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CASE STUDY

An integrated approach for studying the land suitability for ecological corridors through spatial multicriteria evaluations

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Abstract Nature conservation is a very important issue in the sustainability assessments and spatial planning context. Knowledge of the suitability of the land to behave as an ecological corridor thus provides very significant input to land-use planning. Nature conservation and land-use planning are by their nature spatial problems. A family of methods that are rapidly gaining traction for planning and policymaking, named spatial multicriteria evaluations (SMCE), which are based on geographic information systems (GIS) and multicriteria analysis (MCA) coupling, can be an effective support for this area. The present paper proposes the integration of the GIS with a specific MCA technique, named Analytic Network Process to assess the ecological value of the land in the Piedmont Region (northern Italy). The results are obtained in the form of maps to be used as decision variables in planning. The study concludes with some lessons learned during the development of the SMCE and highlights that the applied methodology is an effective tool for decision makers in spatial planning and strategic assessments.

Keywords Spatial multicriteria evaluations · Geographic information systems · Ecological corridors planning · Analytic Network Process · Indicators

1 Introduction

Ecological corridors are areas or structures that enable spreading, migration and exchange of species between core areas and nature development areas inside an ecological network (Jongman and Pungetti 2004).

The two primary components of ecological networks are named hubs, or areas of known ecological value, and links, which are the corridors that connect the hubs to each other.

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Knowledge of ecological networks can thus be used to support conservation-related land-use decisions.

Landscape fragmentation (due to infrastructural developments, industrialization, urbanization and intensive agricultural practices) causes the geographical isolation of the species and reduces the habitat's resilience, thus leading to a process of biodiversity loss. As a consequence, maintaining and restoring landscape connectivity is currently a central concern in ecology and nature conservation, and more generally speaking in territorial planning for achieving sustainable development (Gambino 2004).

Since the 1990s, scientific concerns for habitat and ecosystem fragmentation and landscape and ecological connectivity have entered the political arena, as can be seen in the Global Strategy for Biodiversity (1992), the Habitat Directive (1992), the Pan-European Strategy of Biological and Landscape Diversity (1995) and the Biodiversity Strategy of the European Community (1998). The European Directive on Strategic Environmental Assessment (2011/42/EC) has further fostered the incorporation of sound environmental principles and criteria, such as ecological connectivity at strategic levels, for many types of plans and programs, including regional and urban land-use and infrastructural plans.

Nevertheless, there is a lack of quantitative methods able to assess ecological connectivity or ecological fragmentation at the regional scale and to efficiently support planning processes and the strategic environmental assessment (Marulli and Mallarach 2005).

In such a context, a specific family of decision support systems (DSS; Burstein and Holsapple 2008), named spatial multicriteria evaluations (Malczewski 1999), which are based on geographic information systems (GIS) and multicriteria analysis (MCA) coupling, have been found to be effective.

The main rationale for integrating GIS and MCA is that they have unique capabilities that complement one another. On the one hand, GIS has great abilities for storing, managing, analyzing and visualizing geospatial data required for the decision-making process. On the other hand, MCA offers a collection of procedures, techniques and algorithms for structuring decision problems, and designing, evaluating and prioritizing decision alternatives (Malczewski 1999). MCA combines factual information (e.g., soil type, slope, infrastructures) with value-based information (e.g., expert's opinion, quality standards, participatory surveys) (Geneletti 2010).

The most significant difference between spatial multicriteria decision analysis and conventional multicriteria techniques is the explicit presence of a spatial component. The former requires data on the geographical locations of alternatives and/or geographical data on criterion values (Sharifi and Retsios 2004) while the latter usually assumes spatial homogeneity within the area under analysis.

Moreover, spatial multicriteria analysis provides significant support for the generation and comparison of alternatives through an active participation of the stakeholders involved in the decision-making process. It is thus becoming one of the most interesting evolutions in the context of environmental assessment procedures (as, for instance, the environmental impact assessment and the strategic environmental assessment) where the comparison of different alternatives represents one of the most important parts of the whole process and where the complexity of the problems and the need for technical support in the decision-making process are particularly real.

From the methodological point of view, the present application proposes the integration between GIS and a specific MCA technique named Analytic Network Process (ANP; Saaty 2005), which represents the evolution of the Analytic Hierarchy Process (AHP; Saaty 1980). The ANP was used to identify potential ecological corridors, which ensure continuity between areas with high environmental and ecological value and stepping stones in the Piedmont Region (Northern Italy). The experimentation was carried out using both the ILWIS 3.3 software[1] and the IDRISI 3.2 one,[2] since the two packages provide different functions for the standardization of the factor maps.

The study thus developed a decision-support model that was based on land-use data and information on significant ecological areas, including important habitats for target species, wetlands, infrastructural impacts and human pressures in order to identify larger areas of ecological priority and potential ecological linkages.

Since the incorporation of the AHP calculation block in the IDRISI 3.2 software package, it has become much easier to apply this technique to solve spatial problems. Applications of the ANP, which is particularly suitable for dealing with complex decision problems that are characterized by interrelationships among the elements at stake, are instead scarce (Nekhay et al. 2009; Neaupane and Piantanakulchai 2006; Levy et al. 2007; Ferretti 2011a; Ferretti and Pomarico 2012).

The present paper has therefore a double purpose; firstly, to investigate the potentialities of the ANP-GIS integration and to present the innovative SMCE methodology with reference to the case study of the Piedmont Region for assessing ecological connectivity and supporting regional planning or strategic environmental assessments. Secondly, to verify to what extent different standardization procedures of the factor maps lead to different results.

After the introduction section, the paper is organized as follows: Sect. 2 presents the SMCE methodological background and offers a brief literature review regarding spatial analysis and the study of ecological corridors. The application of the spatial ANP model to the case study is shown in Sect. 3. Finally, Sect. 4 presents the main findings of the application and Sect. 5 summarizes the conclusions that have been drawn from the study and highlighting the opportunities for expanding the work.

2 Methodological background

2.1 Spatial multicriteria evaluations

In the context of decision support systems (DSS), researchers have often ignored the importance of graphical analysis of spatial information. One of the first experiences concerning the use of maps in decision-making processes refers to the work of McHarg (1969), where the basic concepts that would be later developed in geographic information systems (Charlton and Ellis 1991) are set forth.

Whereas DSS and GIS can work independently to solve some simple problems, many complex situations demand the two systems to be integrated in order to provide better solutions (Li et al. 2004). Following this reasoning, it can be stated that the development of spatial decision support systems (SDSS) has been associated with the need to expand the GIS system capabilities for tackling complex, not well-defined, spatial decision-making problems (Densham and Goodchild 1989). The concept of SDSS evolved in the mid 1980s (Armstrong et al. 1986) and by the end of the decade many works concerning SDSS were available (Densham 1991; Goodchild 1993; Densham and Armstrong 1987; Armstrong 1993). Over the course of the 1990s, there has been considerable growth in the research, development and applications of SDSS and in recent years they have been expanded to

[1] http://www.itc.nl/ilwis/downloads/.

[2] www.clarklabs.org.

include optimization (Aerts et al. 2003; Church et al. 2004), simulation (Wu 1998), expert systems (Leung 1997), multicriteria evaluation methods (Feick and Hall 2004; Malczewski 1999; Thill 1999; Janssen and Rietveld 1990; Carver 1991; Eastman et al. 1993; Pereira and Duckstein 1993; Jankowski and Richard 1994; Laaribi et al. 1996), online analysis of geographical data (Bedard et al. 2001) and visual-analytical data exploration (Andrienko et al. 2003) with the aim of generating, evaluating and quantifying trade-offs among decision alternatives. The field has now grown to the point that it is made up of many threads with different, but related names, such as collaborative SDSS, group SDSS, environmental DSS and SDSS based on spatial knowledge and on expert systems (Malczewski 2006).

With specific reference to GIS-based multicriteria decision analysis, the full range of techniques and applications has been recently discussed in a very interesting survey developed by Malczewski (2006). From 2000, the number of studies has been increasing and several applications can be found in different fields. A detailed analysis of the state of the art of these tools is reported in Ferretti (2011b) who presents a classification of the scientific international literature highlighting the most recent global trends of the research in the SMCE field.

SMCE are most commonly applied to the land suitability analysis in the urban/regional planning, hydrology and water management and environment/ecology fields (Malczewski 2006; Ferretti 2011b), and are usually based on a loose coupling approach and on a value-focused thinking framework (Ferretti 2011b).

From the methodological point of view, a spatial decision-making support tool can be defined as an interactive computer system designed to assist the user, or group of users, to achieve high levels of effectiveness in the decision-making process, while solving the challenge represented by semi-structured spatial decision problems (Malczewski 1999).

An SMCE is thus a procedure to identify and compare solutions to a spatial decision problem, based on the combination of multiple factors that can be, at least partially, represented by maps (Malczewski 2006).

