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Hierarchic species–area relationships and the management of forest habitat islands in intensive farmland

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ABSTRACT

Habitat loss and fragmentation due to land use changes are major threats to biodiversity in forest ecosystems, and they are expected to have important impacts on many taxa and at various spatial scales.

Species richness and area relationships (SARs) have been used to assess species diversity patterns and drivers, and thereby in the establishment of conservation and management strategies. Here we propose a hierarchical approach to achieve deeper insights on SARs in small forest islets in intensive farmland and to address the impacts of decreasing naturalness on such relationships.

In the intensive dairy landscapes of Northwest Portugal, where small forest stands (dominated by pines, eucalypts or both) represent semi-natural habitat islands, 50 small forest stands were selected and surveyed for vascular plant diversity. A hierarchical analytical framework was devised to determine species richness and inter- and intra-patch SARs for the whole set of forest patches (general patterns) and for each type of forest (specific patterns). Differences in SARs for distinct groups were also tested by considering subsets of species (native, alien, woody, and herbaceous).

Overall, values for species richness were confirmed to be different between forest patches exhibiting different levels of naturalness. Whereas higher values of plant diversity were found in pine stands, higher values for alien species were observed in eucalypt stands. Total area of forest (inter-patch SAR) was found not to have a significant impact on species richness for any of the targeted groups of species. However, significant intra-patch SARs were obtained for all groups of species and forest types.

A hierarchical approach was successfully applied to scrutinise SARs along a gradient of forest naturalness in intensively managed landscapes. Dominant canopy tree and management intensity were found to reflect differently on distinct species groups as well as to compensate for increasing stand area, buffering SARs among patches, but not within patches. Thus, the maintenance of small semi-natural patches dominated by pines, under extensive practices of forest management, will promote native plant diversity while at the same time contributing to limit the expansion of problematic alien invasive species.

1. Introduction

Forests have been acknowledged worldwide as essential providers of valuable ecosystem services, from habitat for biodiversity to provision of economic goods (Magura et al., 2008; Proença et al., 2010). The provision of such services is known to be dependent of the high diversity of living organisms inhabiting forest ecosystems (Benayas et al., 2008; Proença et al., 2010). Even so, biodiversity is declining at rapid rates, with the loss of habitat through land-use change, the expansion of alien species, direct exploitation e.g. through hunting and trade, climate change, and pollution identified as major causes (Sala et al., 2000; Trisorio et al., 2010).

Distinct scales of influence have been related to the drivers of change in forest biodiversity patterns, with climate driving changes over large areas (Laughlin et al., 2011), human activities impacting on diversity patterns in intensively managed regions, and land-use and landscape heterogeneity influencing those patterns in local, finer grained contexts (Cayuela et al., 2006). Forest ecosystems have particularly been under the threat of land-use conversion and landscape fragmentation (Bengtsson et al., 2000; Guirado et al., 2007; Trisorio et al., 2010). Effects of habitat fragmentation have been documented for many taxa and at various spatial scales (e.g. Golden and Crist, 1999; Ewers and Didham,

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2006; Gonzalez et al., 2010; Trisorio et al., 2010; Rodríguez-Loinaz et al., 2012). Habitat fragmentation implies not only the pure loss of habitat, but also the reduction in size of the remnant habitat patches and their increasing spatial isolation, and it has been recognised as one of the most important threats to biodiversity, due to its effects on population viability, dispersal, and long-term persistence of species (Ewers and Didham, 2006; Gonzalez et al., 2010; Trisorio et al., 2010; Jamoneau et al., 2011).

Shifts in the way forests have been managed have been related to a decrease in the colonisation ability of plant species in isolated habitat fragments (Godefroid and Koedam, 2003b). Since many forests are intensively managed (Bengtsson et al., 2000; Godefroid and Koedam, 2003b; Proença et al., 2010) and, to a large extent, have been transformed into mono-cultural plantations of exotic species (Magura et al., 2008), a decrease of species richness and structural diversity in forest habitats has been observed (e.g. see Godefroid and Koedam, 2003a; Proença et al., 2010; Lomba et al., 2011).

The analysis of species richness and area relationships (SARs) has been stressed as a promising tool for the assessment of species diversity patterns (Tjørve, 2009, 2012). Highly applicable in the establishment of biodiversity conservation priorities and management programs (e.g. see Lawesson et al., 1998; Wang et al., 2011), SARs seem to be especially useful in the case of highly fragmented and disturbed landscapes where many smaller and few larger landscape units are characteristic (Lawesson et al., 1998; Pereira and Daily, 2006). In such context, in order to understand the capacity of habitats to conserve species diversity, many studies have used SARs to evaluate the effect of patch size on species richness in habitat fragments (Honnay et al., 1999; Godefroid and Koedam, 2003b; Gonzalez et al., 2010). Whilst the role of area in species conservation still remains controversial (e.g. see Godefroid and Koedam, 2003a), the benefit of having a number of smaller areas for conservation of plant species has been an accepted rule (Godefroid and Koedam, 2003b). In such context, relations between plant diversity in isolated patches and patch area (e.g. Zschokke et al., 2000) have been addressed, and different relationships have been observed for distinct species groups, including birds (Magura et al., 2008), plants (Kiviniemi and Eriksson, 2002; Rodríguez-Loinaz et al., 2012), woodland plant species and ancient forest species (Godefroid and Koedam, 2003b). The complementarity among species strategies (life forms; Morgan et al., 2011), their biogeographic history (Turner and Tjørve, 2005), habitat heterogeneity (e.g. related to urbanisation; Godefroid and Koedam, 2003b), origin and management (habitat diversity; Lawesson et al., 1998) have been referred as possible determinants of such differential responses.

