74th Meeting of the European Working Group "Multiple Criteria Decision Aiding"

Integrating Multicriteria Analysis and Geographic Information Systems for studying ecological corridors in the Piedmont Region

Valentina Ferretti [1], Silvia Pomarico [2]*

[1] Politecnico di Torino, Land, Environment and Geo- Engineering Department (DITAG). valentina.ferretti@polito.it
[2] Politecnico di Torino, Department of Housing and City (DICAS). silvia.pomarico@polito.it

Abstract

Territorial transformation projects and, more generally, spatial plans are subject to evaluation and their consequences must be considered and managed. In this context, different and conflicting objectives have to be taken into account, referring to social, cultural and symbolic interferences, that can be addressed through quality assessment, vague use values and imprecise temporal horizons (Roscelli, 2005). This leads to consider urban and territorial transformation processes as “weak” or unstructured problems since they are characterized by multiple actors, many and often conflicting values and views, a wealth of possible outcomes and high uncertainty (Prigogine, 1997; Simon, 1960).

Speaking about spatial planning, a very important issue refers to nature conservation and biodiversity. The importance of the topic is stressed above all in the European Directive on the Strategic Environmental Assessment of plans and programmes (Directive 2001/42/EC) where ecological conservation is defined as one of the key topics to address.

Knowledge of the land suitability to behave as an ecological corridor thus provides a very useful input to land-use planning. Given the spatial nature of the problem, an efficient support is provided by a family of methods that are rapidly gaining traction for planning and policy-making, named Multicriteria-Spatial Decision Support Systems (MC-SDSS; Malczewski, 1999), which underpins on Geographic Information Systems (GIS) and Multicriteria Analysis (MCA) coupling.

The present paper proposes the integration of the GIS with a specific Multicriteria Analysis technique, named Analytic Network Process (ANP) (Saaty, 2005) to assess the land ecological value of the Piedmont region (northern Italy) and to generate cartographic results to be used as decision variables in planning. The approach relies on ecological indicators and on the application of Multicriteria Analysis in a Geographic Information System context, paying attention to issues such as transparency and applicability.

The purpose of the research is thus to study the ecological connectivity of the region under analysis in order to highlight potential ecological corridors by generating a suitability map.

The application allows dependence relationships among the aspects and criteria to be assessed and the relative importance of all the elements that play an influence on the final choice to be elicitated. Mention should be made to the fact that the analysis takes into account the opinion of several experts in determining the importance of the different elements of the model.

The results are obtained in the form of maps and have been analyzed through both the IDRISI Andes software and the ILWIS 3.3 one in order to compare their respective spatial solutions.

The study concludes with some lessons learned during the development of the MC-SDSS and highlights that the applied methodology is an effective tool in providing decision support for spatial planning.

Keywords: Multicriteria- Spatial Decision Support Systems, Geographic Information Systems, Ecological corridors planning, Analytic Network Process, Environmental analysis, Suitability map.

** 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, 3.2.2.1 and 3.2.2.2 while Silvia Pomarico undertook the research described in paragraphs 2.2, 3.1, 3.2.3, 3.2.4 and 4. The abstract and paragraph 5 are the result of the joint work of the two authors.*

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 as a matter of fact hubs, or areas of known ecological value, and links, which are the corridors that connect the hubs to each other. Knowledge of ecological networks can thus be used to support conservation-related land-use decisions.

As a consequence, maintaining and restoring landscape connectivity is currently a central concern in ecology and biodiversity conservation, and more generally speaking in territorial planning for achieving sustainable development.

As a matter of fact, since the 1990s, scientific concerns for habitat and ecosystem fragmentation and landscape and ecological connectivity has 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) or the Biodiversity Strategy of the European Community (1998). Finally, the European Directive on Strategic Environmental Assessment (2011/42/EC) has 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, urban, land use and infrastructural plans.

Nevertheless, there is a lack of quantitative methods able to assess ecological connectivity or ecological fragmentation at regional scale and to efficiently support planning processes and the Strategic Environmental Assessment (Marulli e Marallach, 2005).

In such a context a useful support is provided by a specific family of Decision Support Systems (DSS; Burstein and Holsapple, 2008), named Multicriteria- Spatial Decision Support Systems (MC-SDSS; Malczewski, 1999) which is based on Geographic Information Systems (GIS) and Multicriteria Analysis (MCA) coupling. MC-SDSS thus integrate the sustainability dimensions while offering a systematic approach able to prove the importance of “where” in addition to “what” and “how much”.

Speaking about sustainability assessments of territorial transformation projects, a very important advantage offered by MC-SDSS refers to the possibility of evaluating the potential impacts for landscape and ecological connectivity of the proposed project or plan.

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) by combining 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 thus the explicit presence of a spatial component. The former as a matter of fact 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 study area.

Moreover, spatial multicriteria analysis provide significant support for the generation and comparison of the alternatives through an active participation of the stakeholders involved in the decision-making process, thus becoming one of the most interesting evolution in the context of environmental assessment procedures (such as the Environmental Impact Assessment and the Strategic Environmental Assessment) where the comparison of different alternatives represents the heart of the whole process and where the complexity of the problems and the need for technical support in the decision-making process is 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), recent evolution of the Analytic Hierarchy Process (AHP, Saaty, 1980) in order to identify potential ecological corridors and stepping stones in the Piedmont Region (Northern Italy). The study thus develops a decision support model that is 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.

The present paper has thus a double purpose; first, to present the MC-SDSS 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 compare the results obtained using both the ILWIS 3.3 software[1] and the IDRISI 3.2 one[2] in order to verify whether different standardization procedures lead to different results.

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, 2011). The present study thus represents one of the first experimentations at both the national and international level.

After the introduction section, the paper is organized as follows: section 2 presents MC-SDSS 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 study case is shown in section 3, according to the four-stage decision-making process proposed by Simon (1960). Finally, section 4 presents the main findings of the application and section 5 summarizes the conclusions that have been drawn from the study, putting in evidence the opportunities for expanding the work.

2. Methodological background

2.1 Multicriteria Spatial Decision Support Systems

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. GIS provide an important way of enabling Decision Markers (DMs) to make better decisions by conducting spatial analysis and displaying spatial information.

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). In this context, 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 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 these common decision support functions have been expanded to 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; Jankowski, 1995; Laaribi *et al*., 1996; Malczewski, 1996; Janssen and Herwijnen, 1998) on-line analysis of geographical data (Bedord *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).

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

With specific reference to GIS-based multicriteria decision analysis, the full range of techniques and applications has been recently discussed in a very interesting study developed by Malczewski (2006). From 2000 the number of studies has been increasing and several applications can be found in different fields. Multicriteria-Spatial Decision Support Systems are commonly applied to land suitability analysis (Malczewski, 2006; Ferretti, 2011b) and are usually based on a loose coupling approach and on a value focused thinking framework (Ferretti, 2011b). Mention can be made of some recent researches in the sphere of urban and environmental planning (Geneletti and Abdullah, 2009), environment/ecology (Dragan *et al.,* 2003; Geneletti, 2007; Hala and Hegazy, 2009; Zucca *et al.,* 2007), transportation (Keshkamat *et al.,* 2008), undesirable facilities location problems (Tegou *et al*., 2010; Changa *et al*., 2008; Agouti *et al*., 2008), hydrology (Al-Adamat *et al.*, 2010; Gül *et al*., 2010; Anane *et al*., 2008) and natural risk management (Vadrevu *et al*., 2010; Akgun and Türk, 2010).

From the methodological point of view, a spatial decision 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 MC-SDSS 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). As previously indicated, the MC-SDSS framework is based on the integration of GIS capabilities and Multicriteria Analysis (MCA) techniques and takes advantage of both. GIS techiques have an important role in analyzing decision problems, while MCA provides a full range of methods for structuring decision problems and for designing, evaluating and prioritizing alternative decisions (Malczewski, 2006).

Spatial multi-criteria analysis therefore represents a significant step forward compared to 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 study area 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), the decision-making process can be divided into four main stages, named intelligence, design, choice and review (Fig. 1).