Spatial multicriteria analysis therefore represents a significant step forward compared with conventional MCA techniques because of the explicit spatial component, which requires both data knowledge and representation of the criteria (criterion maps) and the geographical localization of the alternatives, in addition to the decision makers' preferences. In fact, conventional non-spatial MCA techniques typically use the average or the total impact of an alternative on the environmental system, considering them appropriate for the whole area under consideration. In other words, conventional approaches assume spatial homogeneity within the area under analysis but this assumption is clearly unrealistic since the evaluation criteria, or rather the attributes that are used to measure them, vary spatially.

According to the model proposed by Simon (1960, 1991) and considering the work of Steinitz (1993), Sharifi and Rodriguez (2002) have developed a framework for planning and decision-making process (Fig. 1). In this model, there is a flow of activities moving from intelligence to design to choice phase as well as sub-steps in each phase (Sharifi 2007). The framework highlights how each phase of the decision-making process involves the methodological contribution of both GIS and multicriteria evaluation methods. Firstly, the intelligence phase refers to the examination of the environment in order to identify a problem or opportunity situation and includes the structuring of the problem, during which the system under consideration is defined and the objectives to pursue are explored. One or more criteria, or attributes, are then selected to describe the degree of achievement of each objective (Keeney 1992).

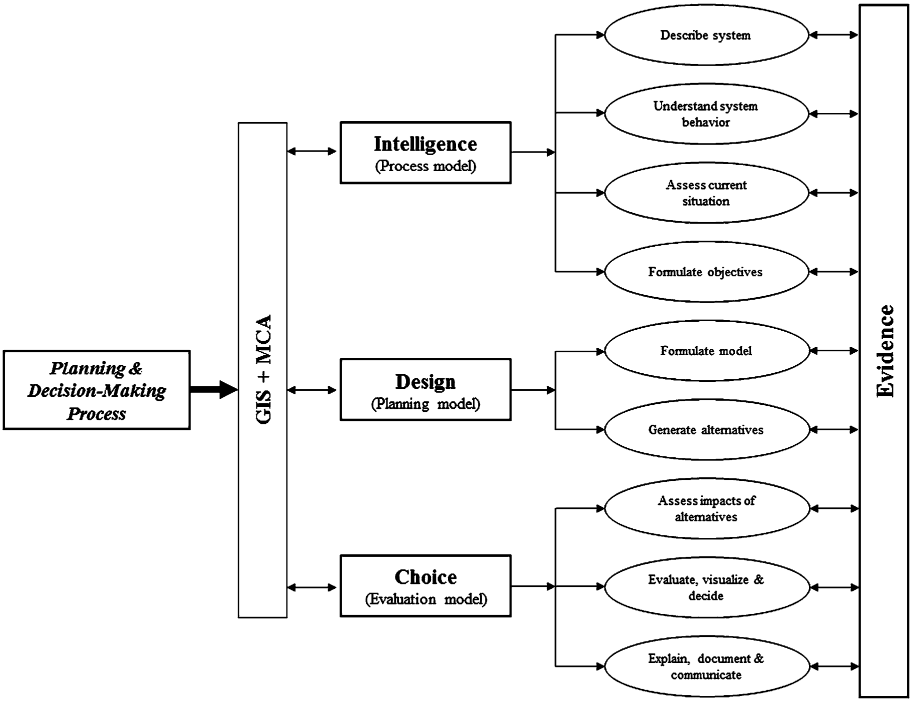

Fig. 1 Framework for planning and decision-making process (*Source*: adapted from Sharifi and Rodriguez, 2002)

Secondly, the design phase involves the development and analysis of possible courses of action. This phase is the innovative part of the process and refers to the data collection and processing, as well as to the development of multicriteria analysis through the definition of the relationships between objectives, attributes and preferences of the decision maker (Malczewski 1999). In this phase, the alternatives are generated by performing a spatial multicriteria evaluation which uses the criteria structure and the set of constraints identified in the intelligence phase in order to generate a suitability map (Zucca et al. 2007).

Finally, during the choice phase, alternatives are evaluated and a selection of specific courses of action is performed; furthermore, detailed analyses, such as a sensitivity analysis, are deemed appropriate in order to obtain useful recommendations.

Evidence is defined as the total set of data, information and knowledge at the disposal of the planner, decision makers and analysts.

2.2 Ecological corridors and spatial analysis

The reduction and fragmentation of natural and semi-natural habitats, as an outcome of agricultural intensification, infrastructure networks and urbanization, has been suggested as the main reason for the current nature conservation crisis (Foley et al. 2005; Gurrutxaga et al. 2010).

Ecological planning is playing an increasingly important role in natural conservation policies and strategies, thus recognizing the necessity to integrate protected areas of an entire territory both ecologically and socio-economically (Bennett 2004; IUCN 1994).

In this context, it is important to develop coherent and functional conservation networks, known as ecological networks. Opdam et al. (2006) define ecological networks as a set of ecosystems of one type, linked with a spatially coherent system through flows of organisms, and interacting with the landscape matrix in which it is embedded. Hence, the ecological network is a multispecies concept, linking ecosystems, whereas the term habitat network as defined by Hobbs (2002) refers to the habitat of a single species.

According to Gurrutxaga et al. (2010), ecological networks are characterized by their emphasis on nature conservation at the ecosystem, landscape or regional level. The focus is on maintaining or strengthening ecological coherence and in ensuring the protection of critical areas against effects of possibly harmful external activities, while at the same time taking into consideration the restoration of degraded ecosystems (Bennett and Wit 2001). One of the main contributions derived from this delimitation of coherent ecological networks is the definition of critical interaction areas between the protected natural territory network and its surrounding matrix of artificial urban land and communication infrastructures. Adequate management of these critical areas is decisive for conservation policies to be effective (Bruinderink et al. 2003). Finally, ecological networks typically promote opportunities for sustainable use of natural resources, encouraging complementary facets between land-use objectives and those of nature conservation (Opdam et al. 2006).

The complexity of the phenomenon is affected by the multitude of pressures and constraints acting on the ecosystem as well as the need to maintain and develop the links between the ecosystems.

At the landscape scale, patches are spatially structured, and they interact with each other and with their environment. As a consequence, a spatial approach is necessary (Vogt et al. 2007). Geographic information systems (GIS)-based models are widely used tools for the design of ecological corridors, and least-cost modeling stands out as an efficient technique because of the explicit results it yields and because it allows for parameterization and testing through empirical studies (Noss and Daly 2006; Theobald 2006).

The spatial design of ecological networks has lead to their implementation in landscape planning (Huber et al. 2007; Opdam et al. 2006) and in turn has had an effect on land-use policy and the evaluation processes for the environmental impact assessment of plans and projects.

Whereas GIS techniques have commonly been applied to ecological studies in order to identify ecological networks (Gurrutxaga et al. 2010; Vogt et al. 2007; Opdam et al. 2006; Vuilleumier and Prélaz-Droux 2002; Baschak and Brown 1995), SMCE applications in this field are still an experimental approach (Duriavig 2008).

3 Case study

3.1 Research objectives and description of the case study

In order to test the potentialities of the SMCE approach in the ecological planning field, the present study proposes the development of a decision and planning support tool at the regional scale. The area under analysis refers to the Piedmont Region (Fig. 2) and is situated in the North-West of Italy. It covers a surface area of 25,402 km^2 and has a population of about 4.4 million inhabitants.

The Piedmont Region is surrounded on three sides by the Alps, including the Monviso and the Monte Rosa massifs. The geography of Piedmont is 43.3 % mountainous, along with extensive areas of hills (30.3 %) and plains (26.4 %). The territory is occupied to the

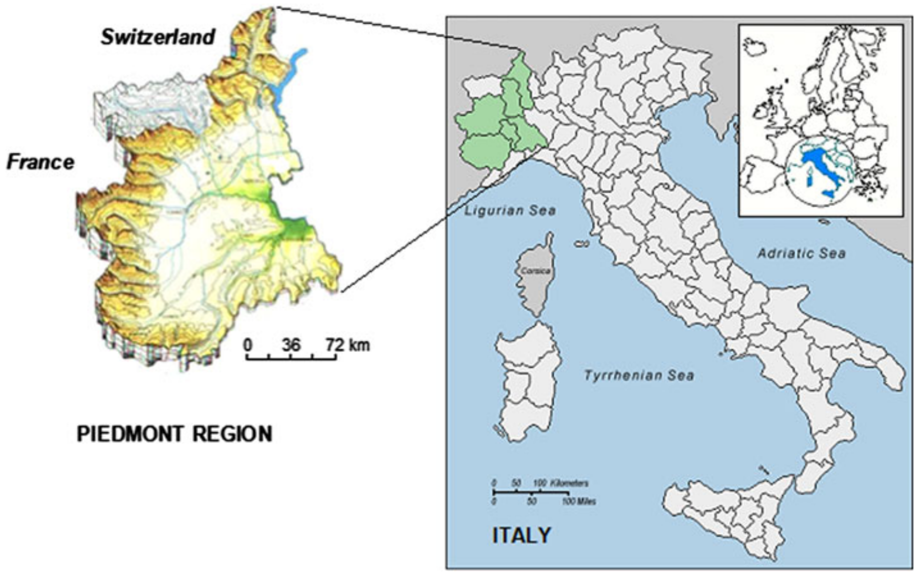

Fig. 2 Area under examination

East by the Padana Plain, crossed by the longest river in Italy, the Po, and its many tributaries.

