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Biodiversity, roads, & landscape fragmentation: Two Mediterranean cases

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A B S T R A C T

The most pervasive threats to biological diversity are directly or indirectly linked to the road networks. For this reason, over the last few decades, interest in the study of the ecological characteristics of the edges associated with roads has increased. This work aims to investigate the effect of roads as a human-induced disturbance on the plant diversity in two managed Mediterranean forest sites, focusing on the responses of plants species richness, evenness, composition and taxonomic diversity.

A stratified random sampling was performed in two protected areas located in Tuscany, Central Italy. The species richness, composition and abundance were measured in 53·20 × 20 m plots. Ordinary Least Square and quantile regressions were used to study the effect of the roads on species richness, evenness and taxonomic distinctness, and redundancy analysis was used to examine the species composition. Generalized linear models in conjunction with an *Information Criterion-based approach* to model *selection* were used to test the role of road distance in the structure of forest plant biodiversity.

Our findings indicated a clear relationship between road distance and different plant biodiversity facets, which showed its maximum effect in the first 0–20 m forest-to-road segment and a mitigation after the 200 m threshold. Furthermore, the presence and abundance of many key forest species, such as *Fagus sylvatica* and *Abies alba*, were influenced more by the road distance than by other environmental gradients. The few remnants of core forest habitats in the Mediterranean basin highlight the need to recognize that road construction and maintenance have several ecological implications and accordingly require long-term monitoring programs.

Introduction

The construction of roads represents one of the most widespread forms of natural landscape transformation (Gao & Liu, 2012; Noss & Cooperrider, 1994; Patarasuk & Binford, 2012; Van der Ree, Jaeger, van der Grift, & Clevenger, 2011). Over the last few decades, studies in a variety of terrestrial and aquatic ecosystems have demonstrated that many of the most pervasive threats to biological diversity (e.g., habitat destruction and fragmentation, edge effect, exotic species invasion, pollution, over-hunting and genetic barriers) are directly or indirectly linked to roads. As a result, interest in the study of the ecological characteristics of edges associated with transportation corridors has increased (Holderegger & Di Giulio, 2010; Jackson & Fahrig, 2011; Lapaix, Harper, & Freedman, 2012; Reed et al., 1996; Watkins, Chen, Pickens, & Brosofske, 2003).

Roads and utility corridors subdivide natural areas into "islands", causing a reduction in interior habitats over the landscape (Andrews, 1990). In addition, the proximity to roads exposes organisms to the conditions of a different surrounding ecosystem. Due to what have been termed "edge effects" (Fahrig, 1997; Hill & Curran, 2001; Murcia, 1995), the edges may affect the organisms in a fragment by causing changes in the biotic and abiotic conditions, such as species composition, temperature, moisture, light availability and wind speed (Delgado, Arroyo, Arévalo, &

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Fernández-Palacios, 2007; Flory & Clay, 2009; Parendes & Jones, 2000; Watkins et al., 2003). In particular, road edges contain few regionally rare species, have relatively high plant species richness and are generally dominated by disturbance-tolerant and exotic species (Forman & Alexander, 1998; Tyser & Worley, 1992). Moreover, roads may alter ecosystem processes and functions (e.g., productivity) on the surface, and these alterations are generally directly proportional to the roads' widths (Brothers & Spingarn, 1992; Flory & Clay, 2009).

In landscapes where almost the whole native vegetation has been removed for cultivation, natural road edges are considered valuable reservoirs of biological diversity because they may maintain a number of native-plant communities (Delgado et al., 2007; Reed et al., 1996). Instead, the disturbance linked to roads is more evident in forest habitats, with a distinctive set of major ecological effects (Forman & Alexander, 1998). In fact, discontinuities in forest cover due to roads inhibit the persistence of a core forest habitat (McGarigal, Romme, Crist, & Roworth, 2001), which is fundamental both for the functionality of the whole ecosystem and for the preservation of rare species, which need old-growth interior environmental conditions (Reed et al., 1996; Wei & Hoganson, 2005). Road expansion into forest habitats, which was principally justified by the management of forest resources, has radically changed in the last decades with the advent of mechanization (Kivinen, Moen, Berg, & Eriksson, 2010). Forest roads, although generally narrow and unpaved, are known to affect soil erosion and the sedimentation of aquatic ecosystems, vegetation and vertebrates (Donaldson & Bennett, 2004; Forman et al., 2002; Lugo & Gucinski, 2000). Road construction and maintenance have direct ecological effects on forest ecosystems, such as habitat alteration, changes in soil chemistry and water balance, increased fragmentation of formerly continuous habitats, exotic species dispersal and species behavior modifications (Benítez-López, Alkemade, & Verweij, 2010; Forman & Alexander, 1998; Forman et al., 2002; Trombulak & Frissell, 2000). Thus, roads may change forest spatial patterns by fragmenting the original habitats, interrupting horizontal natural processes and reducing the critical variability in natural processes and disturbances (Delgado et al., 2007; Forman & Alexander, 1998; Hawbaker, Radeloff, Clayton, Hammer, & Gonzalez-Abraham, 2006). Moreover, roads open linear gaps into the forest habitat, thus creating a new ecosystem with different and opposite properties compared with the forest interior (Forman & Alexander, 1998; Murcia, 1995; Trombulak & Frissell, 2000).