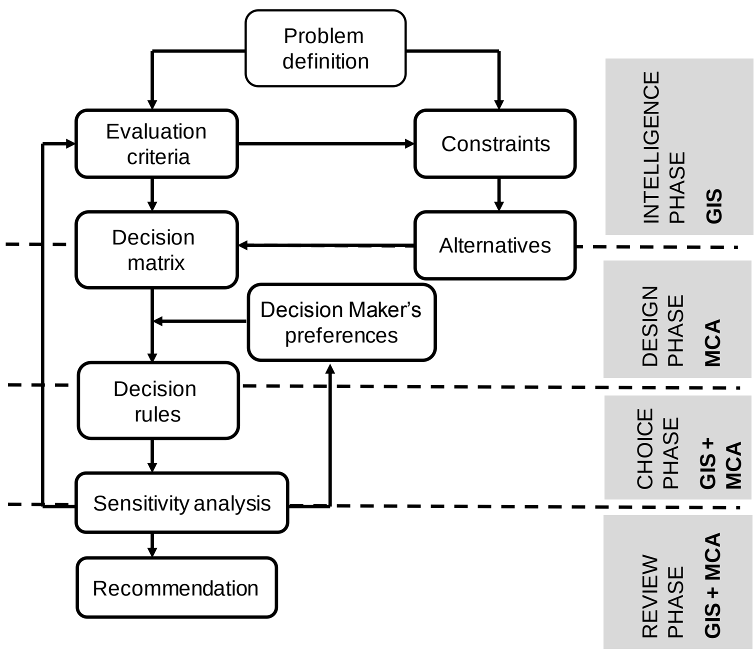

Figure 1 *– Spatial multicriteria analysis framework (Source: adapted from Malczewski, 1999 and Simon, 1960)*

The framework shown in Figure 1 highlighs how each phase of the decision-making process involves the methodological contribution of both GIS systems and multicriteria evaluation methods.
The intelligence phase refers to 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).
The design phase involves data collection and processing, as well as the development of multi-criteria analysis through the definition of the relationship between objectives, attributes and preferences of the Decision Maker (Malczewski, 1999).
During the choice phase alternatives are evaluated and, finally, during the review phase, detailed analyses, such as the sensitivity analysis, are deemed appropriate in order to obtain some recommendations.
This framework underpins the development of the model for the study aiming at highlighting potential ecological corridors presented in the following sub-sections.

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, have been suggested as the main reasons for the current biodiversity crisis (Fahrig, 2003; Foley *et al.*, 2005; Gurrutxaga *et al.,* 2010).
Ecological planning is playing an increasingly important role in natural conservation policies and strategies, recognizing that it is necessary to integrate protected areas of an entire territory both ecologically and socio-economically (Bennett, 2004; IUCN, 1994; Mùgica *et al.*, 2002; Smith and Maltby, 2003).
In this contest it is important to develop coherent and functional conservation networks, known as ecological networks. Ecological networks are identified by the location of ecological corridors linking protected natural areas and by the location of buffer zones between the above mentioned elements and the landscape matrix (Bennett and Mulongoy, 2006; Gurrutxaga *et al*., 2010). Opdam *et al.* (2006) define ecological networks as a set of ecosystems of one type, linked into 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 multi-species 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 biodiversity 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 biodiversity conservation (Opdam *et al*.,2006).
The complexity of the phenomena is directed 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 (Broquet *et al*., 2006; Noss and Daly, 2006; Theobald, 2006).
The design of ecological networks in an explicitly spatial manner allows for their implementation in landscape planning (Huber *et al.*, 2007; Jongman and Pungetti 2004; Opdam *et al*., 2006) and in

turn has an effect on land use policy and the evaluation processes for environmental impact of plans and projects.
GIS techniques are commonly applied to ecological study in order to identify ecological networks and mention can be made of some researches in the sphere of ecological planning (Gurrutxaga *et al*., 2010; Vogt *et al*., 2007; Opdam *et al*., 2006; Vuilleumier *et al*., 2002; Baschak and Brown, 1995). MC-SDSS applications in this field are still an experimental approach but it is important to mention an interesting study for establishing ecological corridors to connect forest fragments in a tropical region (Duriavig, 2008).

3. Case study

3.1 Presentation of the study area and research objectives

In order to test the potentialities of the MC-SDSS 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.

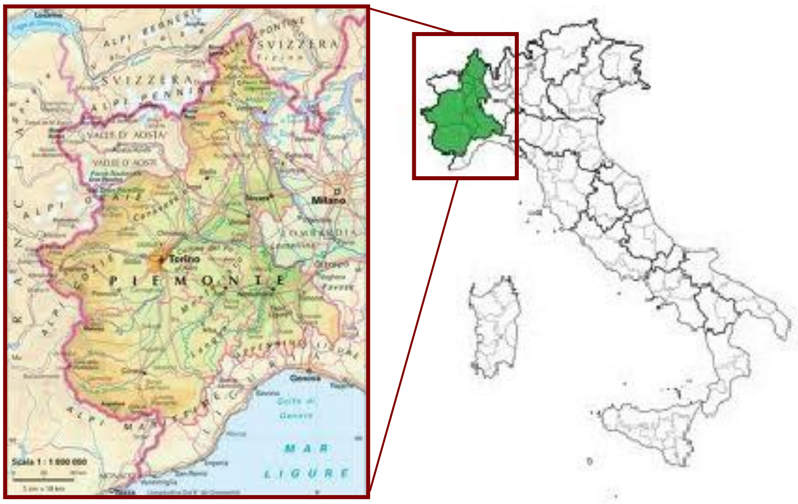

Figure 2 *- Territorial context of the area under examination*

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 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” (Fig. 3) and the “Val Grande” covering a total area of 48.500 ha. Among protected areas, a particular important role is played by the Po river system that covers an area of 35.515 ha.
Finally, mention should be made to the fact that seven regional protected areas, named “Holy Mountains” were inserted in the World Heritage List of UNESCO in 2003.

Figure 3 *- Gran Paradiso National Park (source: www.pngp.it)*

The study described in the following subsections has the objective to put in evidence the most important areas for biodiversity conservation due to their high natural and environmental quality value, in order to preserve the natural heritage of the region. The final goal is 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 network linking natural protected areas. The proposed methodology generates cartographic results to be used as decision variables during planning procedures in order to provide answers to landscape and local planning conflicts between societal development and biodiversity in a human disturbed landscape. The result should contribute to a better understanding of wildlife dispersal in fragmented landscapes, providing in the end effective tools for conservation planning (Vuilleumier *et al*., 2006). Spatial planners can then use these results as decision variables in the planning process thereby gaining undoubted benefit from the integration of this information (Bottero *et al*., 2011).

3.2 Model development

The present application aims at highlighting ecological corridors in the Piedmont region and has been carried out using both the IDRISI and the ILWIS software, in order to verify whether different standardization procedures lead to differences in the results. In accordance with the decision-making process phases (Simon, 1960), the MC-SDSS model has been developed through the following steps:
(i) intelligence phase;
(ii) design phase;
(iii) choice phase;
(iv) review phase.
The different steps of the MC-SDSS model development are illustrated in the subsequent sub-sections.

3.2.1 Intelligence phase

Starting from the overall objective of the analysis, which is to study ecological connectivity in the Piedmont region, a comprehensive set of evaluation criteria that reflect all the concerns relevant to the decision problem has been identified (Fig. 4).
Due to the presence of different interrelated factors and to the intrinsic spatial nature of the problem, the ANP method has been coupled with Geographic Information Systems (GIS). The reasons for using an ANP-based decision approach in the present analysis are: (i) the assessment of the land suitability to behave as potential ecological corridor is a multicriteria decision problem; (ii) there are dependencies among groups of criteria and between these to be analyzed, (iii) the detailed analysis of the inter-relationships between criteria forces the Decision Makers (DMs) to carefully reflect on their project priority approach and on the decision-making problem itself. This helps DM to gain a better understanding of the problem and to make a more reliable final decision.
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

inter-relationships within and between clusters, thus providing a more accurate modelling 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 has been developed according to the simple network structure. Mention should be made to the possibility of structuring the decision problem according to the complex network structure (Saaty, 2005) which is usually based on four sub-networks: Benefits, Costs, Opportunities and Risks. These sub-networks allow all the dimensions of the decision problem to be considered.
The network structure of the problem and the interdependences between the clusters have been simulated using Super Decisions 1.6.0 Software[3], which automatically creates a list of the pairwise comparisons needed to run the evaluation.
It is necessary to put in evidence that the criteria considered in the present application have been selected based on the legislation on protected areas and on sustainability assessments (Habitats Directive, Birds Directive, European Directive on Strategic Environmental Assessment) which provide a list of aspects to be considered for the protection and valorisation of ecological networks.
12 attributes have thus been identified for the evaluation process clustered in three main groups including factors relevant to the physical environment, biotic factors and human pressures (Fig. 4).