The region under analysis is characterized by a relevant presence of natural protected areas. There are 63 protected areas established by a regional law covering a total surface of 210,625 ha which represents 7.6 % of the territory. In addition to the regional protected areas, the Piedmont Region has two national parks: the "Gran Paradiso" and the "Val Grande" covering a total area of 48,500 ha. Among these protected areas, a particularly important role is played by the Po river system that covers an area of 35,515 ha.

Finally, seven regional protected areas, named "Holy Mountains" were inserted in the World Heritage List of UNESCO in 2003.

The study described in the following sub-sections aims to highlight the most relevant areas for nature conservation due to their high natural and environmental quality value. The rationale is thus to support the decision-making process concerning ecological planning and management, highlighting the areas to be conserved and valorized and identifying potential areas for ecological networks, which link natural protected areas. The proposed methodology generates cartographic results to be used as decision-making variables during planning procedures in order to provide answers to landscape and local planning conflicts between societal development and nature conservation in a human disturbed landscape. The result should contribute to a better understanding of wildlife dispersal in fragmented landscapes, and so provide effective tools for conservation planning (Vuilleumier and Prélaz-Droux 2002).

3.2 Model development

The present application represents a research study aiming at testing the usefulness of the proposed method as a decision-making support tool in the ecological planning field by highlighting ecological corridors in the Piedmont Region.

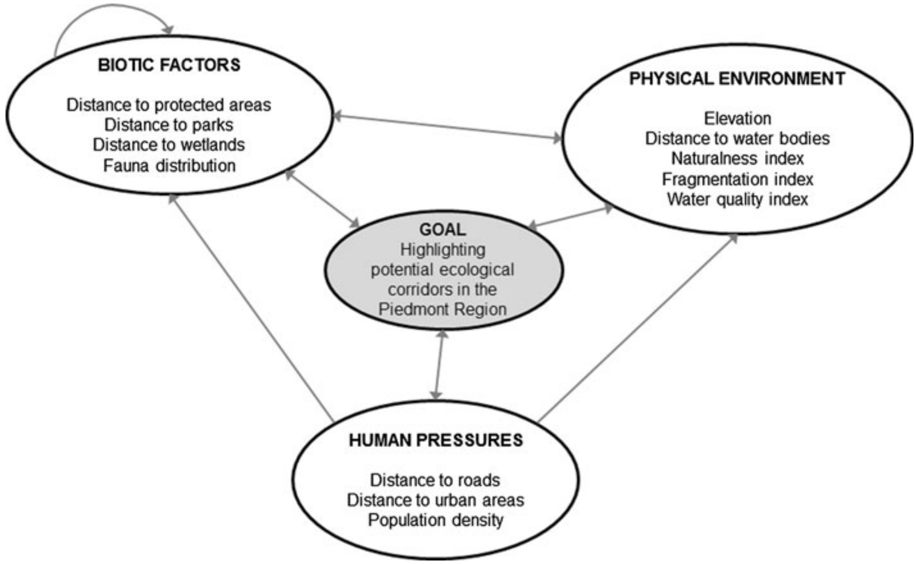

Fig. 3 The ANP network structure for the case under examination

The different stages of the SMCE model which we developed are illustrated in the subsequent sub-sections.

3.2.1 Structuring of the decision-making problem

Starting from the overall objective of the analysis, which is to study ecological connectivity in the Piedmont Region, a comprehensive set of evaluation criteria was identified that reflect all the relevant concerns to the decision-making problem (Fig. 3).

Due to the presence of different interrelated factors and to the intrinsic spatial nature of the problem, the ANP method was coupled with geographic information systems (GIS). The ANP is a multicriteria measurement theory that is used to derive relative priority scales of absolute numbers from individual judgments. It offers a general framework to deal with complex decisions which provides a comparison of the different options and it requires a network structure to represent the problem, as well as pairwise comparisons to establish the relationships within the structure. The reasons for using an ANP-based decision approach in the present analysis are: (1) the assessment of the land suitability to behave as a potential ecological corridor is a multicriteria decision-making problem; (2) there are dependencies among groups of criteria which need to be analyzed, (3) the detailed analysis of the interrelationships between criteria forces the decision makers (DMs) to carefully reflect on their project priority approach and on the decision-making problem itself, thus gaining a better understanding of the problem and making more reliable final decisions and (4) the integration with GIS constitutes an innovative approach of which it could be interesting to investigate limits and potentialities.

According to the ANP, the problem structuring phase involves identifying groups (or clusters) constituted by various elements (nodes) that influence the decision. All the elements in the network can be related in different ways since the network can incorporate feedbacks and complex interrelationships within and between clusters, thus providing a more accurate modeling of complex settings. The network construction thus represents an important and very creative phase in the problem-solving process.

In the present application, the model was developed according to the simple network structure. Decision problems can also be structured according to the complex network structure (Saaty 2005).

The network structure of the problem and the interdependences between the clusters were simulated using Super Decisions 1.6.0 Software,[3] which automatically creates a list of the pairwise comparisons needed to run the evaluation.

The criteria considered in the present application were selected in accordance with the legislation on protected areas and on sustainability assessments (Habitats Directive, Birds Directive, European Directive on Strategic Environmental Assessment) which provides a list of aspects to be considered for the protection and valorisation of ecological networks.

The selected criteria refer to quantitative ecological and environmental indicators and were clustered into three main groups: factors relevant to the physical environment, biotic factors and human pressures (Fig. 3).

According to the ANP methodology, once the network has been identified, it is necessary to represent the influences among the elements. This task was approached in the following way. Firstly, all the elements in the clusters were supposed to have an influence on the general goal. Secondly, further relationships were identified concerning the potential influences among the elements of each cluster.

The direction of the arrows in Figure 3 illustrates the interdependence relationships between the factors. A single direction arrow shows the dominance of one factor over another. A double direction arrow shows mutual influence between the factors. Loops indicate inner dependences.

These influences reflect the natural dynamics of the environmental and territorial systems, where link and interaction pathways exist between individual elements, which can, positively or negatively, affect each other (Bottero and Ferretti 2011). For example, the “naturalness index” is influenced by the “distance to protected areas,” the “distance to wetlands” and the “distance to urban areas” (Fig. 3).

It is worth noting that evaluation criteria, named in this context factors, are compensatory criteria that contribute to a certain degree to the output (suitability). There are two types of factors: (+) benefit criteria and (−) cost criteria (Fig. 4). A benefit criterion contributes positively to the output (the higher the values, the better), while a cost criterion contributes negatively to the output (the lower the values, the better).

The present application did not consider any constraint in the model since the least suitable areas to host ecological corridors, such as urban areas, are excluded from the analysis through the standardization procedure which is discussed in the following paragraph.

The identified factors were then represented as thematic map layers in a GIS database. Figure 4 shows the criteria tree with the associated thematic maps for this case study modeled through the ILWIS interface.

A raster map was thus linked with each criterion, in order to represent the spatial distribution of the criterion performance with reference to the objective of the analysis. Vector data collection was performed and maps were computed through basic raster GIS operations (map overlay, buffering, distance mapping, spatial queries, etc.).

The vector data sources used to represent the factors were provided by the regional administration environmental geo-database portal and a spatial resolution of 25 m was

[3] www.superdecisions.com.

