Early Dynamics of Plant Communities on Revegetated Motorway Slopes from Southern Spain: Is Hydroseeding Always Needed?

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Abstract

The increasing global rate of road construction is leading to a parallel increase of areas of degraded soil conditions and steep slopes that need revegetation. Hydroseeding with commercial seeds of fast-growing grasses and legumes is a common practice in revegetation of motorway slopes. We carried out 3 years of monitoring of vegetation dynamics on hydroseeded and nonhydroseeded motorway slopes (48 slopes) in a maritime Mediterranean zone in Málaga (southern Spain). Our main objectives were to test whether hydroseeding significantly increases species richness and plant cover and whether hydroseeded species act as *starters*, facilitating the establishment of the vegetation and quickly disappearing once the communities are established. A hydroseeding success index (HSI, ranging from 0 to 1) was used to assess the relative abundance over time of the 14 species from the hydroseeding mixture. Species richness and cover was significantly higher on embankments (50–70 species per embankment, 80–90% cover) than on roadcuts (6–10 species per roadcut, 18–30% cover). Performance of hydroseeded species was poor from the very beginning (HSI, 0.2–0.3). On embankments, either presence or abundance of hydroseeded species did not significantly vary throughout the study. Both hydroseeded and nonhydroseeded communities exhibited a significant decrease in species richness, a significant increase in plant cover, and a highly dynamic species composition over time, with Sorensen index of 0.3–0.5 between years. There were no significant differences in plant cover, species richness, and aboveground biomass between hydroseeded and nonhydroseeded plots on embankments throughout the study. Our results demonstrate that there are situations in which the use of hydroseeding for revegetation is not needed. Further research should focus on understanding the establishment of autochthonous species and identifying environmental conditions under which the addition of commercial seeds may not be needed, or indeed situations where it may be harmful in suppressing autochthonous species.

Key words: hydroseeding, motorway slopes, plant cover, restoration, species composition, species richness.

Introduction

The European motorway network increases on average more than 1,000 km/yr, and in Spain alone, the 10,000-km motorway network increases approximately 3% per year (Dirección-General-de-Carreteras 2004). This construction work generates large areas of bare soil with steep slopes and frequent bedrock patches that should be restored (Martínez-Alonso & Valladares 2002; Bochet & García-Fayos 2004; Matesanz et al. 2005). Despite the increasing worldwide importance of roadside vegetation, our knowledge of its ecology and dynamics is quite scarce (Schaffers & Sýkora 2002). Common practices to restore these degraded areas include spread of topsoil (Rokich et al. 2000; Patzelt et al. 2001; Bote et al. 2005), hydroseeding, plantings, and use of geotextile (Hernández & López-Vivie 1998; Jochimsen 2001; Holl 2002; Mitchell et al. 2003). Surprisingly, multipurpose objectives of the restoration of motorway slopes are short term and focused on the technical necessity of mechanical stabilization and support, including the enhancement of herbaceous cover to prevent erosion (Andrés & Jorba 2000). However, most motorway restoration projects do not specifically include a global long-term target, and no clear criteria appear in relation to the characteristics of the plant communities to be favored in the slopes. Prevalence of short-term goals and lack of long-term criteria to define revegetation success leads to hydroseeding with fast-growing, cheap to obtain commercial species, usually to enable the introduction of species other than those initially present in the mixture, acting as *starter* species (Merlin et al. 1999). The usage of these species usually represent the introduction of exotic genotypes, which are not well adapted to local conditions, particularly those of arid or Mediterranean environments, and the competitive exclusion of autochthonous species (Brown & Rice 2000; Picon-Cochard et al.

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2001; Liedgens et al. 2004; San Emeterio 2004). Even though some studies report the successful use of autochthonous plant material—seeds, seedlings, and cuttings—for slope revegetation (Hernández & López-Vivie 1998; Paschke et al. 2000; Petersen et al. 2004), the usual situation involves commercial seed mixtures with low percentage of autochthonous species.

Ecological restoration is the process of assisting the recovery of ecological integrity (Harris & Hobbs 2001). This definition can be well applied to those situations in which there is a prior natural condition to return to, such as in projects of revegetation of bare soil patches in degraded arid lands (Visser et al. 2004) or reintroduction of grazing in former seminatural grasslands (Lindborg & Eriksson 2004). However, there are no prior natural conditions for motorway slopes; thus, there is no clear reference to guide their restoration beyond that of natural roadside vegetation in the corresponding geographical area, which is frequently not specific enough because it develops under different environmental conditions (soil type, slope angle). Because the communities established on motorway slopes are emerging ecosystems and both species composition and functional properties are new (Valladares et al. 2004; Hobbs et al. 2005), the success of the revegetation of motorway slopes can be considered high when the species from the hydroseeding mixture colonize the slopes and provide stabilization and protection against erosion (Muller et al. 1998). However, this success quantification does not take into consideration the ecological characteristics of the emerging communities, their dynamics over time, and the ecological implications at the landscape scale of the use of exotic species or genotypes. Furthermore, monitoring is usually restricted to the first months after the hydroseeding (Andrés et al. 1996; Andrés & Jorba 2000; Bochet & García-Fayos 2004). Changes in species composition and abundance must be monitored over time to understand ecosystem functions (Reay & Norton 1999), which may allow to re-create natural communities (Sluis 2002). Consequently, ecological knowledge of both natural roadside vegetation and plant communities of revegetated motorway slopes is highly needed for a solid definition of the goals and the eventual success of revegetation projects on motorway slopes.

Understanding how plant communities of hydroseeded and nonhydroseeded slopes evolve in the short term and midterm is crucial to disentangle the relative importance of natural colonization versus artificial seed addition, particularly in dry or semiarid conditions, where standard hydroseeding frequently render poor results (Andrés & Jorba 2000). This study was aimed at understanding the short term and midterm dynamics of plant communities established on hydroseeded and nonhydroseeded motorway slopes in southern, Mediterranean Spain. We hypothesized that (1) hydroseeded species act as *starters*, facilitating the establishment of the vegetation, quickly becoming marginal in the community and eventually disappearing as indicated by Bautista et al. (1997) and (2) hydroseeding increases cover and species richness as found by Muller et al. (1998).