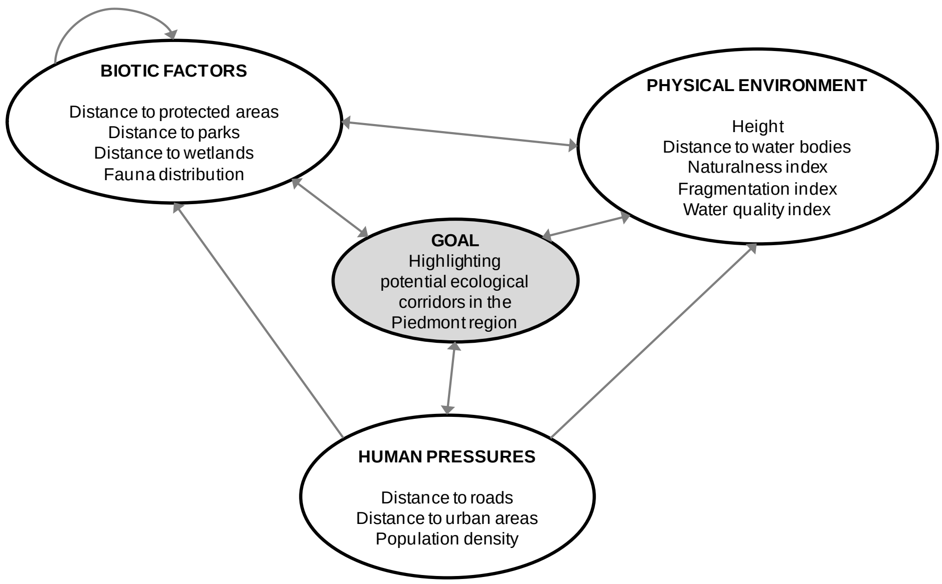

Figure 4 *– The ANP network structure for the case under examination*

According to the ANP methodology, once the network has been identified, it is necessary to represent the influences among the elements. It has been chosen to approach this task according to the following strategy. To start with, all the elements in the clusters are supposed to have an influence on the general goal. Further relationships have then been identified concerning the potential influences among the elements of each cluster.
The direction of the arrows in Figure 4 thus indicates the interdependence relationships between the factors. A single direction arrow shows the dominance of one factor by 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 “index of naturalness” is influenced by the distance to natural and urban areas (Fig. 4).
In the next phase, evaluation criteria, named in this context factors, have been represented as thematic map layers in a GIS database.
It is worth specifying that 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. 5). A

[3] www.superdecisions.com

benefit criterion contributes positively to the output (the higher are the values, the better it is), while a cost criterion contributes negatively to the output (the lower are the values, the better it is).
Mention should be made to the fact that the present application does 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 will be illustrated in the following paragraph.
Maps were then computed through basic raster GIS operations (map overlay, buffering, distance mapping, spatial queries, etc.).
Figure 5 shows the criteria tree with the associated thematic maps for the case study under analysis modeled through the ILWIS interface.

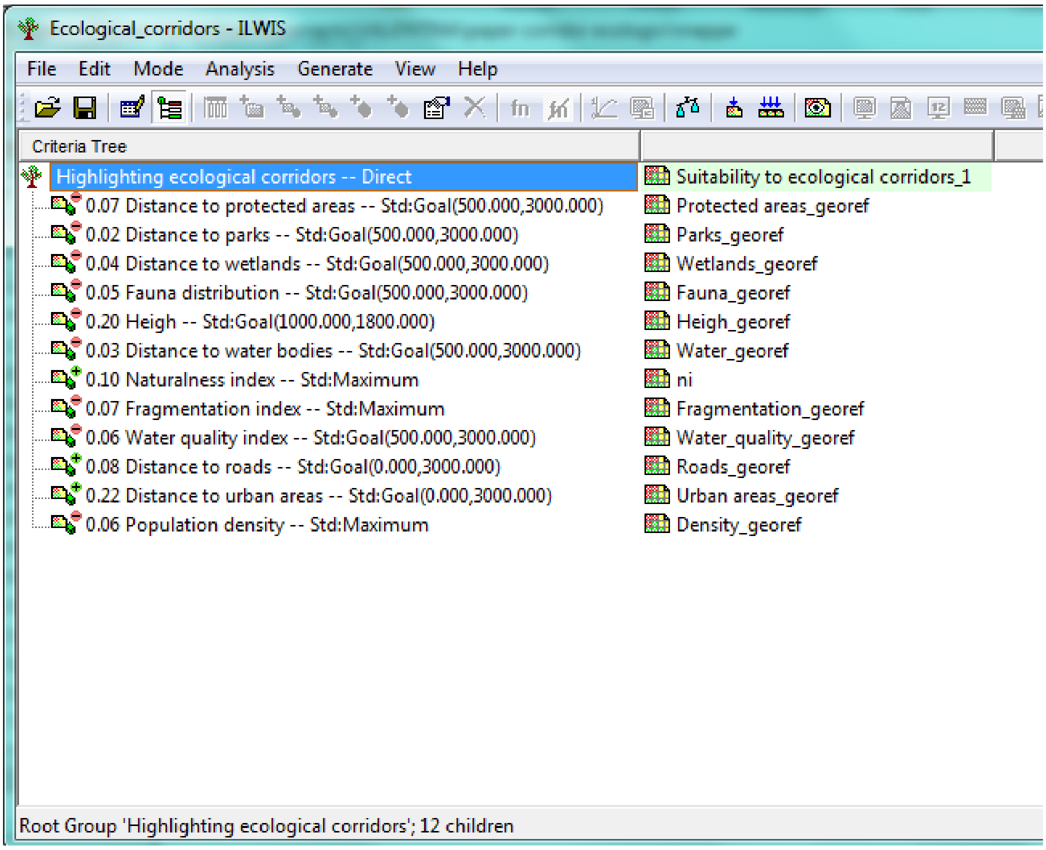

Figure 5 *- The criteria tree used in the analysis. On the left are factors and associated weights with descriptors. On the right the corresponding file names of the digital maps spatially representing factors. The interaction structure is from the ILWISs SMCE module (ILWIS 3.3, 2005).*

3.2.2 Design phase

3.2.2.1 Standardization of the factors

The design phase involves the standardization and weighting of all the factors being considered in the analysis.
As previously explained, each criterion is represented by a map. For decision 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).
In the present study standardization was performed by using both linear function (in the ILWIS model) and sigmoidal monotonically decreasing function (available in the IDRISI model). Through standardization the original factor scores (each expressed in its own unit of measurement) are converted into dimensionless scores in the 0 (worst situation) 1 (best situation) range.

Linear standardization functions assumes 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 1 explains how each criterion has been standardized in the present study.
It is worth specifying that the control points used for the standardization of each criterion have been discussed and shared during a focus group with experts in the ecological and in the sustainability assessments fields.