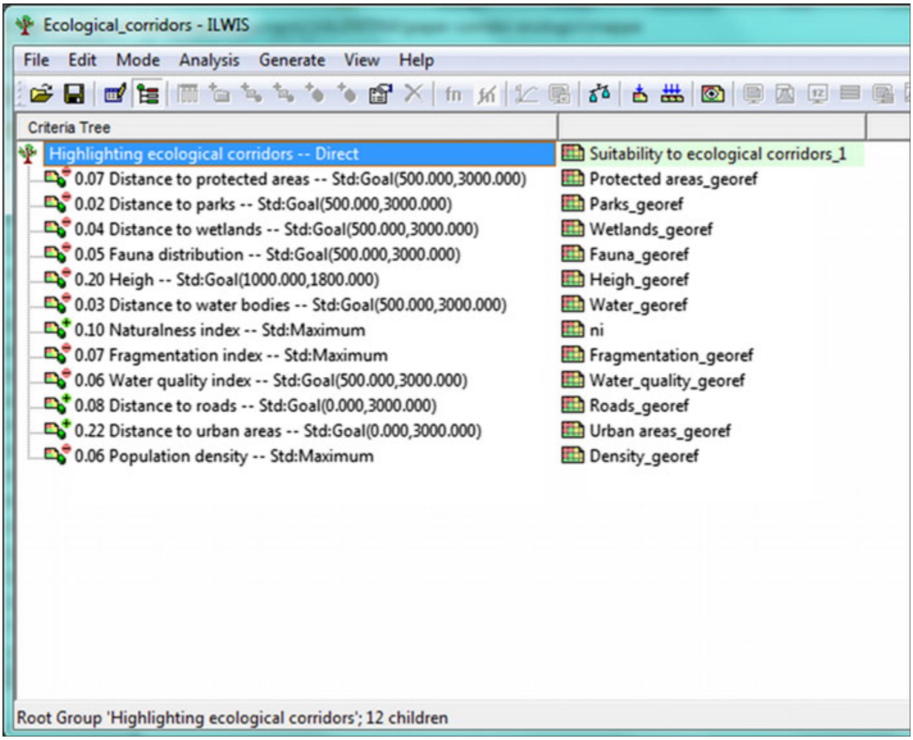

Fig. 4 The criteria tree used in the analysis. On the *left* are the factors and associated weights with descriptors. On the *right* are the corresponding file names of the digital maps spatially representing factors. The interaction structure is from the ILWISs SMCE module (ILWIS 3.3 2005)

adopted for the analysis. Data with a 25-m cell size were taken as a standard to represent environmental and land-use processes and patterns on the landscape scale, as in many European countries (Nunes de Lima 2005; Geneletti 2007).

Table 1 illustrates the vector data sources and the basic spatial GIS operations performed to generate each factor map. Among the data collected for the development of the model, those relating to the fauna distribution have a lower level of detail compared with the others. Nevertheless, they were considered in the analysis since we believe that this information constitutes an important element for the evaluation of the land ecological value.

3.2.2 Standardization and weighing of criteria

The design phase involves the standardization and weighing of all the factors being considered in the analysis.

As previously explained, each criterion is represented by a map. For decision-making analysis, the values and classes of all the maps should be converted into a common scale, which is called utility. Utility is a measure of appreciation of the decision maker with respect to a particular criterion, and relates to its value/worth (measured in a scale from 0 to 1). Such a transformation is commonly referred to as standardization (Sharifi and Retsios 2004).

Table 1 List of vector data sources and spatial elaborations performed for each criterion

Criteria	Vector data sources	Scale	Spatial editing operations
Distance to protected areas	Piedmont region sites of community interest (SCI) map	1:25,000	Buffering and distance
Distance to parks	Map of the parks	1:25,000	Buffering and distance
Distance to wetlands	Corine land cover map	1:1,000,000	Spatial query and distance
Fauna distribution	Habitat distribution of the typical alpine fauna	1:25,000	Layer union and distance
Elevation	Altimetry map	1:100,000	Spatial query
Distance to water bodies	Hydrographic map	1:100,000	Buffering and distance
Naturalness index	Corine land cover map	1:1,000,000	Attribute table editing and calculations on record values
Fragmentation index	Map of the roads, highways and railways Administrative boundary map—municipal areas	1:10,000 1:10,000	Intersect and attribute table editing
Water quality index	Hydrographic map	1:100,000	Attribute table editing and spatial editing
Distance to roads	Map of the roads, highways and railways	1:10,000	Buffering and distance
Distance to urban areas	Corine land cover map	1:1,000,000	Spatial query and distance
Population density	Administrative boundary map—municipal areas	1:10,000	Attribute table editing

Since both standardization and weighing of the factors are largely subjective, in the present application both the procedures were carried out through a focus group with several technical experts. The focus group was organized with the aim of creating a multidisciplinary group in order to tackle the complexity of the problem under analysis. The focus group was made up of five technical experts in the field of sustainability assessment of territorial transformations, ecological evaluations, multiple criteria decision aiding and spatial analysis. Through the discussion and the sharing of expertise, the different experts have thus agreed on the standardization approach to be adopted in each case and on the relative importance of the considered factors. They worked together in order to achieve a consensus by simulating the decision-making process with the help of the thematic maps derived from the model development. Furthermore, the focus group was supported by a facilitator to ease the understanding of the standardization and weighing procedures.

In particular, standardization was performed by using both linear functions and sigmoidal monotonically decreasing functions (Table 2). Through standardization, the original factor scores (each expressed in its own unit of measurement) are converted into dimensionless scores in the 0 (worst situation) to 1 (best situation) range.

Linear standardization functions assume that a linear relationship exists between the impact scores and the perceived significance of the impacts. This method offers the advantage of keeping the ratio between the original impact scores and the standardized ones. The sigmoidal function is instead based on the cosine function and evaluates the fuzzy set membership values (possibilities) of data cells (Eastman 2006).

Table 2 Factors description and standardization

Criteria	Description	Standardization
Distance to protected areas	The criterion maps the distance to protected areas (sites of community importance and special protection areas)	Distances ≤500 m are standardized to 1. Distances between 500 and 3,000 m are first standardized according to the linear function (the lower the distance, the higher the score) and then according to the sigmoidal monotonically decreasing function (Fig. 6) in order to see to which extent the different approaches affect the results. Distances ≥3,000 m are standardized to 0
Distance to parks	The criterion maps the distance to regional and provincial established parks	Distances ≤500 m are standardized to 1. Distances between 500 and 3,000 m are first standardized according to the linear function (the lower the distance, the higher the score) and then according to the sigmoidal monotonically decreasing function in order to see to which extent the different approaches affect the results. Distances ≥3,000 m are standardized to 0
Distance to wetlands	The criterion maps the distance to wetlands	Distances ≤500 m are standardized to 1. Distances between 500 and 3,000 m are first standardized according to the linear function (the lower the distance, the higher the score) and then according to the sigmoidal monotonically decreasing function in order to see to which extent the different approaches affect the results. Distances ≥3,000 m are standardized to 0
Fauna distribution	The criterion maps the distance to areas that are considered habitats for the typical alpine fauna, including the ruminant, the ungulates and bats that are considered as keystone species of the Piedmont Region (Osservatorio Faunistico 2011)	Distances ≤500 m are standardized to 1. Distances between 500 and 3,000 m are first standardized according to the linear function (the lower the distance, the higher the score) and then according to the sigmoidal monotonically decreasing function in order to see to which extent the different approaches affect the results. Distances ≥3,000 m are standardized to 0
Elevation	The criterion maps the elevation of the land	Elevations ≤1,000 m are standardized to 1. Elevations between 1,000 and 1,800 m are standardized according to the linear function (the lower the elevation, the higher the score) and elevations ≥1,800 m are standardized to 0
Distance to water bodies	The criterion represents the distance to surface water bodies since the proximity to the considered factor creates positive conditions from the ecological point of view	Distances ≤500 m are standardized to 1. Distances between 500 and 3,000 m are first standardized according to the linear function (the lower the distance, the higher the score) and then according to the sigmoidal monotonically decreasing function in order to see to which extent the different approaches affect the results. Distances ≥3,000 m are standardized to 0

Table 2 continued

Criteria	Description	Standardization
Naturalness index	The index of naturalness is calculated by assigning a value between 0 and 1 to each patch in the area under analysis (the higher the natural value of the area, the higher the score) and by multiplying this value for the area of the considered patch (OCS 2002)	The criterion is standardized according to the linear function (the higher the index, the higher the score).
Fragmentation index	The index of infrastructural fragmentation describes the level of fragmentation of each municipality[a]	The criterion is standardized according to the linear function (the higher the index, the lower the score)
Water quality index	The criterion maps the distance to the best performing classes of water quality index	Distances $\leq$500 m are standardized to 1. Distances between 500 and 3,000 m are first standardized according to the linear function (the lower the distance, the higher the score) and then according to the sigmoidal monotonically decreasing function in order to see to which extent the different approaches affect the results. Distances $\geq$3,000 m are standardized to 0
Distance to roads	The criterion represents the road network system inside the area under examination	The criterion is standardized according to the linear function (the higher the distance, the higher the score). Distances $\geq$3,000 m are standardized to 1
Distance to urban areas	The criterion maps the distance to human settlements	The criterion is standardized according to the linear function (the higher the distance, the higher the score). Distances $\geq$3,000 m are standardized to 1
Population density	The criterion assigns to each municipality the population density value (Comuni Italiani 2011)	The criterion is standardized according to the linear function (the higher the population density, the lower the score)

[a] The index of infrastructural fragmentation is calculated according to the following formula (1):

$$\mathrm{IFI} = \left[\sum_i (Li * oi)\right] * [N/A] * p \qquad (1)$$

where Li is the length of the infrastructure, oi is the weight in a 0–1 range assigned to each type of infrastructure (highways and railways have the highest weight while local roads have the lowest weight), N is the number of parts in which each municipality is fragmented due to the presence of infrastructures, A is the area of each municipality and P is the perimeter of each municipality (Lega 2004)

Table 2 explains how each criterion was standardized in the present study. The control points used for the standardization of each criterion were discussed and decided during the aforementioned focus group.

