A GIS-based method for landscape ecological forest planning

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Abstract

Geographical Information System (GIS) applications offer many tools by which to produce the information needed in multi-objective decision making. Especially the methods enabling information from different sources to be connected and used in analyses are of central importance in the development of multi-objective planning methods. Cartographic modelling is an area of application for spatial analysis employing concurrent analyses of many sources of information. Combining cartographic modelling, spatial analysis and modern decision-analysis methods based on general decision theory enables closer integration to be achieved among the various objectives and numerical planning methods than has been the case hitherto.

This paper presents a method in which the aforementioned methods and techniques are utilised in order to combine different kinds of criteria affecting the total utility of the forest area in landscape ecological planning. The method is illustrated by way of a simple example in which the purpose is to select targets to be set aside from logging for ecological reasons. In order to succeed in choosing the appropriate forest stands, the decision maker needs to know what kind of habitats the various species require. On the other hand, one has to know how to combine and emphasise the different needs of the species and the different objectives of the various forest uses. The method presented in this study represents an endeavour to select stands to be set aside from logging to enable maximum total utility in relation to the objectives set for the use of the forest area.

Keywords: geographical information systems, landscape ecological planning, cartographic modelling, multicriteria evaluation, spatial analysis

1 Introduction

Nowadays, the objectives set for forest use are more diverse than in the past. They vary according to forest owner, but values such as recreation, landscapes beauty and biodiversity have gained prominence alongside traditional wood-production values. These are the results of changes in forest owners' values on the one hand and increase environmental consciousness among the public on the other. More diverse information is needed for decision-making related to forest use because of changes in people's objectives and their relative importance.

Constant research is taking place to produce new knowledge about the impacts that forest treatment has on individual forest uses. The impact of forest treatment for example on the scenic value of the landscape and on the recreational use of the forests has been the subject of study for many years. Lately, the emphasis has been especially on the production of knowledge related to biodiversity. Furthermore, there has been an endeavour to extend the approach to cover landscape ecological planning and thereby to estimate the significance to species of the areas immediately adjacent to their habitats.

Ecological research, for instance, currently produces plenty of knowledge about the habitat requirements of the various species. For this knowledge to be efficiently utilised, we need methods and channels capable of bringing the knowledge into the field of practical forestry. In Finland, a high proportion of commercial forests is within the sphere of woodlot-specific forest planning, which enables the use of forest planning as a link between ecological knowledge and practical realisation, for instance. The problem at the moment is in that even if there were sufficient data available, it is very seldom that these data are in formats enabling their direct utilisation in multi-objective forest planning. The efficient exploiting of ecological data requires methods whereby data from a variety of sources and differing in format can be linked to numeric forest planning.

This paper presents a GIS-based method in which spatial analyses, cartographic modelling and modern decision-analysis technique are utilised to produce information needed in multi-objective decision-making situations.

2 GIS applications in producing data for multi-objective planning

The term Geographic Information System (GIS) refers to computer-based systems used in entering, analysis management and outputting of geo-referenced data (Aronoff 1989). The status of GIS applications in the management of natural-resource data has strengthened day by day. Most of the organisations dealing with natural resources use georeferenced data. Although the principal use of GIS applications in these organisations is connected to management of georeferenced data and to producing maps, GIS applications offer many tools for producing the data needed in multi-objective decision-making situations, too. Especially spatial-analysis functions and methods whereby information from different sources can be linked and analysed are important instruments in the development of multi-objective forest planning.

2.1 Spatial analysis

Spatial analysis is the process of seeking out patterns and associations in data that are distributed over space in order to help characterise, understand and predict spatial phenomena (Bonham-Carter 1994). Spatial analysis functions use spatial and non spatial attribute data in combination to answer questions about the real world. Typical spatial analysis functions include the following: various retrieval, classification and measurement functions, overlay analysis; neighbourhood operations, and connectivity functions (Aronoff 1989). Especially overlay analyses, visibility analyses, and the forming of buffer zones have been utilised in the endeavour to produce the data needed in multi-objective forest planning (e.g. Store 1996).