Table 1 – *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).	Using ILWIS, distances ≤ 500 m are standardized to 1, distances between 500 m and 3000 m are standardized according to the linear function (the lower the distance, the higher the score) and distances ≥ 3000 m are standardized to 0 (Figure 6c). Using instead IDRISI, distances between 500 m and 3000 m are standardized according to the sigmoidal monotonically decreasing function (Figure 6d).
Distance to parks	The criterion maps the distance to regional and provincial established parks.	Using ILWIS, distances ≤ 500 m are standardized to 1, distances between 500 m and 3000 m are standardized according to the linear function (the lower the distance, the higher the score) and distances ≥ 3000 m are standardized to 0. Using instead IDRISI, distances between 500 m and 3000 m are standardized according to the sigmoidal monotonically decreasing function.
Distance to wetlands	The criterion maps the distance to wetlands.	Using ILWIS, distances ≤ 500 m are standardized to 1, distances between 500 m and 3000 m are standardized according to the linear function (the lower the distance, the higher the score) and distances ≥ 3000 m are standardized to 0. Using instead IDRISI, distances between 500 m and 3000 m are standardized according to the sigmoidal monotonically decreasing function.
Fauna distribution	The criterion maps the distance to areas that are considered habitats for the typical alpine fauna or for protected species (Osservatorio Faunistico, 2011)	Using ILWIS, distances ≤ 500 m are standardized to 1, distances between 500 m and 3000 m are standardized according to the linear function (the lower the distance, the higher the score) and distances ≥ 3000 m are standardized to 0. Using instead IDRISI, distances between 500 m and 3000 m are standardized according to the sigmoidal monotonically decreasing function.
Height	The criterion maps the elevation of the land.	In both ILWIS and IDRISI heights ≤ 1000 m are standardized to 1, heights between 1000 m and 1800 m are standardized according to the linear function (the lower the height, the higher the score) and heights ≥ 1800 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	Using ILWIS, distances ≤ 500 m are standardized to 1, distances between 500 m and 3000 m are standardized according to the linear function (the lower the distance, the higher the score) and distances ≥ 3000 m are standardized to 0. Using

Criteria	Description	Standardization
	positive conditions from the ecological point of view.	instead IDRISI, distances between 500 m and 3000 m are standardized according to the sigmoidal monotonically decreasing function.
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).	In both ILWIS and IDRISI 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[4].	In both ILWIS and IDRISI 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.	Using ILWIS, distances ≤ 500 m are standardized to 1, distances between 500 m and 3000 m are standardized according to the linear function (the lower the distance, the higher the score) and distances ≥ 3000 m are standardized to 0. Using instead IDRISI, distances between 500 m and 3000 m are standardized according to the sigmoidal function.
Distance to roads	The criterion represents the road network system inside the area under examination.	In both ILWIS and IDRISI the criterion is standardized according to the linear function (the higher the distance, the higher the score). Distances ≥ 3000 m are standardized to 1.
Distance to urban areas	The criterion maps the distance to human settlements.	In both ILWIS and IDRISI the criterion is standardized according to the linear function (the higher the distance, the higher the score). Distances ≥ 3000 m are standardized to 1.
Population density	The criterion assigns to each municipality the population density value (Comuni Italiani, 2011).	In both ILWIS and IDRISI the criterion is standardized according to the linear function (the higher the population density, the lower the score).

With the aim of giving an example, Figure 6 shows the source map (Figure 6a), the standardized one (Figure 6b) and both the standardization functions (Figures 6c and 6d) used for the factor “distance to protected areas”. In particular, on the left (Figure 6c) the linear standardization function with control points 500 m and 3000 m provided by the ILWIS software is shown while on the right (Figure 6d) the sigmoidal monotonically decreasing function with the same control points available in the IDRISI software is displayed. According to this last function, areas less than 500 m are assigned a set membership of 1 (on a scale from 0-1), those between 500 m and 3000 m are assigned a value which progressively decreases from 1 to 0 in the manner of an s-shaped curve,

[4] The index of infrastructural fragmentation is calculated according to the following formula: $IFI = \left[\sum_i (Li * oi)\right] * [N / A] * p$

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 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).

and those beyond 3000 m to a protected area are considered to be too far away (they have thus been assigned a value of zero).

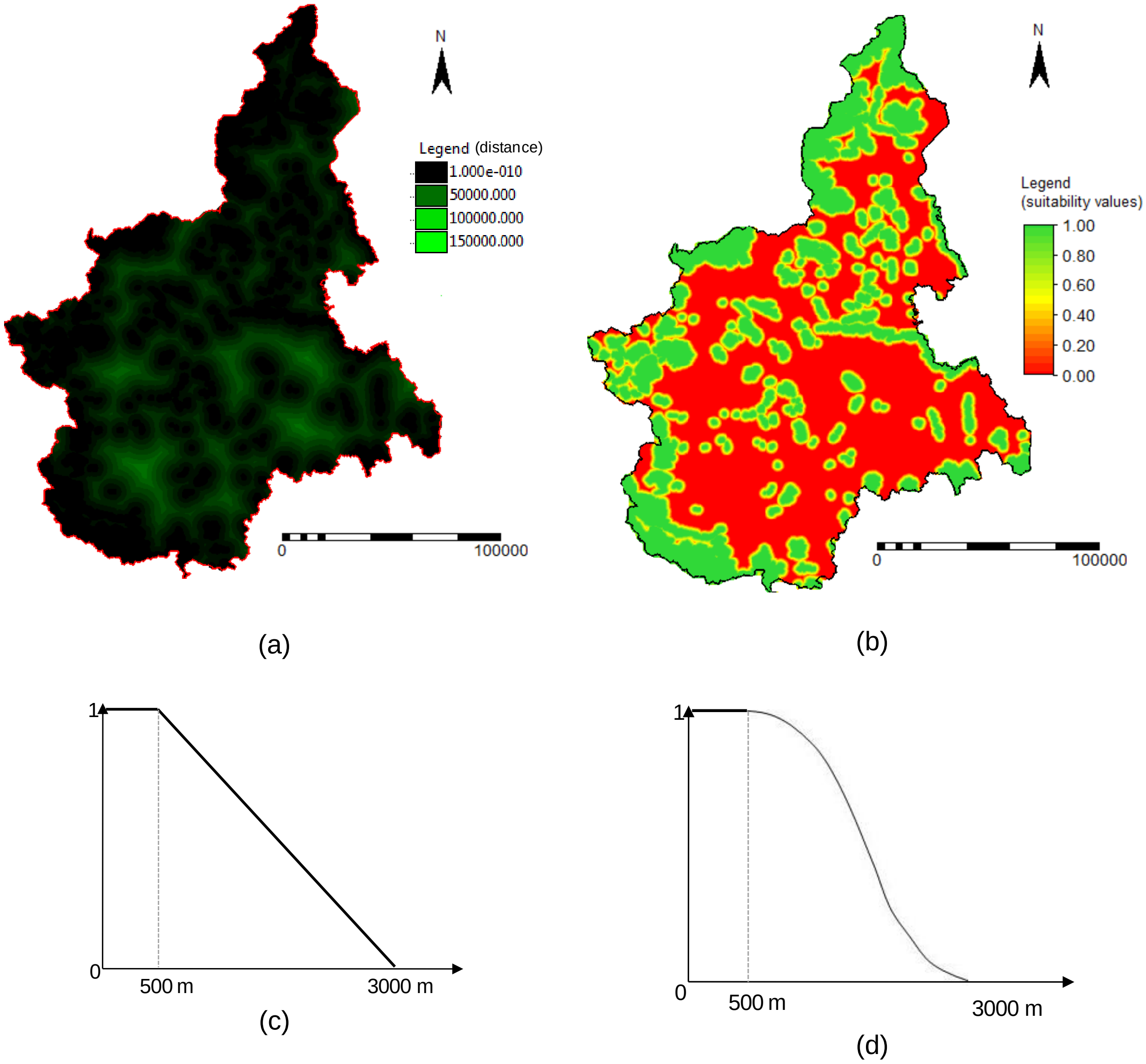

Figure 6 – *Source map (a), standardize map (b) and standardization functions (c and d) for the factor "distance to protected areas"*

3.2.2.2. Criteria weighting

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 underpins 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. During this phase the following three supermatrices are obtained:

(i) the "initial supermatrix", made by all the eigenvectors that are derived from the pairwise comparison matrices of the model;

(ii) the "weighted supermatrix" obtained by multiplying the initial supermatrix values by the cluster weight matrix;

(iii) 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.

Mention should be made to the fact that technical experts in the field of sustainability assessment of territorial transformation evaluated the relative importance of the considered factors during a focus group.
Table 2 shows the final priorities of the factors resulting from the limit supermatrix.

***Table 2** – Priorities of the model elements*

		Elements	Weights
CLUSTERS	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)	Height	0,20
		Distance to water bodies	0,03
		Naturalness index	0,10
		Fragmentation index	0,07
		Water quality index	0,06
	HUMAN PRESSU-RES (0,30)	Distance to roads	0,08
		Distance to urban areas	0,22
		Population density	0,06

The result of the participative procedure adopted for weighting the elements considered in the model 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 the “height” in the “physical environment” cluster.