Methods

Description of the Study Site

The study was conducted in the A7 motorway between Estepona (Málaga; lat 36°25′N, long 5°9′W) and Torreguadiaro (Cádiz, south of Spain). The total length of the studied section was 12 km, from 136 to 148 km. Altitude ranged between 100 and 200 m, and distance to the Mediterranean sea was on average 2.5 km. This section was built between 2000 and 2001, with most of the study slopes being finalized by the end of 2001. Slopes were simultaneously hydroseeded 1–2 months after their construction. Intensive sampling was carried out in the 2002–2004 period.

Climate is maritime Mediterranean, with an average temperature of 18.3°C and an average rainfall of 1,017 mm for the past 16 years (Casares climatic station, data from Instituto Nacional de Meteorología, Spain). Two meteorological stations based on Hobo data loggers (Onset, Pocasset, MA, U.S.A.) were located on two slopes of contrasting orientations to get a more detailed description of the local climatic conditions. Rainfall, irradiance, and air temperature were recorded every 5 minutes. Average annual temperature for the slopes during 2002 and 2003 was 19.2 and 17.0°C, respectively, with absolute maximum temperature of 31.6 and 30.5°C and absolute minimum of 5.2°C in 2002. Average rainfall from April 2002 to April 2003 was 944 mm, being evenly distributed through the year except during the summer drought. Irradiance peak took place in July, when 61 moles PAR m^{-2} day^{-1} were received. Vegetation surrounding the study slopes consisted in a complex matrix with *Chamaerops humilis* L. and *Pistacia lentiscus* L. shrubland remnants alternated with crop fields and Castor oil plant (*Ricinus communis* L.), cultures mixed with Cork oak (*Quercus suber* L.), open forest, and small patches of Kermes oak (*Q. coccifera* L.).

Hydroseeding Mixture, Slope Characteristics, and Experimental Design

Slopes were hydroseeded during the autumn and winter of 2001. The mixture used was composed of a blend of commercial seeds, mostly species belonging to the *Leguminosae* and *Poaceae* (35 g/m^2) and several compounds to stabilize and fertilize the soil. The 14 species that were present in the mixture are listed in Appendix 1. All these species were identified in the field but *Agropyrum intermedium* and *Festuca rubra*. The ingredients of the hydroseeding mixture were stabilizer (Stable, dose of 10 g/m^2; Projar, Valencia, Spain), slow-release NPK blend (Multigro, dose of 20 g/m^2; Haifa Chemicals Ltd., Haifa Bay, Israel), humic acids (Femabon, dose of 5 cc/m^2; Infertosa, Valencia, Spain), and mulch (generic, dose of 100 g/m^2, Projar). Final dose was 3 L/m^2 and was evenly distributed on the slopes. The mixture was applied with a hydroseeding machine (FINN; Hydrograsscorp, Pittsfield, ME, U.S.A.). Once the hydroseeding was applied, the midterm evolution of plant communities was followed over the first 3 years after the construction of the slopes.

We propose a hydroseeding success index (HSI), to determine the relative contribution of hydroseeding to the community. It was defined as follows:

$$\mathrm{HSI} = \mathrm{HydC}/\mathrm{TC},$$

where HydC is absolute cover of hydroseeded species and TC is total cover of the plot in percentage. Species used in the hydroseeding mixture were not likely to be present in the natural seed bank of the soils because they were not recorded either on the nonhydroseeded slopes or in the surrounding vegetation.

The study was carried out on a total of 48 slopes, 26 of them roadcuts (resulting from the excavation) and 22 embankments (resulting from the accumulation of materials). Slope angle for both roadcuts and embankments was rather similar (27°–34°), but vegetation developed differently. Due to the very low vegetation cover on roadcuts, comparison of hydroseeded and nonhydroseeded slopes and estimation of the relative contribution of hydroseeding to the community were carried out in more detail on embankments. Due to logistic requirements, hydroseeding was carried out over entire slopes, leading to hydroseeded and nonhydroseeded slopes randomly distributed over the motorway sections studied. Because A7 motorway runs from northeast to southwest, prevalent aspect of resulting slopes is either southeast or northwest. All the slopes studied were large (>20 m long and 15 m in height) due to the irregular and hilly geomorphology of the area. Slope aspect was not considered in the slope selection because aspect was observed in this area not to significantly affect variables of the community such as species richness or cover (Martínez-Alonso & Valladares 2002). Northern and southern slopes were thus chosen randomly within the total length of the studied section. Species richness and cover were systematically recorded together with general information of each slope (slope angle, aspect, size, degree of erosion) by means of three 15-m-long transects parallel to the road during late spring each year, the moment of maximum development of the plant communities. Presence of both hydroseeded and spontaneous species was recorded along each transect. Cover was visually estimated on each slope always by the same observer in three strips (upper, medium, and lower). Each transect was situated in the center of each strip. Total cover for the whole slope was calculated as the mean of the three cover values. The upper and lower 2 m of the slopes was avoided.

To better quantify the contribution of hydroseeded species to the community that developed on embankments, specific cover and species richness were determined in 30 hydroseeded and 6 nonhydroseeded 1-m^2 plots using the point quadrat method (San Miguel Ayanz 2001) in 2003 and 2004. Each plot was sampled using a square grid of 100 squares of 1-dm^2 each. These plots were distributed covering a total surface of 7 ha (5-ha hydroseeded surface and 2-ha nonhydroseeded surface). Nonhydroseeded plots were distributed at 30-m intervals in transects that ran parallel to the motorway, from 137 (lat 36°19′17.78″N, long 5°14.40′16″W) to 138.5 km (lat 36°20′10.02″N, long 5°14′25.34″W). Hydroseeded plots were distributed the same way, from 138.5 (lat 36°20′36.12″N, long 5°14′25.34″W) to 147 km (lat 36°24′15.12″N, long 5°11′44.68″W). Aboveground biomass was measured in 2003 using an adjacent plot of the same size located 1 m from those studied with the point quadrat method. Aboveground biomass was estimated for the whole plant community by clipping all aerial plant parts in the plots and drying the samples to constant weight in an oven at 65°C. For species nomenclature we used Flora Vascular de Andalucía Occidental (Valdés et al. 1987) and Flora Europaea (Tutin et al. 2001).

