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A GIS-based decision support system to identify nature conservation priorities in an alpine valley

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Abstract

This paper describes a methodological approach based on the integrated use of Geographical Information Systems (GIS) and Decision Support Systems (DSS) to identify nature conservation priorities among the remnant ecosystems within an alpine valley. The ecosystems are first assessed by means of landscape ecological indicators, and then ranked by using multicriteria analysis (MCA) techniques. Several conservation scenarios are generated so as to simulate different evaluation perspectives. The scenarios are then compared to highlight the most conflicting sites and to propose a conservation strategy for the area under evaluation. The paper aims at exemplifying and discussing the effectiveness of spatial decision-support techniques in land-use planning for nature conservation.

Keywords: Ecological evaluation; Land allocation; Nature conservation; Multicriteria analysis; Landscape ecological indicators

Introduction

Nature conservation can be defined as the protection of the natural richness of a landscape (Ploeg and Vlijm, 1978). The process of assessing the significance of an area for nature conservation is termed ecological evaluation (Spellemberg, 1992). The main objective of ecological evaluation is to provide criteria and information that can be used to identify conservation priorities, and therefore to support decision-making in nature conservation. For this reason, ecological evaluation can be seen as the link between the science of ecology and the practice of land management. By identifying the most ecologically valuable areas, planning and management practices can be applied so as to maintain the areas' value (Smith and Theberge, 1987). This involves, for example, the establishment of protected areas (Wildlife reserves, Biotopes, Site of Special Scientific Interest, etc.), as well as other land-use decisions, such as the identification of the least-damaging location for a new settlement or infrastructure.

Planning authorities undertake ecological evaluations to gain insights into the features of the land under their jurisdiction. In particular, ecological evaluation complements other and more traditional methodologies for natural resources assessment, such as land evaluation and land capability classification (Davidson, 1992; FAO, 1976; Klingebiel and Montgomery, 1961). These methodologies are biased toward production-related activities and aim at classifying the land mainly according to its potential rural or forestry use (Zonneveld, 1995).

In order to make the results of an ecological evaluation operational, they must be conveyed to decision-makers in the most efficient and transparent way. This means that the framework adopted during the evaluation (i.e. the criteria and indicators that have been selected) must be made explicit, so as to allow tracking of the influence of each factor on the evaluation results. Moreover, all possible scenarios resulting from the evaluation must be considered, so as to redirect further discussion toward the conflicting aspects only. This is optimally achieved by resorting to a Decision Support System (DSS), which can be defined as an interactive computer-based system that can help to utilize data and models to solve a decision problem (Malczewski, 1999).

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Most of the information required for ecological evaluation, and for environmental planning in general, is characterised by a spatial component. Consequently, such a DSS should be linked to a Geographic Information System (GIS) containing the relevant thematic layers. Coupling GIS and DSS is becoming a common strategy to deal with decision problems related to environmental planning and land allocation (Thomas, 2002; Joerin et al., 2001; Herwijnen, 1999; Keisler and Sundell, 1997; Malczewski, 1996; Jankowski and Richard, 1994; Pereira and Duckstein, 1993; Carver, 1991).

This research proposes an approach based on the integrated use of GIS and DSS to identify nature conservation priorities among the remnant ecosystems within a study area. The ecosystems are first assessed by means of landscape ecological indicators, and then ranked by resorting to multicriteria analysis techniques (Laukkanen et al., 2002; Geneletti, 2001a; Lahdelma et al., 2000; Bodini and Giavelli, 1992). The resulting nature conservation scenarios are compared to test their robustness and to highlight the most critical areas. As a result, a conservation strategy is proposed for the area under evaluation. The case study is represented by the management for nature conservation of an alpine valley located in the Trentino region (northern Italy).

Case study

The area studied in this research includes the southernmost stretch of the Non Valley, an alpine valley located within the Autonomous Province of Trento, in northern Italy (see Fig. 1). The Non Valley is famous for its high-quality apple production, and consequently most of its favourably exposed soil is devoted to apple orchards. The remaining areas are covered by urban settlements and infrastructures, as well as by remnant patches of the original forest. The area investigated covers about 5000 ha, of which about 15% is forest remnants. These scattered remnants of natural vegetation consist mainly of wetlands and ash, beech, pine and fir woodlands. Due to their scarcity within the valley floors, they represent relevant sites for nature conservation. Moreover, they provide important stepping stones to guarantee connectivity among the natural habitat of the surrounding mountains. Fig. 2 shows the distribution of the forest remnants within the study area.

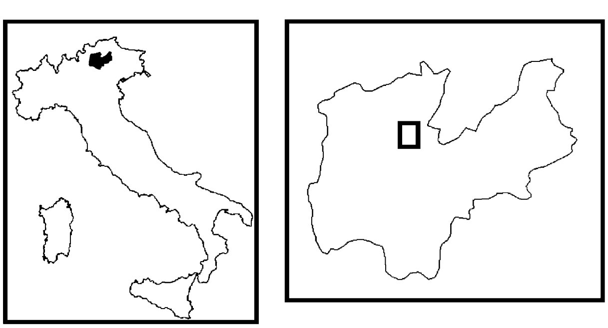

Fig. 1. Location of the Autonomous Province of Trento in Italy (left) and of the study area in that province (right).

The decision problem of the case study consists of the selection of the 200 ha of remnant forest characterised by the highest relevance for nature conservation. In other words, given that a maximum of 200 ha can be allocated to conservation, the study is to provide a support for the identification of the most significant forest patches. This decision problem represents a typical issue in land-use planning to which ecologists are asked to contribute (see for instance Sierra et al., 2002; Geneletti, 2001b; Lee et al., 1999; Steward and Joubert, 1998).