3.2.3 Choice phase

Once the maps have been obtained for each criteria and the factor weights have been established, it is necessary to combine all the information in order to achieve the overall suitability map. In this case, a weighted linear combination has been used that combines all the factors maps according to equation 1:

$$Sj = \sum Wi * Xi \qquad (1)$$

where *S* is the suitability for pixel *j* to behave as a corridor; *Wi* is the weight of factor *I* and *Xi* is the standardized criterion score of factor *i*.
In the present application a suitability map was generated for each software where each cell is assigned a score in the 0-1 range expressing its degree of suitability to behave as ecological corridors. Higher values of suitability indicate for each pixel high appropriateness to host ecological corridor while low suitability values correspond to areas unsuitable for the corridor development.
Figure 7a represents the suitability map generated with the ILWIS software and Figure 7b is the map obtained by the IDRISI software. It is possible to notice that regardless of the GIS software used for the development of the model, we achieved a similar result. In fact, from a statistical study of the frequency histogram of the cells values of both the images, we obtained equal outcomes; in particular, the lower suitability value is 0,20 for the map generated by the Ilwis software and 0,21 for the map produced by the Idrisi software, on the other hand the higher suitability value reached is 0,96 for both the images.

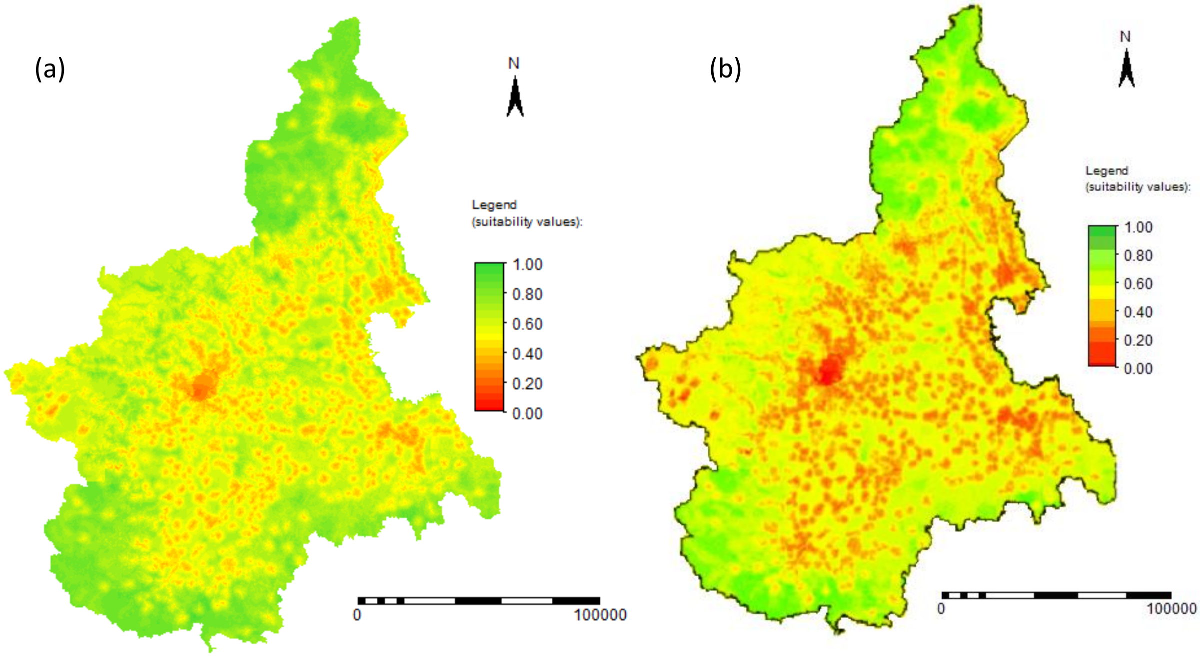

Figure 7 *– Final suitability maps for identifying ecological corridors: on the left is the map obtained with the ILWIS software (a) and on the right is the map generated by the IDRISI software (b).*

The map obtained is the final result of the analysis and 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 fact in the final map it is clear the influence of the negative pressure of the widespread urbanization which leads to a fragmentation and degradation of ecosystem reducing the capability to sustain its original biodiversity.

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 insure links between ecosystems (Vuilleumier *et al.,* 2002).

3.2.4 Review phase

In order to test the stability of the model, it is useful to perform a sensitivity analysis. The sensitivity analysis is concerned with a “what if” kind of question to see if the final answer is stable when the inputs, whether judgments or priorities, are changed. Particularly, in multicriteria spatial decision models the aim of the analysis is to see how these changes modify the final generation of alternatives; in fact, if changes do not significantly affect outputs, the model is considered robust, on the contrary it is required to modify some phases of the process in an appropriate way, by identifying objectives and attributes of the decision problem and also assign again criteria preferences (Ferretti and Pomarico, 2011).

In the present study we generated three scenarios by changing each time the weight of the three clusters in order to made one cluster predominant each time.

The first scenario shows the situation where physical environment related aspects have the greatest weight in determining the most suitable areas for identifying ecological corridors; in the second scenario biotic factors have the greater importance, and finally in the third scenario human pressure cluster represent the most important aspect. Figure 8 shows the results of the sensitivity analysis. It is clear that suitable areas for ecological corridor identification decrease when the importance of biotic factors increases (Fig. 8b). It is possible to see that 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 influences the natural habitat.

In Figure 8a, where physical environment related aspects have more influence, the final suitability map is almost unchanged. Figure 8c shows the third scenario, in this case there is a slight decrease of suitable area round urban areas due to high population density and widespread urbanization. Change in results is evident in the map shown in Figure 8b where biotic factors more affect land suitability. In this scenario suitability values decrease in most of the area under examination except round the natural protected areas and the areas along the border with the mountains.

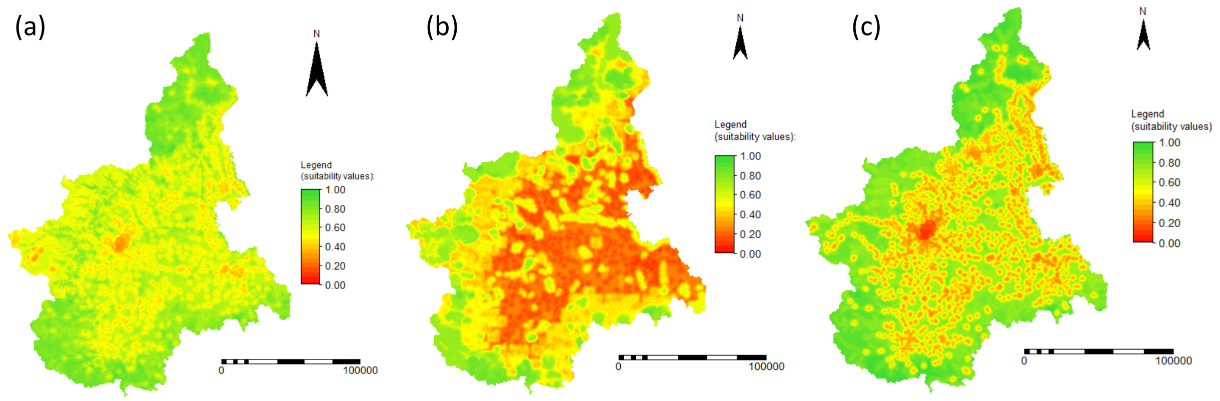

Figure 8 – *Sensitivity analysis scenarios.*

4. Results

As a first attempt, from the final suitability map, a sub-area of the region has been extracted in order to draw a possible ecological network connecting the natural protected areas. Figure 9 shows the sub area under analysis surrounding the Gran Paradiso National Park, where the existing protected areas have been highlighted.

