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Landscape metrics as indicators of avian diversity and community measures

Federico Morelli*, Yanina Benedetti, Petra Šímová

Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Department of Applied Geoinformatics and Spatial Planning, Kamýcká 129, CZ-165 00 Prague 6, Czech Republic

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ABSTRACT

The identification of landscape metrics that could be used as surrogate of biodiversity is still of broad and current interest in ecology. Several landscape metrics used to provide a quantitative description of environmental structure and related to the landscape heterogeneity were proposed in ecological modelling procedures as surrogates or indicators of biodiversity metrics. Most frequently, the species occupancy in a given area is related to the niche availability, which is correlated with the spatial heterogeneity of the landscape (e.g. number of different land use patches). However, the effectiveness of biodiversity indicators (biotic indicators: e.g. species, group of species; abiotic indicators: e.g. environmental characteristics, landscape metrics) is still discussed and more efficient surrogates are needed.

In this study, we explored the associations among the most common landscape metrics and several diversity and community metrics calculated for bird assemblages in the Czech Republic. Using Generalized Linear Models, we compared the strength and direction of these associations as well as their performance in three different environments.

Overall, taxonomic diversity was explained by landscape metrics most accurately, even across different types of environments. The most effective landscape metric for bird species richness was the mean patch size, which was negatively correlated. In mixed environments, the functional evenness was positively correlated with the Simpson evenness, the reason probably lying in the fact that both are measures of the regularity of the distribution of relative abundances. Finally, the surrogacy of landscape metrics was weak in forest environments, where even the most effective predictor, the Simpson evenness was only poorly associated to diversity metrics. In this regard, we hypothesize that for modelling more accurately diversity metrics in forest environments, vertical data (e.g. vegetation structure, LiDAR) could be required. Our findings are useful for ecological modelling, enabling the selection of the most appropriate landscape metrics to predict each diversity metric.

1. Introduction

Ecological indicators are measurable surrogates of environmental characteristics such as overall biodiversity, number of species or density of populations (Burger, 2006). The concept of surrogates is applied in different disciplines of environmental sciences, based on a balance among robustness, communicability, accuracy, cost-effectiveness and good transferability of the “indicator” into praxis (Lindenmayer et al., 2015). However, effectiveness of biodiversity surrogates continues to be debated (Grantham et al., 2010; Marfil-Daza et al., 2013), and it is widely acknowledged that more efficient and reliable bioindicators are needed (e.g. Caro, 2010; Sattler et al., 2014).

The identification of landscape metrics possibly serving as surrogates of biodiversity, which could be used as bioindicators for modelling, is still a hot topic in ecology (Banks-Leite et al., 2011; Morelli et al., 2013; Schindler et al., 2015). However, recent studies have drawn attention to some additional concerns coming into light when trying to focus the association between landscape heterogeneity and biodiversity patterns: First, where the environmental features are used to estimate the landscape metrics, it’s important to take into account the spatial scale (Bar-Massada et al., 2012; Morelli et al., 2013; Moudrý and Šímová, 2012; Schindler et al., 2013). Second, different components of biodiversity (or indices used to assess biodiversity) can reflect different behaviors on the space (patterns) (Boersma et al., 2016; Carmona et al., 2012; Devictor et al., 2010; Maire et al., 2015; Morelli et al., 2017a,b), and for this reason the identification of specific mutual relationships can provide towards on the theory of indicators (specifically the use of abiotic indicators as surrogates of biodiversity or community measures) and conservation planning. Finally, we can hypothesize that associations between landscape metrics and diversity metrics can be conditioned by the type of environment where these associations are established (Morelli et al., 2018).

* Corresponding author.
E-mail address: fmorellius@gmail.com (F. Morelli).

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Numerous landscape metrics have been used to provide a quantitative description of landscape structure (McGarigal, 2015; Šímová and Gdulová, 2012; Sklenicka et al., 2014). These landscape descriptors, calculated by means of spatial data analysis (Símová, 2017), can be used to indicate biodiversity patterns at local, regional and/or global spatial scale. In fact, many landscape metrics often form an integral part of modelling procedures as predictors of the diversity on plant and animal species distribution (Flick et al., 2012; Hasui et al., 2017; Ramesh et al., 2016; Stirnemann et al., 2014; Thuiller et al., 2008). Hence, landscape metrics can be in the broad sense considered as indicators of species richness or biodiversity (O'Dea et al., 2006; Schindler et al., 2015; Stirnemann et al., 2014). The reason for that lies in the fact that at the landscape level, an environmental gradient can induce changes in the number of species or species richness (Martínez-Morales, 2005; Schindler et al., 2008). From this point of view, an excessive level of habitat fragmentation can be associated with a decrease in biodiversity (Fahrig, 2003; Schindler et al., 2008), while moderate levels can on the contrary enhance the habitat functional heterogeneity, favoring an increase in biodiversity (Benton et al., 2003; Fahrig et al., 2011). The ecological rationale behind the association between landscape metrics and diversity metrics is based on the premise that landscape heterogeneity indicates a spatial organization of features in relation both to the number of different land cover types (composition) and to their spatial arrangement (configuration). For this reason, any change in the landscape heterogeneity can be related to changes in the number of available niches for animal or vegetal species, and, as a consequence, changes of the overall biodiversity (Kisel et al., 2011).