Forming an buffer zone is a technique whereby a new area is generated by surrounding the desired spots, lines or areas within a certain distance (Congalton and Green 1992). Forming an buffer zone has often been used in identifying items which are less than or over a certain distance from a given spot or line (e.g. Hart 1985 et al., Walsh and Butler 1989). Visibility analysis is a matter of determining what areas can be seen and what areas cannot be seen from a certain spot determined according to level and elevation coordinates (Dangermond 1984). Visibility analyses enable one to determine the targets from which the clear cutting of a certain compartment (stand) would be visible (Davidson 1992 et al.).

In the case of overlay analyses, a new map layer is produced by superimposing two or more digitized map layers one on top of the other. In an arithmetical overlay analyses, the information contained by the map layers is edited by adding, removing, dividing or multiplying the desired values of the map layer using the values of another map layer equivalent in terms of its location. A logical overlay analysis can be used to seek out the targets in which certain conditions are in effect simultaneously. It often happens that overlay analyses are used in the planning land use; they are used to pinpoint areas in which the requirements by the use form actualise simultaneously (e.g. Jensen and Christensen 1986, Siderelis and Tribble 1988).

GIS-based techniques suitable for developing multi-objective forest planning are not usually ready for use as such, but instead comprise a varying number of analyses, which are linked to one another by means of certain rules. This is referred to as cartographic modelling.

2.2 Cartographic modelling

Cartographic modelling is a process of combining maps together by linking several map-algebra statements to form more complex algorithms

(Bonham-Carter 1994). It is a case of application of GIS analysis requiring the integrated analysis of many sources of information. Cartographic modelling has often been used when looking for areas suitable for a specific use form (e.g. Shaw and Atkinson 1988, Reisinger and Kennedy 1990, Wadge et al. 1993).

Usually the objective in land-use planning connected to cartographic modelling is to locate the area or areas where the given criteria apply. Locating of these areas takes place by connecting the map layers by means of logical overlay analyses in numeric format; each map layer then represents one criterion. If the map layers are connected applying absolute Boolean rules, the final result will always be a map in binary format with each pixel containing the value zero or one depending on whether or not the pixel fulfils all the given criteria. The rules applying to connecting maps are usually based on empirical observations and measurements, but sometimes also on the phenomenon's physical and chemical properties.

The final outcome in land-use applications based on Boolean logic is a map depicting those areas which simultaneously fulfil all the set conditions. The problem with the method is, however, that it does not offer any analytical method for examining which of the areas fulfilling the criteria are the most appropriate for the purpose of use in question or which areas are the best beyond the feasible areas. In order that the method might be better suited for multi-objective forest planning, it must also be able to provide information on how well a given area fulfils the set objectives. To facilitate this, the map layers must be connected using arithmetical overlay analyses and this has to be accompanied by methods developed for multi-criteria evaluation.

3 Multi-criteria evaluation methods and GIS

Multi-criteria evaluation (MCE) methods provide the tools for investigating a number of choice possibilities in the light of multiple criteria and conflicting objectives (Voogd 1983). The methods developed for multi-criteria evaluation may be divided into compensatory and non-compensatory methods. In the case of non-compensatory methods, a low criterion score for a alternative cannot be compensated by another criterion's high score, whereas this is possible when using compensatory methods. Compensatory methods can be further divided into additive techniques and ideal-point techniques. With additive techniques, the total score for each alternative is calculated by multiplying the criterion score by its weight factor and then adding the results together. Weighted linear summation is probably the best known example of this category. The principal problem encountered in connecting map layers is the realisation of the weighting of the map layers and of individual map-layer categories and of combining the criteria measured using different measurement scales or units (Carver 1991).

It often happens when processing GIS and natural-resources related data that the information related to the various criteria has been measured using units and scales which defy direct comparison. This is why standardisation methods have been developed and these enable the user to transform the criterion scores to one common measurement scale and measurement unit. These methods usually enable the variation of a criterion to be scaled between zero and one.

