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Post-fire and post-quarry rehabilitation successions in Mediterranean-like ecosystems: Implications for ecological restoration

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ABSTRACT

Resilience against sudden changes in the environment is a very desirable trait in plants used for ecosystem restoration. Mediterranean-like vegetation exhibits particularly strong fire resilience. There are two main functional groups of fire-prone species among Mediterranean-like vegetation: seeders and resprouters. Our aims were to describe how the theory of succession after fire relates to rehabilitation and to use this knowledge to improve the results of rehabilitation attempts in Mediterranean-like ecosystems. Eight post-fire (PF) sites, 14 post-rehabilitated (PR) quarry sites and two woodland sites were sampled. Detrended Canonical Correspondence Analysis (DCCA) showed that PF and PR successions were quite different. Both displayed an increasing abundance of resprouters over time, but seeder density increased throughout PR succession and decreased during PF succession. Nine species were common to both successions in all studied stages. The results showed that until 15–21 years of succession, the post-rehabilitation sites had not become as resilient to fires as sites populated by indigenous vegetation due to the lack of a seeder seed bank. However, after 21 years of PR succession, the exponentially increasing seeder population may allow for seed bank formation and thus eventually improve the fire resilience of the site.

1. Introduction

Regions with a Mediterranean climate have a long history of intensive human occupation that has been accompanied by frequent changes in land use and replacement of the original vegetation (Gams et al., 1993; Blondel and Aronson, 1999). Terrestrial vegetation in a Mediterranean-like climate stretches over several areas adjacent to deserts in the western portions of continents. Examples of these regions include parts of coastal California, the Mediterranean basin, southwestern Australia, coastal Chile and austral South Africa. All of these sites have Mediterranean-like vegetation adapted to hot and dry summers and mild and rainy winters (Saunders et al., 1993; Lomolino et al., 2006). Fires and limestone quarries are common disturbance factors in karstic Mediterranean-like ecosystems. Both have been associated with the threat of desertification (Peñuelas et al., 2004; Hanafi and Jauffret, 2008).

These two disturbances differ mainly in duration, intensity, frequency and distribution. Post-fire and post-quarry successions in Mediterranean-like ecosystems initiate under different biotic and abiotic conditions, but when post-quarry restoration activities use indigenous species, later succession is influenced by the resilience traits of vegetation. Here we assume the concept of ecological resilience, that is, the ability of the ecosystem to withstand shocks and to functionally maintain itself through multiple equilibria, which allows for robust, stable landscapes (Folke, 2006). High fire resilience is a widespread characteristic of terrestrial Mediterranean-like ecosystems. Under most burning regimes community structure shifts slightly, and the species composition at a given time after the fire does not change appreciably from one fire cycle to the next (Keeley, 1986). Two basic regeneration strategies have been widely recognized (Keeley and Zedler, 1978): resprouting from below-ground vegetative parts (resprouters), and/or recruitment of seedlings from soil-stored seeds (seeders). The high fire resilience observed in Mediterranean-like vegetation is therefore driven by these two major functional groups of plants (Pausas and Verdú, 2005; Pausas et al., 2006a). The species of each type show different demographic patterns throughout the post-fire succession (Keeley, 1986; Clemente et al., 2004).

On the other hand, quarrying activities result in complete removal of vegetation and propagules, soil depletion, and deep

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changes in topography. Drainage and the physical and chemical erosion of the substrate cause an impoverishment of nutritional and hydric status (Puigdefábregas and Mendizabal, 1998; Clemente et al., 2004), hindering natural germination and establishment of young plants. In the past, quarries were abandoned after extraction, and recovery was left to slow natural processes. Many of these sites are situated either inside natural parks and reserves or near urban centers. Governments have reinforced their reclamation efforts to accelerate vegetative recovery and reintegration into the landscape. In this context, artificial revegetation of abandoned quarries can reduce the negative impact of vacant terraces on the landscape. Mitigation efforts, including restoration, in which the area is returned to the pre-existing ecosystem, or rehabilitation, in which this end-point is only partly achieved, have applied ecological information common to Mediterranean-like ecosystems and are becoming common at these quarry sites (Dixon and Hambler, 1984; Gams et al., 1993; Williams, 1993; Sort and Alcañiz, 1996; Muzzi et al., 1997; Correia et al., 2001; Werner et al., 2001; SER, 2004).

Despite numerous studies that have assessed the ecology of Mediterranean-like ecosystems, essential gaps still exist in critical issues that would guide research on restoration of these ecosystems (Valladares and Gianoli, 2007). Although much ecological information has been published, seed dispersion, succession and functionality in Mediterranean ecosystems remain fundamental concerns for the advancement of restoration practices (Tormo et al., 2006; Wang et al., 2007; Mendez et al., 2008).