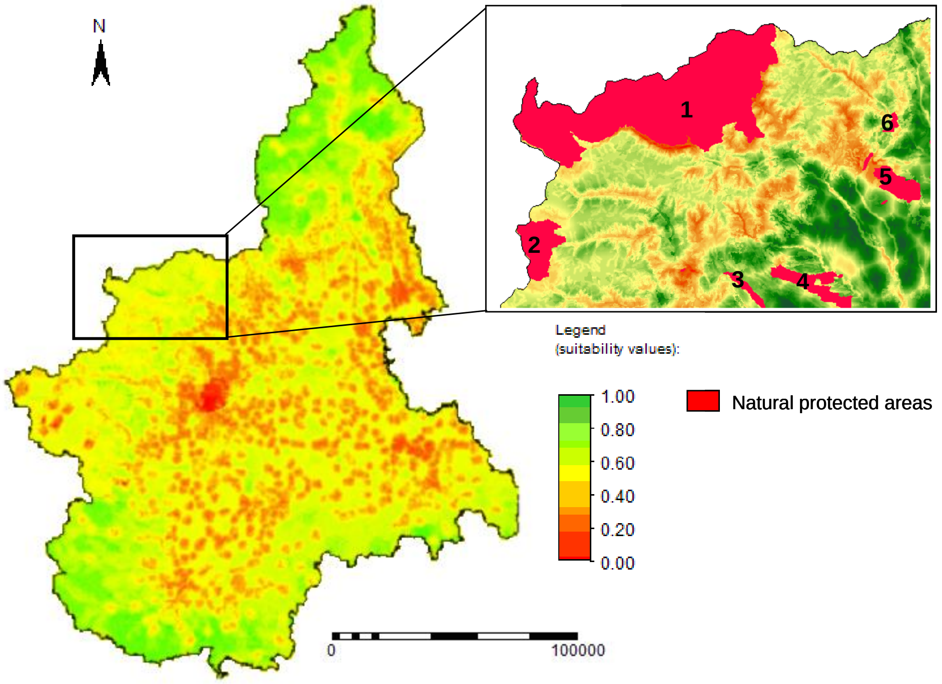

Figure 9 – *Sub area under examination*

With the aim to find the optimal corridors linking the natural protected areas we used the PATHWAY module of the IDRISI software. This algorithm determines the least cost route between one or more targets and one or more lower terminal cells on an a cost surface, which represents a surface where distance from a starting point is measured as the cost (in terms of effort, expense,

etc.) (Eastman, 2006). In order to determine the cost distance from each natural protected area we used the suitability map for establishing ecological corridors. In this way an high value of suitability implies a low cost distance. Clearly it is the contrary for low suitability values.
The first attempt for generating ecological corridors in the area under analysis through the PATHWAY module is shown in Figure 10.

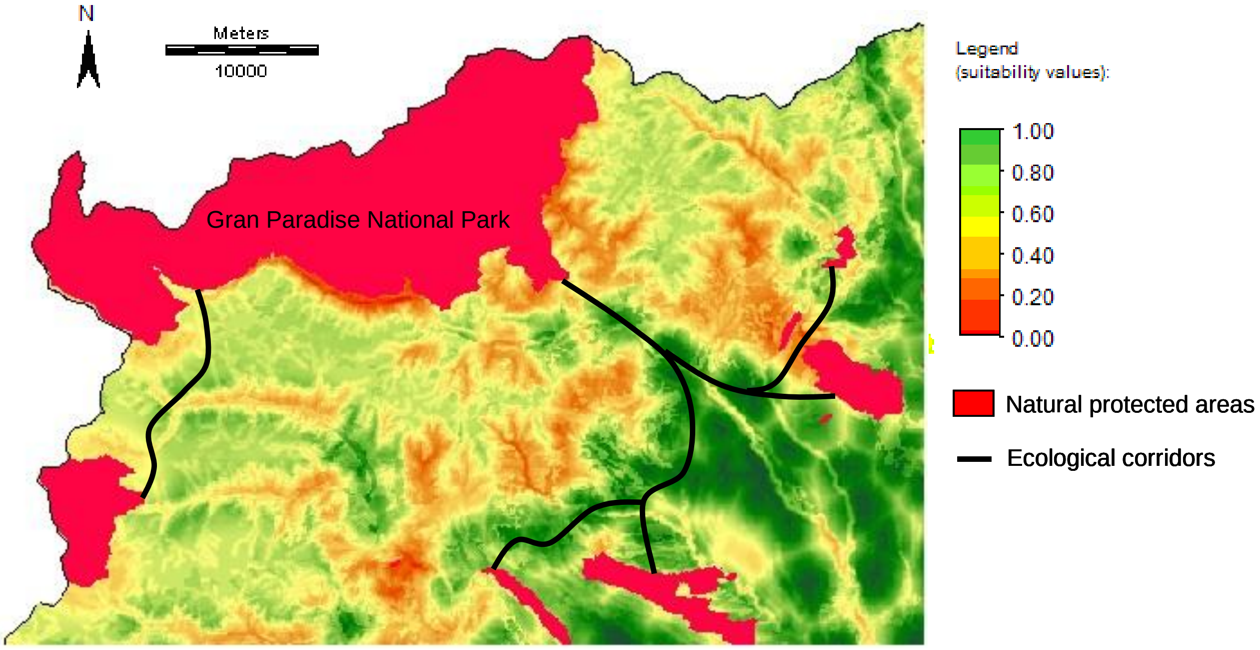

Figure 10 – *Hypothetical ecological corridors connecting the Gran Paradiso National Park with the other natural protected areas.*

Finally, we compared our results with a recent study carried out by the Environmental Protection Regional Agency (ARPA, Maffiotti and Vietti, 2006). This study allows a preliminary identification of areas of ecological connection by the biological permeability and the ecological connectivity assessment, starting from the identification of the potential areas with high biodiversity on the territory. From a preliminary comparison, the suitability map (Fig. 7) obtained by the development of the MC-SDSS model is coherent with the ecological connectivity map of the Environmental Protection Regional Agency study. Furthermore, current developments of the present application refers to the identification of areas worth of protection and on the opposite hand, of areas for which specific monitoring programs should be established.

5. Discussion and conclusions

Sustainable development is a widely accepted strategic framework in decision-making concerning the future use of land (IUCN, 1994). However, ecological sustainability is not yet well developed in landscape planning. The explicit inclusion of ecological principles in landscape planning is as a matter of fact quite a recent advancement (Ahern, 2002).
New planning tools are thus needed to maintain and increase biodiversity in fragmented landscape. (Bruel and Baudry, 1999).
The undertaken research has proposed the development of a Multicriteria-Spatial Decision Support System to assess the land suitability to behave as an ecological corridor. The proposed methodology has been illustrated with reference to the case study of the Piedmont region (northern Italy) in order to highlight potential ecological corridors and stepping stones and thus provide a useful support for planning ecological networks.
The method proposed in the present paper for assessing ecological connectivity at the regional level allows quick assessments and applications, which can be very effective for regional and metropolitan land use planning and strategic impact assessments.

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.
The study also underlines the relevant role land suitability analyses play in spatial planning. In fact, 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 population needs 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.
The main advantage of this integration is the fact that Decision Makers can insert their own opinions (preferences with respect to evaluation criteria) in the decision-making process based on Geographical Information Systems and receive feedback on their impact in policy evaluations through the visualization of specific maps.
In addition, these tools help to improve communication and comprehension within a group of Decision Makers, thus facilitating the achievement of consensus. Another advantage associated with MC-SDSS is the ability to provide a flexible problem-solving environment where it is possible to explore, understand and redefine a decision-making problem (Bottero *et al*., 2011).
Future developments of the work refer to the possibility to implement the present model according to the fuzzy sets theory (Zadeh, 1965), which represents attribute values according to membership classes. As a matter of fact, uncertainty can be associated with fuzziness concerning the criterion weight assessment as well as the spatial attribute values (Malczewski, 1999).
Based on the suitability values provided by the present study, it would also be interesting to perform more detailed analyses focusing 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 field of sustainability assessments and more specifically ecological planning since the integrated approach allows to express, understand and analyze ecological links between ecosystems, taking into account information about conflicting areas (human activities and ecological networks) and highlighting 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.

Bibliographic References

Aerts, J.C., Esinger, E., Heuvelink, G.B., Stewart, T.J., 2003. Using integer linear programming for multi-site land-use allocation. Geogr. Anal. 35, 148–169.

Ahern, J., 2002. Greenways as strategic landscape planning: theory and application, Dissertation, Wageningen University, Waseningen, The Netherlands.

