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Dominant plant species modulate responses to hydroseeding, irrigation and fertilization during the restoration of semiarid motorway slopes

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ABSTRACT

Restoring roadside slopes in semiarid regions of the Mediterranean Basin is often constrained by the difficulties arising when developing restoration projects (absence of nearby natural ecosystems serving as reference sites and slow natural colonization) and by the contradictions found between short-term (reduce soil erosion) and long-term (increase plant diversity) restoration goals. Restoration techniques developed in temperate climates are commonly applied in these regions without taking into account their specific characteristics; as a consequence, they often fail. We evaluated the effectiveness of three treatments widely used by practitioners (hydroseeding, fertilization and irrigation) to foster community composition changes that control soil erosion and increase species diversity (restoration goals) during the restoration of motorway embankments. The study was carried out during an 18-month period in five embankments from semiarid central Spain. The most outstanding result was that responses of the plant community to the treatments evaluated were site-specific. Several fast-growing dominant species, some hydroseeded and some already present in the study sites, were responsible for this idiosyncratic variation between sites. On embankments, where plant cover can easily reach values high enough to prevent erosion, the use of non-native herbs that can potentially dominate the community should be avoided. These fast-growing species, although effective as starters the first years following motorway building, can constrain vegetation dynamics in the long term. Our results indicate that these species should be controlled in the field, and their presence avoided in the commercial seed mixtures when the target is to enhance biodiversity and ecosystem stability and resilience.

1. Introduction

Roads are one of the human constructions causing a major environmental impact (Briggs and Giordano, 1992). The adjacent slopes created or transformed after road building are abundant habitats worldwide (Valladares et al., 2008). Despite the abundance and environmental impacts that these constructions promote, there is a lack of basic information on the ecology of the degraded lands resulting from motorway construction (Bradshaw and Huttl, 2001), as well as on the best strategies to restore them (Matesanz et al., 2006). However, designing projects to restore roadside slopes in semiarid areas of the Mediterranean Basin is not an easy task. First of all, these environments have been intensively transformed by humans for centuries (Naveh and Dan, 1973), making it difficult to select a nearby natural ecosystem as a reference site (Hobbs et al., 2006). Secondly, the slow colonization of these slopes by natural vegetation is seriously conditioned by water availability (García-Fayos et al., 2000), the lack of propagules (Tormo et al., 2007) and the adverse climatic and soil conditions (Bochet and García-Fayos, 2004) characterizing these environments. In addition, there are apparent contradictions between the achievement of short-term (e.g., controlling soil erosion, Andrés et al., 1996) and long-term (e.g., increasing plant diversity to enhance ecosystem resilience to future environmental conditions and disturbances, Hooper et al., 2005) restoration goals.

The existence of widespread landscape transformations like extensive agriculture, introduction of non-native species (Blondel and Aronson, 1995) or wildfire incidence (Pausas, 2004) can complicate the selection of the reference site that could serve as

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a model for planning a restoration project (SER, 2004). Moreover, ongoing environmental changes and the increasing prevalent anthropogenic disturbance may result in novel ecosystems whose composition and/or function differ from any historical system (Jackson and Hobbs, 2009). Thus, little is known about the factors controlling ecosystem functioning in this potentially new successional context, as well as about the suitability of widely used restoration treatments for the recovery of vegetation in these novel ecosystems (Matesanz et al., 2006). In these cases, key questions to be answered are which restoration goals must be set and what is the baseline for comparisons and reference. Recovering ecosystem services and promoting ecosystem functioning could be an appropriate restoration objective (Hobbs et al., 2006) and a critical aspect in disturbed Mediterranean environments (Méndez et al., 2008). There is consensus that diversity is essential for maintaining ecosystem functioning and the stability of ecosystem processes in human-dominated and fast-changing environments (Loreau et al., 2001). Therefore, promoting shifts in community composition that increase species diversity at short-time scales seems a reasonable strategy to restore degraded ecosystems when reference sites are not available.

The colonization of semiarid motorway slopes by natural vegetation is typically very slow (Bochet and García-Fayos, 2004). This process is restricted by low water availability levels (García-Fayos et al., 2000), lack of propagules due to the prevalence of inefficient dispersal based on mixospermy and even atelechory (Tormo et al., 2007), and by the adverse climatic and soil conditions found for most commercial seed mixtures in many restoration sites (Bochet and García-Fayos, 2004). The stabilization of slopes and the control of soil erosion through the establishment of a dense herbaceous cover is a priority in the restoration of recently built roadside slopes (Andrés et al., 1996). Hydroseeding is widely used for this purpose in temperate climates (Sheldon and Bradshaw, 1997) and has also become very popular in semiarid Mediterranean areas to restore roadside slopes (Andrés et al., 1996; Albaladejo et al., 2000; Matesanz et al., 2006; Tormo et al., 2007). The commercial hydroseeding mixtures are mainly composed by highly competitive forage grass and legume species non-native to these areas (Martínez-Ruiz et al., 2007; Tormo et al., 2007). However, in many cases, this technique renders poor results in terms of species richness and aboveground biomass (Matesanz et al., 2006), and therefore leads to poor protection from soil erosion (Andrés et al., 1996; Tormo et al., 2007).