Different criteria often have a different weight values when decisions are made. This being the case, one must be able to evaluate the criteria in relation to one another and to connect to the criteria the weight coefficients reflecting their significance. The said weight coefficients can be derived in a number of ways. Voogd (1983) presents the following alternatives for determining a set of weights: preference analysis, behavioural analysis, direct system description, indirect system description, and hypothetical priorities. Setting the weight coefficients for the criteria usually has a crucial influence on the solution to the decision problem.

By merging MCE methods with GIS-based tools, it is possible to produce an index map instead of a binary map, with the values of the map elements (pixels, areas) on the index map depicting how well it fulfils the set objectives. These maps are produced by merging several map layers together so that some of the map layers serve as absolute constraints delimiting certain areas from being examined whereas flexible constraints determine how well a certain pixel fulfils the set objectives.

In the simplest form, the map layers are in binary format (a particular map element can obtain only the value of zero or one) in which case each map layer can be weighted with only one weight coefficient. This means that an index map is formed by multiplying every map layer by its weight coefficient and by then merging the map layers using Boolean or arithmetic operators. With multi-category maps, too, binary weighting with Boolean expressions can be used to convert them into binary maps.

With multi-category maps, weighting is performed by multiplying the values of the categories by the weight coefficients related to the map layers. When weighting multi-category maps, each map-layer category can be allocated its own coefficient in addition to map-layer-specific weight coefficients. Sensitivity analyses have been used in some studies to demonstrate to the decision maker the effect that the inaccuracies and the uncertainty included in the objectives and weightings have on decision recommendations (e.g. Pereira and Ducstein 1993).

4 Hypothetical example

The following fictitious example represents one way of using GIS and MCE techniques to classify forest areas on the basis of certain criteria. In the example, the objective is to prioritise the target area's old forests with respect to requirements of three species. Based on species habitat requirements, the method first yields an index map for each of the species with the index value representing the suitability of the area for the species in question. Then the index maps per species are combined to form an index map per species group (Fig. 1).