Agouti, T., Eladnan, I.M., Tikniouine, A., Aitouahman, A., 2008. A hybrid model of mathematical programming and analytic hierarchy process for the GISMR: The industrial localization. WSEAS Trans. on Comput. Res. 3 (4), 234-241.

Akgun, A., Türk, N., 2010. Landslide susceptibility mapping for Ayvalik (Western Turkey) and its vicinity by multicriteria decision analysis. Environ. Earth Sci. 61 (3), 595-611.

Al-Adamat, R., Diabat, A., Shatnawi, G., 2010. Combining GIS with multicriteria decision making for siting water harvesting ponds in Northern Jordan. J. of Arid Environ. 74 (11), 1471-1477.

Anane, M., Kallali, H., Jellali, S., Ouessar, M., 2008. Ranking suitable sites for Soil Aquifer Treatment in Jerba Island (Tunisia) using remote sensing, GIS and AHP-multicriteria decision analysis. Int. J. of Water. 4 (1-2), 121-135.

Andrienko, G., Andrienko, N., Jankowski, P., 2003. Building spatial decision support tools for individuals and groups. J. of Decis. Syst. 12, 193–208.

Armstrong, M.P., 1993. Perspectives on the development of group decision support systems for locational problem solving. Geogr. Syst. 1, 69–81.

Armstrong, M.P., Densham, P.J., Rushton, G., 1986. Architecture for a microcomputer-based decision support system. In: 2nd International Symposium on Spatial Data Handling, 6-10 July 1986 Williamsville New York. International Geographical Union, 120-131.

Baschak, L.A., Brown, R.D., 1995. An ecological framework for the planning, design and management of urban river greenways. Landscape and Urban planning, 33, 211-225.

Bedard, Y., Merrett, T., Han, J., 2001. Fundamentals of spatial data warehousing for geographic knowledge discovery, in: Miller, H., Han, J. (Eds.), Geographic Data Mining and Knowledge Discovery. Taylor and Francis, London.

Bennett, G., 2004. Integrating biodiversity conservation and sustainable use: lessons learned from ecological networks. Gland, Switzerland and Cambridge, UK: IUCN.

Bennett, G., Mulongoy, K.J., 2006. Review of experience with ecological networks, corridors and buffer zones. Montreal: Secretariat of the Convention on Biological Diversity.

Bennett, G., Wit, P., 2001. The development and application of ecological networks: a review of proposals, plans and programmes. Amsterdam: AID Environment.

Bottero, M., Comino, E., Duriavig, M., Ferretti, V., Pomarico, S., 2011. The application of a Multicriteria Spatial Decision Support System (MCSDSS) for the assessment of biodiversity conservation in the Province of Varese (Italy), Journal of Land Use Policy (currently under revision).

Bottero, M., Ferretti, V., 2011. An Analytic Network Process (ANP) based approach for location problems: the case of a new waste incinerator plant in the Province of Torino (Italy). Journal of Multicriteria Decision Analysis. 17: 63-84.

Broquet, T., Ray, N. ,Petit, E., Fryxell, J.M., Burel,F., 2006. Genetic isolation by distance and landscape connectivity in the American marten (Martes americana). Landscape Ecology, 21, 877–889.

Bruinderink, G.G., VanDerSluis, T., Lammertsma, D., Opdam,P., Pouwels, R., 2003. Designing a coherent ecological network for large mammals in northwestern Europe. Conservation Biology, 17, 549–557.

Bruel, F., Baudry, J., 1999. Ecologie du paysage, Concepts, methods et application. Edition Technique et Documentation, Paris.

Burstein, F., Holsapple, W.C. (eds) 2008. Handbook on Decision Support Systems. Springer-Verlag, Berlin.

Carver, S., 1991. Integrating multi-criteria evaluation with geographical information systems. Int. J. of Geogr. Inf. Sys. 5, 321–339.

Changa, N.B., Parvathinathanb, G., Breedenc, B., 2008. Combining GIS with fuzzy multicriteria decision making for landfill siting in a fast growing urban region. J. of Environ. Manag. 87 (1), 139-153.

Charlton, M. and Ellis, S., 1991. GIS in planning. J. of Environ. Plan. and Manag. 34 (1), 20-26.

Church, R.L., Scaparra, M.P., Middleton, R.S., 2004. Identifying critical infrastructure: The median and covering facility interdiction problems. Ann. of the Assoc. of Am. Geog. 94, 491–502.

Comuni Italiani, 2011. www.comuni-italiani.it (accessed on September the 14th, 2011).

Densham, P.J., 1991. Spatial decision support systems, in: Maguire, D.J., Goodchild, M.F., Rhind, D.W., (Eds.), Geographical Information Systems: Principles and Applications. John Wiley and Sons, New York, pp. 403-412.

Densham, P.J., Armstrong, M.P., 1987. A spatial decision support system for locational planning: Design, implementation and operation, Proceedings of the Eighth International Symposium on Computer-Assisted Cartography (AutoCarto 8), Baltimore, Maryland, pp. 112–121.

Densham, P.J., Goodchild, M.F., 1989. Spatial decision support systems: a research agenda, in: Proceedings GIS/LIS'89, Orlando, pp. 707-716.

Dragan, M., Feoli, E., Fernetti, M., Zerihun, W., 2003. Application for a spatial decision support (SDSS) to reduce soil erosion in northern Ethiopia. Environ. Model. and Softw.18, 861-868.

Duriavig, M., 2008. Dove corre un corridoio. Sistemi di supporto alla decisione: un'applicazione nel Sud Est di Bahia, Brasile. Proceedings of the X National congress f the SIEP-IALE on "landscape ecology and governance" 22-23/05/2008, Bari, Italy.

Eastman J.R. 2006. IDRISI Andes. Guide to GIS and Image Processing. Clark University.

Eastman, R.J., Kyen, P.A.K., Toledno, J., 1993. A procedure for Multiple- Objective Decision Making in GIS under conditions of Conflicting Objectives, in: Hents, J., Ottens, H.F.L., Scholten, H.J. (Eds.), Fourth European Conference on GIS (ESIG'93) Proceedings, Genova (IT), 1 (2), pp. 438-447.

Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution and Systematics, 34, 487–515.

Feick, R.D., Hall, B.G., 2004. A method for examining spatial dimension of multi-criteria weight sensitivity. Int.J. of Geogr. Inf. Sci. 18, 815–40.

Ferretti, V., 2011a. A Multicriteria- Spatial Decision Support System (MC-SDSS) development for siting a landfill in the Province of Torino (Italy), Journal of Multi-Criteria Decision Analysis (in press).

Ferretti, V., 2011b. Multicriteria- Spatial Decision Support Systems (MC- SDSS): un approccio integrato per le valutazioni strategiche degli interventi di trasformazione territoriale, Ph.D. thesis in Environment and Territory, Estimate and Assessment, Politecnico di Torino, March 2011.

Ferretti, V., Pomarico, S. 2011. The development of a Multicriteria- Spatial Decision Support System for siting a waste incinerator plant in the Province of Torino (Italy). Journal of Waste Management (currently under revision).

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., (2005). Global consequences of land use. Science, 309, 570–574.

Geneletti, D., 2007. An approach based on spatial multicriteria analysis to map the nature conservation value of agriculture land. J. of Environ. Manag. 83, 228-235.

Geneletti, D., 2010. Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. Waste Manag. 30 (2), 328-337.

Geneletti, D., Abdullah, A. (eds.) 2009. Spatial decision support for urban and environmental planning. A collection of case studies, Academic Press, Kuala Lumpur.

Goodchild, M.F., 1993. The state of GIS for environmental problem solving, in: Goodchild, M.F., Parks, B.O., Steyaert, L.T. (Eds.), Environmental Modelling With GIS. Oxford University Press, New York.

Gül, A., Fistikoğlu, O., Harmancioğlu, N., 2010. Hydrospatial approach to assist decision making on reservoir protection zones. J. of Hydrol. Eng. 15 (4), 297-307.

Gurrutxaga, M., Lozano, P.J., Del Barrio, G., 2010. GIS-based approach for incorporating the connectivity of ecological networks into regional planning. Journal for Nature Conservation, 18, 318-326.