Roads perform crucial economic and social functions in rural systems, such as the connection between country and urban areas, forest fire control, forest management, tourism incentives and access to forest goods for country dwellers (Badia, Serra, & Modugno, 2011; Gucinski, Furniss, Ziemer, & Brookes, 2001; Patarasuk & Binford, 2012). However, they often play a key role in altering plant community composition, ecosystem processes and functions. Nevertheless, the majority of scientific literature has focused on their relationship with exotic and invasive plants (Flory & Clay, 2009; Parendes & Jones, 2000; Pauchard & Alaback, 2004; Spellerberg, 1998).

Most studies considering the effect of roads on plant diversity refer to the temperate regions of Europe and North America or to tropical regions (see, e.g., Buckley, Crow, Nauertz, & Schulz, 2003; Decocq et al., 2004; Laurance, Ferreira, Rankin-de Merona, & Laurance, 1998; Nagendra, Pareeth, & Ghate, 2006; Patarsuk &Binford, 2012), but studies in the Mediterranean region are still lacking.

The Mediterranean basin is considered a biodiversity hot spot (Médail & Quézel, 1997) that is particularly sensitive to global changes due to land use/cover changes, intense human activity and pressure, precipitation totals and extremes, and seasonal extremes of temperature (Aragón, López, & Martínez, 2010; Valladares, 2004). Currently, its conservation represents an enormous challenge to scientists and land managers (Scarascia-Mugnozza, Oswald, Piussi, & Radoglou, 2000). Habitat fragmentation, largely favored by road openings, usage, and maintenance, is considered one of the most prominent threats to Mediterranean forest biodiversity (Jordán-López, Martínez-Zavala, & Bellinfante, 2009; Riitters, Coulston, & Wickham, 2012). Therefore, an assessment of the impact of roads on the diversity of complex forest systems, such as the Mediterranean system, is urgently needed.

This paper represents one of the first attempts to evaluate the effect of roads on plant diversity in Mediterranean forests, focusing on the response of plants species richness, evenness, composition, and taxonomic diversity. The general hypothesis to be tested is that roads cause a loss in forest ecosystem integrity and, hence, in plant diversity. In addition, the role of forest roads in shaping the patterns of all used diversity metrics is expected to be different with increasing forest-to-road distances.

Under this framework, the specific goals of this work are the following: (*i*) to detect the effect of the road distance on species richness, evenness, and taxonomic distinctness, evaluating for each diversity metric the depth at which changes in the forest habitat are detectable; (*ii*) to study the role of the distance to the road in shaping species richness, evenness, and taxonomic distinctness compared with other potential environmental drivers and, (*iii*) to investigate the response of plant communities to different forest-to-road distance thresholds.

Materials and methods

Study sites

The study occurred in two Sites of Community Importance (SCI), named "Bocca Trabaria" (IT5310010) and "Foreste del Siele e Pigelleto di Piancastagnaio" (IT5190013), located in Tuscany (Central Italy, centroid coordinates: longitude 11° 26′ 54″ E, latitude 43° 10′ 12″ N, datum WGS84; Fig. 1). Their altitude ranges from 700 to 1100 m a.s.l. They host many different forest habitats, such as broadleaved oak forests, mixed broad-leaved forests, mountain conifer plantations and, beech forests. Furthermore, the two studied SCIs comprise small areas with two priority forest habitat types: Apennines beech forests with *Abies alba* (9220) and Apennines beech forests with *Taxus baccata* and *Ilex aquifolium* (9210; Habitat Directive 92/42/CEE) (Table 1).

In this work, we considered only the forest habitat area included in the SCIs, which covers approximately 85% of the Bocca Trabaria SCI and approximately 98% of the Foreste del Siele e Pigelleto di Piancastagnaio SCI (APAT, 2005, pp. 36–39). In total, the forest habitat covers 3.571 ha (Table 2). In more detail, these forest areas are dominated by willow oaks (*Quercus cerris* and *Quercus pubescens*) and copper beeches (*Fagus sylvatica*) (Table 2; APAT, 2005, pp. 36–39). These forests underwent an intense coppicing pressure in the past and are now partially abandoned in support of a naturalistic management of the woods. However, some forest portions are still coppiced to maintain a few pasturing areas.

All selected forests were bordered and crossed by numerous gravel or clay roads, sometimes large enough to be suitable for heavy vehicles. These roads were mostly used in the past for stand management purposes, and they are also used today for recreational activities. The roads have been yet to be fixed with different types of materials (in most cases, local materials) when the original substrate has eroded or slipped down. The erosion of the forest roads is more marked in the late autumn-early winter and spring periods, as the rainfalls are concentrated in these seasons. Furthermore, during the year, water drainage ditches and road verges are managed with more or less frequent clearings of vegetation to allow the water to flow and the movement of motorized