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Research Paper

Woody colonization of road embankments: A large spatial scale survey in central Spain

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HIGHLIGHTS

- Woody colonization on embankments shows a highly site-dependent pattern.
- Spontaneous succession may be an effective passive restoration tool on embankments.
- Conservation measures on the surrounding matrix are critical for roadside restoration.

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ABSTRACT

Planting of woody species is a commonly used method to restore road embankments. Given the importance of road verges as potential corridors and refuge for biodiversity, natural plant regeneration processes may also play an important role in establishing vegetation into these novel landscape elements. Most studies on woody colonization of roadsides have considered only a few sites covering a very limited environmental range. Therefore, it is unclear whether or not there are general patterns that may explain the development of woody vegetation. We analyzed woody vegetation colonization in embankments over a large and heterogeneous territory, using aerial photographs, available repositories of environmental and land management data sets and some embankment features. We addressed the following questions: (1) To what extent does the presence of planted woody plants influence patterns of natural recruitment in road embankments? and (2) What are the key factors underlying natural/passive plant colonization in road embankments? We used Multi-Model Inference (MMI) analysis to model woody vegetation cover. According to our results, woody-planted vegetation does not have a facilitating effect on natural colonization, questioning the efficiency of reforestation measures in the ecological integration of areas affected by road construction. Passive natural plant colonization occurs spontaneously in road verges and shows a highly site-dependent pattern, driven mainly by the age of embankments and the immediate surrounding vegetation. Therefore, we suggest that natural succession may be sufficiently effective as a passive restoration measure on embankments in the long term.

1. Introduction

Road verges act as a source/sink for biodiversity, and represent important connectors between habitat remnants, by providing continuous habitat linkages that aid in the dispersal of both native and exotic flora (Coulson, Spooner, Lunt, & Watson, 2013; Jodoin et al., 2008; Tikka, Högmander, & Koski, 2001; Zeng et al., 2011). At a landscape scale, they increase environmental heterogeneity and can provide refugia for restricted-range and other native species (Spooner & Smallbone, 2009; Tikka, Koski, Kivelä, & Kuitunen, 2000). This function is critical in fragmented landscapes where linear marginal lands can often harbour plant species from the surrounding areas (Corbit, Marks, & Gardescu, 1999; Schmitz, Sánchez, & de Aranzabal, 2007).

Road embankments and other areas immediately adjacent to road surfaces are newly created structures susceptible to colonization and succession (Bochet, García-Fayos, & Tormo, 2007; Jiménez et al., 2013). These areas affected by road construction (known as

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the "road effect zone"; Forman et al., 2003) can also play a key role in plant community dynamics by generating new ecological flows inwards and outwards from the road verge (Lugo & Gucinski, 2000). However, after construction, road embankments are often devoid of all vestiges of biological communities, where hydrological and geomorphological features have been greatly altered. Thus, some restoration measures are commonly applied to increase ecosystem carrying capacity.

Under Mediterranean conditions, current roadside restoration measures include topsoil spreading, hydroseeding with commercial seeds of fast-growing plant species, and in some cases, low density plantings of tree seedlings and shrubs. Although these plantings are typically performed for aesthetic purposes, this vegetation is meant to play an important role on soil stabilization and have a catalytic effect on the succession process (Singh, Raghubanshi, & Singh, 2002). Woody vegetation is a well-known landscape engineer (Jones, Lawton, & Shachak, 1994; Wilby & Shachak, 2004) acting as a facilitator for the establishment of other species by improving abiotic conditions, such as enhanced soil nutrients and water availability and microclimatic heterogeneity (Bruno, Stachowicz, & Bertness, 2003; Gómez-Aparicio et al., 2004). Moreover, woody vegetation nuclei are expected to provide local seed sources and serve as attractors of seed-dispersal vectors, increasing connectivity between different patches at the landscape scale (Rey Benayas, Bullock, & Newton, 2008). In many cases, woody species introduced in roadsides areas are often not well-adapted to the local environment that results from the interaction of Mediterranean climatic conditions and the stressful conditions derived from construction processes (Hartley, 2002). In this sense, there is great uncertainty associated with the performance of plantings in these environments, which translates into higher costs for the companies responsible for roadside maintenance and conservation.