Statistical Analysis

Comparisons of species richness and cover between roadcuts and embankments were determined using one-way analysis of variance (ANOVA). Changes over time in species richness, cover, percentage of noncoincident species, and percentage of hydroseeded species were determined on embankments using repeated-measures ANOVA (RM ANOVA) and paired *t* test as post hoc test, using Bonferroni correction to adjust for multiple comparisons. Prior to analysis, data were checked for normality and homogeneity of variances. Changes in the relative abundance of hydroseeded species (HSI) was tested using Mann–Whitney *U* test because data could not be normalized. To determine changes in species composition, we defined coincident species as species that occurred in 2 years and noncoincident species as species that were present only in 1 year. Total number of species in a pair of years (e.g., 2002–2003) was calculated as the sum of coincident and noncoincident species. The floristic similarity over the years was measured by the Sorensen coefficient (So):

$$\mathrm{So} = 2a/(2a + b + c),$$

where a is the number of coincident species to the two compared samples, and b and c are the numbers of species present only in the first and second samples, respectively. The effect of hydroseeding and time in species richness, cover, and aboveground biomass were tested with two-way ANOVA. Results are expressed as mean ± SE throughout the paper, and the level for statistical significance was set at $p \leq 0.05$. All the analyses were performed with Systat version 11.0 (Systat Software Inc., 2004, CA, U.S.A.).

Table 1. Total number of plant species, genera and families, and number and percentage of species belonging to the three dominant families recorded during the 3-year study in 48 slopes in the A7 motorway (Málaga, Spain).

	2002	*2003*	*2004*	*Total*
Number of species	225	189	177	322
Number of genera	143	117	105	180
Number of families	46	32	36	50
Main families (no. of species, %)				
Leguminosae	50 (22.2)	40 (21.6)	40 (22.6)	65 (20.2)
Compositae	36 (16)	35 (18.5)	31 (17.5)	54 (16.8)
Poaceae	34 (15.1)	29 (14.8)	23 (13)	49 (15.2)

Total column refers to percentage of all species present over the study. Complete species list is in Appendix 1.

Results

Short-Term Dynamics of the Plant Communities

A total of 322 plant species belonging to 50 families were recorded throughout the 3 years of study on the 48 slopes (Table 1; Appendix 1). The most abundant families were Leguminosae (20%), Compositae (17%), and Poaceae (15%), which was observed during the 3 years of study (Table 1). The dominant species according to both cover and frequency on the slopes were the naturally established *Hedysarum coronarium* L., *Scorpyurus spp.* L. (Leguminosae), *Torilis nodosa* (L.) Gaertner (Umbeliferae), or *Chrysanthemum coronarium* L. (Compositae), and the hydroseeded *Lolium rigidum* Gaudin (Poaceae), *Onobrychis viciifolia* Scop., and *Medicago sativa* L. (Leguminosae) (see Appendix 1 for cover values).

Vegetation establishment differed between embankments and roadcuts. Species richness (mean for all embankments all years) was significantly higher on embankments (54.08 ± 2.25, $\overline{X}$ ± SE) than on roadcuts (8.87 ± 0.92, $\overline{X}$ ± SE; one-way ANOVA, $F_{[1,46]} = 198.7$, $p < 0.001$). The same pattern was true for cover, being significantly higher on embankments (80.5 ± 2.30, $\overline{X}$ ± SE) than on roadcuts (24.00 ± 3.01, $\overline{X}$ ± SE; one-way ANOVA, $F_{[1,46]} = 276.9$, $p < 0.001$).

On embankments, species richness declined during the 3 years of study (Fig. 1a), being significantly higher in 2002 than in the following years (RM ANOVA, $F_{[2,42]} = 7.792$, $p = 0.035$). The number of species decreased this year from 66 ± 9 species per slope ($\overline{X}$ ± SE) to 46 ± 3 species per slope in 2002 (paired *t* test, $p < 0.05$), but it was not significantly different between 2003 and 2004. In contrast, cover increased significantly during the study (RM ANOVA, $F_{[2,42]} = 3.521$, $p = 0.034$), from 84.4 ± 6.0% to 95.4 ± 1.8% ($\overline{X}$ ± SE) in 2002 and 2004, respectively (paired *t* test, $p < 0.05$). No differences were observed between 2003 and 2004 (Fig. 1b).

Significant differences in species composition on embankments were found throughout the 3 years of study (RM ANOVA, $F_{[2,42]} = 11.573$, $p = 0.003$). The percentage of different or noncoincident species was significantly higher between 2002 and 2003 (59.3 ± 3.6%) than comparing 2003 with 2004 (48.8 ± 2.2%), and common species between 2002 and 2004 were only 30% of the total. The same pattern was observed for Sorensen index (RM ANOVA, $F_{[2,42]} = 9.657$, $p = 0.006$). It ranged from 0.40 ± 0.036 between 2002 and 2003 to 0.51 ± 0.022 between 2003 and 2004 and dropped to 0.31 ± 0.035 between 2002 and 2004. This was also observed in the overall species number of the most abundant families (Leguminosae, Compositae, and Poaceae; Fig. 2a, 2b, & 2c, respectively). Number of common species for the three families was lower between 2002 and 2004 than between 2002 and 2003 and 2003 and 2004. The number of new species decreased over time as observed with the total number of species.