The responses of vegetation to environmental factors have created an urgent demand, as well as global effort, mainly related to plant functional traits (Cornelissen et al., 2003). We know that different responses from different plant functional types allow fast regeneration of Mediterranean-like vegetations after fire (e.g. Keeley, 1986). Models simulating Mediterranean-like ecosystem successions based on the response of plant functional types have been used to predict long term dynamics after fire disturbances, most of them based on the post-fire response of two main groups of plants, resprouters and obligate seeders (e.g. Perry and Enright, 2002; Pausas et al., 2006a; Millington et al., 2009).

One of the fundamental questions about the dynamics of Mediterranean-like ecosystems is, how fast and deterministic is the succession? Although long-term studies of succession are still lacking, dynamics, as well as information on the functional status of ecosystems are helpful for identifying biotic and abiotic factors that hinder recovery and for setting priorities on restoration practices. Furthermore, severe perturbations (such as quarrying activities) can lead to parallel series with unpredictable traits and end points, possibly different from those of the expected autosuccession in Mediterranean-like ecosystems (Mendez et al., 2008).

Analyzing different biotic and abiotic conditions affecting post-fire recovery and post-quarry rehabilitation of Mediterranean-like vegetation with a considerable amount of data of chronosequence series from both successions, this study aims to compare the major community types of Arrábida's Mediterranean vegetation that develop either after fires or following quarry rehabilitation and to answer the questions: (i) Are post-fire and post-quarry successions parallel? (ii) Has the most common widespread disturbance of Mediterranean-like ecosystems, fire, potential to interfere with post-quarry succession in rehabilitated areas? (iii) What is the time required to restore fire resilience in post-quarry rehabilitated sites of Mediterranean-like ecosystem? (iv) Can some of the studied, rehabilitated quarried areas be considered restored with the typical resilience of Mediterranean-like vegetation?

2. Materials and methods

2.1. Study area

Our study was performed in Serra da Arrábida Natural Park, where both disturbances, fire and quarrying activities, are present, leading to patchy habitats. The vegetation of Serra da Arrábida Natural Park can assume a seemingly unlimited number of variations, depending on local conditions and human land use history, especially the elapsed time since the last fire. The variety of degradation and regeneration stages found in this landscape yield a distinct mosaic of habitats (Catarino et al., 1982; Clemente et al., 1996).

Arrábida Natural Park is situated in Arrábida Chain, an elongated mountain located on the southern border of the Setubal Peninsula, about 40 km south of Lisbon (Portugal) (from 38°27′ to 38°30′N latitude and 8°55′ to 9°02′W longitude), which reaches its maximum height at Formosinho (501 m) and boasts several tops over 300 m.

Serra da Arrábida is established on Jurassic limestone formations, and soils are classified as Mediterranean red soils (Pedro, 1991). Its complex geomorphology resulted in a strong relief with steep slopes. Due to this strong relief, true soil profiles are almost absent, although better developed soil profiles can be found in forest patches (Catarino et al., 1982).

The Serra da Arrábida has a well-preserved Mediterranean flora with 128 species of shrubs and trees (Catarino et al., 1982), and has been the subject of many geological and botanical studies, mainly by Ribeiro (1986), Pedro (1942), and Braun-Blanquet et al. (1972). The vegetation forms vary from shrubland to woodland (Catarino et al., 1982).

The climate is a Mediterranean type with an oceanic influence and is classified as a sub-humid, warm variant according to Emberger's coefficient (Catarino et al., 1982). The average annual precipitation at the closest meteorological station (Setúbal, about 15 km from Arrábida) is 735 mm, with a pronounced drought from June to August and an average of 30 mm rain per three-month interval. The mean annual temperature is 16 °C, the mean minimum annual temperature of the coldest month is 5.3 °C and the mean maximum temperature for the hottest month is 29.3 °C. Due to the complex topography, different microclimates and soils generate conditions favorable for the development of various types of vegetation. The native vegetation belongs to *querci* communities (Catarino et al., 1982).

The major disturbances affecting vegetation within this area are wildfires and quarry activities. The area has a long tradition of limestone quarrying; the largest quarry is at Outão, in the eastern part of the Arrábida chain, next to a concrete factory. To compare the communities found at Arrábida sites subjected to different recovery regimes (time since fire or post-rehabilitation quarrying), previously studied sites were selected for further analysis. We compared communities comprising a chronosequence from 2 to 80 years and from 3 to 21 years after fire and quarry rehabilitation, respectively (sites A–D) (Table 1), as well as woodlands in protected valleys that display late successional vegetation, more than 100 years without fire (sites E and F). From the starting point of succession, all selected sites remained undisturbed over time and had the same planting procedures.

Sites A–C burned in 1983, 1986 and 1991, respectively, and covered with maquis and garrigue vegetation dominated by *Quercus coccifera*, *Phillyrea angustifolia*, *Pistacia lentiscus*, *Rosmarinus officinalis*, *Arbutus unedo*, *Erica arborea*, *Lavandula luisieri* and several *Cistus* species. *Juniperus phoenicea* is often present as well, especially on south-facing slopes (Table 1).

Site D is located in one of the largest limestone quarries of this region (SECIL, Outão), with a total area of 482.7 ha. About 86 ha are used for quarrying limestone, which is processed in a