneous decisions.

3.2 Expert systems

Expert systems are computer programs able to simulate actions of an expert in a particular field when solving complicated tasks . Other authors [**20**, **5**] describe expert system as software or combination of software and hardware, which can complete the exercise of specific complex tasks. These tasks can also be solved by a human expert, but require significant expertise in the solution. Expert systems provide a powerful tool for solving many problems that often cannot be solved by other, more traditional methods. The usage of expert system has proved to be crucial in the process of decision support and problem solving [8]; therefore, their usage has spread into many sectors. They are considered a sub-category of knowledge-bases systems. They are based on symbolic representation of knowledge and its implementation in an inference mechanism. Experts in the given field present the source of knowledge and procedures. These systems are able to justify solution procedures. They are used primarily for tasks difficult to structure and algorithmize, e.g. problems with recognition of situations, diagnosis of status, construction, planning, monitoring of status, corrections, management and decision-making. However, experience and intuition have to be part of the solution. Certain authors [10] look at the expert analyst required to operate the system as posing a barrier to decision makers who must translate the problem into a form that can be understood by experts who, in turn must translate their understanding of the problem into a form that can be evaluated and solved [21].

3.3 Ecosystem Management Decision Support (EMDS)

EMDS - is a product which if interconnected with ArcGIS provides a comprehensive SDSS product. The supplement comes from the Pacific Northwest Research Station U.S. Forests Service. According to its authors it integrates logical formalism justified on the basis of the knowledge base in the GIS environment. It provides support for decisions on evaluation and assessment of landscape from an ecological point of view. The EMDS decision-making pattern is based on a knowledge base that uses fuzzy logic, network architecture and object-based approach. The basic architecture of objects of EMDS knowledge bases enables an increase in development of dependent complicated knowledge data. Up-to-date modern research methods dispose of mathematical models characterised by very specific mathematical dependencies between the status of monitored objects and the processes influencing them. Fuzzy logic tools significantly enhance the ability to work with incomplete or vague information. The proposed network architecture of EMDS knowledge bases allows evaluation of the influence of the missing information and has the ability to come to conclusions with incomplete information. The current version of EMDS is the 4.1 version that ensures compatibility with ArcGIS 9.x and includes a newly designed hotlink browser tool, which speeds up work and provides graphical representation of the knowledge base for landscape features chosen from topics intended for analysis. Internet presentation of maps is secured via ArcIMS.

4 Methodology

Many researches were done in the field of determining ecotones [9, 15]. Comprehensive study based on representing transitional zones and determining their borders was also carried out [2]. Based on upper text, fuzzy theory brings apparatuses how to deal with specific fuzzy sets. In the case, that we accepted the representation of ecotones by fuzzy sets, whole ecotone same as its transitional borders can be modelled.

The research on ecotones was carried out in the catchment area of the stream Trkmanka in South Moravia. The boundaries of the region are formed by the boundaries of the Trkmanka catchment area as taken from the hydrological map. The Trkmanka catchment area comprises the regions of Břeclav, Hodonín, and Vyškov in the south-east Moravia. This narrow territory drops from the north-east to the south-west. Its area covers approximately 380 km2. The Trkmanka catchment area lies in the Carpathian part of the Czech Republic. It consists of the flysh belt of the outer part of the Western Carpathians and the Vienna Basin. Its prevailing parts are formed by sedimentary fill. Lowest parts have a flat alluvial relief and belong to the vale Dolnomoravský úval. Three modelling areas were Kobylí, Ždánice and Rakvice.

The landscape assessment process based upon an expert system allows a multidisciplinary view of a landscape. The landscape was assessed from four viewpoints according to the selected indicators. Monitored ecological indicators mainly include an ecological stability coefficient (1st indicator) showing an ecosystem's ability to compensate for changes caused by external factors in order to keep its natural properties and functions. This closely relates to the erosion hazard (2nd indicator) and landscape storage capacity (3rd indicator). A modern tool for nature conservation is the economic assessment of ecosystems (4th indicator) and their non-productive functions. It enables us to compare ecological values and economic profits in the same terms and hence provides for better reasoning in decision-making processes. In the assessment the ecological value of nature is always taken into consideration.

