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Landscape heterogeneity metrics as indicators of bird diversity: Determining the optimal spatial scales in different landscapes

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ABSTRACT

Species distribution models are often used to study the biodiversity of ecosystems. The modelling process uses a number of parameters to predict others, such as the occurrence of determinate species, population size, habitat suitability or biodiversity. It is well known that the heterogeneity of landscapes can lead to changes in species' abundance and biodiversity. However, landscape metrics depend on maps and spatial scales when it comes to undertaking a GIS analysis.

We explored the goodness of fit of several models using the metrics of landscape heterogeneity and altitude as predictors of bird diversity in different landscapes and spatial scales. Two variables were used to describe biodiversity: bird richness and trophic level diversity, both of which were obtained from a breeding bird survey by means of point counts. The relationships between biodiversity and landscape metrics were compared using multiple linear regressions. All of the analyses were repeated for 14 different spatial scales and for cultivated, forest and grassland environments to determine the optimal spatial scale for each landscape typology.

Our results revealed that the relationships between species' richness and landscape heterogeneity using 1:10,000 land cover maps were strongest when working on a spatial scale up to a radius of 125–250 m around the sampled point (circa 4.9–19.6 ha). Furthermore, the correlation between measures of landscape heterogeneity and bird diversity was greater in grasslands than in cultivated or forested areas. The multi-spatial scale approach is useful for (a) assessing the accuracy of surrogates of bird diversity in different landscapes and (b) optimizing spatial model procedures for biodiversity mapping, mainly over extensive areas.

1. Introduction

In the face of continuous global changes, understanding the way in which many factors affect biodiversity is becoming increasingly relevant (Coblentz and Riitters, 2004). The role of biodiversity is very important in the conservation of functioning ecosystems. Conservation biologists now recognize that the biodiversity issue involves more than just species' diversity or endangered species (Noss, 1990). Moreover, biodiversity can be studied in different ways taking into account species' richness (Alpha, Beta and Gamma biodiversity; Whittaker, 1977) and taxonomic, phylogenetic and functional diversity (Devictor et al., 2010). However, the study of biodiversity is particularly complex, and requires a large amount of time, a great deal of effort and significant funds. In many cases, the data on biodiversity are hard to collect, and for this reason it is very useful to have a tool, or a set of tools, with which to estimate it indirectly. One approach is to identify measurable attributes that are used as surrogates or indicators, taking them from environmental inventories, monitoring work, existing maps, and assessment programmes (Noss, 1990).

Indicators are measurable surrogates of environmental characteristics such as biodiversity. Ideally, an indicator should be: sufficiently sensitive to provide an early warning of environmental change; widely applicable; able to provide a continuous assessment over a wide range of stress factors; relatively independent of the size of the sample; easy and cost-effective to measure or collect; able to discriminate between natural cycles or trends and those that are induced by anthropogenic stress; and relevant to ecologically significant phenomena (Caro and O'Doherty, 1999; Jeffrey and Madden, 1991; Munn, 1988; Noss, 1990; Sheehan, 1984). The use of indicators should be part of a comprehensive strategy to analyze landscape quality by focusing on key habitat characteristics that include corridors, mosaics and other landscape structures, as well as species (Landres et al., 1988; Paoletti, 1999).

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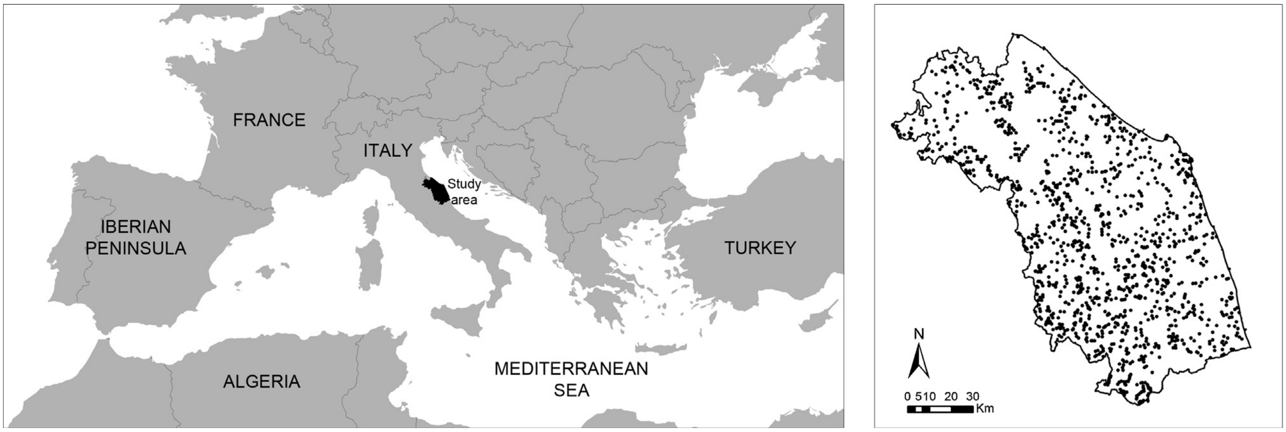

Fig. 1. Distribution of sampled sites (black dots) with the breeding bird atlas data in the Marche region, Central Italy.