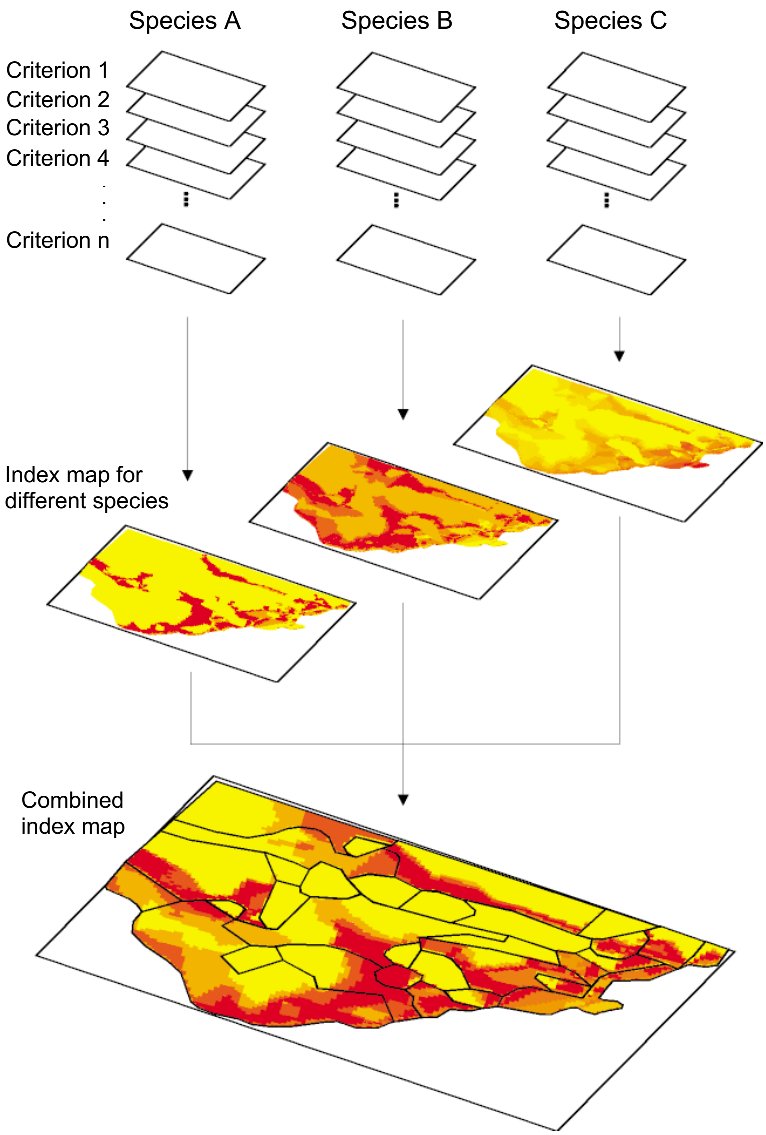

Figure 1. Producing and combining index maps per species to facilitate index maps per species group.

First, the area to be examined is reduced by means of absolute constraints. These absolute constraints can be the same for all the species and they can be related to the habitat requirements of the species or to the technical requirements of planning. In the example, the absolute constraints are the limits of the planning area and the maturity of the forest stands with respect to timber felling. Furthermore, real-life situations often include species-specific absolute habitat requirements. Following the first stage, Boolean logic-based overlay analyses are used to choose the areas, which are located within the planning area and carry mature timber.

The majority of habitat requirements can be considered to be flexible constraints. Areas which remain are examined at the second stage of the method and they are categorised using flexible constraints in order of goodness from the point of view of these three species. Fig. 2 shows the categorisation of the areas from the point of view of one species. Following absolute constraints, the distance

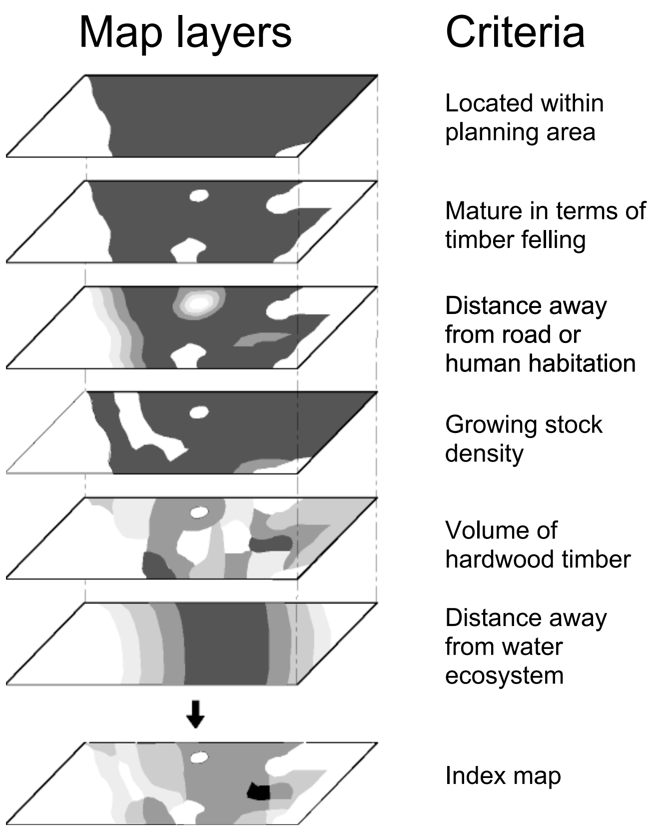

Figure 2. Criterion scores and index map for one species.

away from the road and human habitation, growing stock density, volume of hardwood timber, and distance away from a water ecosystem are chosen as the flexible constraints.

Standardisation of the flexible criteria is carried out in this example by using the pairwise comparisons of the analytic hierarchy process (AHP, Saaty 1980). Standardisation here was carried out by categorising the values of each criterion and by comparing the criteria categories by means of pairwise comparisons. This was followed by replacing the values of the criteria with the standardised category value, category by category. The weight coefficients of the criteria were obtained using a similar technique by comparing the importance of the criteria in pairs. Combining the criteria and the generation of the final index onto the rasterised cells were performed by multiplying the standardised values of the criteria by the weight coefficients and by adding the weighted map layers together.