Methodology

The approach consists of the following four main steps:

(1) Definition of criteria to evaluate the forest remnants;
(2) evaluation of criteria and setting-up of a GIS database;
(3) multicriteria analysis and priority ranking of the forest remnants and
(4) generation and analysis of conservation scenarios and decision-making.

Criteria definition

In order to assess the relevance for nature conservation of the different forest patches, a set of evaluation criteria, and relevant indicators to measure such criteria, must be selected. Quite a number of review works on the criteria proposed in evaluation schemes for nature conservation can be found in the literature (Geneletti, 2002; Fandiño, 1996; Smith and Theberge, 1986; Usher, 1986). Most of the criteria were proposed in the 1970s and in the early 1980s. After the late 1980s, the main contribution to such evaluations was provided by findings in the discipline of landscape ecology.

Landscape ecology addresses the relationship between spatial patterns and ecological processes (Turner, 1989; Forman and Godron, 1986). As such, it contributes to ecological evaluation by analysing the role played by the landscape structure and the spatial distribution of the ecosystems for the survival of species and the conservation of nature (Burke, 2000; Bridgewater, 1993; Hannson and Angelstam, 1991).

Typical criteria adopted by landscape ecological studies refer to the dimension and the shape of the

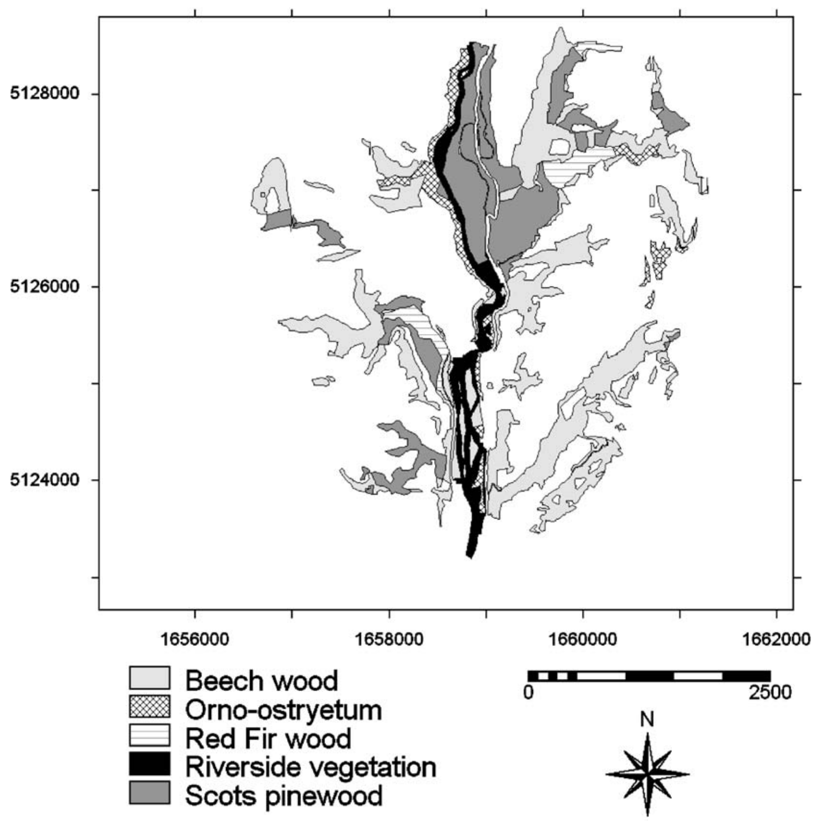

Fig. 2. Distribution of the forest remnants within the study area.

habitat patches, as well as to their connectivity and distribution throughout the landscape. Such criteria can be defined as abiotic criteria (Lee et al., 2001) because they are not related to species information. Abiotic criteria are particularly useful when floristic and faunistic data are unavailable or incomplete. This is often the case in landscapes dominated by artificial land uses, as in the area studied in this research. However, by using abiotic criteria only, it is difficult to provide an adequate assessment of the relevance of a site for nature conservation. Information is also needed on the biotic composition of the different ecosystems. For this reason, the evaluation framework set out in this research encompasses both biotic and abiotic criteria.

For what concerns biotic aspects, commonly employed criteria are rarity (i.e. a measure of how frequently an ecosystem type is encountered), diversity (i.e. a measure of the different habitats that exist in a given area), and naturalness (i.e. the degree to which an ecosystem is free from biophysical disturbance caused by human activities, Lesslie et al., 1988). Among those, rarity was preferred because it has a clearer interpretation and it is the most frequently used in ecological evaluations (Smith and Theberge, 1986). Furthermore, protection of rare ecosystems is often considered as the single most important function of biodiversity conservation (Margules and Usher, 1981). The rationale behind the use of the rarity criterion is the consideration that the rarer a feature, the higher is its probability of disappearance, and therefore its conservation relevance. A number of indicators have been proposed in the literature to measure ecosystem rarity (see, for example, Smith and Theberge, 1986; Pressey and Nicholls, 1989; Wittig et al., 1983). An indicator that proved to be effective and relatively easy to compute is represented by the potential area remaining (PAR) of an ecosystem type (Geneletti, 2003). This is the percentage ratio between the actual cover of an ecosystem type within a reference area (e.g. a province or region) and the potential cover within that area, i.e. the cover that was found to occur before human intervention. The PAR indicator offers the advantage of providing a quantitative estimation of rarity and of requiring fairly basic data, such as maps of the actual ecosystems and maps of their potential cover within the area (e.g. potential vegetation maps).