Hala, E., Hegazy, M.N., 2009. Application of MultiCriteria Evaluation in GIS Environment for an Agricultural Development Scenario in the Egyptian Deserts, GIS Ostrava, Ostrava.

Hobbs, R.J., 2002. Habitat networks and biological conservation. In: Gutzwiller, K.J. (Ed.), Applying Landscape Ecology in Biological Conservation. Springer Verlag, New York, pp. 150–170.

Huber, P.R., Roth, N.E., Beardsley, K., Thorne, J.H., McCoy, M.C., Meade, R., 2007. Potential impacts of urban growth on an ecological network in the San Joaquin Valley. San Francisco: Association for American Geographer's.

Jankowski, P.,1995. Integrating Geographical Information Systems and Multiple Criteria decision making methods. Int. J. of Geogr. Inf. Syst. 9 (3), 241-273.

Jankowski, P., Richard, L., 1994. Integration of GIS based suitability analysis and multicriteria evaluation in a spatial decision support system for route selection. Environ. and Plan. 21, 323-340.

Janssen, R., van Herwijnen, M., 1998. Map transformation and aggregation methods for spatial decision support, in: Beinat, E., Nijkamp, P. (Eds.), Multicriteria analysis for land-use management. Kluwer Academic Publishers, Dordrecht, pp. 253-270.

Janssen, R., Rietveld, P., 1990. Multicriteria analysis and GIS; an application to agricultural landuse in the Netherlands, in: Scholten, H.J., Stillwell, J.C.H, (Eds.), Geographical Information Systems and Urban and Regional Planning. Kluwer Academic Publishers, Dordrecht, pp. 129-139.

Jongman, R.H.G., Pungetti,G. 2004. Ecological networks and greenways. Concept, design, implementation. Cambridge: Cambridge University Press.

Keeney, R.L., 1992. Value-focused thinking: a path to creative decision making. Harvard University Press, Cambridge.

Keshkamat, S.S., Looijen, J.M., Zuidgeest, M.H.P., 2008. The formulation and evaluation of transport route planning alternatives: a spatial decision support system for the Via Baltica project, Poland. J. of Transp. Geogr. 17, 54-64.

ILWIS 3.3, 2005. The Integrated Land and Water Information System. ITC, Enschede, http://www.itc.nl/ilwis/.

IUCN, 1994. Parks for life. Action plan for protected areas in Europe. Gland, Switzerland: IUCN Commission on National Parks and Protected Areas.

Laaribi, A., Chevallier, J.J., Martel, J.M., 1996. A spatial decision aid: a multicriterion evaluation approach. Comput. Environ. Urban Syst. 20 (6), 351–366.

Lega, P, 2004. La frammentazione infrastrutturale del territorio nella Provincia di Piacenza. Rapporto Interno n. 05/04.

Leung Y., 1997. Intelligent Spatial Decision Support Systems, Springer-Verlag, Berlin.

Levy, J.K., Hartmann, J., Li, K.W., An, Y., Asgary, A., 2007. Multi-criteria decision support systems for flood hazard mitigation and emergency response in urban watersheds. J. of the Am. Water Resourc. Assoc. 43 (2), 346-358.

Li, Y., Shen, Q., Li, H. 2004. Design of spatial decision support systems for property professionals using MapObjects and Excel. Autom. in Constr. 13, 565-573.

Maffiotti, A., Vietti, D., 2006. Carta delle reti ecologiche in Piemonte. Convegno ARPA "Fauna Selvatica e attività antropiche:Una convivenza possibile" 3/04/2006 Torino.

Malczewski, J., 1996. A GIS based approach to multiple criteria group decision making. Int. J. of Geogr. Syst. 10 (8), 955-971.

Malczewski, J., 1999. GIS and Multicriteria Decision Analysis, John Wiley and Sons, New York.

Malczewski, J., 2006. GIS-based multicriteria decision analysis: a survey of the literature. Int. J. of Geogr. Inf. Sci. 20 (7), 703-726.

Marulli, J., Mallarach, J.M., 2005. A GIS methodology for assessing ecological connetivity:application to the Barcelona Metropolitan Area. Landscape and Urban Planning, 71, 243-262.

McHarg, I.L., 1969. Design with nature, Wiley, New York.

Mùgica, M., DeLucio, J.V., Martìnez, C., Sastre, P., Atauri–Mezquida, J.A., Montes, C., 2002. Territorial integration of natural protected areas and ecological connectivity within Mediterranean landscapes. Seville: Juntade Andalucìa.

Neaupane, K.M., Piantanakulchai, M., 2006. Analytic Network Process Model for Landslide Hazard Zonati. Eng. Geolog. 85 (3/4), 281- 294.

Nekhay, O., Arriaza, M., Boerboom, L., 2009. Evaluation of soil erosion risk using Analytic Network Process and GIS: A case study from Spanish mountain olive plantations. J. of Environ. Manag. 90, 3091-3104.

Noss, R.F., Daly, K.M., 2006. Incorporating connectivity into broad–scale conservation planning. In K. Crooks, M. Sanjayan (Eds.), Connectivity Conservation (pp. 587–619). Cambridge: Cambridge University Press.

OCS - Osservatorio Città Sostenibili 2002. Indice del grado di naturalità del territorio. OCS Doc 2/2002, Dipartimento Interateneo Territorio del Politecnico e dell'Università di Torino.

Opdam, P., Steingröver, E., van Rooij, S., 2006. Ecological networks: a spatial concept for Multi-actor planning of sustainable landscapes. Landscape and Urban Planning, 75, 322-332.

Osservatorio Faunistico, 2011. Regione Piemonte, www.regione.piemonte.it/agri/osserv_faun/index.htm (accessed on September the 20th, 2011).

Pereira, J.M.C., Duckstein, L., 1993. A multiple criteria decision making approach to GIS-based land suitability evaluation. Int. J. of Geogr. Inf. Syst. 7 (5), 407–424.

Prigogine, I. 1997. The end of certainty. New York: The Free Press.

Roscelli, R., 2005. Misurare l'incertezza. Celid, Torino.

Saaty, T.L., 1980. The Analytic Hierarchy Process, McGraw-Hill, New York.

Saaty, T.L., 2005. Theory and applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs and Risks, RWS Publications, Pittsburgh.

Sharifi, M.A., Retsios, V. 2004. Site selction for waste disposal through spatial multiple criteria decision analysis. J. of Telecommun. and Inf. Technol. 3, 28-38.

Simon, H.A., 1960. The New Science of Management Decision, Harper and Row, New York.

Smith, R.D., Maltby, E., 2003. Using the ecosystem approach to implement the Convention on Biological Diversity: key issues and case studies. Gland, Switzerland and Cambridge, UK: IUCN.

Tegou, L., Polatidis, H., Haralambopoulos, D.A., 2010. Environmental management framework for wind farm siting: Methodology and case study. J. of environ. Manag. 91 (11), 2134-2147.

Theobald, D.M., 2006. Exploring the functional connectivity of landscapes using landscape networks. In K.R. Crooks, M. Sanjayan (Eds.), Connectivity conservation. Cambridge: Cambridge University Press, pp. 416–443.

Thill, J.C., 1999. GIS and Multiple Criteria Decision Making: A Geographic Information Science Perspective, Ashgate, London.

Vadrevu, K.P., Eaturu, A., Badarinath, K.V.S., 2010. Fire risk evaluation using multicriteria analysis—a case study. Environ. Monit. and assess. 166 (1-4), 223-239.

Vuilleumier, S., Prélaz-Droux R., 2002. Map of ecological network for landscape planning. Landscape and Urban Planning, 58, 157-170.

Vogt, P., Riitters, K.H., Iwanowsky M., Estreguil C., Kozak, J., Soille, P., 2007. Mapping landscape corridors. Ecological Indicators, 7, 481-488.

Wu, F., 1998. SimLand: A prototype to simulate land conversion through the integrated GIS and CA with AHP-derived transition rules. Int. J. of Geogr. Inf. Sci. 12, 63–82.

Zadeh, L.A., 1965. Fuzzy set. Inf. and Control. 8, 338–353.

Zucca, A., Sharifi, A., Fabbri, A., 2007. Application of spatial multi criteria analysis to site selection for a local park: a case study in the Bergamo Province, Italy. J. of Environ. Manag. 88, 752-769.