Many studies, however, highlight the importance of promoting natural colonization from surrounding vegetation as a useful restoration measure, which is highly cost effective and also has the advantage of increasing local diversity in these human-made ecosystems (Prach & Hobbs, 2008). Spontaneous plant colonization in roadsides has been positively correlated with surrounding vegetation structure and the availability of seed sources (Bochet, García-Fayos, & Tormo, 2007). In some cases, construction and maintenance of the road (i.e., earthworks, grading) may favour the arrival of woody plants adapted to frequent disturbances (Spooner, 2005; Spooner, Lunt, Briggs, & Freudenberger, 2004). However, the steepness of the slope, the aspect and the area of the roadslopes mainly constrain the arrival and establishment of long-term viable plant communities (Cano, Navia, Amezaga, & Montalvo, 2002; Deckers, Becker, De Honnay, Hermy, & Muys, 2005). Furthermore, the age of the roadslope, described as the time elapsed since the road was constructed (García-Palacios et al., 2011), seems to be a relevant driver of plant community development (i.e., changes in plant cover and composition) in these scenarios (Olander, Scatena, & Silver, 1998; Spooner & Smallbone, 2009). However, most studies of natural succession in road verges have considered only a few sites covering a very limited geographical area (but see Deckers et al., 2005; Spooner & Smallbone, 2009). Thus, it is difficult to determine whether the results obtained reflect a general pattern or are site-dependent. Moreover, the effect of other environmental factors operating at larger scales such as land use, lithology or climate, have not been previously explored in these environments. The effects of both regional and local factors and corresponding patterns can only be assessed by considering many sampling points distributed over a vast territory (Lugo & Gucinski, 2000; Novák & Prach, 2003; Prach, Pysek, & Jarosík, 2007).

During the last few decades, great effort has been devoted to build up a restoration ecology paradigm (Choi, 2007). However, its complete scope and universality is constrained by the lack of studies conducted across large temporal and spatial scales (Manning, Lindenmayer, & Fischer, 2006; Novák & Prach, 2003; Parker, 1997). Recognizing general patterns and processes involved in the colonization of road verges is highly demanding in so far as regeneration of native woody species can be considered a surrogate of restoration success (Prach & Hobbs, 2008). Moreover, understanding the factors affecting roadside vegetation dynamics at larger scales would shed light on the ecosystem services derived by these habitats (e.g., biological corridors and refuge of biodiversity) and lead to restoration measures. With this in mind, the aim of this study was to investigate patterns of woody vegetation establishment in road verges over a large and environmentally heterogeneous territory. Our working hypothesis is that landscape configuration and seed source patterns are critical (even more than tree-plantings) in the spontaneous recovery of woody vegetation in road verges. Specifically, we addressed the following questions: (a) To what extent does the presence of planted woody plants influence patterns of natural recruitment in road verges? and (b) What are the key factors (site, large scale) that influence the recruitment of woody plants in road verges? We modelled the performance of woody vegetation by Multi-Model Inference (MMI) and a complete set of predictors taken across local and regional scales (aerial photographs, available repositories of environmental and land management data sets and local features).

2. Materials and methods

2.1. Study area

We conducted the study on the motorway and highway network in the region of Madrid, Spain, covering an area of 8022 km^2. This network has an approximate length of 800 km, spanning an altitudinal range from 430 m a.s.l. at the Tajo River Valley, to 1430 m a.s.l. at the Guadarrama Sierra. The climate is mostly continental Mediterranean with mesoclimatic variations associated with altitude. The mean annual temperature along the road network varies between 8.9 °C and 14.5 °C and mean annual rainfall ranges from 389 to 822 mm (Ninyerola, Pons, & Roure, 2005). This large territory covers two major lithographic and geographic areas: a mountain area and its ramp, formed by acid rocks (granites, gneisses and arkoses); and moors and countryside areas, mainly dominated by basic materials (limestone, gypsum and marls). Approximately two-thirds of the studied road network has been constructed on a basic substrate. Climate, topography and human activities have contributed to landscape heterogeneity by introducing a wide variety of vegetation types: forests (e.g., Scots pines, holm oaks, Pyrenean oaks), scrublands, grasslands and crops.

2.2. Site inventory

Among the different components of road verges, we focused on embankments because they provide a more favourable testing ground for colonization processes as they are isolated patches, spatially well-defined and devoid of vegetation after construction. We identified and characterized the embankments with aerial photographs taken in 2009 by the Aerial Orthophotography National Plan of the National Geographic Institute of Spain (2011). We preselected all road embankments with at least a 6 m width. From this first set of sites, we discarded poorly defined roadfills as well as metropolitan embankments. Ultimately, we retained 351 sites (Fig. 1).

Embankments were polygonized and characterized at different scales by measuring a complete set of variables (Table 1) with ArcGIS 9.3 (ESRI, 2011). The complete list included the geographical coordinates (*X* and *Y* centroids), aspect, area and perimeter of the