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Short communication

Ecological land suitability analysis through spatial indicators: An application of the Analytic Network Process technique and Ordered Weighted Average approach

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ABSTRACT

Multicriteria-Spatial Decision Support Systems (MC-SDSS) are increasingly popular tools in decision-making processes and in policy making, thanks to their significant new capabilities in the use of spatial or geospatial information.

Many spatial problems are complex and require the use of integrated analysis and models. The present paper illustrates the development of a MC-SDSS approach for studying the ecological connectivity of the Piedmont Region in Italy. The MC-SDSS model considers ecological and environmental spatial indicators which are combined by integrating the Multicriteria Decision Aiding (MCDA) technique named Analytic Network Process (ANP) and the Ordered Weighted Average (OWA) approach. The ANP is used for the elicitation of attribute weights while the OWA operator function is used to generate a wide range of decision alternatives for addressing uncertainty associated with interaction between multiple criteria. The usefulness of the approach is illustrated by different OWA scenarios that report the ecological connectivity index on a scale between 0 and 1. The OWA scenarios are intended to quantify the level of risk taking (i.e., optimistic, pessimistic, and neutral) and to facilitate a better understanding of patterns that emerge from decision alternatives involved in the decision-making process.

The purpose of the research is to generate a final map representing the ecological connectivity index of each area in the region under analysis, to be used as a decision variable in spatial planning. In particular, by using the resulting index map as a means of analysis, it is possible to identify, for the sake of nature conservation, some critical areas needing mitigation measures. In addition, areas with high ecological connectivity values can be identified and monitoring procedures can therefore be planned. The study concludes highlighting that the applied methodology is an effective tool in providing decision support for spatial planning and sustainability assessments.

1. Introduction

Maintaining and restoring landscape connectivity is currently a central concern in ecology and nature conservation, and more generally speaking in territorial planning with the objective of achieving sustainable development.

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). 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.

In order to efficiently support planning processes and Strategic Environmental Assessment, there is a need of quantitative methods able to synthesize a multi-habitat (or multi-species) connectivity.

In the current debate regarding environmental assessment and integrated approaches, Multicriteria-Spatial Decision Support Systems (MC-SDSS) play a fundamental role by solving semi-structured spatial problems through the integration of Geographic Information Systems (GIS) and Multicriteria Decision Aiding (MCDA) techniques.

An integrated evaluation approach can go beyond spatial and hierarchical limits to consider the different components and their interrelations, clarify weights, recognize different priorities and

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define appropriate strategies, while also including social participation and a dynamic dialog among different experts (Lee, 2006).

Spatial decision-making problems can involve the evaluation of many alternatives based on multiple qualitative and/or quantitative criteria. Not only do they often involve numerous technical requirements, but they also concern economic, social, environmental and political dimensions with potentially conflicting values and goals. Solutions to these problems involve highly complex processes of spatial data analysis and frequently require advanced means for addressing conditions of physical suitability, while considering multiple socio-economic variables.

Current GIS can be used in all stages of the preparation of environmental assessments (from the screening to scoping phases, in project description, in the establishment of the environmental baseline, in the definition of impact mitigation and control, in public consultation and participation, and in monitoring and auditing), especially because of their capabilities for spatial data integration. However, they lack mathematical modeling applications, iterative equation solving abilities, and the simulation capabilities necessary for many spatial decision-making situations (Girard et al., 2012). In order to consider these needs, MC-SDSS can facilitate such decision-making conditions through an application that allows users to specify their criteria and preferences interactively via an easy-to-use interface. This allows the exploration of possible options, along with analytical functions that can generate feasible solutions based on specified criteria and preferences. The most significant difference between spatial multicriteria decision-making analysis and conventional multicriteria techniques is thus the explicit presence of a spatial component. In particular, 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 assume 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, thus becoming one of the most interesting evolutions in the context of environmental assessment procedures (such as Environmental Impact Assessment and Strategic Environmental Assessment). In this context the comparison of different alternatives represents one of the most important parts of the whole process and the complexity of the problems and the need for technical support in the decision-making process is particularly real.

This paper explores the potential of MC-SDSS in the field of land use planning and ecological corridor development. Ecological corridors are areas or structures that enable the 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 hubs, or areas that are known to have 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.

The ecological network concept indicates essentially a strategy for landscape and biodiversity protection based on the connection of areas of environmental and ecological value in a continuous network. Different ways of understanding ecological network exist (APAT, 2003; Bennett, 2004; Jongman and Pungetti, 2004) and the approach followed in the present application is the one that considers ecological networks as systems of natural protected areas (and/or parks), in which the hubs coincide with the natural protected areas themselves and the link between them represents a landscape corridor under the planning point of view. Consequently, the present analysis aims at supporting strategic planning processes and thus does not focus on a specific habitat, but considers ecological corridors as an element of continuity between natural protected areas.

From the methodological point of view, the present application proposes the integration between GIS and a specific MCDA technique called Analytic Network Process (ANP; Saaty, 2005) in order 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 is carried out using the IDRISI 3.2 software (www.clarklabs.org) and makes use of the Ordered Weighted Average (OWA) aggregation rule. Using the OWA method different scenarios of land suitability as an ecological corridor are generated and evaluated. 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-making problems that are characterized by interrelationships among the elements at stake, are instead scarce (Ferretti, 2011a; Ferretti and Pomarico, 2012a, 2013; Levy et al., 2007; Neaupane and Piantanakulchai, 2006; Nekhay et al., 2009).

This study thus develops a decision-making support model 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 areas of ecological priority and potential ecological connections.

The objective of this analysis is thus to provide an innovative methodological approach for the integration of spatial ecological and environmental indicators in order to generate an index map representing the ecological connectivity of each area in the region under investigation.

The first part of the article (Section 2) illustrates the MC-SDSS methodological background and contextualizes the research within the existing literature. Section 3 presents the ANP-GIS integrated approach for the analysis of the land suitability of the Piedmont Region as ecological network. Finally, Section 4 presents the main findings of the application and Section 5 summarizes the conclusions that have been drawn from the study, highlighting the opportunities for expanding the work.

2. Methodological background

2.1. Multicriteria-Spatial Decision Support Systems

Multicriteria-Spatial Decision Support Systems (Malczewski, 1999) combine Geographic Information Systems and Multicriteria Decision Aiding in order to provide a collection of methods and tools for transforming and integrating geographic data (map criteria) and Decision Maker's preferences and uncertainties (value judgments) to obtain information for decision-making and an overall assessment of the decision alternatives.

Whereas Decision Support Systems 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 problems (Densham and Goodchild, 1989).

Over the years there has been considerable growth in the research, development and applications of SDSS in order to include different functions. 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, 2006a).