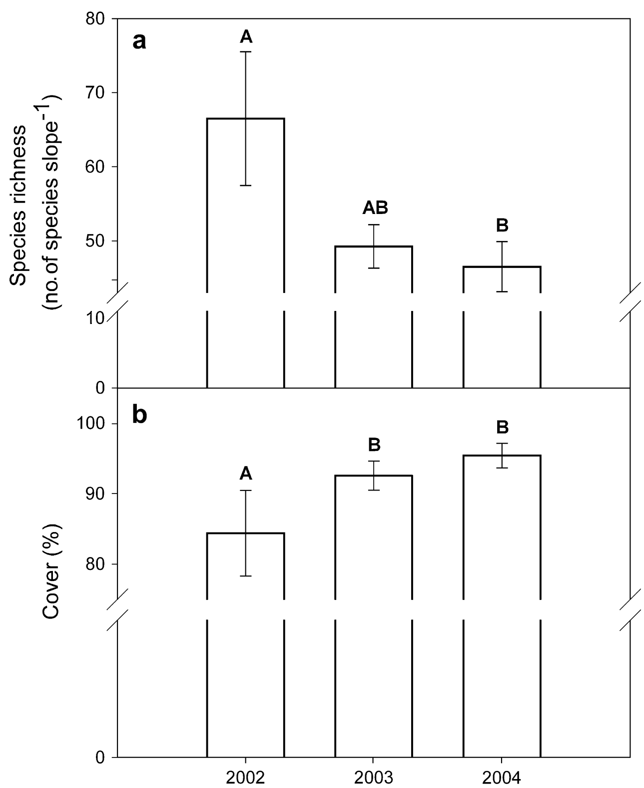

Figure 1. Mean number of plant species (a) and cover (b) on embankments during the 3-year period of study. Different letters above bars indicate differences among years (RM ANOVA, $p < 0.05$). Error bars indicate SE.

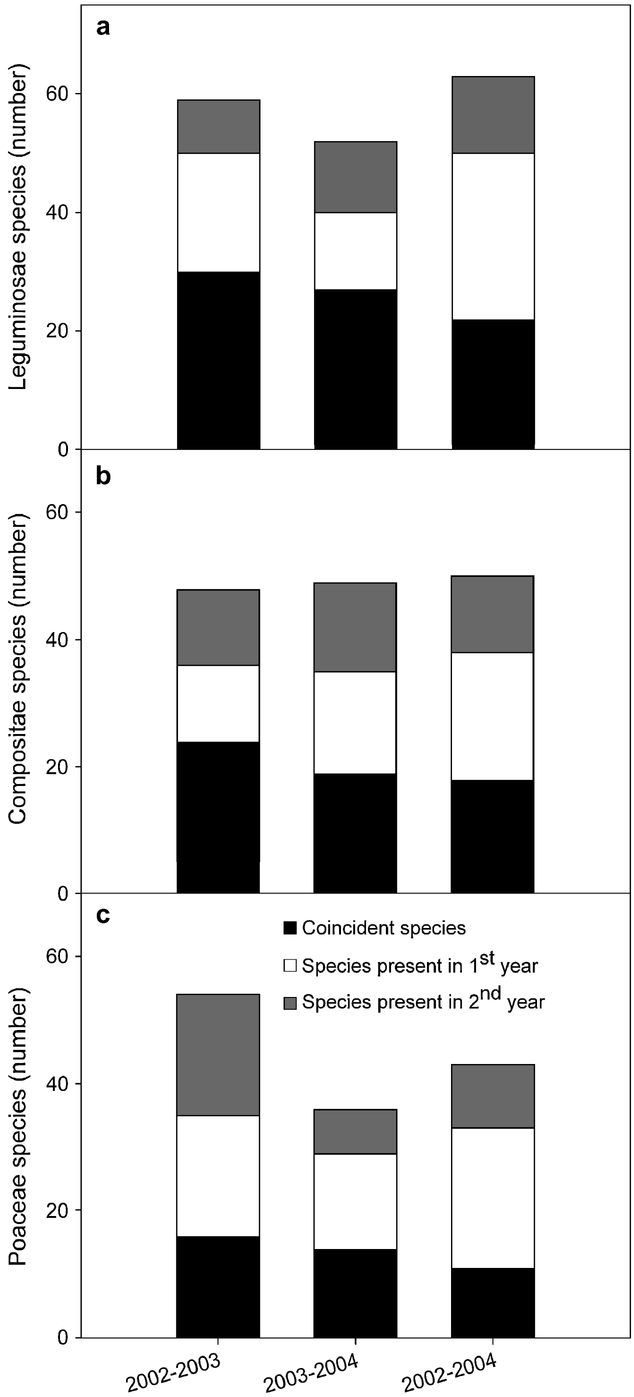

Figure 2. Number of coincident and noncoincident species between years over the 3-year period of study in the three main families: (a) Leguminosae, (b) Compositae, and (c) Poaceae.

Hydroseeding Success

The hydroseeding mixture included seeds from 14 species. Most hydroseeded species (85%) were recorded in the overall list of species. However, the largest number of hydroseeded species present per slope was only five (35%). The percentage of hydroseeded species present (mean for all years on each slope) was 52.2 ± 4.6% on roadcuts and 8.4 ± 2.8% on embankments, where more than 90% of the species were present as a result of natural colonization.

There were not significant differences in the percentage of hydroseeded species present (successful) on embankments in the different years of study (RM ANOVA, $F_{[2,42]} = 0.731$, $p = 0.508$; Fig. 3a). No differences were found in the relative abundance of the hydroseeded species from 2003 to 2004 (relative HIS; $U_{MW} = 311.0$, $p = 0.578$). HSI, which ranges from 0 to 1, was always low, varying from 0.26 ± 0.06 in 2003 to 0.20 ± 0.04 in 2004 (Fig. 3b).

Neither the treatment (hydroseeded–nonhydroseeded plots) nor the time (2003–2004) nor the treatment × time interactions had significant effects on plant cover (two-way ANOVA, treatment: $F_{[1,68]} = 1.044$, $p = 0.310$; time: $F_{[1,68]} = 2.688$, $p = 0.106$; treatment × time: $F_{[1,68]} = 0.615$, $p = 0.436$; Fig. 4a). And the same was true for the species richness (two-way ANOVA, treatment: $F_{[1,68]} = 3.418$, $p = 0.069$; year: $F_{[1,68]} = 1.084$, $p = 0.302$; treatment × time: $F_{[1,68]} = 1.584$, $p = 0.213$; Fig. 4b & 5), and for the aboveground biomass ($F_{[1,34]} = 0.510$, $p = 0.480$).

