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Research paper

Limitations to recruitment of native species in hydroseeding mixtures

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ABSTRACT

To ensure the success and sustainability of restoration actions, native plant species are increasingly recommended due to their presumed ability to adapt to local abiotic and biotic conditions. However, topography, substrate characteristics and water shortage are known to cause failure of native species in Mediterranean areas, and even when such factors are not limiting their establishment and growth can still be very low or null. This study intended to identify causes for such failures.

A greenhouse experiment was set up to simulate the hydroseeding procedures used in a Mediterranean quarry, and to study the behaviour of five target species. Seeds of native species (including generalists) were mixed in the usual slurry and applied to pots filled with quarry substrate, using three treatments: (i) each target species sown alone; and each target species and four generalists, (ii) at a low seeding density (15 g/m^2), and (iii) at a high density (30 g/m^2, the usual seeding density at the quarry). Plant germination, density, development and cover were monitored for two growth seasons to evaluate the effects of the presence of other species and seeding density on the success of the target species.

The results explained the previously observed low success of the target native species in the quarry. Germination and establishment were not limited by the substrate and slurry components. With enough water available after seeding, the major constraint on target seedling recruitment was the morphology and fast growth of the co-seeded generalist species, despite the fact that the latter were also native and had not been previously expected to strongly outcompete the former. The dominance of the generalists might be partly explained by the significantly higher proportion of their seeds in the mixture. The experiment also indicated that seeding densities currently used for restoration of Mediterranean degraded areas may be reduced without compromising the development of the plant cover. However, this reduction alone does not ensure the success of all native species. The effective introduction of a given native species requires that adequate mixture compositions and densities be determined taking into account the species' germination speed and seedling morphology (leaf and stem sizes). This is most relevant when the co-seeded species (e.g. generalist grasses) display more competitive growth traits and should therefore be included in lower proportion.

1. Introduction

Scarcity of rainfall and coincidence of drought and high temperatures in summer, as well as poor soils, have strongly designed Mediterranean plant communities, and are also important constraints on the restoration of severely degraded Mediterranean areas (Alday et al., 2010; Martínez-Ruiz et al., 2007). In addition, these ecosystems are often dominated by woody, slow-growing and late-successional plant species, as opposed to the herbaceous, fast-growing species commonly used in restoration projects worldwide. In the Mediterranean region, roadside and post-mining slopes are commonly subject to such practices, in order to stabilize slopes, reduce erosion, and minimize the negative aesthetic impact of bare surfaces (García-Palacios et al., 2010; Moreno-de las Heras et al., 2008).

The scientific community is increasingly proposing the use of native species – either through natural colonization or artificial introduction – for the rehabilitation of degraded areas (Kiehl et al., 2010; Tinsley et al., 2006) including those in the Mediterranean region (Bochet et al., 2010a,b; Martínez-Ruiz et al., 2007; Moreno-de las Heras et al., 2008). However, practitioners use such species in restoration efforts primarily to comply with environmental legislation (when it exists) or local authority requirements, particularly when the target area is close to, or within areas of high conservation value. Low-cost strategies that provide rapid ground cover, which

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Table 1
Seed densities and proportions used for each target species. Seed densities were the same in each of three experimental treatments: target species alone (T), target species in a low density seed mixture with generalists (TGL), and target species in a high density seed mixture with generalists (TGH). Please note that the originally selected *O. natrix* (chamaephyte) was replaced by *O. pubescens* (see Section 2 for details).

Target species	Life form	Seed density		Proportion in the mixture (%, g/g)		
		g/m^2	seeds/m^2	*T*	TGL	TGH
Brachypodium phoenicoides	Hemicryptophyte	1.5	422	100	10.0	5.3
Cistus salviifolius	Nanophanerophyte	1.2	1079	100	8.2	4.3
Coronilla glauca	Nanophanerophyte	1.5	222	100	10.0	5.3
Ononis pubescens	Therophyte	1.5	192	100	10.0	5.3
Thymbra capitata	Chamaephyte	0.3	1697	100	2.2	1.1

do not usually include native species, are generally preferred (Holl, 2002). Drawbacks such as low market availability and high costs (Bochet et al., 2010b; Dickson and Busby, 2009), insufficient knowledge of their ecology (Andrés et al., 1996; Bochet et al., 2010a,b) or propagation requirements (Commander et al., 2009; Piotto and Di Noi, 2003; Sheley and Half, 2006), and apparent low success in the field (Oliveira et al., 2007; Tinsley et al., 2006) limit the use of native species.