In addition to rarity, three abiotic criteria were selected: patch dimension, isolation, and exposure to external disturbances. The selection of these three criteria was motivated by the fact that they are broadly used in landscape ecological evaluations, have a straightforward meaning, and are representative of the characteristics of a natural area. In general, larger and connected ecosystems are better at conserving their

Table 1
The criteria and indicators used for the evaluation

Criterion	Indicator	Unit
Rarity	Ratio between actual cover and potential cover	%
Isolation	Average edge-to-edge distance from surrounding patches	m
Dimension	Core area	m^2
Exposure to disturbance	Average distance from surrounding settlements and infrastructures	m

biodiversity and structure than smaller and isolated ones (Southerland, 1995). This is because large and connected patches tend to host a higher number of species, and populations less subject to extinction with respect to smaller and isolated patches (Noss et al., 1997; Wickham et al., 1997; Usher, 1985). As for exposure to external disturbances, it is evident that an increase undermines the ecosystem viability, especially in man-dominated landscapes, where ecosystems are usually subjected to a significant pressure from the surrounding non-natural matrix (Hunter, 1996).

Having defined the three criteria (i.e. the "standard of judging" according to which the relevance for nature conservation is to be assessed), the next step consists in selecting suitable indicators (i.e. the parameters to be used in practice to measure the selected criteria).

In order to measure the dimension of an ecosystem patch, the core area indicator was selected (McGarigal et al., 2001; Baskent, 1999; Laurence and Yensen, 1991). This indicator is computed by measuring the size of a patch, deprived of its outer belt. This allows to consider the area of a patch characterised by the absence of edge effects extending from its boundaries. The isolation criterion was expressed by using the average edge-to-edge distance between a forest patch and the surrounding ones as an indicator. Finally, exposure to external disturbances was expressed by measuring the average distance of a patch from the surrounding sources of disturbance, such as urban areas and infrastructures. Table 1 provides an overview of the criteria and the indicators selected for the evaluation of the relevance of the forest patches for nature conservation.

Criteria evaluation and setting-up of a GIS database

The four indicators can be computed by using typical functionalities of raster-based GIS, such as distance operators and spatial filters. The GIS package ILWIS 3.0 (ILWIS, 2001) was used because it is provided with powerful tools for analysis and transformation of raster data. The following paragraphs give an overview on the operations performed. A detailed step-by-step description can be found in Geneletti (2002).

The core area was computed by applying a morphologic filter that shrinks the original forest patches along their edges. The edge-to-edge distance was computed by generating the Thiessen-polygon map (Burrough and McDonnell, 1998), i.e. a map that assigns each location to the closest forest patch, and by considering the average distance of the boundary pixels of each polygon. The distance from the surrounding sources of disturbances was computed through distance functions by using as input maps the map of the forest patches and a land use map. Finally, the PAR indicator was computed through the GIS by comparing the actual area cover of each ecosystem type with its potential cover.

The potential cover was retrieved by a potential-vegetation map of the study area (Pedrotti, 1982). Such a map represents the vegetation types that potentially could grow in the area on the basis of its climate, soil, water conditions, geology and topography. Therefore, potential-vegetation maps are to reproduce the features of a landscape as they were before human disturbances and interventions took place. The scale of analysis is typically broad, because these maps can only provide a prediction of the expected distribution of ecosystems, and they cannot account for micro-variability of the factors considered. However, potential-vegetation maps provide a quantitative representation of the original conditions, and a reference for drawing a balance on the ecosystem types that experienced the highest loss.

The result of these computations consisted in the generation of an attribute table (linked to the forest map) that contains the indicators' measurements for each of the remnant forest patches. This represented the starting point for the subsequent multicriteria analysis.

Multicriteria analysis and priority ranking of forest patches

Multicriteria analysis (MCA) techniques support the solution of a decision problem by evaluating the possible alternatives from different perspectives and by analysing their robustness with respect to uncertainty (Beinat and Nijkamp, 1998; Janssen, 1992; Nijkamp et al., 1990). Although it has evolved in recent years to a range of decision aid techniques (Beinat and Nijkamp, 1998), MCA in its strict sense refers to a sequence of well-established procedural steps that allow to rank a set of competing alternatives, and to select the best performing ones. Such procedural steps were applied in this research, as illustrated next.

In this case study, the alternatives to be evaluated and ranked are represented by the different forest ecosystems. Each ecosystem was assessed by considering four criteria, and measuring the relevant indicators, each one expressed in its own units (see Table 1). In order to relate to the degree of relevance for nature conservation of the ecosystem under analysis, the measurements of the indicators need to be transformed from their original units into a value scale. This operation is performed by generating a value function, i.e. a curve that expresses the relationship between the indicator measurement and the corresponding value score (cf. Beinat, 1997). In other words, the measurements lose their dimension and become an indication of the achievement of the evaluation objectives, expressed into a given value range (e.g. between 0 and 1). This operation is referred to as ''standardisation'' and represents the first formal step of MCA. Examples of methodologies for the construction of value functions in ecological evaluation can be found in Pereira and Duckstein (1993) and Crance (1987).

As different criteria are usually characterised by different importance levels, the subsequent step of MCA is the prioritisation of the criteria. This is often achieved through the assignment of a weight to each criterion that indicates its importance relatively to the other criteria under consideration. Once the weights are assigned to each criterion, the aggregation can be performed. This is done by using a decision rule that dictates how best to order the alternatives. The most widely used decision rule is the weighted linear combination. According to this rule, an overall score is calculated for each alternative by first multiplying the valued indicator scores by their appropriate weight, and then summing the weighted scores for all criteria.