Nonetheless, landscape changes are leaded by land use modifications, which can affect other diversity metrics than species richness. We can hypothesize for instance that some metrics of heterogeneity could be associated to the abundance of specialist species, then increasing overall functional diversity of community assemblages. For this reason it is necessary to focus on the different levels of community diversity: from taxonomic diversity, to functional and phylogenetic diversity. The species inhabiting the same area determine the species assemblage or community (Elton, 1927). However, the species compositions vary as a function of the relative abundance of each species belonging to the community, changing the overall biodiversity. Even if species richness provides one of the simplest univariate measures of community diversity (Magurran, 2004), this measure is limited by the failure to take into account the ecological role of species in communities and the different contributions they make to ecological communities (Safi et al., 2013). For this reason, an approach based on multiple indices or metrics is a better way to assess the overall diversity of a given community (Carmona et al., 2012; Guilhaumon et al., 2015; Morelli et al., 2017a). Many diversity and community metrics were proposed to be used as surrogates of biodiversity in species assemblages in terrestrial ecosystems (Laureto et al., 2015; Luck et al., 2013; Santini et al., 2016; Tucker et al., 2016). However studies focusing comprehensively on the most adequate abiotic indicators (e.g. land use composition, land cover configuration, spatial indices, etc.) of each diversity or community metric are still missing. Additionally, no systematic assessments have been addressed to recognize how these associations (surrogacy) could vary on different types of environments. Briefly, the main implications of these associations are relevant for spatial modelling, optimizing the selection of specific ecological indicators, and dealing also the type environment where associations are focused.

In this study, for the estimation of diversity and community metrics we focused on bird assemblages. The use of birds have a long tradition of studies in ecology (Gregory et al., 2003; Morelli et al., 2014, 2013; Pointereau et al., 2010). Birds present many advantages: They are widely distributed, are easy to detect, and breeding bird records are relatively easy to obtain due to the popularity of birding all over the world (Carrascal et al., 2012; Padoa-Schioppa et al., 2006). The aim of this study is to identify the most adequate landscape metrics indicators of taxonomic, functional and phylogenetic diversity of birds' communities on a fine spatial scale. We hypothesize that (i) different landscape metrics are associated to each diversity and community metric; (ii) associations between landscape metrics and diversity and community metrics vary among landscape types; (iii) the explained variance of models reflects the effectiveness of each biodiversity surrogate (landscape metrics) for each type of environment.

2. Methods

2.1. Study area and input data

The study was conducted in the western part of the Protected Landscape Area Žďárské vrchy, Czech Republic (ESM, Fig. S1). The study area (103 km^2) is a highland landscape (500–700 m a.s.l.), consisting of a mosaic of larger coniferous forests (especially spruce) and patches of agricultural land, combined with smaller patches of wet meadows, peat-bogs, trees and shrubby vegetation (groves, tree-lines, hedgerows), small fishponds and small villages (80–600 inhabitants).

We mapped the occurrence of diurnal bird species using point sampling method (Bibby et al., 1992). We noted all individual birds seen or heard in 150-m surrounding of the sampling point during 5-min periods. The sampling has been conducted between sunrise and 9:30 a.m. on days with little or no precipitation and gentle or no wind, during the high breeding season (in the longitudinal and altitudinal conditions of the study area, this means during second half of May and the first week of June). We focused bird community composition during the breeding season because this period characterizes a greater spatial stability of most bird populations, with many individual birds restricted to relatively small areas, actively defending a territory or spending much time around a nest and because the typical territorial behavior of breeding birds increase species detectability (Bibby et al., 2005). Bird point counts were selected in different landscape types with distance 300 meters between them, to avoid overlapping data. The sampling locations were chosen by the targeted selection of suitable areas covering the main types of environments focused in the study. This census method provides reliable information about the distribution and abundance of diurnal songbirds (Bibby et al., 2005). Applying this methodology, we have examined the total of 1139 points since 1999 to 2003.

The input layer for the calculation of landscape metrics were created in ArcGIS environment using a Base map of the Czech Republic at a scale of 1:10,000 acquired from the State Administration of Land Surveying and Cadastre in 2003. From this map, we created a layer consisting of 10 land cover categories: arable land, grassland, forest, forest corridor, trees, lake, stream, peat-bog, rock, road, village and garden. For each point, landscape metrics were calculated from that layer in PatchAnalyst extension for ArcGIS 10 (ESRI, 2012) using a buffer of 150 m. The percentages of arable land and forests (the two most common categories in the study area) within a 150 m buffer radius were also calculated. Sampling sites were subsequently classified according to the dominant environment: Sites were classified as arable land (or croplands) and forest where the representation of any of these land cover categories at the site was > 60% (Morelli et al., 2013). Sampling sites with mixed compositions where neither of these two land-use types reached 60%. In all, 313 sites were classified as arable lands, 422 sites as forest environments and 404 sites as mixed environments.

2.2. Landscape metrics (LM)

Following landscape metrics (computed on the landscape level) were estimated in this study (see McGarigal (2015) for detailed description):

- MPS – Mean Patch Size (mean area of landscape patches, i.e. mean area of polygons in GIS terminology),