Local versus landscape-scale effects of anthropogenic land-use on forest species richness

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ABSTRACT

The study investigated the effects of human-induced landscape patterns on species richness in forests. For 80 plots of fixed size, we measured human disturbance (categorized as urban/industrial and agricultural land areas), at 'local' and 'landscape' scale (500 m and 2500 m radius from each plot, respectively), the distance from the forest edge, and the size and shape of the woody patch. By using GLM, we analyzed the effects of disturbance and patch-based measures on both total species richness and the richness of a group of specialist species (i.e. the 'ancient forest species'), representing more specific forest features. Patterns of local species richness were sensitive to the structure and composition of the surrounding landscape. Among the landscape components taken into account, urban/industrial land areas turned out as the most threatening factor for both total species richness and the richness of the ancient forest species. However, the best models evidenced a different intensity of the response to the same disturbance category as well as a different pool of significant variables for the two groups of species. The use of groups of species, such as the ancient forest species pool, that are functionally related and have similar ecological requirements, may represent an effective solution for monitoring forest dynamics under the effects of external factors. The approach of relating local assessment of species richness, and in particular of the ancient forest species pool, to land-use patterns may play an important role for the science-policy interface by supporting and strengthening conservation and regional planning decision making.

1. Introduction

Forest ecosystems are considered among the most important global repositories of terrestrial biodiversity (Liang et al., 2016). Forests contribute more than any other terrestrial ecosystems to climate relevant cycles and processes, at local, national, and global level. Forests also provide essential ecosystem services, like carbon storage, hydrological protection, air and water purification, improvement of urban and peri-urban living conditions and amenity values such as aesthetic enjoyment and recreation (Costanza et al., 1997; Pearce, 2001). Despite substantial efforts to support the preservation and sustainable use of forest biodiversity, in many industrialized countries, forests are often isolated patches embedded in an anthropogenic matrix, mostly represented by agricultural and built-up areas, which are the dominant elements of the landscape. Anthropogenic activities, such as agriculture, industry and urbanization, have been recognized as major drivers of biodiversity loss worldwide, exerting profound effects on the structure and function of remnant natural ecosystems (Del Vecchio et al., 2015; Guirado et al., 2006; Lindenmayer and Likens, 2011; Matson et al., 1997; Millennium Ecosystem Assessment, 2005; Newbold et al., 2015; Tilman et al., 2001).

Human-induced landscape-level transformations directly affect forest ecosystems by reducing available space for their development and permanence, and fragmenting the remnant patches (Amici et al., 2015; Liu et al., 2003). Due to the adjacency of non-forest habitats, fragmentation has also indirect effects, such as changes in light availability (Cayuela et al., 2009) or wind influences (Svensson et al., 2010). Both direct and indirect effects lead to environmental deterioration and decreased habitat quality (Kinzig and Grove, 2001; Wei and Hoganson, 2005).

In recent decades, several studies have identified such spatial attributes of landscape elements as their size, shape, and extent as influencing population processes and the richness and composition of assemblages (Fischer and Lindenmayer, 2007; McKinney, 2008; Steffan-Dewenter and Tscharntke, 2000). Species richness, in particular, has been repeatedly linked to the spatial characteristics of ecosystems and has proved to be particularly sensitive to the influence of human land-use (Jentsch et al., 2012; McKinney, 2008), thereby being identified as an essential tool for biodiversity monitoring (Bitencourt et al., 2016; Del Vecchio et al., 2016; Janišová, 2014).

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One problem that arises in such research is the scale dependence of both diversity and disturbance, namely they can depend on the scales at which they are sampled. The striking role of the scale has been well recognized, becoming one of the unifying concepts in ecology (Van Dobben and Lowe-McDonnel, 1975; Wiens, 1989), concerning all organizational levels (from individuals to ecosystems). It represents a primary issue in the interpretation of environmental heterogeneity (Battisti and Fanelli, 2015; Levin, 1992; O'Neill et al., 1991), since different patterns can be revealed by different spatial scales of observation (Hanke et al., 2014). Moreover, such habitat properties as composition and structure may arise from the interaction of both coarse landscape- and fine local-scale filters (Buffa et al., 2007; Dale, 1999; Gigante et al., 2016b; Lortie et al., 2004), i.e. in addition to local physical and biotic factors, the response of a population to disturbance can also be influenced by larger-scale phenomena (Hanski, 1998). Thus, although no preferred scale exists (Levin, 1992), the scale at which environmental patterns are quantified influences the result (Turner et al., 2001; Wiens, 1989; Wu, 2004) and inappropriate scales may fail in detecting patterns (Li and Wu, 2004).

