Landscape Ecology for Sustainable Land Use Planning: a GIS approach in a Man-dominated Landscape

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Abstract

This paper illustrates an approach for the design of ecological networks in an Italian man-dominated landscape. Ecological networks represent one of the main potential contribution of landcape ecological studies to sustainable land use planning and environemntal management. An ecological network provides a re-interpretation of the landscape by identifying four main structural elements: core conservation areas, buffer zones, connection corridors, and stepping stones. The methodology followed in this research is based on the computation of spatial indices in a GIS environment. The output of the study aims at complementing more traditional data and tools used by planning authorities for resource assessments and land allocation.

1. Introduction and objectives

During the last decade, the nature conservation policies in many European countries have been based on landscape ecological research, especially focusing on the role played by landscape structure and land use patterning for the survival of species (Ahern 1999, Arts *et al*. 1995). One of the main results of this approach consists in the design and the establishment of ecological networks. The planning of an ecological network can be seen as an interface between the science of landscape ecology and the practice of land use planning, where guidelines have be articulated for promoting ecologically sustainable use of land (Langevelde 1999). In this framework, the challenge for landscape ecology is to derive indications on optimal landscape patterning, out of the typical spatial analyses carried out by studies in this discipline. In other words, spatial indicators, such as the ones expressing landscape connectivity and diversity, need to be integrated with information on biodiversity distribution and habitat significance, so to contribute to the design of ecological networks and to promote nature conservation (Burke 2000; Hannson and Angelman 1991). In the present study, the structure of the landscape of a study area was analyzed and described by means of a set of spatial ecological indicators. The results were integrated with information on ecosystem naturalness and significance and used to design possible ecological networks. The research aims at providing the planning authorities with an ecological characterization of the area, to support and integrate more traditional tools for land use planning. The results of the analysis, indeed, can be used for identifying the most critical sites for nature conservation and suggesting low-impact location for future developments and activities. A GIS turned out to be an essential tool for such a study, allowing the computation of spatial indices and the generation of landscape scenarios. Furthermore, the output results can be directly integrated with the spatial information system used for land use planning. The proposed approach was applied to a typical European man-dominated landscape. From a landscape ecological perspective, a man-dominated landscape is characterized by a non-natural landscape matrix and by scattered remnants of natural ecosystems, such as forest patches or wetlands. In industrial countries, these landscapes often represent the most natural environment, consequently their management becomes a priority for nature conservation (Arts *et al.* 1995).

2. The study area

The study area is located in northern Italy, within the province of Cesena (see Figure 1). It covers about 500 km^2, extending from the Adriatic Sea shore to the Apennine foothills. The area includes several landscape types, characterized by different gradients of human disturbance. In particular, moving from North-East to South-West, the following main landscapes can be identified (see also the land use map in Figure 2):

- Adriatic sandy shoreline;
- alluvial plain intensively used for agriculture;
- hill land mainly covered by patchy woodlands;
- pre-Apennine relief.

The area experienced a strong deforestation during the 20's and 30's, but, especially after World War II, the population tended to migrate towards the major cities in the plain and natural vegetation start recolonizing previously cultivated areas. Nowadays, the general trend is for woodlands to expand and for agricultural land to shrink. Nevertheless, the landscape matrix is still mainly represented by artificial ecosystems, such as cultivated fields, orchards and settlements. Furthermore, infrastructures and urbanization heavily disturb and interrupt the remnant natural ecosystem, posing a threat to the conservation of their biodiversity. A preliminary landscape ecological analysis of the study area is discussed in Geneletti and Pistocchi 2001.

3. Methodology

3.1 Introduction

The methodology proposed in this research aims at supporting the design of ecological networks within man-dominated landscapes. An ecological network provides a re-interpretation of the landscape where each element is assessed and classified according to its functional ecological role. One of the most common paradigms used for planning ecological networks involves the identification of four main landscape elements: core conservation areas, buffer zones, connection corridors, and stepping stones. Core areas include the most significant ecosystems and natural sites to be protected and/or restored. They represent the main biodiversity sources of the study region. Buffer zones extend around core areas with the purpose of reducing and absorbing external disturbances. They typically consist of agro-ecosystems or woodland plantations. Corridors are linear elements that provide linkages between core areas and determine the degree of connectivity of the landscape. Connectivity ensures organism and nutrient flows and has a strong influence in determining the overall ecological sustainability, especially in fragmented landscapes (Forman and Godron 1986). Stepping stones are small patches of natural ecosystems that can be used by organisms while moving between core areas. Core areas, buffers, corridors, and stepping stones have to be identified and distinguished from the surrounding landscape matrix that, in man-dominated landscapes, is typically made of settlements and agricultural fields. Despite the broad agreement on the usefulness of ecological networks, only few examples of methodologies for their actual implementation and design were found in literature (Malcevschi 1996, Arts *et al*. 1995). In this paper we propose a semi-automatic approach based on the computation of spatial ecological indices in a GIS environment and on the use of such indices for generating decision rules that allow identifying the fundamental landscape elements. The approach is described in the following four sub-sections.

