



## Landscape structure effects on forest plant diversity at local scale: Exploring the role of spatial extent



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### ABSTRACT

Since landscape attributes show different patterns at different spatial extents, it is fundamental to identify how the relation between landscape structure and plant species diversity at local scale varies with scale. Then, it is fundamental to assess the appropriate extent at which landscape factors affect plant species richness at the local scale. To investigate this relation, data on plant species richness of forest communities at plot scale were extracted from a large data set and landscape metrics were calculated around the same plots for a range of extents (250–3000 m). Then, multiple regression models and variance partitioning techniques were applied to assess the amount of variance explained by the landscape metrics on plant species richness for a range of extents. In general, we found that increasing extent of the surrounding landscape analyzed, improved the strength of relationship between the landscape metrics and the properties of plant communities at plot scale. The medium-large extent was most informative as it combined a decent total variance explained with high variance explained by the pure fractions of complexity, fragmentation and disturbance and the minimum of collinearity. In conclusion, we found that it is possible and beneficial to identify a specific extent, where the redundancy in the predictor variables is minimized and the explanatory power of the pure fractions (or single groups) maximized, when examining landscape structure effects on local plant species richness.

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## 1. Introduction

Plant community composition and diversity are influenced by complex interactions of biotic and abiotic factors (Crawley, 1986). At the local or plot scale, patterns of plant diversity are traditionally explained by local factors as climate and soil, as well as disturbance regimes and competitive interactions (Tilman, 1982; Ellenberg, 1988; Doreen et al., 2005). Shifting from local to coarser spatial scales, recent advances in landscape ecology and macroecology revealed the importance of the landscape structure (Turner, 1989) on local community assemblages and diversity (Dunning et al., 1992; Hanski, 1999; Lindborg and Eriksson, 2004; Wisser and Buxton, 2008). Since ecological processes operate on a

range of spatial scales, often larger than a single study patch, spatial relationships among landscape features are certainly one of the key drivers of local diversity (Wiens, 1989; Dauber et al., 2003). Several studies have shown that the spatial arrangement of a landscape influences many ecologically relevant processes, such as the distribution of materials and nutrients or the persistence and movement of organisms (Walz, 2011), and is an important determinant of species diversity (Hernandez-Stefanoni, 2005; Kadmon and Allouche, 2007; Hannus and Von Numers, 2008).

Forest ecosystems can be particularly sensitive to landscape configuration effects on species richness and composition, as many forest species are highly specialized for the interior habitat and may feature dispersal mechanisms (or limitations) that prevent them to colonize isolated forest patches (Honnay et al., 2002; Cadenasso and Pickett, 2008; Geri et al., 2010; Amici et al., 2012). In particular, the consequences of land use and land cover changes and the integration of human and ecological factors are crucial in

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driving forest landscape dynamics of the Mediterranean region, where the interactions between the peculiar climate and an extremely long history of human exploitation (Grove and Rackham, 2001) have shaped the landscape mosaic (Naveh, 1998; Henkin et al., 2007).

It is widely recognized that discontinuities in forest cover inhibit the persistence of a core forest habitat (McGarigal et al., 2001) and this affects the functionality of the whole ecosystem as well as the preservation of forest interior specialists (Reed, 1996; Wei and Hoganson, 2005). Moreover, studies focusing on Temperate or Boreal regions of Europe and North America demonstrated that the increased fragmentation of previously continuous habitats negatively affects forest ecosystems, in terms of habitat alteration, changes in soil chemistry and water balance, species composition, species behaviour and alien species (Forman and Alexander, 1998; Trombulak and Frissell, 2000; Benítez-López et al., 2010). However, a low amount of papers explicitly dealt with the influence of landscape structure on forest diversity in the Mediterranean (Torrás et al., 2008).