These procedural steps were followed in order to obtain a ranking of the forest ecosystems, which will be subsequently used to support the selection of the 200 ha of forest area most suitable for nature conservation. The MCA steps were performed by using the DEFINITE DSS (Janssen et al., 2001). Even though not provided with spatial-analysis functionalities, this DSS was chosen because it has an extensive and user-friendly set of tools to support the selection of value functions and weights. The fact that DEFINITE does not handle the spatial dimension (i.e. it cannot work with criteria and alternative expressed by maps) represents a minor inconvenience in this research: it is straightforward to link the output of the MCA analysis (i.e. the value score of the different forest ecosystems) with the GIS database.

First of all, the indicator measurements were standardised by applying value functions. The shape of such functions has a clear influence on the results of the standardisation, and consequently of the overall evaluation. For this reason, the value functions should be generated very carefully, and if possible by resorting to the opinion of a group of experts (Beinat, 1997).

Two standardisation approaches were followed. The first one is based on the use of linear functions for all the four criteria, as shown in Fig. 3. The endpoints of each of the functions (corresponding to the value zero and one) are represented by the minimum and the maximum value measured for the relevant indicator. It is worth noting that the isolation and rarity criteria are characterised by a decreasing function. This is because smaller values (i.e. respectively rarer patches and patches closer to each other) are considered as more valuable than larger ones. The other three criteria have increasing functions, in accordance to the meaning of the indicators to which they refer.

In the second approach, value functions of different shapes were used by taking into account the opinion of an expert in ecological evaluation (see Fig. 4). As can be seen, concave, convex, as well as S-shaped functions were used. However, it goes beyond the scope of this paper to discuss in detail the construction of the value functions. The idea is simply to simulate different perspectives, and study their effect on the evaluation results.

After the standardisation, weights must be assigned to the four criteria. In order to include into the analysis different perspectives, three sets of weights were considered (see Table 2). In the first set, a high priority was given to the only biotic criterion (i.e. rarity), at the a-biotic criteria's expenses. The second set, on the contrary, prioritises abiotic criteria. Finally, in the third set equal weights were assigned to all the four criteria. These three sets of weights were combined with the two standardisation approaches, so as to generate six different assessments of the forest ecosystems (see Table 3). In each of the assessment, the weighted

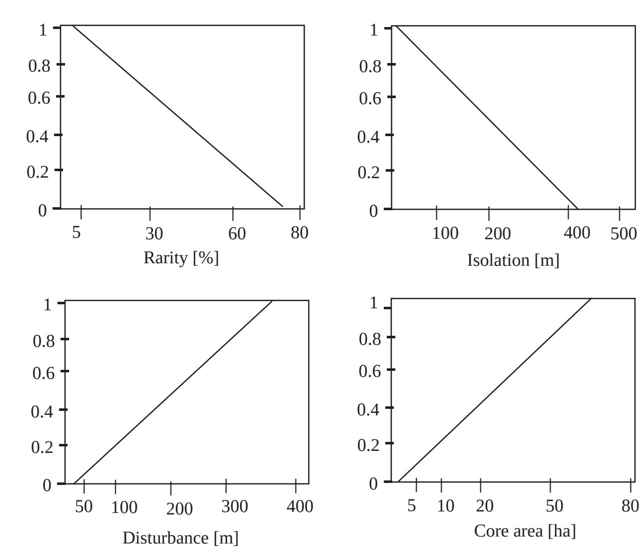

Fig. 3. Linear value functions for the four indicators.

summation method was employed to attach a conservation value to the different forest ecosystems. These values were brought back into the GIS database and used to generate the relevant maps (see Fig. 5). Such maps show the conservation value of the different forest remnants, according to the six assessment approaches synthesised in Table 3.

It is worth noting that several other MCA approaches different from the one adopted here exist. A common feature of all of them is that the evaluation is based on a number of explicitly formulated criteria that provide indications about the performance of the different alternatives. Such criteria are measured by suitable indicators, which are typically expressed by different units of measurement. An overview of the different techniques that have been proposed and applied in the literature to perform the different operational steps of MCA can be found in Herwijnen (1999) and Lahdelma et al. (2000).

In this study, it was decided to carry out the criteria aggregation by using the weighted summation technique because, besides being methodologically sound, easy to explain and transparent (Janssen, 2001), it offers the advantage of providing a quantitative ranking of the alternatives. That is, each forest patch is not only given an ordinal position in the ranking, but also a performance score. This score allowed to perform most of the analyses on the conservation scenarios described in the next section. In the domain of environmental management, other popular aggregation techniques are the Concordance analysis, the Regime method, and the Evamix method (Janssen et al., 2001). The first two were not considered suitable to this application because, besides providing ordinal rankings only, they are both based on a pairwise comparison of the alternatives, which appeared very cumbersome here given the high number of forest patches to be compared. Finally, the third method was discarded because it is meant to be used when both quantitative and qualitative criteria score are present.

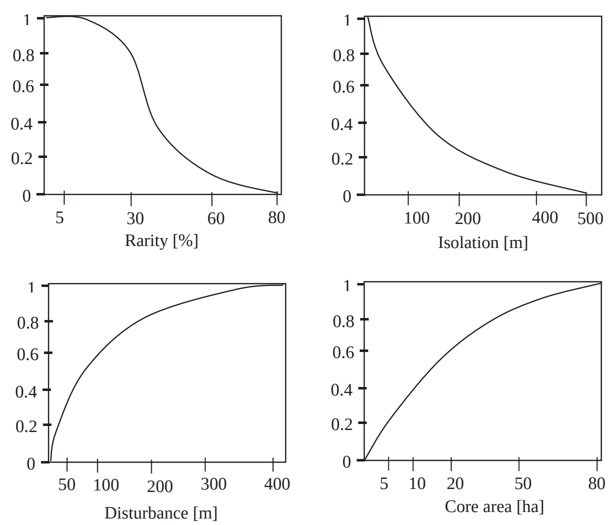

Fig. 4. Non-linear value functions for the four indicators.