Several reasons have been suggested to explain the poor performance of native species in the restoration of degraded Mediterranean such as adverse microclimatic conditions or substrate characteristics, low germination capacity, seed dormancy, additives in the hydroseeding slurry, and interspecific competition (Bochet et al., 2010a; Cano et al., 2002; Merlin et al., 1999; Matesanz and Valladares, 2007; Oliveira et al., 2012). It has been shown that the amount and duration of soil water availability determine germination success in semiarid conditions (Bochet et al., 2007; García-Fayos et al., 2000). Moreover, environmental conditions that favour standard commercial species (e.g. high soil fertility and water availability) tend to have the opposite effect on native species (de la Riva et al., 2011; Jenkins et al., 2004; Oliveira et al., 2007; Pinaya et al., 2000).

The main goal of this study was to identify possible causes for the lack of success of some native species introduced through hydroseeding in previous restoration projects in a Mediterranean limestone quarry (Correia, 2000; Oliveira et al., 2007). In those projects, the failure of such species was not due to low germination capacity or water shortage (Oliveira et al., 2012). The field situation was simulated under greenhouse conditions – same substrate, seeding season and density, and similar slurry composition (additives and seed mixture) – then plant performance was evaluated for two growth seasons. These conditions were expected to allow for a more detailed survey of the early period following hydroseeding than would be logistically possible on the quarry slopes. The goal of the experimental design was to identify possible constraints on seedling emergence and/or early growth of the target species due to the type of substrate and the non-seed components of the slurry, the presence (co-seeding) of other species, and the seeding density. The results would contribute to improvement of the success of native species in revegetation actions at the target quarry and similar degraded areas.

2. Materials and methods

The experiment was designed to imitate field conditions and hydroseeding procedures and schedules as much as possible. It was carried out in a greenhouse (plant nursery) at the quarry site operated by the cement company Secil-Companhia Geral de Cal e Cimento S.A., at Outão. This quarry is located within the Natural Park of Arrábida (southwest Portugal, 38°29′48″ N, 8°56′24″ W). Restoration efforts favouring the convergence of the degraded areas with the surrounding landscape are legally required, and must avoid the introduction of species that are not represented in the local flora. For this reason, only species recorded in plant surveys of Serra da Arrábida (Pedro, 1997) were used in the present study and referred to as "native species".

Three treatments were applied for each native target species: i) sown alone (T); and sown with native generalists in ii) a low-density seeding mixture (ca. 15 g/m^2, TGL) and iii) a high-density seeding mixture (ca. 30 g/m^2; TGH) (Tables 1 and 2). The usual seeding density at the target quarry was 30 g/m^2, which is within the ranges reported for revegetation of similarly degraded slopes in the Mediterranean region (e.g. Andrés et al., 1996; Brofas et al., 2007; Muzzi et al., 1997; Tormo et al., 2007). Four replicates of each target species-treatment combination were deployed. Four additional replicates were also prepared for each of the two seeding densities (GL and GH), using the seed mixtures without target species.

The five target species selected for this study were the perennials *Brachypodium phoenicoides* (L.) Roem. et Schult. (Gramineae), *Cistus salviifolius* L. (Cistaceae), *Coronilla glauca* L. (Leguminosae), *Ononis natrix* L. (Leguminosae) and *Thymbra capitata* (L.) Cav. (Labiatae). These species had been unsuccessfully used in the hydroseeding of local quarry slopes, despite their good germination potential (Oliveira et al., 2012), but they remained potentially interesting for revegetation purposes because they are early successional species tolerant of dry and sunny conditions such as those on the quarry slopes. Moreover, improvement of nutrient availability was expected from the introduction of the nitrogen-fixing species (Leguminosae). A seed mixture was designed consisting of perennial grasses and legumes in proportions similar to those used at the quarry. Four generalists were used: *Dactylis glomerata* L. (Gramineae), *Sanguisorba minor* Scop. (Rosaceae), *Anthyllis vulneraria* L. and *Trifolium repens* L. (Leguminosae). In contrast with the higher number of species often included in hydroseeding mixtures, only these were used due to logistical constraints and the limited range of eligible species. They were selected according to the following criteria: low tendency for dominance (as observed in previous hydroseedings at the quarry site); representation of main functional and structural plant groups (e.g. grasses and legumes); and seed availability. All nine species are present in the Serra da Arrábida plant community (Pedro, 1997) and have been previously used in revegetation actions at the site. Seeds of the generalist species and of *O. natrix* were purchased from nonlocal suppliers in 2008, however instead of *O. natrix*, the provided seeds were actually from an annual species of the same genus (*O. pubescens*, also belonging to the local flora), a fact that was only noticed during the course of the experiment. The seeds of the other four target species were collected from undisturbed areas surrounding the quarry in the summer and autumn of 2008. Preliminary greenhouse tests of all the seed lots on quarry substrate showed germination levels between 43% and 72%.

Seeding density and proportions were similar to those used for hydroseeding in this quarry, but adjustments were made according to the expected germination of the target species (Oliveira et al., 2012). Calculations were based on the number of seeds, rather than on their weight-proportion in the mixture, thus resulting in slightly