Whole process of evaluating landscape stands as primary phase in determining of ecotones. Results computed by expert system are primary data which were used as initial data in the ecotones determined by botanist. Such an assessment can be performed with common accessible data, including the land use, biotype mapping of the Czech Republic which was processed by methodology introduced by NATURA 2000, pedoecological unit (soil-ecological unit in Czech terminology, used for land appraisal), forest topology and contour lines. A layer of "soil ecological units for soil rating" was nationally special. Soil ecological unit for soil rating of the agricultural parcels is a five-digit numerical code of the main soil and climatic conditions that affect the productive capacity of agricultural land and its economic valuation. Forest typology is the classification system consisting of differentiation in the management of the forest lands. This is a nationwide database of permanent environmental conditions. This database standardizes the potential natural vegetation in relatively homogeneous territorial units in forests. It is necessary for economic planning of forest management. Described layers are finally set up into specified structure and evaluated in system Assessment in Ecosystem Management Decision Support (EMDS). In many real cases, the available data are crisp, precise, but they hold uncertain on their reliability for several reasons: either because the agencies that are the source of the data cannot be entirely trusted, or because one knows that the means of acquisition are not enough sophisticated and generate systematic errors; not least because data are a result of a subjective analysis, such as surveyed data. Uncertainty on precise or imprecise data can be represented by associating a degree of confidence or credibility, or reliability with them [4].

5 Results

Three methodologies based were used to determine the indicator of landscape stability coefficient. The data was valid for the year 2007 and the analysis did not cover the whole study area, but only parts. We obtained quite varying values for particular land categories from the category of above-average land use with distinct disturbances in the natural structures to the category of natural landscape or landscape close to it. Another indicator of landscape stability is long-term soil loss. It was determined using a Universal Soil Loss Equation (USLE) to assess the danger of water erosion to agricultural land (Fig. 4). It gives the potential amount of soil which could be removed due to water sheet erosion. It however does not include its deposit at the site or into the lower layers underneath. This parameter is directly linked to direct runoff. The Runoff Curve Number Method (CN) was applied to determine the value (Fig. 3). All model areas have the greatest representation of values for the zero runoff. The greatest runoff values were those for urban areas and roads. In addition, the modified Hessen biotope assessment method was applied to that part of the study area if the required data was available. The price of one segment means the average costs of increasing the land value by one ecological degree for one square meter of land. In the view of mathematics, ecotones are areas where the particular points can, with a certain probability, be considered as belonging to one ecological stratum or, with another probability, to another one.

Assessment of landscape by expert system based on EMDS system is composed of several parts. Mainly from algorithmized decision schema for appraisal landscape segments (network in NetWeaver for EMDS), simultaneously is formed and filled knowledge base about landscape. NetWeaver knowledge bases use an object-based approach, which makes them very modular; therefore, they are easily created and maintained. Moreover, the system enables interactive tuning in an arbitrary stage of the creation of the knowledge base. This significantly speeds up the development process. Fuzzy logic provides calculation methods which do not require directive expression. NetWeaver is completely object-oriented system. This means that networks and data links are programming objects that represent or substitute objects or notions of the real world (Reynolds, 1998). Implementation of this knowledge embodied in interconnection between an appraisal network and input entry about landscape with datalinks in network. Optimized data model with series of reclassification tables has to be done for connection with entry data. Assessment of landscape segments by an appraisal network is achieved finally in EMDS.

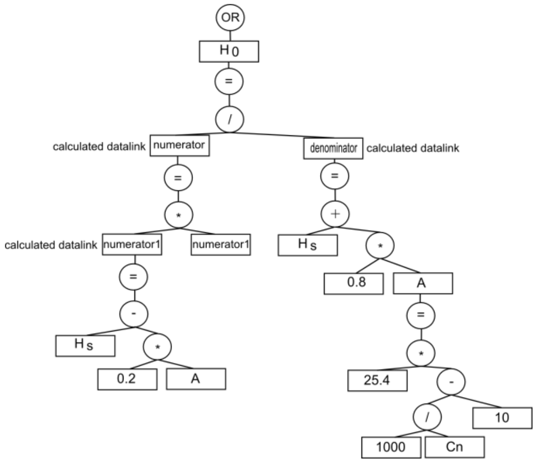

Fig. 3. An appraisal grid for the Runoff Curve Number Method (CN method)