Table 2
The three sets of weights

Criterion	Weight set 1 (Priority to biotic criterion)	Weight set 1 (Priority to abiotic criteria)	Weight set 1 (equal priority)
Rarity	0.50	0.15	0.25
Isolation	0.15	0.30	0.25
Dimension	0.20	0.35	0.25
Exposure to disturbance	0.15	0.20	0.25

Conservation scenarios and decision-making

As stated in Section 2, the objective of the case study was to identify the most suitable 200 ha of forest remnants to be allocated to nature conservation. Consequently, after having generated the six evaluation maps shown in Fig. 5, the next step consisted in selecting, within each map, the top-scoring forest patches up to cover an area of 200 ha. In order to allow the selection of entire patches, the 200-ha target was approximated by $\pm 10\%$. This means that the proposed conservation area may cover from about 180 to 220 ha.

The six conservation scenarios are shown in Fig. 6. Each scenario represents the best solution to the

Table 3
Characteristics of the six assessments

Assessment	Standardisation	Weight set
Assessment 1	Linear value functions	Equal priority
Assessment 2	Linear value functions	Priority to biotic criterion
Assessment 3	Linear value functions	Priority to abiotic criteria
Assessment 4	Non-linear value functions	Equal priority
Assessment 5	Non-linear value functions	Priority to biotic criterion
Assessment 6	Non-linear value functions	Priority to abiotic criteria

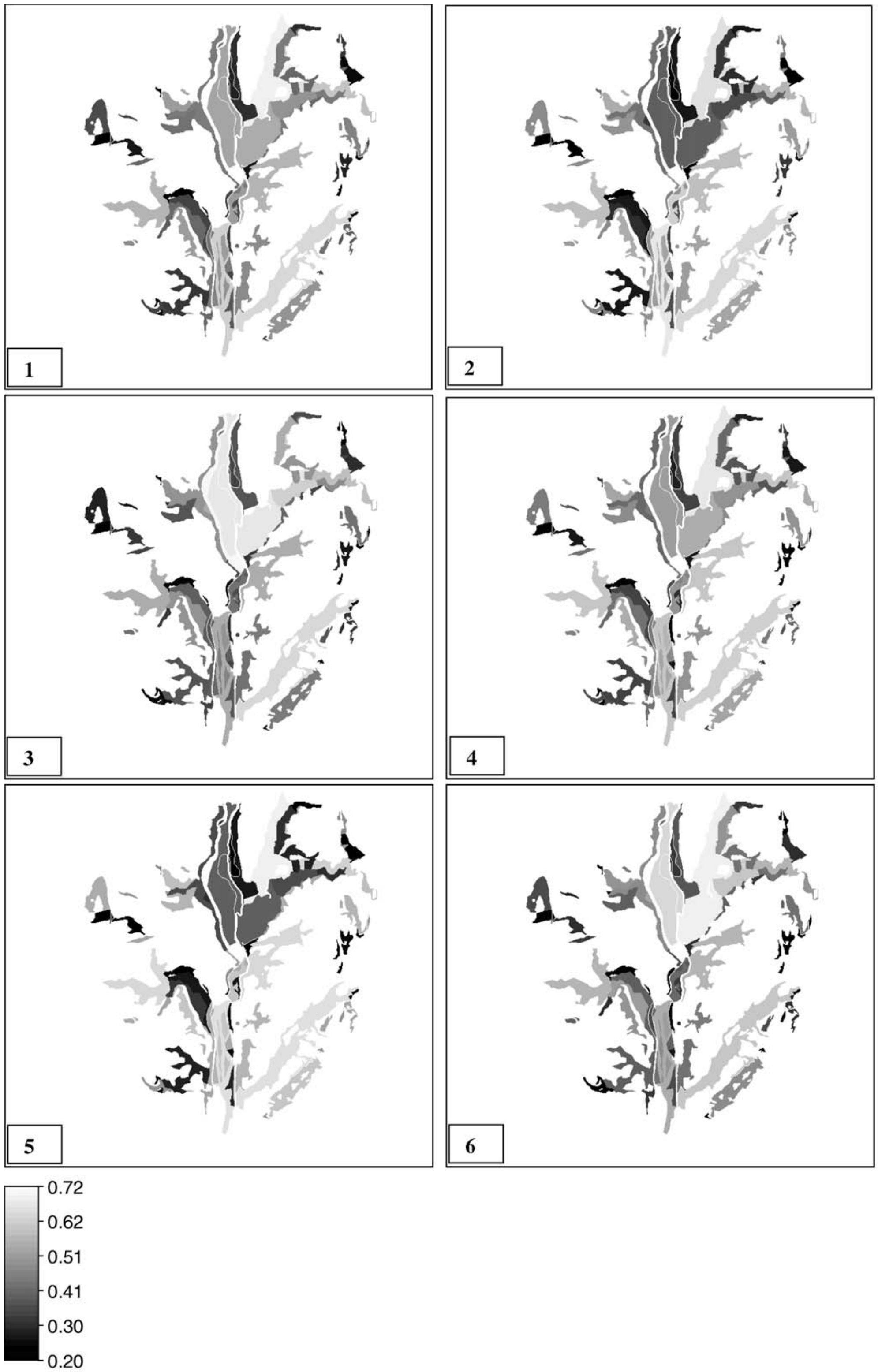

Fig. 5. Value maps of the six assessments.

decision problem, according to the assessment "perspective" that was adopted (i.e. standardisation functions and weights). This is a common situation in environmental decision-making. Map scenarios reflecting the opinion of different experts or stakeholders involved in the analysis must be compared in order to highlight the robustness of the solution and support decision-making.