3.2 Identifying core areas

First of all, it is necessary to select the ecosystem types considered ecologically relevant and, therefore, to be protected and connected. This was done by comparing the actual land cover (see Figure 2) with knowledge on the potential vegetation over the area. As a result three types of broadleaf woodlands were selected: Oak, Beech and Chestnut woods. For all the landscape patches covered by such forest types a set of spatial indices (such as size, shape, and proximity to roads) were computed and assessed.

Afterwards, the patches more suitable to become 'core areas' were identified, by means of dedicated decision rules based on their size, degree of dispersion over the landscape, distance from source of disturbances, and so on.

3.3 Delimiting buffer zones

Around each core area, a buffer zone was delimited by including all semi-natural ecosystems (such as meadows, shrubs, and wood plantations) laying within a certain distance. This distance was proportional to the size of the relevant core area. In the location where suitable buffers could not be identified, indications on possible land conversion were provided.

3.4 Delineating connection corridors

Two types of corridors were considered: fluvial corridors and 'land' corridors. The first ones were identified considering the most natural water streams in the area that play a role in connecting core areas. As for the latter ones, they were automatically delineated by implementing in a GIS an algorithm based on optimization of distances from the core areas (Geneletti and Pistocchi 2001, Patrono and Saldana 1997).

3.5 Identifying stepping stones

The patches of vegetation not included in the core areas (e.g. because too small) were assessed for their suitability as stepping stones. This involved least-distance computation and analysis of their degree of dispersion and of their potential contribution to the enhancement of the connectivity over the whole landscape. Visual interpretation was also used to complement the results of the spatial indices.

4. Preliminary results and remarks

A preliminary proposal for an ecological network in a subset of the study area is shown in Figure 3. This result was obtained by combining ecological index maps with subjective decision rules. Indeed, expert's opinion and judgments are fundamental for the final design of ecological networks. Nevertheless, the computation of landscape ecology indices proved to be a useful support, especially in the early procedural stages, by highlighting the main features and spatial structure of the landscape. The approach proposed in this research promotes ecologically sustainable land use planning, by explicitly including ecological criteria in the land evaluation and by suggesting ecologically suitable scenarios for land allocation. The results aim at complementing more traditional data and tools used by planning authorities for resource assessments and land allocation. Socio-economic issues, such as land demand for different uses, may also be included in the analysis, so to implement ecological networks in harmony with the needs of the local community and to contribute to the promotion of sustainable development.

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Figure 1. Location of the study area.

Figure 2. Land use map (legend was simplified for b/w representation).

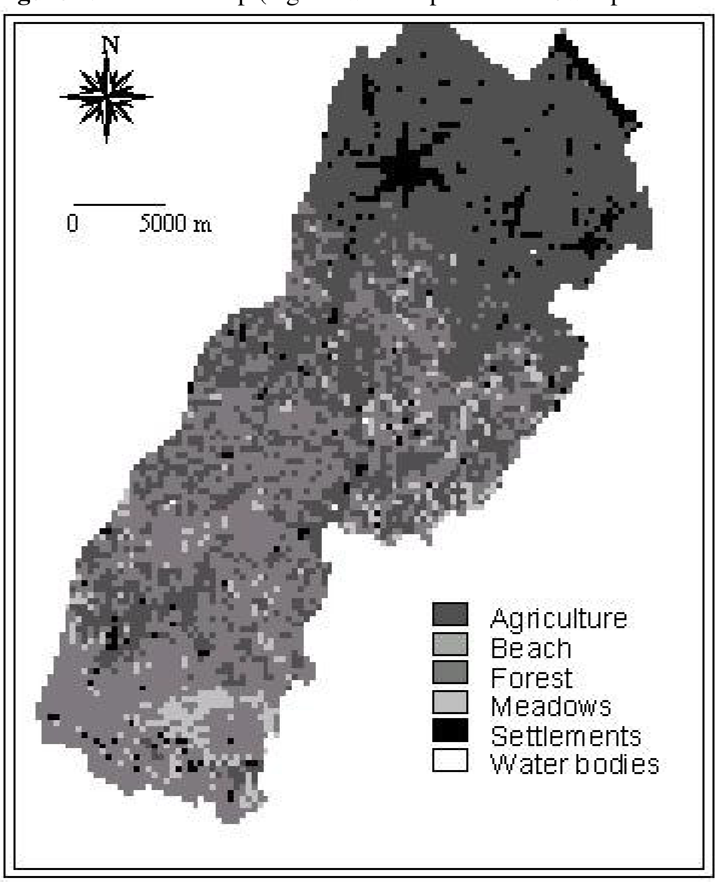

Figure 3. Preliminary ecological network in a southeastern subset of the study area.