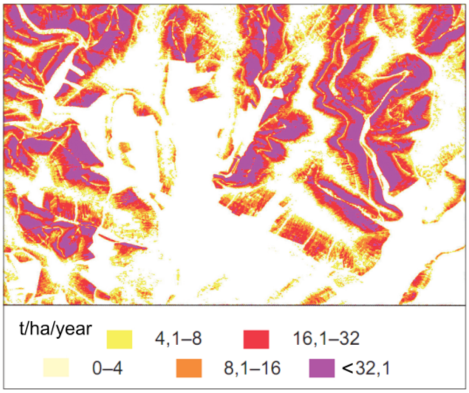

Fig. 4. The long-term average soil loss of agricultural land and forestland in a model area of Ždánice

The highest ecological stability is calculated in modeled area Ždánice. The lowest endangered area by water erosion calculated by USLE (Universal Soil Loss Equation) is in modeling area of Kobylí. At suggested precipitation 12 mm is a level of straight runoff equated to 0. Appraisal of landscape by the modified Hessen method is also significant due to the evaluation of landscape. All this information is taken into consideration for the final evaluation of possible occurrence of ecotones. Predicted areas were faced with data of field survey and aerial photography.

6 Conclusion

The main idea of this work was practically to test possibilities of SDSS capability in GIS software for mapping remarkable landscape structure. Role of ecotones in the landscape is important and ecotones are formed in a special part of the landscape. They can be distinguished mainly by field work which was proofed by botanists, because of their blur border and many ecological factors which affect them. It was extremely difficult to model all conditions, which come into the process of developing ecotones. Only datasets which build up the expert system were not efficient to map ecotones in the study area. In the other hand, in our model was not decided to calculate with this amount of factors. It was mainly considered as a pilot and testing application for help with mapping ecotones. As the one of the crucial problems were considered uncertainties in datasets and also mapping measure of GIS analysis. This measure was derived from the measure of less detailed map layer. Uncertainty of entering data is mainly based on the form how the agencies collect them. This data have to be analysed and tested for accuracy in the field, due to their error. The second problem was based on problematic expression of ecotones in fuzzy theory in GIS. Basic ideas of use of fuzzy set theory and fuzzy logic in geography and geoinformatics can be found in many sources including [6], [8], [12] and [17]. Almost no of those sources provide some kind of workflow how to deal with imprecise data in GIS. As suggested in [6] that this fact may be caused by lack of tools for work with fuzzy sets and fuzzy logic in the widespread GIS. The problem probably lays deeply in the structure of current GIS. As most of today’s software GIS highly rely on mathematics and informatics which structure is extremely connected to both Boolean logic and crisp set theory. Cause of this is probably fact that alternative theory to crisp set theory and Boolean logic exists only since 1960’s but both other are much older and thus more rooted in mathematics and informatics. EMDS was chosen as final tool for developing a appraisal grid. EMDS including NetVeawer was considered as a very powerful tool with large field of application. Ability of implementation of fuzzy sets into expert systems is in this case inestimable. Final results of this research stand only like partially data, which can be used as base point for future analysis of ecotones in the landscape. Future visions stand on developing more sophisticated expert system, which will better utilize fuzzy theory and will implemented more variables into the appraisal grid for assessment the landscape. This approach of mapping by expert system will be subsequently applied in a recent project such as monitoring sub-urban areas.

Acknowledgments

This work was supported by the Czech Science Foundation grant GA205/09/1159. The intelligent system for interactive support of thematic map design.