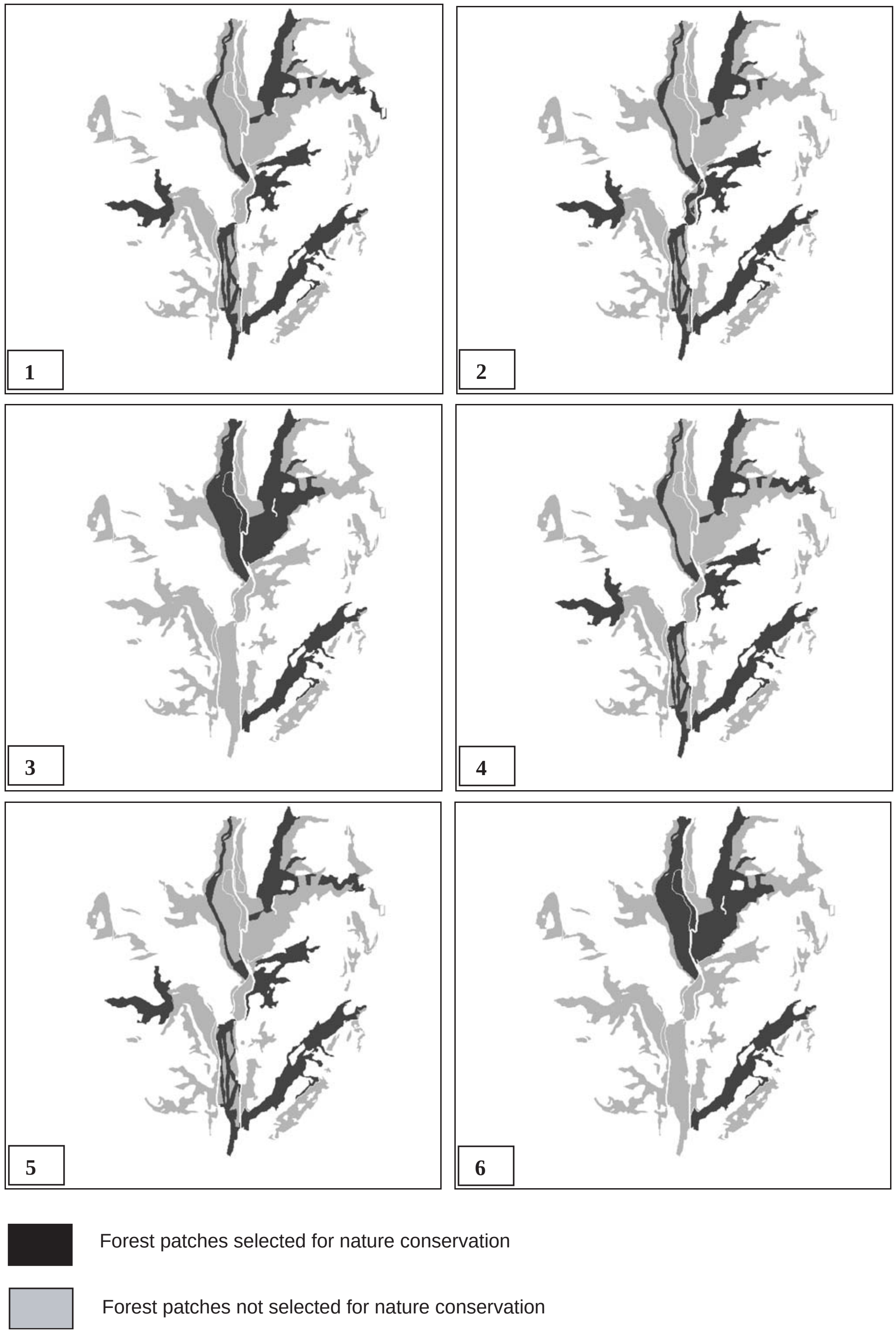

Fig. 6. Conservation scenarios of the six assessments.

A first robustness analysis on the six scenarios consisted in classifying the forest patches into the following three categories:

1. Patches selected for nature conservation in all scenarios;
2. Patches selected for nature conservation in at least one of the scenarios;
3. Patches never selected for nature conservation.

The result of such a classification is shown in Fig. 7. This map provides a synthetic overview of the critical aspects of the decision problem. Patches falling in category one and three do not represent an issue in that they can be, respectively, selected and excluded from the area to be allocated to nature conservation. As shown by the