With the aim of providing a complete overview, Fig. 5 shows the standardized maps for each factor. For the sake of simplicity, those maps that were standardized using both the linear approach and the sigmoidal one are shown only once since at this scale of representation the difference between the two images would not be detectable. Particularly, for those maps, the figure shows only the results of the sigmoidal standardization function.

In order to clarify the explanation, Fig. 6 illustrates the standardization function graphs used for the factor "distance to protected areas." On the left (Fig. 6a), the linear standardization function with control points 500 and 3,000 m is shown while on the right

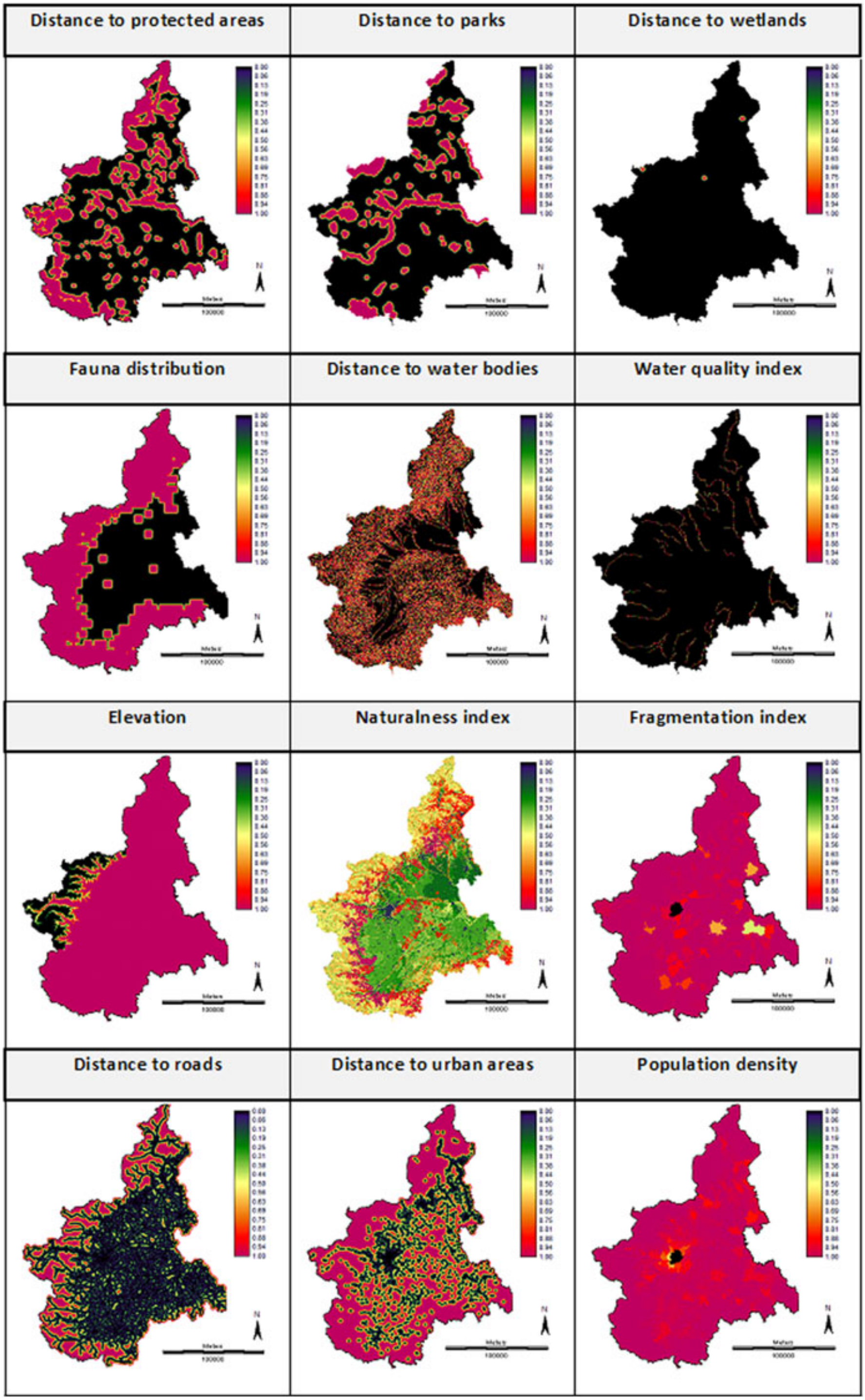

Fig. 5 Standardized factor maps

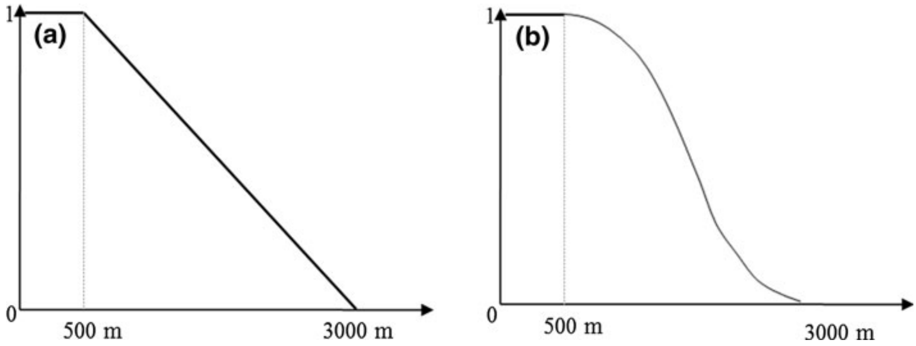

Fig. 6 Standardization functions for the factor "distance to protected areas:" on the *left* is the linear standardization function (**a**) and on the *right* is the sigmoidal monotonically decreasing function (**b**)

(Fig. 6b), the sigmoidal monotonically decreasing function with the same control points is displayed. According to this last function, areas less than 500 m are assigned a set membership of 1 (on a scale from 0 to 1), those between 500 and 3,000 m are assigned a value which progressively decreases from 1 to 0 in the manner of an s-shaped curve, and those beyond 3,000 m to a protected area are considered to be too far away (they have thus been assigned a value of zero).

After criteria map standardization, the next step of the analysis consists in assigning a weight to each factor. According to the ANP methodology, the comparison and evaluation phase is based on the pairwise comparison of the elements under consideration which can be divided into two levels: the comparison between clusters which is more general and strategic and the comparison between nodes which is more specific and detailed.

In paired comparisons, the smaller element is used as the unit, and the larger element becomes a multiple of that unit with respect to the common property or criterion for which the comparisons are made. A ratio scale of 1–9, that is, the Saaty's fundamental scale, is used to compare any two elements. The main eigenvector of each pairwise comparison matrix represents the synthesis of the numerical judgements established at each level of the network (Saaty 1980).

During this phase, the following three supermatrices are obtained.

1. The "initial supermatrix," made by all the eigenvectors that are derived from the pairwise comparison matrices of the model.
2. The "weighted supermatrix" obtained by multiplying the initial supermatrix values by the cluster weight matrix (which is the one obtained at the cluster level).
3. The "limit supermatrix" obtained by raising the weighted supermatrix to a limiting power, in order to converge and to obtain a long-term stable set of weights that represent the final priority vector. Table 3 shows the final priorities of the factors resulting from the limit super matrix.

The result of the participative procedure adopted for weighing the elements highlights that the most important factors in determining the suitability of the land to behave as ecological corridor are the "distance to urban areas" (0.22) in the "human pressures" cluster and "elevation" (0.20) in the "physical environment" cluster.

Table 3 Priorities of the elements in the model

Clusters	Elements	Weights
Biotic factors (0.16)	Distance to protected areas	0.07
	Distance to parks	0.02
	Distance to wetlands	0.04
	Fauna distribution	0.05
Physical environment (0.54)	Elevation	0.20
	Distance to water bodies	0.03
	Naturalness index	0.10
	Fragmentation index	0.07
	Water quality index	0.06
Human pressures (0.30)	Distance to roads	0.08
	Distance to urban areas	0.22
	Population density	0.06

3.2.3 Generation of the suitability map

Once the maps were standardized for each criterion and the factor weights were established, it is necessary to combine all the information in order to obtain the overall suitability map.

In this case, a weighted linear combination was used that combines all the factor maps and calculates a suitability index for each pixel according to Eq. 2:

$$S_j = \sum W_i * X_i \quad (2)$$

where S_j represents the suitability for pixel j to behave as a corridor, W_i represents the weight of factor i and X_i represents the standardized criterion score of factor i. Factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map.

A suitability map was thus generated where each cell was assigned a score in the 0–1 range expressing its degree of suitability to behave as ecological corridor. Higher values of suitability indicate for each pixel high appropriateness to host ecological corridor while low suitability values correspond to unsuitable areas for the corridor development.

