Ecological Indicators 67 (2016) 238–249

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Habitat ecological integrity and environmental impact assessment of anthropic activities: A GIS-based fuzzy logic model for sites of high biodiversity conservation interest

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ARTICLE INFO

Article history:
Received 29 May 2015
Received in revised form 4 February 2016
Accepted 11 February 2016
Available online 25 April 2016

Keywords:
Anthropic impacts
Ecological vulnerability
Fuzzy logic
Habitat biodiversity
Landscape metrics
Principal component analysis

ABSTRACT

In literature, an effective method enabling the classification, based on a single indicator, of habitats that need a priority protection intervention has not been identified yet. Moreover, the excessive number of landscape metrics, used to quantify integrity of habitats, can cause confusion, often providing redundant and inconsistent results.

The aim of this work is to develop a method for evaluating the ecological vulnerability of the habitats in sites of high biodiversity conservation interest. In the first phase, we selected and analyzed, by using principal component analysis (PCA) and fuzzy logic, the landscape metrics, in order to obtain the map of the intrinsic ecological vulnerability index. In the second step, the result of this intrinsic vulnerability was connected, through another fuzzy model, to anthropogenic impacts, obtaining the integrated ecological vulnerability index. We developed specific spatial indicators (landscape metrics), which can examine the mutual position and morphology of the habitats present, along with indicators of human pressure, related to the type and intensity of use of the anthropic territory, with reference to the habitat itself as well as to the areas immediately adjacent. The developed fuzzy models are innovative, compared to the current ecological studies, and examine landscape metrics as well as the impact of human activities.

The case study is the "Val Basento-Ferrandina Scalo" Site of Community Importance, Ferrandina-SCI (Basilicata Region, Southern Italy). The results allowed us to build a rank of the habitats based on their intrinsic and integrated ecological vulnerability. Moreover, the results show that, in the Ferrandina-SCI, the most important source of concern is not human activities, but rather the inherent risk of ecological fragility caused by geographical and landscape features of the different patches of habitats themselves.

This model aims to be a tool for decision support in sustainable landscape management. It is easy to use and to apply on other regions, although it should always be accompanied by a sensitivity analysis to reduce the subjectivity.

1. Introduction

The planning of measures for protection and conservation of habitats in protected areas is a priority. Environmental protection is an important objective to safeguard the landscape integrity. The initial pass to protect a landscape, generally, is to quantify its integrity. This integrity can be assessed by landscape metrics that is an index, which allows you to perform structural and functional analysis of the area, defining a standard of landscape structure through the study of cartography and/or remote sensing data.

The concept of biodiversity and issues relating to the progressive reduction of biological diversity due to human activities, have become the subject of numerous international conventions from the 80s onwards. In 1992, with the Rio Convention on Biological Diversity (CBD), all member states of the European Community recognized that the conservation in situ of ecosystems and natural habitats is a priority. This convention had the purpose to anticipate and prevent the causes of significant reduction or loss of biological diversity, protecting its intrinsic value and its ecological, genetic, social, economic, scientific, educational and cultural value. All these purposes have been pursued by establishing a European ecological network known as "Natura 2000 Network", that is a network of areas of particular environmental value, elected for the conservation of biological diversity. Its aim is to ensure the long-term

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http://dx.doi.org/10.1016/j.ecolind.2016.02.038
1470-160X/

survival of the most valuable and threatened species and European habitats (Directive 92/43/EEC, Directive 79/409/EEC), by instituting SCIs (Sites of Community Interest) and SPAs (Special Protection Areas).

In the Basilicata Region (Southern Italy), 50 SCIs and 17 SPAs were identified, with a total area of 53,573 ha, which represent approximately 5.32% of the total area of the region.

The rise and expansion of human activities, combined with a constantly change in natural processes, are the main causes of fragmentation of habitats (Tomaselli et al., 2011). A fragmented habitat is potentially vulnerable and it is not adequate to guarantee biodiversity (Bascompte and Rodríguez, 2001; Brooks et al., 2002; Chust et al., 2006; Hoffmeister et al., 2005). The study of the landscape, therefore, is related to the evaluation of fragmentation and vulnerability of habitats. To this end, various types of indicators (landscape metrics), that are able to highlight critical issues and/or excellence of each habitat, have been developed in the literature. These metrics are widely used in ecology and are often calculated with the software FRAGSTAT 3.3 (McGarigal and Marks, 1995).

In recent years, landscape metrics (or landscape indices) represent a key factor for the study of landscape ecology and for spatial planning (Uuemaa et al., 2009). They are a measure and quantification of the landscape at specific scales and resolutions (Herold et al., 2003).