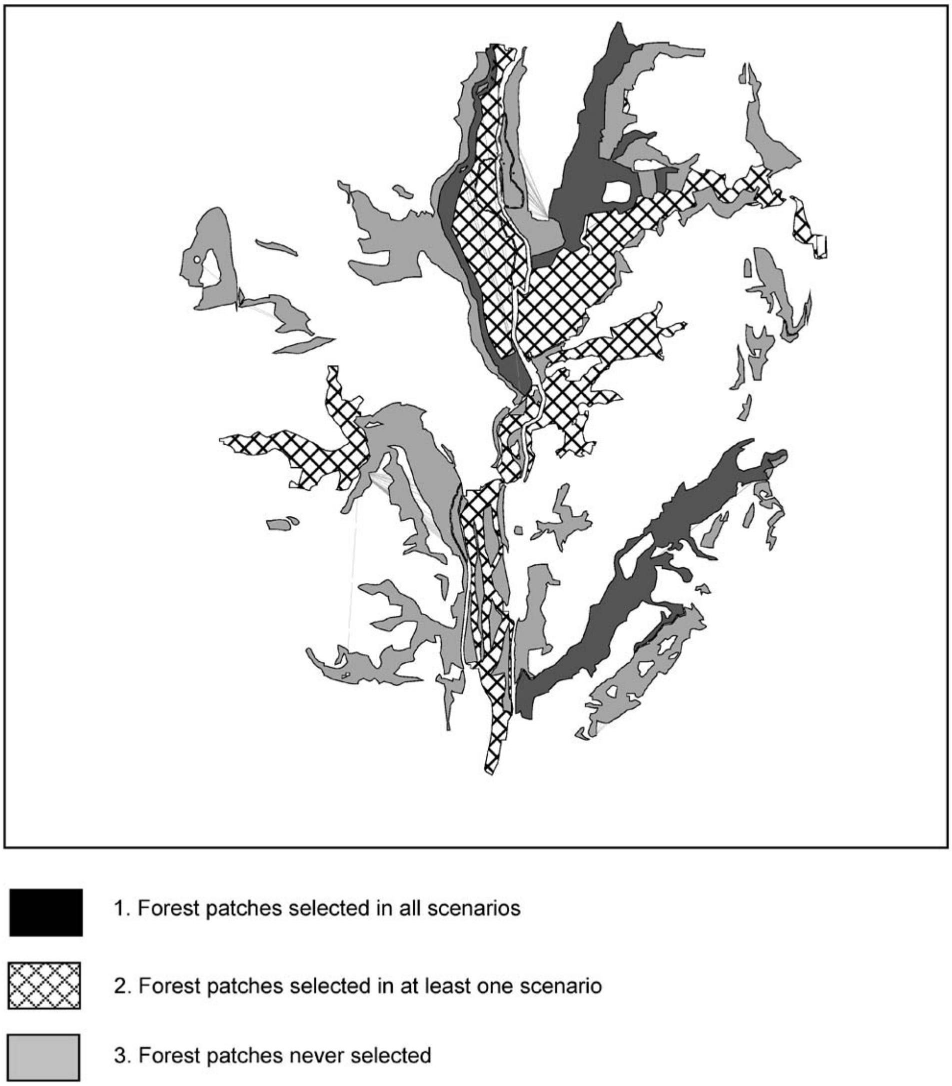

Fig. 7. Synthetic map of the six conservation scenarios.

histogram of Fig. 8, forest patches of category one cover an area of about 125 ha. Consequently, 75 more hectares have to be identified, among the patches that were selected in at least one scenario. Thus, the decision problem has been framed down to selecting 75 ha out of the about 225 ha of forest falling into category 2 (see Fig. 8).

Several strategies can be followed to support such a choice. One could for instance choose the patches that were selected more frequently in the six scenarios. Another possibility consisted in generating what can be defined as an "optimistic" and a "pessimistic" solution. This required a two-step approach, as illustrated next.

First of all, two new value maps were generated by assigning to each forest patch respectively its maximum and its minimum value obtained in the six assessments shown in Fig. 5. Then, an optimistic solution was constructed by allocating to nature conservation

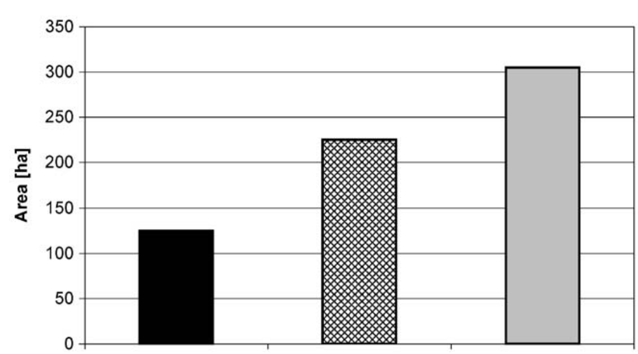

Fig. 8. Histogram of the synthetic map (see legend in Fig. 9).

(additionally to the 125 ha previously selected) the patches corresponding to the best 75 ha according to the map containing the maximum values. Analogously, a pessimistic solution was constructed by allocating to nature conservation the patches corresponding to the best 75 ha according to the map containing the minimum values. These two allocation solutions are shown in Fig. 9.

This approach was preferred because, instead of providing directly a solution, it took into account all the perspectives considered during the evaluation, and highlighted the critical patches, i.e. the patches whose score is more sensitive to changes in the value functions and weights. By considering the maximum and minimum value of each patch, the whole range of results obtained with the different assessments was considered.