Discussion

As expected, the short term and midterm dynamics of our studied system was similar to that found for most developing herbaceous communities: species richness decreased and plant cover increased over time after the initial establishment of the community. Also, the species shifts in composition were highly intense during the first years. However, and contrary to the working hypothesis, we found that hydroseeding did not have significant effects on species richness, cover, and aboveground biomass on the study embankments. Also contrary to the hypotheses, the successfully established hydroseeded species did not decrease in abundance significantly over time. Obviously, these results should be taken with caution because the studied period is relatively short. In any case, our results suggest that these species did not act as starters, favoring the initial establishment of plant communities and disappearing after the first growing season.

Hydroseeding, the most widespread revegetation method, is primarily aimed at the mechanical stabilization of the degraded area and at the control of erosion. Petersen et al. (2004) obtained good results seeding autochthonous species in the revegetation of a national park in Utah (U.S.A.) and Arienzo et al. (2004) proposed the use of *Lolium perenne* L., a common species in many hydroseeded mixtures, for revegetation of soils in Italy. However, hydroseeding rendered undistinguishable results from natural processes on embankments at least in terms of richness, cover, and composition, and the hydroseeded species exhibited low cover values. These findings open the question of the real success of hydroseeding in our study site. Many authors have highlighted the importance of quantifying restoration success, which is not always easy. Reay and Norton (1999) emphasized the importance

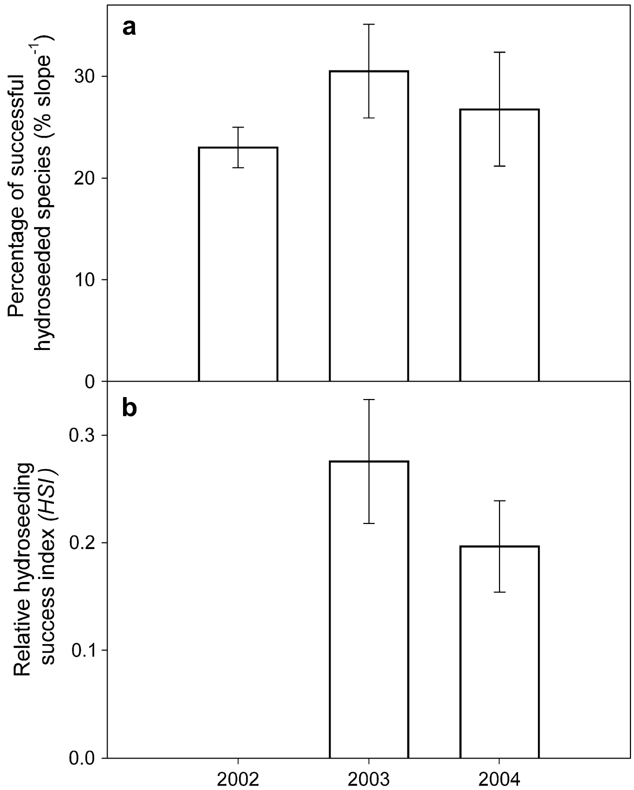

Figure 3. (a) Percentage of successful hydroseeded species ($\overline{X} \pm 1$ SE). (b) Relative HSI in $30 \times 1\text{–m}^2$ hydroseeded plots. Mean values did not differ among years (RM ANOVA and Mann–Whitney *U* test, $p > 0.05$).

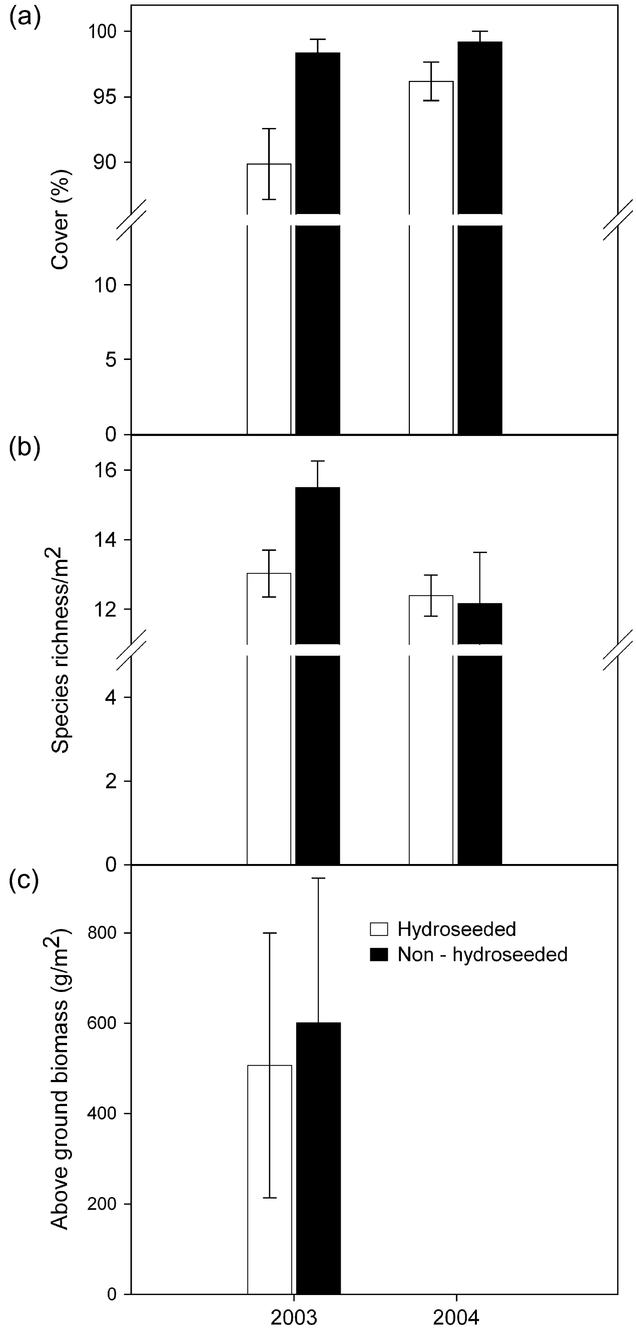

Figure 4. Mean (±1 SE) plant cover (a), species richness (b), and aboveground biomass (c) in $30 \times 1\text{–m}^2$ hydroseeded plots and $6 \times 1\text{–m}^2$ nonhydroseeded plots. There were no significant effects of either hydroseeding, time, or the interaction hydroseeding × time (two-way ANOVA, $p > 0.05$).