Numerous experiences can be found in international literature on the use of landscape metrics in various environments and at various spatial and temporal scales of application. In recent years, studies have been conducted in order to identify a specific set of landscape metrics, able to assess the status of the landscape, and guidelines to generate this set (Cushman and Mcgarigal, 2008). In fact, the most effective operation is to use the smallest number of independent metrics. Moreover, some metrics are inherently and/or empirically redundant, because they represent the same information and/or some aspects of the landscape under investigation that are correlated. Among the numerous class-level and landscape-level metrics, Cushman and Mcgarigal (2008), for example, applied principal component analysis (PCA) in order to identify independent components to be selected to evaluate the landscape structure at the class- and landscape-levels. The analysis of these metrics is often complicated. The difficulty is often observed in the interpretation of these metrics, as they are not included in a crisp numerical range. In effect, Hargis et al. (1998) studied the behavior of these metrics with an artificial landscape model that reproduces the processes of fragmentation and at the same time analyses the variations of the landscape metrics. Moreover, landscape metrics have been used to evaluate the processes of fragmentation. In some studies, for example, these indices were used to analyze the changes in land use (Di Fazio et al., 2011), by studying landscape dynamics in relation to urban and rural systems.

In literature, however, there is a lack of studies that deepen the application of methods able to integrate more indices at the same time. To this end, we defined the intrinsic and the integrated habitat vulnerability. The habitat intrinsic vulnerability integrates, with a fuzzy method, different independent landscape metrics, while the latter takes the effects of anthropogenic impacts into account as well.

Many studies aiming at the classification of environmental conditions and natural or anthropogenic changes are based on fuzzy logic. This logic, first developed by Zadeh (1965), was created as a mathematical theory able to deal with vague and imprecise data, expressed in natural language. It is now universally recognized as a robust mathematical and computer tool, able to resolve non-probabilistic uncertainty problems (Chavas, 2000). Some applications that can be found in literature are: epidemiology in medical science (Massad et al., 2003), aquifer vulnerability (Caniani et al., 2011, 2013, 2015; Gemitzi et al., 2006; Masi et al., 2012), environmental risk (Caniani et al., 2008; Sadiq, 2005; Sdao et al., 2013) and decision-making for the identification of sites for the location of landfills (CSP Ojha et al., 2007).

Usually, ecologists do not think with numbers and calculations, but with logical thoughts and linguistic expressions and often must deal with non-probabilistic uncertainty. Therefore, fuzzy logic could be very useful (Lu et al., 2012; Li et al., 2009; Tyson, 2001). In fact, literature proposes several applications in the sectors of environmental modeling, development of indices and data analysis. Silvert (2000), for example, uses fuzzy logic to establish an index of environmental conditions, in order to solve many common problems, such as uncertainty and inaccuracy. Li et al. (2009), for example, applied a fuzzy analytic hierarchy process for assessing the eco-environmental vulnerability in a reservoir area. Combining the fuzzy membership functions, maximum entropy modeling and geographical information system (GIS), Lu et al. (2012) obtained the suitable range of each factor affecting plant growth and spatial distribution of habitat suitability assessment. There is a lack, however, of studies in which fuzzy logic is used for the definition of an integrated vulnerability index based on independent landscape metrics and anthropic impacts. This kind of integrated index could be very useful for the planning of conservation and protection measures in protected areas such as the Sites of Community Importance of the "Natura 2000 Network".

Specifically, a fuzzy index allows you to capture the nuanced nature of ecosystems and its real ecological value, thanks to qualitative variables and not ordinal classes.

The aim of this study is to evaluate the ecological vulnerability of habitats. This analysis has been carried out through a specific set of landscape metrics related to fuzzy logic.

This study consists of two steps. In the first phase, we selected and analyzed, by using PCA and fuzzy logic, the landscape metrics, in order to obtain the map of intrinsic ecological vulnerability. In the second step, we determined the integrated ecological vulnerability index, by integrating the intrinsic ecological vulnerability and the impact of human activities. These models can be used as prediction tools, useful to find the most sensitive habitats that need to be protected first. This product aims to be a tool for decision support in sustainable landscape management.

2. Materials and methods

2.1. Study area

The "Val Basento-Ferrandina Scalo" Site of Community Importance (hereinafter defined 'Ferrandina-SCI') is located in the Basilicata Region (Southern Italy) and has an area of 732.94 ha (Fig. 1). Latitude and longitude in this area are 40° 31′ 21″ N and 16° 29′ 30″ E (Greenwich) respectively. The site runs across two municipalities (Ferrandina and Pomarico). Elevations range from 65 to 306 m.

The site is crossed by the Basento River, which divides the territory into two areas that are orographically and vegetatively very different. The east riverside is characterized by a discontinuous orography, with the characteristic badlands called "calanchi" (Fig. 2), while the west riverside has a flat orography.

In this SCI, we can find a good grassy and shrub cover with wild grasses and meadows polyphite (*Festuca arundinacea*, *Dactylis glomerata*, *Phleum pratense*, *Lolium multiflorum*). The riparian areas have sparse zones of black tamarisks and poplars, many brooms, esparto, with short stretches of reeds and bushes. The southern side of the badlands is more prone to erosion, and is characterized by a vegetation with a prevalence of grassy cover, salsola, thistle, etc.