Land management related to intensive dairy agriculture in lowland of the Northwest of Portugal has produced landscape mosaics composed of disperse settlements and small forest patches scattered throughout an intensive cropland matrix (Lomba et al., 2011). Traditionally dominated by maritime-pine (*Pinus pinaster* Ait.), and functionally coupled with agriculture (e.g. see Fangueiro et al., 2008), these patches have lost most of their economic and cultural importance, and are currently used as waste areas or have been converted to small-scale or industrial-scale forestry, with the latter being more frequent in the larger stands (Lomba et al., 2010; Mendes, 2007). Agricultural intensification and landscape fragmentation (Gonzalez et al., 2010; Lomba et al., 2010), together with an increasing density in urban and peri-urban areas (e.g. Gonzalez et al., 2010), underpin a pressing need of analytical frameworks to assess the potential of forest remnants in agricultural landscapes as refuges for regional native plant diversity (Godefroid and Koedam, 2003b; Cayuela et al., 2006; van Halder et al., 2008; Lomba et al., 2011). Such frameworks should consider the heterogeneity of conditions in forest patches which can be common at regional scales (Godefroid and Koedam, 2003b; Benayas et al., 2008; van Halder et al., 2008). Here a hierarchical approach is proposed to achieve a deeper understanding on the relationship between plant species richness and patch area (SAR) of small forest islets in intensive farmland, and to address the impacts of decreasing forest naturalness on such relationships. The proposed analytical framework consists of two major steps defined by the set of forest patches used in each analysis. The first step, corresponding to the first research question and level of analysis, focused on the assessment of regional SARs for the whole set of surveyed patches. The second step (i.e. second research question and level of analysis) dissected regional SARs within forest types (*Pinus* dominated stands, *Eucalyptus* dominated stands and mixed *Pinus* and *Eucalyptus*). Additionally, the same approach was applied to SARs of species groups according to their biogeographic origin (native *versus* alien plant species) and growth habit (herbaceous *versus* woody species). Finally, implications of the results are discussed in the context of landscape planning and management.

2. Methods

2.1. Study area

The study was conducted in the "Entre-Douro-e-Minho" Dairy Farming Region, part of the highly urbanised Metropolitan Area of Porto, in the Northwest of Portugal (8°48′–8°18″W, 41°39′–41°10″N; Fig. 1). In this intensive farming area, elevation ranges from sea-level along the coast to ca. 500 m, mean annual temperature ranges from 13 to ca. 15 °C, and mean annual precipitation shows a west-east gradient from 1160 to 1458 mm. Dominant bedrock types are granite and schist, both generating acid, nutrient poor soils, with sandy soils occurring along the coast and alluvial soils in narrow strips along main rivers. This area is quite homogeneous in terms of climate, geology and topography, and so it was considered suitable to address the effects of spatial and structural features on the patterns of biodiversity in forest stands (Lomba et al., 2011).

Due to high levels of urbanisation and intensive agricultural practices (Lomba et al., 2011), the current landscape of the study area is a highly simplified mosaic, in which large annual crop stands devoted to forage production are dominant. Since urban expansion coexists with intensive dairy farming practices, frequent changes in land use occur. Patterns of land cover and the associated land use are influenced by local terrain morphology, with intensive dairy farming mostly located in valleys and on gentle slopes where suitable soils are more frequent, and industrial forestry mainly of *Eucalyptus globulus* Labill. (exotic) and *P. pinaster* Aiton (native but mostly planted), developed on slopes with drier, nutrient-poor soils. Whereas the larger forest stands are usually dominated by *Eucalyptus* and are always devoted to industrial exploitation, the smaller forest fragments (which can be dominated by *Eucalyptus* and/or *Pinus*) are found scattered within the agricultural landscape, typically surrounded by forage annual crops.

In these landscape mosaics, small forest stands were historically used as complementary to dairy agricultural practices, as sources of fuel or heath for cattle bedding; more recently, they are often used as excess manure deposition areas (Mendes, 2007; Lomba et al., 2010, 2011). In recent decades, with external inputs of synthetic fertilizers, forest patches have lost most of their economic and cultural importance, and they are currently used as waste areas or have been converted to small-scale industrial forestry based on the exotic blue-gum tree (*E. globulus* Labill.) (Mendes, 2007; Lomba et al., 2011). Eucalypt stands in the study area are always related to intensive wood production for the pulp industry. They are considered profitable regardless of their size and provided that they are managed by land owners (e.g. to promote the growth