of monitoring the changes of abundance and species composition over time to measure restoration success in a temperate New Zealand forest. In our study, the use of a relative index to determine the success of hydroseeding instead of an absolute index (e.g., hydroseeding species cover) avoided confusion arising from situations with a general poor plant performance, which is the norm in arid and semiarid Mediterranean climates. And even this relative index indicated a low hydroseeding success throughout the study. However, the communities established on the embankments were species rich, had high plant cover, and remained mechanically stable (i.e., no landslides or rills were observed) throughout the study. Thus, our results indicate the existence of situations in which hydroseeding is simply not needed.

There are a number of environmental conditions that must be considered before any decision on whether hydroseeding is appropriate (Fig. 5). First, the climate conditions of the area, because low and variable precipitation and extreme temperatures have been reported to compromise the success of any revegetation attempt (Call & Roundy 1991; Visser et al. 2004). Second, the type of slope must be taken into account. We found important differences from roadcuts (excavation slopes) to embankments (accumulation slopes) in the establishment of vegetation, and several authors support these results, showing that unfavorable conditions of roadcuts lead to low plant cover and species richness (Martínez-Alonso & Valladares 2002). Third, slope inclination and soil features must be considered (Fig. 5). Slope angles greater than 27°–32° hinder vegetation establishment because seeds are susceptible to

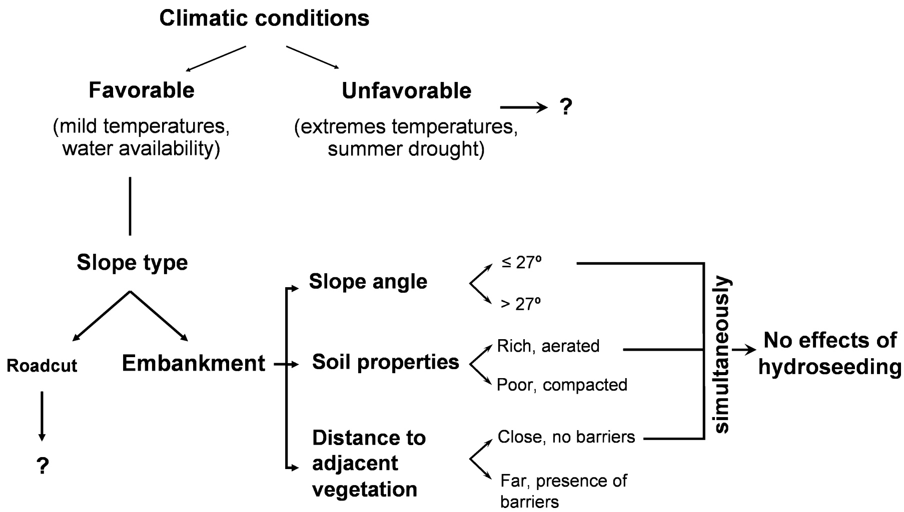

Figure 5. Conditions under which hydroseeding may or may not have a significant effect on plant cover and species richness. "?" indicates difficult conditions for plant colonization under which hydroseeding success is unknown.

be dragged downward (Bochet & García-Fayos 2004). Finally, the existence of a source of propagules and seeds nearby—the threshold of maximum distance depending on the dispersal mechanisms of the surrounding vegetation—must be assessed because it can significantly facilitate the colonization by native plants. When conditions are favorable according to these four criteria simultaneously, the use of hydroseeding must be reconsidered because it might not be needed. Any other combination of conditions may make hydroseeding appropriate, but the success of the hydroseeding is unknown and highly dependable on other local conditions, which suggests the need of specific pilot studies prior to any large-scale initiative.

Regardless of the low-average success of the hydroseeding, established species from the hydroseeding mixture like *Lolium rigidum, Medicago sativa*, and *Onobrychis viciifolia* remained present and their abundance was similar on the embankments during the 3 years of study. Muller et al. (1998) found that 5 years after hydroseeding some degraded areas in France, the average abundance of introduced species decreased but had not disappeared (from 93 to 46%) and there was still one grass species that persisted as dominant after 8 years. Bautista et al. (1997) found that introduced species disappeared 6–12 months after hydroseeding a semiarid region in eastern Spain. *Lolium sp*. has been reported as a highly competitive species (González Ponce 1998; Hoffman & Isselstein 2004), and ongoing studies are showing unwanted effects of *L. rigidum* in the early colonization of motorway slopes in dry Mediterranean conditions (Matesanz et al. 2005). Also, San Emeterio et al. (2004) showed the allelopathic potential of *L. rigidum* on the early growth of *L. multiflorum*, *Dactylis glomerata* L., and *M. sativa*. Because all these four species were present in commercial hydroseeding mixtures such as the one used in our study, more attention must be paid to the planning of hydroseeding: *L. rigidum* may hinder not only the establishment of autochthonous species but also that of the other species of the hydroseeding mixture.

As a consequence of the relative failure of hydroseeding in our study area, the communities established on embankments were primarily made of native species that were present as a result of both the local seed bank and the dispersion from the surrounding areas. In agreement with this, communities on both hydroseeded and nonhydroseeded embankments followed patterns and dynamics similar to those reported for other more natural plant communities. Significant changes in species richness, plant cover, and species composition over time such as those found here have been reported in many studies (Gotelli & Colwell 2001; Cornwell & Grubb 2003; Stevens et al. 2003).