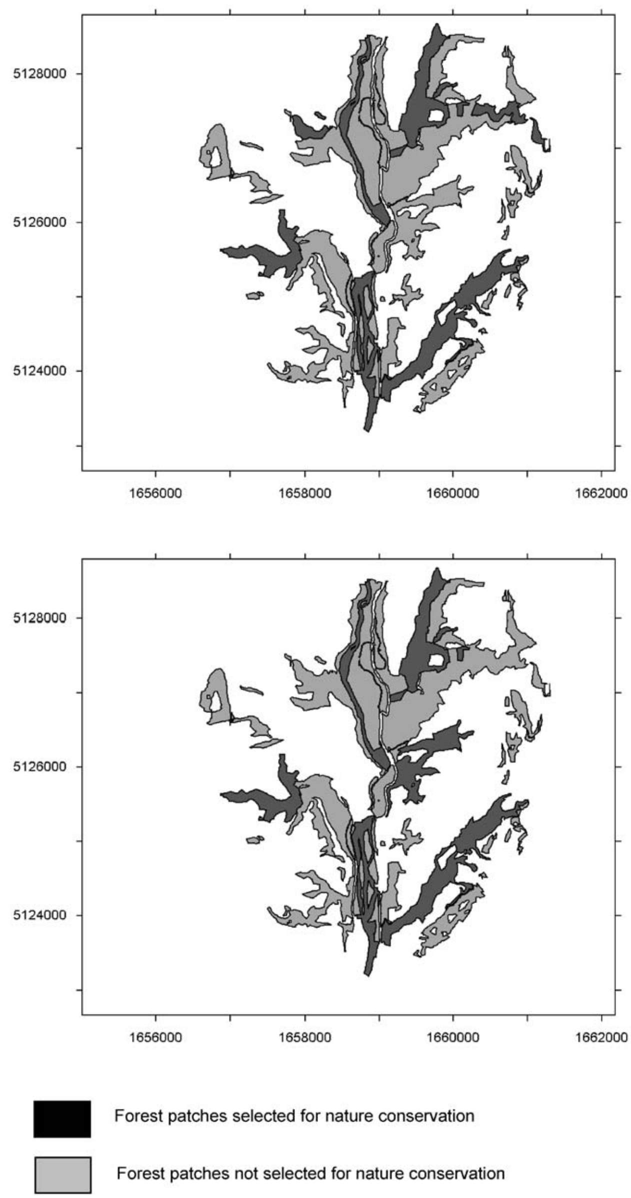

Fig. 9. "Optimistic" solution (above) and "pessimistic" solution (below).

As shown in Fig. 9, the differences between the two solutions are quite small. Only five forest patches emerge as problematical, i.e. they are selected in only one of the two solutions. Such patches cover an area of about 40 ha. This means that the decision problem can be considered as narrowed down to these 40 ha. On the other hand, the selection of the remaining 160 ha is "robust" with respect to fluctuation of the patch values within the range of all possible values resulting from the six assessments.

The choice between the optimistic and the pessimistic solution could be made by decision-makers according to their risk aversion. Another approach could be based on other considerations, such as the fact that the "optimistic" solution seems to enhance the overall connectivity of the area allocated to conservation. However, rather than at coming-up with a solution, the performed analyses aimed mainly at broadening the understanding of decision-makers about the issues at stake, so as to better support their choice.

Discussion and conclusions

This paper presents a methodological approach based on the link between a GIS database and a Decision Support System to perform an ecological evaluation of forest ecosystems, and to consequently support the identification of conservation priorities. The main objective of the paper was to exemplify and discuss the effectiveness of spatial decision-support techniques in land allocation for nature conservation. In particular, the approach aimed at guiding the identification of conservation priorities starting from a limited set of ecological information. Land-use decisions concerned with nature conservation often have to be taken in similar conditions. This is because, apart from few outstanding sites, ecological data are generally scarce, and their acquisition is very resource demanding. Consequently, land-use planners are rarely provided with adequate background on the relevance of the land in term of biodiversity conservation. This is especially true in man-dominated landscapes, i.e. areas characterised by a non-natural matrix (settlements, agricultural fields, etc.) and by scattered natural ecosystems (such as forest or wetland remnants).

The lack of biotic information was overcome in this research by resorting to abiotic indicators proposed in landscape ecology to estimate the conservation relevance of ecosystem patches within a landscape. Such indicators offer the advantage of being easily measured and easily understood (Lee et al., 2001). Hence they represent a suitable surrogate for species-related information in man-dominated landscapes, such as the valley floor considered in this study. Due to the scarceness of unspoilt areas, there is a growing interest, especially in

Europe, on the conservation of biodiversity within such a type of landscapes (Arts et al., 1995).

The generation and comparison of conservation scenarios highlighted the critical issues of the decision problem, i.e. the forest ecosystems whose conservation relevance is most sensitive to changes in the evaluation perspective. This represents an important contribution to effective decision-making because it allows one to gradually narrow down a problem. For example, the results of the scenarios' comparison (refer back to Figs. 7 and 9) could be used to steer additional information acquisition toward where it is actually needed to broaden the scientific basis of the decision. This is of paramount importance because resources allocated to investigate the nature-conservation potential of an area are scarce (especially in the light of other and more profitable uses of land) and planners cannot afford to waste them. Such resources must be mainstreamed toward the actual problematic and controversial aspects. For example, in this case study, further ecological surveys could be planned only on the forest ecosystems characterised by conflicting allocation results.

The spatial DSS that have been presented is focused on the ecological side of the decision problem. Therefore, it is to be used by experts in conservation, because they are the ones that have to draw value functions or decide upon the relevance of the different criteria. However, the identification of nature-conservation sites goes beyond the mere ecological issues and involves also socio-economic aspects.

The actual decision-making will be more complex than what presented here because other concerns are at stake: agricultural value of the land, suitability for residential use, proximity to infrastructure corridors, etc. For this reason, ecologists must make sure that their analysis, and its conclusion, is provided to decision-makers in the most clear and transparent way. Only by knowing the relevance of an ecosystem patch, and its robustness with respect to the different perspectives of the team of expert involved, decision-makers can decide, for instance, to what extent that patch can be traded with another one. That is, to what extent ecological priorities can be traded with other issues of concern.

In a real context, the spatial DSS illustrated here is to be integrated with similar analyses resulting from socio-economic assessments of the sites under consideration. This is to offer decision-makers a comprehensive basis to better orient their strategy and take a decision.

In conclusion, the analyses carried out in this research developed an evaluation framework to soundly generate conservation scenarios and assess their robustness. It is envisaged that a similar approach be routinely undertaken to support land-use planning for conservation, even when dealing with human-disturbed areas and when only limited ecological data are available.

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