The structure of a landscape, i.e. the composition and spatial arrangement of individual patches, can be described and quantified by means of a variety of indices (Uuemaa et al., 2009; Walz, 2011), that have been developed and applied within a wide range of spatial scales (e.g. McGarigal and Marks, 1995; Rescia et al., 1997; Uuemaa et al., 2009). Many studies aimed at elucidating the relationships between landscape structure and species diversity at habitat scale, demonstrated how landscape metrics could significantly support the understanding of species diversity–environment relationships (e.g. Roy et al., 1999; Collingham et al., 2000; Bar Massada et al., 2012). However, landscape and spatial pattern metrics are heavily dependent on the multi-scalar arrangement of landscape structures (e.g. Wu, 1999; Werner, 1999; Wu et al., 2000; Burnett and Blaschke, 2003; Lischke et al., 2007). Landscape metrics are known to be affected by scale, and often exhibit distinctive scaling patterns which considerably vary among metrics and habitat types (Wu et al., 2003; Wu, 2004; Bar Massada et al., 2012). Moreover, the different spatial scales at which species or communities interact with landscape structure, differentially affect key drivers of plant diversity such as vegetation dynamics (Bhar and Fahrig, 1998; Jules and Shahani, 2003; Sork and Smouse, 2006). Thus, the determinants of ecosystem processes acting at the landscape scale, such as habitat fragmentation (Franklin et al., 2002), human disturbance (Zurlini et al., 2006) and natural or human-induced complexity (Cadenasso et al., 2006), need to be analyzed at different spatial scales. The concept of scale consists of two components: grain, sometimes referred to as resolution, and extent (Turner, 1989; Wiens, 1989). Extent is the overall area encompassed by an investigation or the area included within the landscape boundary; from a statistical perspective, the spatial extent of an investigation is the area defining the parameters we wish to measure (Turner et al., 2001; Wu, 2004). Studies demonstrated the relationship between landscape structure and increasing extent and grain, allowing for exploration of general scaling relations (Wu et al., 2003). Nevertheless, aspects related to the effects of grain have been more investigated than those of extent and these latter still deserve much investigation.

The basic aim of this work is to explore the effects of changing extent in the analysis of the relationship between forest plant species richness at local scale and the surrounding landscape patterns. We expect that the effects of landscape variables on local plant species richness will change with changing extent of investigated landscape. In particular, we expect to find that increasing the extent on which the landscape metrics are calculated, will provide an increasing power in explaining local (i.e., plot-scale) species richness up to a certain threshold and then decrease again. This because wider spatial extents up to a certain

value are likely to increase the probability of including landscape features that may be effective in controlling local species diversity, e.g. barriers to plant dispersal. Our test was performed in different forest communities of a Mediterranean district, where the long-lasting human activity may result in a lower predictive power of climatic models compared to other study areas. More specifically, this study addresses the following questions: (i) what is the landscape extent at which the predictive power of the surrounding landscape structure on local plant species richness is maximized? (ii) which landscape structure metrics have the higher predictive power on plant species richness patterns at habitat scale in Mediterranean forests? (iii) what is the landscape extent at which the redundancy in the predictor variables is minimized? (iv) does the predictive power of the landscape metrics differ when considering specialized forest plants vs. open-habitat species at different spatial extents?

## 2. Materials and methods

### 2.1. Study area

The study was carried out within the Sites of Community Importance (SCIs) of the Siena Province, Central Italy (Fig. 1). The province has an area of about 3821 km<sup>2</sup> (centroid: longitude 11°26'54" E, latitude 43°10'12" N, datum WGS84). The 17 sampled SCIs range in size from 5 km<sup>2</sup> to 140 km<sup>2</sup>, and have a cumulative area of 588 km<sup>2</sup> (15.6% of the whole province). The macro-climate is Mediterranean, with significant variability due to differences in altitude, relief and other geographic factors. The dominant land-use types are represented by forests (about 78% of the area) and agricultural areas (20%). The most widespread forest vegetation types include termo-xerophyllous evergreen woods dominated by *Quercus ilex*, termophyllous deciduous woods dominated by *Q. pubescens* and *Q. cerris*, and mesophilous deciduous forests dominated by *Fagus sylvatica* or *Castanea sativa*. The network of SCIs hosts a high plant species diversity, especially due to the larger scales gradients (Chiarucci et al., 2012).

### 2.2. Floristic data and response variables

The dataset used in this study was extracted from an extensive survey of the vascular plant diversity of the whole protected area network of the Siena province (Chiarucci et al., 2008, 2012). Sampling design was based on a grid of cells of 1 km × 1 km, with one random point selected within each cell. A 10 m × 10 m plot was centred in each sampling point, once located with a high precision GPS (submeter accuracy). Each plot was divided into 16 smaller (2.5 m × 2.5 m) subplots to facilitate plant data collection. In each plot and subplot, all vascular plant species were recorded. However, the analyses in the present work are based on the presence/absence data at the plot scale only. Nomenclature and taxonomy were standardized following Pignatti (1982) and Conti et al. (2005). Details on sampling and data can be found in Chiarucci et al. (2012). All the plots which were classified as “forest” during the field survey (on the basis of tree cover exceeding 50%) were used for the present study, resulting into a dataset of 291 plots (Table 1).

The species recorded in the selected plots were classified into three groups according to their habitat as indicated by Pignatti (1982): “forest species”, i.e. species exclusive of forest habitats, “non-forest species”, i.e. species specialized for open habitats such as fields, grasslands or wood margins, and “generalist species”, i.e. species which can grow in a wide spectrum of habitats and/or those species for which a clear preference of forest habitats is not clear (Amici et al., 2013). Then, the species richness of each group

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