However, several studies evidence that the importance of environmental, external factors strongly differs not only across spatial scales but also among taxonomic groups (Laurance et al., 2002; Polyakova et al., 2016; Turtureanu et al., 2014). Dauber et al. (2003) further suggested that species richness patterns of different species groups are often not correlated and their dependence on the landscape pattern varies among groups. These studies consistently indicate that environmental changes both at local and landscape scales do not affect all species and taxa equally, but the effects depend on species traits. Arguably, different groups of species can respond in a different way to a given event, or respond to different events or to different intensities of the same event. Especially for species which do not possess evolutionary adaptations enabling them to cope with large scale disturbance, anthropogenic changes may have a much more dramatic effect relative to other species (Honnay et al., 2005). As for forest ecosystems, species such as forest floor plant species, and in particular the ancient forest species, suffer increased extinction probability compared to other forest species, due to their biological and ecological characteristics. Their common features are slow growth, long life-cycle, stress tolerant strategy, early and short flowering, a strong vocation for vegetative propagation, heavy seeds and transient seed bank (Verheyen et al., 2003), limited dispersal power in space and low colonization ability (Buffa and Villani, 2012). Being restricted to a narrow range of ecological requirements, ancient forest species are highly specialized, i.e. species strictly associated with the interior, more protected and undisturbed part of a forest (Hermy, 1994), and therefore indicative of more original forest conditions (Peterken, 1974). Ancient forest species thus meet qualitative (forest quality) as well as quantitative (diversity) conservation criteria (Hermy et al., 1999). Specialist species define the habitat identity, and have a prominent role in assuring the maintenance of its structure and functionality (Del Vecchio et al., 2016; Fantinato et al., 2016; Godefroid and Koedam, 2003). This is particularly important since their extinction may have consequences on the whole ecosystem, leading to ecosystems collapse (Keith et al., 2013), even if the number of specialist species is usually small compared to the total number of species in a habitat. Since specialist species are experiencing higher extinction risk relative to generalist species (Buffa and Villani, 2012; Clavel et al., 2011; Fantinato et al., 2017; Rooney et al., 2004; Slaviero et al., 2016), their presence can be used as a synthetic indicator of the status of a habitat, or fine-filter surrogate species which represent more specific habitat features (Jones et al., 2016; Rodrigues and Brooks, 2007). If attentively selected, specialist species can thus be more effective in describing the relationship between disturbance patterns and biodiversity than the use of total species richness.

Aim of the present paper was to investigate the effects of human-induced landscape patterns on species richness in forests. In particular, we analyzed the trends of total species richness and the richness of the ancient forest species pool and tested if total species richness and the richness of the ancient forest species pool respond in a different way to the disturbance generated by human activities. To evaluate the relationship between local plant species richness and landscape variables, while taking into account the effects of changing extent, we measured human disturbance at two spatial scales, at 'local' (500 m radius from the central point of each plot) and at 'landscape' scale (2500 m radius).

2. Methods

2.1. Study area

The study was conducted in the hilly sector of the Veneto Region (north-eastern Italy). The study area is a historically cultivated landscape, where human activities created a complex landscape where ecological, socioeconomic, and cultural patterns governed the presence, distribution, and abundance of wild species assemblages. Over the last 40 years, the human component has been increasingly dominating in space and time, and the area has faced dramatic land-use changes which include the conversion of complex natural ecosystems to simplified managed ecosystems, and the intensification of resource use, leading to the loss of biodiversity in pristine habitats and traditional, low-intensity agro-ecosystems. New disturbance regimes have transformed the traditional landscape, which is nowadays dominated by land-uses such as cereal cropping, vineyards, horticulture, and tree plantations. Natural and semi-natural habitats such as forests, grasslands and hedgerows, are interspersed with human settlements, roads, and trenches, making the landscape increasingly prone to the risks of rapid biological impoverishment. The remnant forest vegetation is mainly composed of mesophilous broad-leaved deciduous oak forest communities. The tree layer is dominated by *Quercus robur* L., *Q. cerris* L., *Fraxinus ornus* L., *Acer campestre* L., and *Carpinus betulus* L.. Locally, termophilous deciduous woods dominated by *Q. pubescens* Willd., and meso-hygrophilous deciduous forests dominated by *Alnus* spp. can also be found. Other traditional rural landscape components are mesophilous and dry grasslands.

2.2. Data collection

To allow inference about how landscape composition, i.e. the types of different land-uses and their relative proportion, influences species richness and composition in forest remnants, we surveyed 80 georeferenced plots with a fixed surface (8 × 8 m). A preliminary forest stand stratification was conducted according to elevation range (from 100 to 300 m a.s.l.) and bedrock types (neutro-basic limestone) which allowed the identification of 59 patches of mesophilous broad-leaved deciduous oak forest communities, with patch surface ranging from 0.08 to 350 ha. In order to achieve a homogenous and proportional distribution of the plots within the patches, we randomly created 80 points (function "*Create Random Points*" in ArcGIS 9.3), specifying a minimum of 1and a maximum of 5 points per patch (see Appendix 1).

In each plot, all vascular plant species in each vertical layer were recorded.

For each plot we calculated total species richness and the richness of ancient forest species. Ancient forest species, characterizing the herb layer, were defined according to a previous study by Buffa and Villani (2012), in which they have been identified based on life history traits such as morphology (life form), life-cycle, floral and reproductive biology (type of reproduction – vegetative, sexual or both, pollen vector, dispersal mode), and ecological strategy (Grime, 1979; Pierce et al., 2017). Ancient forest species of studied forests have some common traits, such as a strong vocation for vegetative reproduction and ants as preferential dispersal agent. They occupy two different temporal and spatial niches: nearly 50% are small spring geophytes, CSR strategists, with entomophilous pollination (e.g. *Anemone* sp.pl., *Cardamine bulbifera* (L.) Crantz, *Lathyrus vernus* (L.) Bernh., *Polygonatum*