Figure 7a represents the suitability map generated by using only linear standardization functions for all criteria while Fig. 7b shows the map obtained by using linear standardization functions for certain criteria and sigmoidal standardization functions for those criteria for which it seemed more appropriate. As it is possible to notice, the obtained results are quite similar. In particular, from the statistical study of the frequency histogram of the cell values of both the images (for the detailed analysis of the histograms please refer to Table 6 and Fig. 11 in Appendix), we observed that the lower suitability value is 0.20 for the map generated using only linear standardization functions for all the criteria and 0.21 for the map produced by using linear standardization functions for certain criteria and sigmoidal standardization functions for those criteria for which it seemed more appropriate. The higher suitability value reached is 0.96 for both the images. The more frequent value is 0.62 for the map generated using only linear standardization functions for all the criteria and 0.58 for the map produced by using linear standardization functions for certain

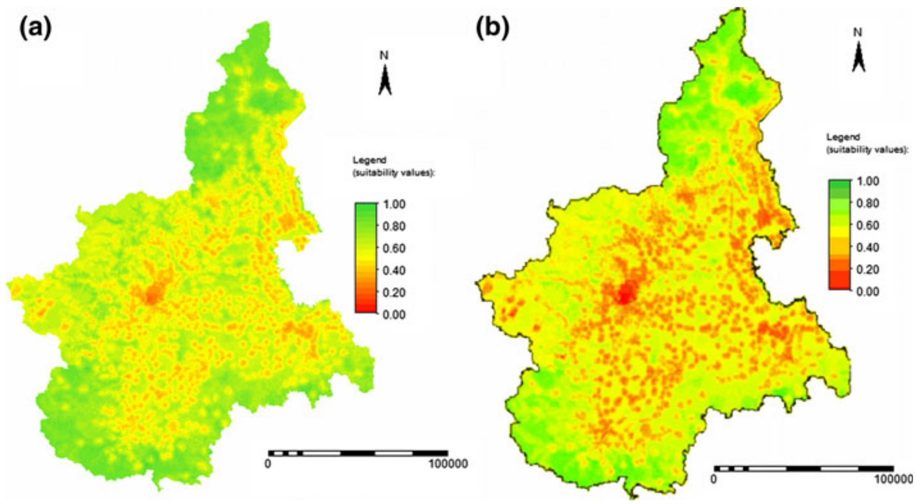

Fig. 7 Final suitability maps for identifying ecological corridors: on the *left* is the map obtained by using only linear standardization functions for all the criteria (**a**) and on the *right* is the map generated by using linear standardization functions for certain criteria and sigmoidal standardization functions for those criteria for which it seemed more appropriate (**b**)

criteria and sigmoidal standardization functions for those criteria for which it seemed more appropriate.

From a technical point of view, it is possible to notice that, although the variation range is the same for the two final maps, if we use only linear standardization functions the resulting final map contains more pixels with high suitability values while if we use sigmoidal standardization functions the final suitability map contains more pixels with low suitability values (Fig. 8).

From the operational point of view, the obtained map represents a decision-support tool in order to spatially identify suitable areas for the development of ecological networks.

The main result permits the analysis and the understanding of the impact of human activities on wildlife dispersal; in fact at the regional scale, urbanization is particularly important and should be considered as a critical threat to the designated linkages. In the final map, the influence of the negative pressure of the widespread urbanization which leads to fragmentation and degradation of ecosystems reducing the capability to sustain its original natural value is evident.

Furthermore, this map helps decision makers in the planning procedure to identify the most suitable use of an area at the local and landscape scale that insures links between ecosystems (Vuilleumier and Prélaz-Droux 2002).

3.2.4 "What-if" analysis

In order to simulate different decision makers' behaviors, a "what-if" analysis was carried out. This type of analysis is concerned with a "what if" kind of question to see how the final answer changes when the inputs, whether judgments or priorities, are changed. Particularly, in multicriteria decision models, the aim of the analysis is to see how these changes modify the final generation of alternatives.

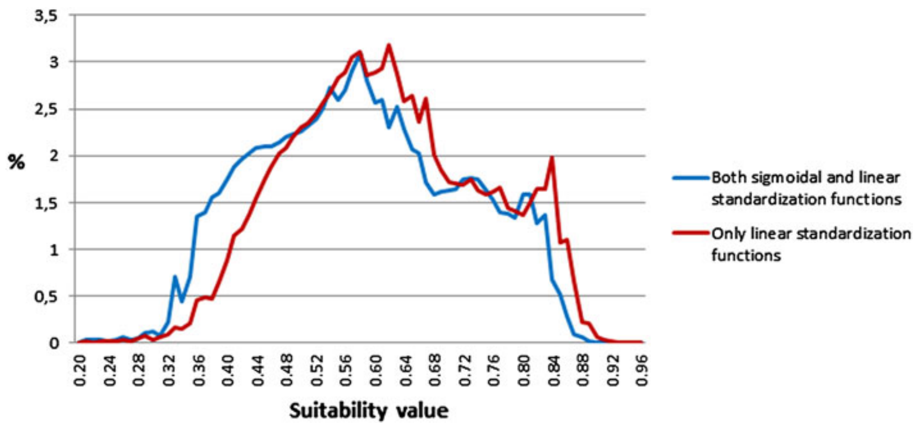

Fig. 8 Statistical analysis of the suitability values distribution

Table 4 Factor weights for the "what-if" analysis simulations

Clusters	Factors	Original weights	Simulation 1	Simulation 2	Simulation 3
Biotic factors	Distance to protected areas	0.07	0.05	0.26	0.05
	Distance to parks	0.02	0.01	0.08	0.01
	Distance to wetlands	0.04	0.03	0.13	0.03
	Fauna distribution	0.05	0.03	0.21	0.03
Physical environment	Elevation	0.20	0.25	0.07	0.08
	Distance to water bodies	0.03	0.04	0.02	0.01
	Naturalness index	0.10	0.12	0.04	0.04
	Fragmentation	0.07	0.09	0.03	0.03
	Water quality index	0.06	0.07	0.02	0.02
Human pressures	Distance to roads	0.08	0.09	0.03	0.11
	Distance to urban areas	0.22	0.19	0.09	0.43
	Population density	0.06	0.04	0.01	0.15

In the present study, we generated three different suitability maps by changing each time the importance assigned to the three clusters according to which the decision problem has been structured. The new set of weights for each simulation was discussed and defined during the focus group in which the different experts were asked to simulate different points of view in order to have one cluster predominant over the others each time. Table 4 summarizes the new factor weights assigned for each simulation.

The first simulation shows the situation where physical environment aspects have the greatest weight in determining the most suitable areas for identifying ecological corridors; in the second simulation, biotic factors have the greater importance and finally in the third simulation, the human pressure cluster represents the most important aspect. Figure 9 shows the results of the "what-if" analysis. It is clear that suitable areas for ecological

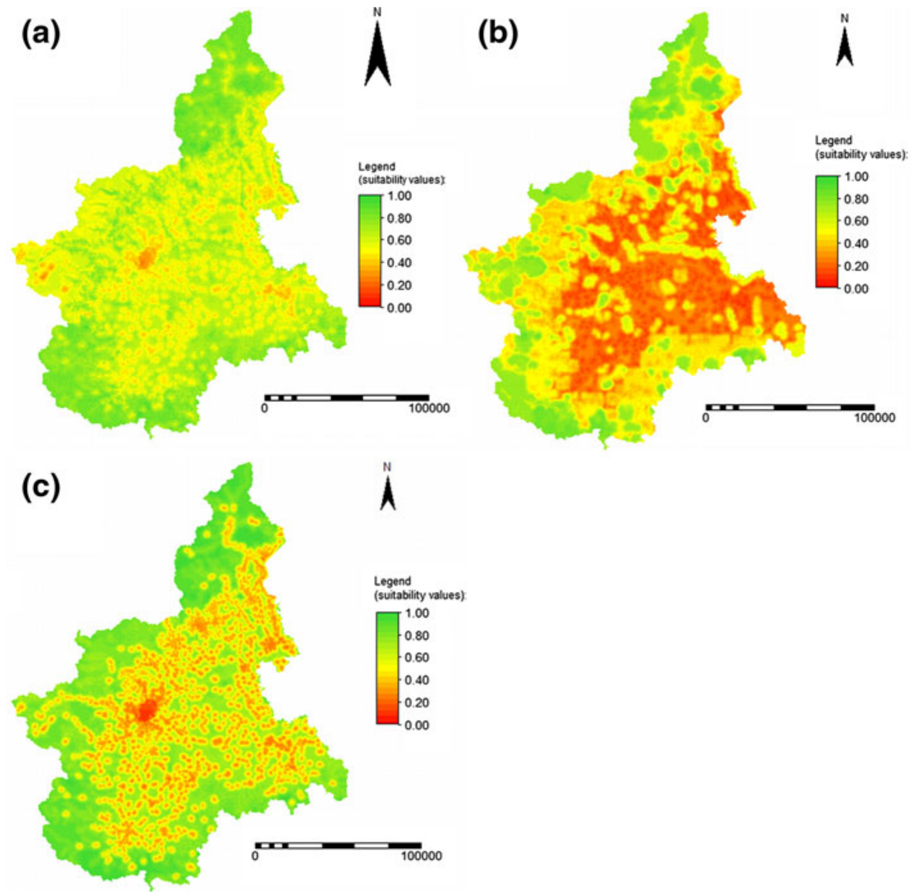

Fig. 9 "What-if" analysis simulations

corridor identification decrease when the importance of biotic factors increases (Fig. 9b). Suitable areas in this case are limited in the outlying areas of the region where the pressure of the urbanization and the human activities less influence the natural habitat.