In conclusion, although hydroseeding has been considered as the most effective restoration method for motorway slopes during the past two decades, our study suggests that it is not needed when a suite of favorable conditions involving climate and slope properties take place simultaneously in the area. Some of these conditions—such as not very steep slope angle or soil properties—can be taken into account and thus improved during the construction of the motorway. The negative ecological implications of the use of exotic genotypes in the hydroseeding mixture make the study of alternative seed mixtures appropriate. Studies indicate that more attention should be given to autochthonous species. Future efforts should focus not only on finding the best restoration method for each site and type of slope but also on monitoring the long-term evolution of hydroseeded and nonhydroseeded slopes, in order to understand the impacts of hydroseeding on herbaceous ecosystems and to minimize its use under favorable environmental conditions.

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Appendix 1. Plant species recorded across the 3 years of study in the 48 slopes studied.

Anacardiaceae	
Pistacia lentiscus	*
Apiaceae	
Bupleurum latifolium	—
Scandix pectin-veneris	—
Araceae	
Arisarum simorrhinum	0.5
Boraginaceae	
Anchusa azurea	0.9
Cynoglosum creticum	*
Echium creticum	—
Echium plantagineum	*
Echium tuberculatum	—
Omphalodes linifolia	—
Campanulaceae	
Jasione montana	—
Cariophyllaceae	
Arenaria hispanica	3.7
Paronychia argentea	*
Petrorrhagia nanteuilii	—
Silene colorata	0.8
Silene gallica	*
Silene vulgaris	—
Silenen nocturna	—
Chenopodiaceae	
Chenopodium murale	*
Chenopodium opulifolium	*
Ciperaceae	
Schoenus nigricans	—
Cistaceae	
Cistus salvifolius	—
Halimium sp.	—
Helianthemum siriacum	—
Compositae	
Anacyclus clavatus	*
Anacyclus radiatus	*
Andryala integrifolia	*
Andryala ragusina	—
Anthemis arvensis	0.5
Asteryscus aquaticus	*
Calendula arvensis	*
Carduncellus caerulens	*
Carduus borgeanus	*
Carduus picnocephalus	0.5
Carduus tenuiflorus	—
Carlina corimbosa	—
Carthamus lanatus	0.5
Centaurea melitensis	*
Centaurea pullata	*
Centaurea solstitialis	—
Centaurea spherocefala	*
Centrantus calcitrapa	—
Chrisantemum coronarium	5.5
Cichorium endivia	*
Crepis taraxacifolia	—
Crepis vesicaria	*
Cynara scholimus	—
Ditrichia viscosa	*
Echinops strigosus	—
Edipnois cretica	*
Filago pyramidata	*
Galactites tomentosa	2.3
Gnaphalium oxyphylum	—
Lactuca serriola	*
Leontodon taraxicoides	2.4
Mantisalca salmantica	*
Otospermum glabrum	*
Phagnalum rupestre	—
Phagnalum saxatile	—
Picris echioides	2.4
Pulicaria dysenterica	—
Reichardia intermedia	*
Scholimus hispanica	*
Scholimus maculatus	*
Scholimus maximus	—
Senecio vulgaris	*
Sonchus asper	4.0
Sonchus oleraceus	0.6
Sonchus tenerrimus	—
Sylibum marianum	*
Tolpis barbata	—
Tragopogon humile	—
Tragopogon hybridus	—
Tragopogon porrifolius	—
Tragopogon pratensis	—
Urospermum glabrum	—
Urospermum picrioides	2.5
Convolvulaceae	
Convolvulus altheoides	*
Convolvulus arvensis	—
Convolvulus bicolor	—
Convolvulus meonanthus	*
Convolvulus tricolor	*
Cruciferae	
Biscutella baetica	*
Brassica nigra	*
Brassica oleraceus	*
Diplotaxis erucoides	*
Diplotaxis virgata	*
Hirschfeldia incana	0.9
Hirsfeldia incana	—
Iberis crenata	—
Lobularia maritima	*
Sinapis arvensis	*
Raphanus raphanistrum	*
Raphistrum rugosum	*
Cuscutaceae	
Cuscuta graveolens	—
Cyperaceae	
Scirpus holoschoenus	—
Dipsacaceae	
Scabiosa atropurpurea	*
Euphorbiaceae	
Euphorbia characias	—
Euphorbia exigua	*
Euphorbia falcata	*
Euphorbia helioscopia	*
Euphorbia peplus	*
Euphorbia segetalis	2.2
Euphorbia sulcata	*
Mercurialis annua	*
Fagaceae	
Quercus coccifera	—
Quercus ilex	—
Fumariaceae	
Fumaria officinalis	*
Fumaria parviflora	*
Fumaria sepium	—
Gentianaceae	
Centaurium eritrea	—
Erodium chium	—
Erodium ciconium	—
Erodium cicorium	—
Erodium cicutarium	*
Erodium malacoides	*
Erodium moschatum	*
Erodium primulaceum	*
Geranium columbinum	0.5
Geranium dissectum	*
Geranium molle	—
Geranium purpureum	*
Geranium rotundifolia	1.5
Geraniaceae	
Avena barbata	*
Avena sterilis	0.8
Brachipodium distachion	*
Brachipodium retusum	—
Briza maxima	—
Bromus diandrus	—
Bromus hordaceus	—
Bromus madritensis	*
Bromus rigidus	—
Bromus rubens	—