5 Conclusions

An efficient instrument is needed for solving complex planning problems and conflict situations related to the use of natural resources. Such an instrument should also enable both the management of the information describing a target and the generation of new information to serve as support for decision-making. GIS applications offer such tools, including tools for combining information in different formats and for their numerical analysis. By using GIS-based tools in combination with state-of-the-art decision-analysis techniques, information more versatile than hitherto can be generated to support decision making. Thanks to this property, GIS applications are gaining in importance as instrument for multi-objective forest planning, for instance.

The method described in the present paper involved combining different georeferenced criteria in generating an index map describing how well a certain area fulfils the habitat requirements of a species group. The use of the index maps of this kind as aids in decision situations adds flexibility to decision-making. From the point of view of successful decisions, this is important because in the field of natural sciences it is extremely difficult, even with detailed models, to include all the factors affecting decisions. With the help of an index map, the decision-maker is able to see the suitability of subareas within a target area for a particular form of use. Having done this, the decision-maker can apply his/her own external evaluation criteria when making decisions.

References

Aronoff, S. 1989. Geographic information systems: A management perspective. WDL publications, Ottawa. 294 p.

Bonham-Carter, G. 1994. Geographic information systems for geoscientists: modelling with GIS. Computer methods in the geosciences volume 13. Pergamon, Ottawa. 398 p.

Carver, S. 1991. Integrating multi-criteria evaluation with geographical information systems. Int. J. Geographical Information Systems. 5(3): 321–339.

Congalton, R. & Green, K. 1992. The abcs of GIS: an introduction to geographic information systems. Journal of forestry 11: 13–20.

Dangermond, J. 1984. A classification of software components commonly used in geographic information systems. Environmental systems research institute, California. p. 57.

Davison, D., Selman, P. & Watson, A. 1992. The evaluation of a GIS for rural environmental planning. EGIS proceedings. p. 135–144.

Hart, J., Wherry, D. & Bain, S. 1985. An operational GIS for Flathead national forest. In: Ripple, W (ed.). Geographic information systems for resource management: a compendium. American Society for Photogrammetry and Remote Sensing and American congress on surveying and mapping. p. 219–228.

Jensen, J. & Christensen, E. 1986. Solid and hazardous waste site selection using digital geographic information system techniques. In: Ripple, W. (ed.). Fundamentals of geographic information systems: a compendium. American Society for photogrammetry and remote sensing and American congress on surveying and mapping. p. 195–206.

Pereira, J. & Duckstein, L. 1993. A multiple criteria decision making approach to GIS-based land suitability evaluation. Int. J. Geographical Information Systems. 7(5): 407–424.

Reisinger, T. & Kennedy, D. 1990. A spatial decision support system for opportunity area analysis on the Jefferson national forest. GIS/LIS '90 proceedings. p. 733–740.

Saaty, T.L. 1980. The analytic hierarchy process. Planning, priority setting, resource allocation. McGraw-Hill, New York. 283 p.

Shaw, D. & Atkinson, S. 1988. GIS applications for golden-cheeked warbler habitat description. GIS/LIS '88 proceedings. p. 401–406.

Siderelis, K. & Tribble, T. 1988. Using a geographic information system to prepare a site proposal for the superconducting super collider: A case study in north Carolina. GIS/LIS' 88 proceedings. p. 459–468.

Store, R. 1996. Maiseman huomioonottavan metsikkökuvioinnin tuottaminen paikkatietojärjestelmällä. Folia Forestalia 1996(3): 245–262.

Wadge, G., Wislocki, A. & Pearson, E. 1993. Spatial analysis in GIS for natural hazard assessment. In: Goodchild, M., Parks, B. & Steyaert, L. (eds.). Environmental modeling with GIS. Oxford university press. New York. p. 332–338.

Walsh, S. & Butler, D. 1989. Spatial pattern of snow avalanche path location and morphometry, Glacier national park, Montana. GIS/LIS' 89 proceedings. p. 286–294

Voogd, H. 1983. Multicriteria evaluation for urban and regional planning. London. 367 p.