In Fig. 9a, where physical environment-related aspects have more influence, the final suitability map is almost unchanged. Figure 9c shows instead a slight decrease in suitable area round urban areas due to high population density and widespread urbanization.

4 Results

In order to provide planners with a complete picture that can be used as a preliminary input for designing the future transformations of the territory, we analyzed the final suitability map with the aim of highlighting the more suitable areas as possible ecological networks connecting the natural protected areas. Through this analysis, it then becomes possible to verify the coherence with the existent ecological network and, above all, to identify areas

Table 5 Description of the five suitability classes

Classes	Suitability values	Description
1	0–0.2	Absence of suitability to host ecological corridors
2	0.2–0.4	Low suitability to host ecological corridors
3	0.4–0.6	Medium suitability to host ecological corridors
4	0.6–0.8	High suitability to host ecological corridors
5	0.8–1	Very high suitability to host ecological corridors

worth of protection and on the opposite hand, areas for which specific monitoring programs should be established.

In order to gain a concise understanding of the results, the suitability values were aggregated into five classes (Geneletti 2007) according to Table 5.

We then generated a map that shows only the areas with high and very high suitability to host ecological corridors as a preliminary input to be compared with other relevant information. This map represents a first attempt and, in order to be more precautionary, is based on the result of the model that uses linear standardization functions for certain criteria and sigmoidal standardization functions for those criteria for which it seemed more appropriate.

Focusing on the regional scale, it is possible to identify four major axes that best represent the ecological network among protected areas. Figure 10 shows the results obtained and underlines that the most suitable areas are concentrated in the peripheral areas of the region along the mountain areas and less subject to human pressures.

The results obtained in the study are of particular interest in the field of nature conservation and land-use management, where there is a strong need for new tools that are able to support the decision-making process in identifying the most valuable areas from the environmental point of view, and those that need planning and management strategies in order to maintain their value (Geneletti 2004).

Based on the obtained results, it will then be possible to deepen the analysis by trying to highlight potential ecological corridors at the local level based on least-cost distance analyses in a GIS environment (Duriavig 2008; Eastman 2006).

Finally, we compared our results with a recent study carried out by the Regional Environmental Protection Agency (ARPA; Maffiotti and Vietti 2006), which allows a preliminary identification of areas of ecological connection through the assessment of biological permeability and the ecological connectivity, starting from the identification of potential areas with high biodiversity in the region. From a preliminary comparison, the suitability map (Fig. 7) obtained by the development of the SMCE model is coherent with the ecological connectivity map of the Regional Environmental Protection Agency study, thus confirming that these tools can be very useful to support strategic planning procedures.

5 Discussion and conclusions

Sustainable development is a widely accepted strategic framework in the decision-making process concerning the future land use (IUCN 1994). However, ecological sustainability is not yet well developed in landscape planning and the explicit inclusion of ecological principles in this field represents quite a recent advancement (Ahern 2002).

New planning tools are thus needed to maintain and increase the importance of the natural value of fragmented landscapes (Bruel and Baudry 1999).

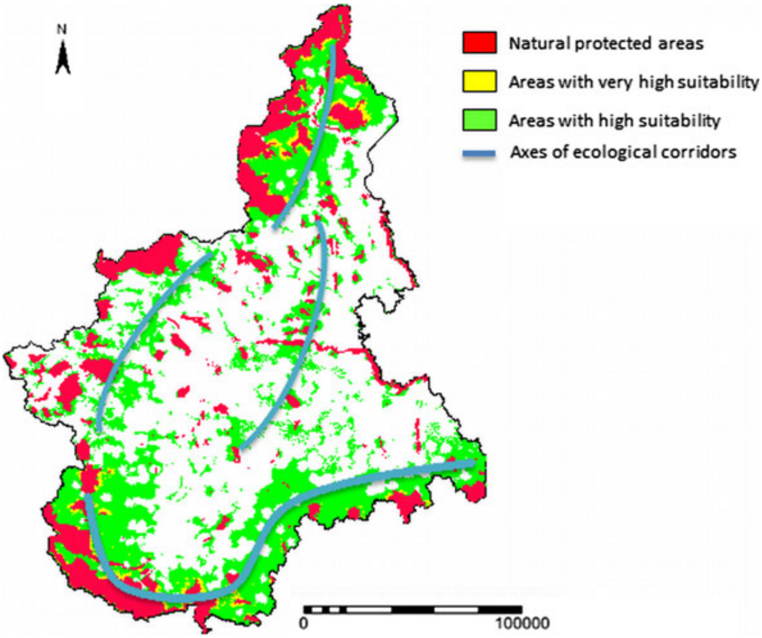

Fig. 10 Major axes for the ecological network at the regional *scale*

This paper describes the development of a spatial multicriteria evaluation to assess if the land is suitable to behave as an ecological corridor. The proposed methodology was illustrated with the case study of the Piedmont Region (Northern Italy) which aimed to highlight potential ecological corridors and stepping stones and thus provides a useful support for planning ecological networks. The experimentation was carried out as a research study with the intention of testing the usefulness of the proposed methodology in the landscape ecology field.

The advantages of the applied method are to effectively support the structuring of the decision-making problem and to allow quick assessments and applications, which can be very effective for regional and metropolitan land-use planning and strategic impact assessments. Moreover, the proposed methodology allows to handle heterogeneous information and provides a significant contribution in the strategic decision-making phase. Besides the aforementioned advantages, one of the most significant strengths of the adopted methodological approach is represented by the fact that the evaluation is organized in a learning perspective. The decision maker thus gains more awareness with reference to the elements at stake while structuring the model and thus learns about the problems throughout the decision process.

Nevertheless, mention has to be made to the fact that the ANP can be perceived as a black box and that it prescribes a high number of comparisons that occasionally become too complex to understand for DMs who are not familiar with the method.

Although the obtained results are based on some assumptions, the method offers a flexible tool to analyze ecological connectivity and provides the possibility to simulate different scenarios.

In particular, by simulating different perspectives, the “what-if” analysis results in an explanatory process by which the decision makers can achieve a deeper understanding of the structure of the problem (Khan and Faisal 2008). Following this reasoning, knowledge of uncertainty factors is bound to increase the awareness of the decision makers about the merit of the different alternatives, and consequently to orient their strategy better. The role of MCA is to convey this information to the decision makers so that they can take a decision according, for instance, to their risk awareness (Geneletti 2007).

The study also underlines the relevant role of land suitability analyses in spatial planning. These analyses allow us to determine and harmonize the guidelines for the various land-use types and intensities, as well as to assess potential conflicts between the need of the population and resource availability.

Furthermore, the paper highlights the advantages of GIS and MCA coupling with specific reference to their ability to support a decision-making process through a systematic, transparent and replicable approach, facilitated by the use of thematic maps.

Interesting considerations also arise from the statistical analysis of the suitability values distribution. According to the present experimentation, linear standardization functions seem to generate more pixels with high suitability values while sigmoidal standardization functions seem to generate more pixels with low suitability values. Through the investigation of different standardization procedures, the study has thus highlighted the importance of the standardization approach since different choices can lead to different results. This is why this phase of the model development should be accomplished by means of a focus group during which technical experts and stakeholders can discuss and reach a consensus about which standardization function to use, according to their attitude toward risk, for instance.

Future developments could be to implement the present model using the fuzzy sets theory (Zadeh 1965), which represents attribute values according to membership classes. Uncertainty can be associated with fuzziness for the criterion weight assessment as well as the spatial attribute values (Malczewski 1999). In this way, it will also be possible to take into consideration and evaluate the imprecision and uncertainty associated with the accuracy of the input data layers of the model.

A further direction could be to use the suitability values from this study to perform more detailed analyses on the municipal scale in order to derive useful considerations for supporting specific planning procedures at the local scale.

In conclusion, any integration of MCA and GIS constitutes a very promising line of research in the sustainability assessments field and more specifically in ecological planning since the integrated approach allows us to express, understand and analyze ecological links between ecosystems, which take into account information about conflicting areas (human activities and ecological networks). This approach thus highlights the need for monitoring those areas that are classified as potential ecological corridors in the evaluation model but that in reality are compromised areas. Consequently, these tools help decision makers to plan activities at the local and landscape scale that ensure proper consideration of the links between ecosystems.