References

1. Aerts, J. C. J. H., K. C. Clarke, et al. (2003) Research Papers - Testing Popular Visualization Techniques for Representing Model Uncertainty. Cartography and geographic information science. 30: 249 (14 pages). 5
2. Arnot, C., Fischer, P. (2007) Mapping the Ecotone with Fuzzy Sets. In Morris, A., Kokhan, S. (eds.) (2007): Geographic Uncertainty in Environmental Security, p. 19-32.
3. Aspinall, R.J., Pearson D.M. (1995) Describing and managing uncertainty of categorical maps in GIS. In: Fisher P (ed) Innovations in GIS 2. Taylor & Francis, London, pp 71–83
4. Bordogna, G. et al. (2007) A flexible decision support approach to model ill-defined knowledge in GIS. In Morris, A., Kokhan, S. (eds.) (2007): Geographic Uncertainty in Environmental Security, p. 19-32.
5. Boss, R. W. (1991) “What Is an Expert System?” ERIC Digest. ERIC Clearing House on Information Resources, Syracuse, NY, 1-3.
6. Burrough, P., McDonnell, A., Rachael A. (1998) Principles of Geographical Information Systems. Second Edition: Oxford University Press, 1998. 356 p. ISBN 0198233655.
7. Crossland, M. D., Wynne, B. E. and Perkins, W. C. (1995) Spatial Decision Support Systems: An overview of technology and a test of efficacy, Decision Support Systems, 14, 3, 219-235.
8. Dragićevic, S. (2005) Multi-Dimensional Interpolations with Fuzzy Sets. In: Petry, F.E.; Robinson, V.B.; Cobb, M.A. (eds.) Fuzzy Modeling with Spatial Information for Geographic Problems. Berlin: Springer, ISBN 3-540-23713-5.
9. Fortin M. J., Olson R. J., Ferson S., Iverson L., Hunsaker C., Edwards G., Levice D., Butera K. and Klemas V. (2000) Issues related to the detection of boundaries. Landscape Ecology 15: 453–466.
10. Goodchild, M. F., (1992) Geographical information science. International Journal of Geographical Information Systems, 6(1), 31–47.
11. Hunter, G.J., and Goodchild, M.F. (1995) A new model for handling vector data uncertainty in geographic information systems. Proceedings, URISA, San Antonio, Texas, pp. 410-419.
12. Hwang, S., Thil, J.C. (2005) Modelling Localities with Fuzzy Sets and GIS In: Petry, F.E.; Robinson, V.B.; Cobb, M.A. (eds.) Fuzzy Modeling with Spatial Information for Geographic Problems. Berlin: Springer, ISBN 3-540-23713-5.
13. Jankowski, P., Nyerges, T. (2001) Geographic Information Systems for Group Decision Making, Taylor & Francis: London. March, 2001. equal contribution; eight chapters synthesizing research 1995-2000.
14. Ji, M. (2002) Fuzzy modelling of African ecoregions and ecotones using AVHRR NDVI temporal imagery. Geocarto International 17(1): 21-30.

15. Kent, M., Gill, W. J., Weaver, R. E., and Armitage, R. P. (1997) Landscape and plant community boundaries in biogeography, Progress in Physical Geography 21: 315-353.
16. Leitner M, Buttenfield BP (2000) Guidelines for display of attribute certainty. Cartography and Geographic Information Sciences 27:3–14.
17. Li, Z., Zhou, Q., Kainz, W. (eds.) (2004) Advances in Spatial Analysis and Decision Making: Proceedings of the ISPRS Workshop on Spatial Analysis and Decision Making. Lisse: Swets & Zeitlinger, ISBN 90-5809-652-1.
18. Malczewski, J. (1999) GIS and Multicriteria Decision Analysis, John Wiley and Sons, 392 pp., New York, NY.
19. Nellis, M.D., Briggs, J.M. (1989) The effect of spatial scale on Konza landscape classification using textural analysis. Landscape Ecology 2(2): 93-100.
20. O'Looney, J. (2000) Beyond maps: GIS and decision making in local government. Redlands, Calif: ESRI Press.
21. Popper, M., Keleman, J. (1998) Expertné systémy. Bratislava. Alfa.
22. Verstraete, J., Hallez, A. and De Tre, G. (2007) Fuzzy regions: theory and applications. Geographic Uncertainty in Environmental Security, pp. 1-17. Springer, Dordrecht
23. Verstraete, J., Hallez, A. and De Tre, G. (2007) Fuzzy regions: theory and applications In Morris, A., Kokhan, S. (eds.) (2007) Geographic Uncertainty in Environmental Security, p. 19-32.
24. White, J.D., Running, S.W., Ryan, K.C. and Key. C.C. (2002) Fuzzy logic merger of spectral and ecological information for improved montane forest mapping. Geocarto International 17(1): 59-66.
25. Zadeh, L.A. (1968) ‘Probability Measures of Fuzzy Events’, Journal of Mathematical Analysis and Applications, 23, 421-427.