Numerous studies have investigated the effects of resource availability over entire plant communities (Fransen, 1998; Cahill, 1999), but few of these studies have been conducted on motorway slopes (Holmes, 2001; Paschke et al., 2000). Furthermore, it has been shown that interactions between the availability of water and nutrients can largely determine the response of herbaceous assemblages (Maestre and Reynolds, 2007). Although fertilization and irrigation often increase herbaceous productivity in the short term (Hooper et al., 2005), they can also prevent long-term vegetation development because of competition with spontaneous colonizers (Holl, 2002). Atmospheric fertilization is more marked in novel ecosystems such as roadside slopes, where N deposition from vehicle emissions represents an important N input to the system (Cape et al., 2004). However, the contribution of hydroseeding, and its joint effects with the increase in soil resources (water and nutrients), to the trade-off between the first step of establishing a dense herbaceous cover that controls soil erosion (Petersen et al., 2004) and the second step of facilitating the establishment of late-successional species is still controversial (Martínez-Ruiz et al., 2007). Therefore, it is necessary to evaluate the potential of these costly techniques and their interactions for restoring semiarid motorway slopes.

In this article, we experimentally evaluated the effects of both hydroseeding and simultaneous changes in the availability of water (irrigation) and nutrients (fertilization) on the restoration of vegetation in degraded motorway slopes. We did this in different motorway embankments located in Central Spain. We considered plant cover and soil erosion as surrogates of slope stability (Norris et al., 2008) and plant diversity and community composition as surrogates of ecological restoration success (Pywell et al., 2002; Smith et al., 2003). As responses are likely to be context dependent in roadside slopes such as studied (Matesanz et al., 2006), we have selected several similar sites sharing a similar climate and construction characteristics. This multi-site approach allows the evaluation of the benefits and generality of the experimental treatments applied, adding further value to this study.

2. Methods

2.1. Study area

The study area is located in the R4 and AP36 motorways, between Pinto (Madrid; 40°14′N, 3°43′W) and Corral de Almaguer (Toledo; 39°45′N, 3°03′W), in the centre of the Iberian Peninsula (altitude *c.* 700 m a.s.l.). The climate is semiarid, with cold winters and a severe summer drought. The mean temperature and precipitation is 15 °C and 450 mm, respectively (Getafe Air Base climatic station 40°18′N, 3°44′W, 710 m.a.s.l., 1971–2000). A meteorological station (Onset, Pocasset, MA, USA) was located in the AP36 motorway to get a more detailed description of the local climatic conditions during the study.

In order to homogenize the slope selection, and to minimize main sources of variation when restoring semiarid roadside slopes (Matesanz et al., 2006), we selected five sites of similar slope type (embankments) and size (greater than 15 m long from top to bottom of the slope and 30 m wide), slope aspect (south) and inclination (between 20 and 30°). Three and two of these sites were located in the R4 (sites 1–3) and AP36 (sites 4 and 5) motorways, respectively. The five sites have poor and alkaline soils with low water holding capacity, but differ in their soil type and construction age (Table 1). The artificial soils of these embankments are constructed using local parent material, gravels and components from external sources that are stored for a while before motorway building (Forman et al., 2003; confirmed by information provided by the motorway builder). In fact, substrate differences between sites are not linked with soil type, but probably caused by the heterogeneity of materials used for embankment construction. Therefore, potential differences in restoration treatment effectiveness between the two motorways studied are not expected to be related with their soil types.

2.2. Experimental design

Three restoration treatments (hydroseeding [HS], fertilization [Fe] and irrigation [Ir]) were evaluated in this study. The full experiment included five different factors (HS, Fe, Ir, block and site). Six blocks containing 12 1 m × 1 m plots per block, with at least 1 m buffer between plots, were randomly established at each of the five sites (Fig. 1). Each block contained a full factorial design with the three treatments employed (HS, Fe and I), which were randomly assigned to the plots within each block and site.

We added three HS levels (control, seeding and seeding + mulch) during December 2006. The control and seeding addition levels consisted of no seeding addition and the application of a commercial seed mixture (Zulueta Corp., La Rioja, Spain; dose of 30 g/m^2; Table 2), respectively. The seed mixture and seed application rate