Bromus scoparius	*
Bromus squarrosus	*
Bromus sterilis	*
Cynodon dactylon†	*
Dactylis glomerata†	*
Desmazeria rigida	*
Elymus repens	*
Festuca arundicacea†	*
Gastridium ventricosum	—
Gaudinia fragilis	*
Hordeum leporinum	*
Hordeum vulgare	—
Hyparrhenia hirta	—
Lagurus ovatus	—
Lofocloa cristata	—
Lolium multiflorum†	—
Lolium rigidum†	14.2
Micropiron tenelum	—
Phalaris aquatica	—
Phalaris brachystachys	*
Phalaris coerulescens	0.5
Phalaris minor	*
Phalaris paradoxa	—
Phleum pratense	*
Phlomis purpurea	*
Piptatherum milliaceum	*
Poa pratensis†	—
Polypogon maritimus	*
Polypogon monspeliensis	—
Stipa capensis	—
Stipa gigantea	—
Stipa pratensis	—
Triticum durum	1.1
Guttiferae	
Hypericum perforatum	*
Iridaceae	
Gladiolus communis	—
Gynandriris sisyrinchium	*
Iris germanica	—
Juncaceae	
Juncus bufonius	—
Labiatae	
Coridothymus capitatus	—
Lamium amplexicaule	*
Lamium purpureum	*
Stachys arvensis	2.0
Stachys germanica	*
Stachys byzantina	—
Teucrium capitatum	*
Leguminosae	
Anthyllis cytisoides	—
Anthyllis tetraphylla	*
Anthyllis vulneraria	—
Astragalus echiamatus	*
Astragalus stella	—
Calicotome villosa	*
Dorycnium rectum	—
Hedysarum coronarium	30.3
Hedysarum humile	—
Hipocrepis ciliata	—
Lathyrus angulatus	*
Lathyrus aphaca	*
Lathyrus clymenum	*
Lathyrus ochrus	2.1
Lotus conglomeratus	—
Lotus corniculatus†	2.8
Lotus edulis	—
Lotus ornithopodiodes	—
Lotus pedunculatus	—
Lotus scorpyoides	1.0
Lupinus luteus†	—
Medicago minima	*
Medicago orbicularis	*
Medicago polimorpha	*
Medicago rigidula	2.3
Medicago sativa†	6.5
Medicago trunculata	*
Medicago turbinata	*
Melilotus alba	—
Melilotus indicus	—
Melilotus sulcata	*
Onobrychis viciifolia†	12.5
Ononis alopecuroides	—
Ononis biflora	—
Ononis laxiflora	—
Ononis mitissima	2.9
Logfia gallica	—
Ononis reclinata	—
Ononis viscosa	—
Ornithopus compresus	—
Psoralea bituminosa	3.9
Scorpyurus sulcatus	8.6
Scorpyurus vermiculatus	—
Tetragonolobus purpureus	0.5
Trifolium angustifolium	*
Trifolium boconeii	—
Trifolium campestre	*
Trifolium cherleri	—
Trifolium glomeratum	*
Trifolium hirtum	—
Trifolium lappaceum	*
Trifolium pratense	*
Trifolium repens	*
Trifolium resupinatum	—
Trifolium scabrum	*
Trifolium squamosum	*
Trifolium stellatum	*
Trifolium sylvaticum	*
Trifolium tomentosum	—
Ulex parviflora	*
Ulex parviflorum	—
Vicia cracca†	*
Vicia laxiflora	*
Vicia lutea	0.7
Vicia sativa	0.8
Liliaceae	
Allium roseum	—
Asparagus albus	—
Asphodelus ramosus	—
Linaceae	
Linum bienne	*
Linum strictum	*
Malvaceae	
Malva hispanica	*
Malva parviflora	0.6
Stegia trimestris	*
Oleaceae	
Olea europaea	—
Orobancaceae	
Orobanche ametkystea	*
Orobanche ramosa	*
Oxalidaceae	
Oxalis pes-caprae	3.4
Palmaceae	
Chamaerops humilis	—
Papaveraceae	
Papaver hibridum	—
Papaver rhoeas	*
Papaver somniferum	*
Paroniquiaceae	
Herniaria glabra	—
Plantaginaceae	
Plantago afra	*
Plantago albicans	—
Plantago bellardii	—
Plantago coronopus	*
Plantago lagopus	*
Plantago lanceolata	*
Plantago major	*
Poaceae	
Aegilops neglecta	*
Aegilops ovata	*
Agropirum repens	—
Agropyron tenelum	—
Anthoxantum aristatum	—
Arundo donax	*
Polygalaceae	
Polygala monspeliaca	—
Polygonaceae	
Rumex bucephaloporus	—
Rumex conglomeratus	*
Rumex pulcher	*
Rumex scutatus	—
Primulaceae	
Anagalis arvensis	4.9
Asterolinon linum-stellatum	—
Coris monspeliensis	—
Ranunculaceae	
Nigella damascena	—
Ranunculus arvensis	—
Ranunculus muricatus	—
Ranunculus paludosus	—
Resedaceae	
Reseda lutea	*
Reseda phyteuma	*
Rhamnaceae	
Rhamnus oleoides	—
Rosaceae	
Rubus sp.	*
Sanguisorba minor†	*
Rubiaceae	
Crucianella angustifolia	—
Ononis natrix	*
Galium parisienne	—
Galium rugosum	—
Galium tricornutum	—
Galium verrucosum	—
Gallium spurium	*
Sherardia arvensis	0.9
Santalaceae	
Tesium humile	—
Scrophulariaceae	
Antirrhinum majur	—
Antirrhinum orontium	—
Asteriscus aquaticus	—

Kickxia spuria	*	Umbeliferae		*Torilis nodosa*	7.5
Linaria ametystea	—	*Amni bisnaga*	*	Urticaceae	
Misopates oronthium	*	*Daucus carota*	*	*Parentucellia viscosa*	—
Scrophularia sambucifolia	*	*Daucus maxima*	*	*Parietaria judaica*	—
Verbascum sinuatum	—	*Ferula communis*	*	Valerianaceae	
Solanaceae		*Foeniculum vulgare*	0.7	*Fedia cornucopiae*	*
Mandragora sp.	—	*Ridolfia segetum*	*	*Fedia scorpioides*	*
Solanum nigrum	*	*Torilis arvensis*	—	*Valerianella discoidea*	—

Quantitative cover data (in percentage) was obtained from the 36 × 1–m^2 plots (mean values for 2003 and 2004).
* cover less than 0.5%; † hydroseeded species; — species not found within the 36 plots.