Land use or landscape parameters can be used as indicators of landscape heterogeneity, and potentially as indicators of biodiversity (Lindenmayer et al., 2002). One of the possible cost-effective surrogates for obtaining appropriate ratings of spatial patterns for species' richness is provided by predictive modelling based on remote sensing and topographic data (Luoto et al., 2004). In particular, land cover metrics could be regarded as good surrogates of species' diversity because, in ecology, habitat diversity is associated with an increase in niche availability for species (Kisel et al., 2011). There is a growing body of literature demonstrating that habitat fragmentation and the heterogeneity of landscapes can lead to changes in species' abundance and biodiversity (Andrén, 1994; Fuller et al., 1997; Morelli et al., 2012; Suarez-Rubio and Thomlinson, 2009).

The opportunity to acquire tools that operate as indicators of biodiversity is very important for management policies and the conservation of habitats and species (Girardello and Morelli, 2012; Morelli et al., 2007; Tobolka et al., 2012). In order to speed up the decision-making process, and to estimate the areas with the greatest species' richness, we used environmental information that is usually obtainable from current maps. However, the use of several measures and tools is important because, as well documented in recent literature on ecological models (Noss, 1990; Hawrot and Niemi, 1996; Luoto et al., 2004; Thuiller et al., 2004), they could have different levels of predictive accuracy depending on the type of landscape, environment, thematic resolution and spatial extent of the map from which the predictors were derived (Brambilla et al., 2009; Chust et al., 2003; Debinski et al., 2001; Morris, 1987; Trani, 2002; Wiens, 1989; Wiens et al., 1993). For this reason, when modelling bird species' diversity and distribution, it is very important to determine the best spatial scale for calculating the environmental data (Cornell and Lawton, 1992; Kuczynski et al., 2010). Moreover, the quality of regional or local environmental data is always conditioned by the spatial resolution of the available maps (vegetation maps, land use and land cover maps, etc.).

In order to analyze how bird species' diversity in communities could be an expression of landscape and land use characteristics, and using bird data as response variables on different spatial scales, we studied the reliability of several of these parameters, which are often used as surrogates of biodiversity. A regional land use map was utilized in the geographic information systems (GIS) project, because it is considered to be the most common source of environmental data on a territory, while the bird data were utilized because they are largely used in the literature and are available around the world (Brown et al., 1995; Gibbons et al., 1993; Mace et al., 2010; Osborne and Tigar, 1992; Van Strien et al., 2001). Furthermore, the accuracy of each parameter and the goodness of fit of a set of modelled parameters were compared at different spatial scales to select the best spatial scale for modelling purposes.

2. Methods

2.1. Study area

The study was carried out during 2011 with the study area being the entire Marche region in Central Italy. This region covers a total surface of 9.366 km^2 (centroid: 43°23′34.63″N, 13°15′32.56″E) (Fig. 1) and is at an altitude ranging from 0 to 2.476 m a.s.l. (Mt. Vettore, Sibillini Mounts). The climate in Central Italy is temperate (Tomaselli et al., 1972) and characterized by high spring and summer temperatures and a marked summer drought. The landscape in the study area consists mainly of cultivated fields (52%), forest (20%), grasslands (10%) and other typologies (18%) (AA.VV., 2008).

2.2. Bird data

The survey of birds was performed between mid-April and the end of July 2011. Point counts (Bibby et al., 1997) were located uniformly over the entire Marche region (Fig. 1) and were at least 1000 m apart. The points were visited between 06.00 and 10.00 h for 10 min, and all of the birds detected both visually and acoustically within a radius of 100 m from the observer were recorded. Only breeding species were considered in this paper. Bird species' richness (BR) was quantified as the total number of bird species recorded per site (Gaston, 1996), because all sites were surveyed with the same sampling effort.

Other data were elaborated on by performing a calculation of the diversity of the trophic level (DTL) to provide more information about the composition of the bird communities. This parameter was used as another indicator of bird community diversity, because higher trophic levels should testify to unaltered food chains and, therefore, communities, ensuring more ecological functions (Mouysset et al., 2012; Sergio et al., 2005). Information about the trophic level for each bird species was extracted from the Complete Birds of the Western Palearctic CD-ROM v.1, 1998 (copyright Oxford University Press) and the British Trust for Ornithology (BTO) website (www.bto.org). The trophic level was classified into five categories (1 = eat vegetal; 2 = eat invertebrate; 3 = eat vegetal and invertebrate; 4 = eat vertebrate and invertebrate; and 5 = eat vegetal, invertebrate and vertebrate). Using these categories, the trophic level diversity for each sampled site was calculated by utilizing the Shannon–Weaver diversity index with the formula $H = \sum p_i \ln p_i$, where the different p_i are the proportions of the different trophic