Acknowledgments The contribution is the result of the joint effort of the authors. Despite the global responsibility for the work being equally shared between the two authors, it should be noted that Valentina Ferretti was responsible for the research outlined in paragraphs 1, 2.1, 3.2.1 and 3.2.2, while Silvia Pomarico undertook the research described in paragraphs 2.2, 3.1, 3.2.3 and 3.2.4. The abstract and paragraphs 4 and 5 are the result of the joint work of the two authors.

Appendix

See Table 6 and Fig. 11.

Table 6 Statistical analysis of the suitability values obtained using (1) only linear standardization functions for all the maps of the factors and (2) both linear standardization functions for certain criteria and sigmoidal standardization functions for the remaining ones

Value	Linear standardization		Sigmoidal standardization		Value	Linear standardization		Sigmoidal standardization	
	Frequency	%	Frequency	%		Frequency	%	Frequency	%
0.20	942	0.00232	0	0	**0.58**	1262762	3.11572	**1,255,525**	**3.09071**
0.21	6,221	0.01535	12,747	0.03138	0.59	1,156,951	2.85464	1,137,991	2.80138
0.22	5,049	0.01246	11,942	0.02940	0.60	1,172,714	2.89353	1,041,454	2.56374
0.23	5,975	0.01474	17,502	0.04308	0.61	1,187,708	2.93053	1,056,513	2.60081
0.24	7,022	0.01733	9,102	0.02241	**0.62**	**1,292,182**	**3.18831**	935,573	2.30309
0.25	9,898	0.02442	16,615	0.04090	0.63	1,166,673	2.87863	1,023,645	2.51990
0.26	15,632	0.03857	26,922	0.06627	0.64	1,049,322	2.58908	927,709	2.28373
0.27	10,425	0.02572	16,809	0.04138	0.65	1,068,702	2.63690	839,839	2.06742
0.28	18,492	0.04563	19,446	0.04787	0.66	957,775	2.36320	825,372	2.03181
0.29	30,496	0.07525	44,050	0.10844	0.67	1,061,113	2.61817	700,223	1.72373
0.30	17,484	0.04314	50,888	0.12527	0.68	817,504	2.01709	642,611	1.58191
0.31	25,303	0.06243	35,117	0.08645	0.69	749,004	1.84808	655,585	1.61385
0.32	36,179	0.08927	94,794	0.23335	0.70	696,932	1.71960	664,381	1.63550
0.33	70,444	0.17381	288,739	0.71079	0.71	690,830	1.70454	670,859	1.65145
0.34	63,727	0.15724	179,851	0.44274	0.72	684,178	1.68813	710,518	1.74908
0.35	88,083	0.21733	285,638	0.70315	0.73	710,991	1.75429	717,929	1.76732
0.36	188,151	0.46424	549,426	1.35252	0.74	658,623	1.62507	708,818	1.74489
0.37	198,006	0.48856	565,647	1.39245	0.75	646,126	1.59424	660,190	1.62518
0.38	191,928	0.47356	633,269	1.55891	0.76	653,170	1.61162	620,055	1.52638
0.39	265,660	0.65548	648,932	1.59747	0.77	675,168	1.66590	568,339	1.39907
0.40	358,442	0.88441	707,696	1.74213	0.78	583,491	1.43970	560,865	1.38068
0.41	462,624	1.14147	762,889	1.87800	0.79	571,882	1.41105	541,539	1.33310
0.42	496,231	1.22439	797,251	1.96259	0.80	554,166	1.36734	642,829	1.58245
0.43	555,532	1.37071	820,394	2.01956	0.81	607,814	1.49971	646,042	1.59036
0.44	623,927	1.53947	844,631	2.07922	0.82	669,887	1.65287	522,426	1.28605
0.45	701,415	1.73066	851,129	2.09522	0.83	664,674	1.64000	555,965	1.36861
0.46	762,034	1.88023	850,663	2.09407	0.84	804,262	1.98442	279,129	0.68713
0.47	820,313	2.02403	868,585	2.13819	0.85	435,029	1.07338	212,424	0.52292
0.48	845,023	2.08499	894,838	2.20281	0.86	445,031	1.09806	112,783	0.27764
0.47	820,313	2.02403	868,585	2.13819	0.87	269,932	0.66603	41,186	0.10139
0.48	845,023	2.08499	894,838	2.20281	0.88	90,501	0.22330	25,501	0.06278
0.49	890,869	2.19811	904,773	2.22727	0.89	84,997	0.20972	10,705	0.02635
0.50	932,567	2.30100	918,887	2.26202	0.90	28,132	0.06941	1,501	0.00369
0.51	954,675	2.35555	944,466	2.32498	0.91	13,968	0.03446	1,198	0.00295
0.52	991,376	2.44610	969,529	2.38668	0.92	11,110	0.02741	299	0.00,074
0.53	1039805	2.56560	1,018,582	2.50,743	0.93	228	0.00056	113	0.00,028
0.54	1082112	2.66998	1,110,293	2.73,320	0.94	174	0.00043	118	0.00,029
0.55	1150104	2.83775	1,055,649	2.59,868	0.95	231	0.00057	120	0.00030
0.56	1,173,407	2.89524	1,094,847	2.69517	0.96	901	0.00,222	4	0.00001

Table 6 continued

Value	Linear standardization		Sigmoidal standardization		Value	Linear standardization		Sigmoidal standardization	
	Frequency	%	Frequency	%		Frequency	%	Frequency	%
0.57	1,238,380	3.05556	1,182,071	2.90989					

Figure 11 shows the histograms obtained from the statistical analysis of the suitability values obtained in the two final maps

Histogram *a* shows the statistical distribution of the suitability values when only linear standardization functions are used

Histogram *b* shows the statistical distribution of the suitability values when certain criteria are standardized according to the linear functions and the remaining according to the sigmoidal monotonically decreasing function

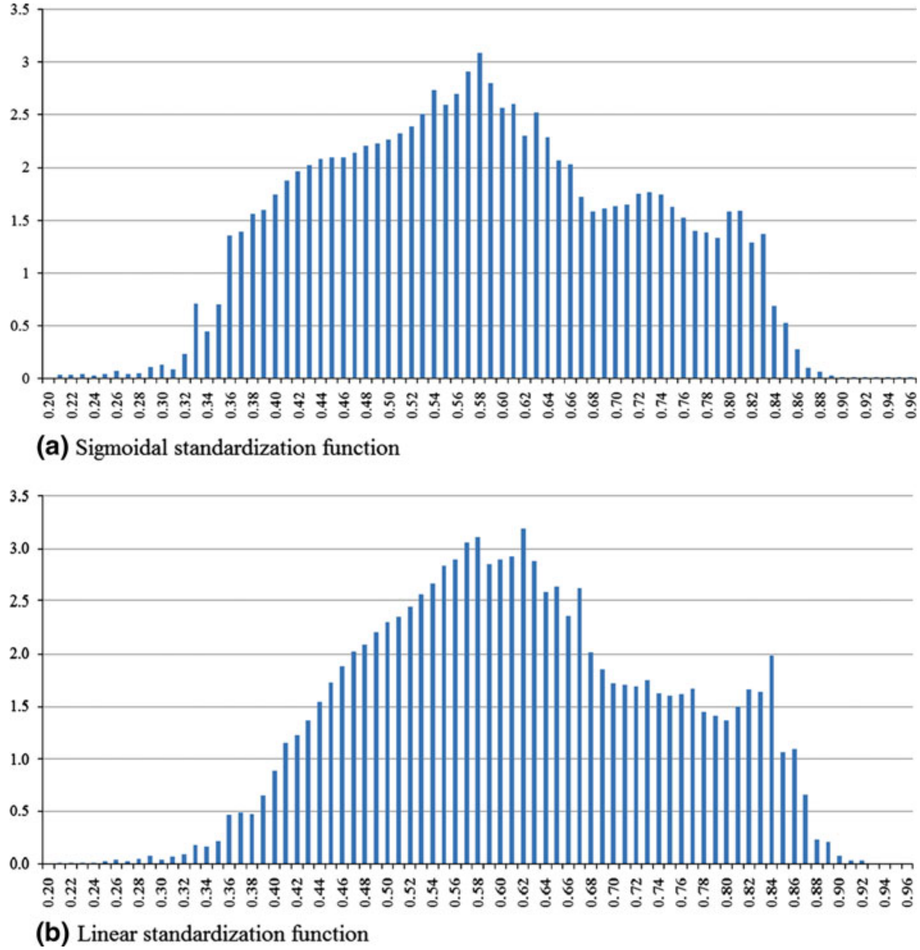

Fig. 11 Histograms of the distribution of the suitability values

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