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Recovering *Quercus* species on reclaimed coal wastes using native shrubs as restoration nurse plants

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ABSTRACT

Facilitative interactions among plants enable a species persist in stressful environments, but its use as a restoration technique of plant cover in degraded man-made ecosystems requires more accuracy. Here, a two-year field experiment was conducted to determine if native colonizer shrubs (*Genista florida* and *Cytisus scoparius*) used as nurse plants enhance *Quercus petraea* and *Quercus pyrenaica* reintroduction in reclaimed open-cast coal mines in Northern Spain. Of each tree species, 400 seedlings and 940 acorns were planted under four different treatments combining the influence of nurse shrubs and herbivory/predation upon *Quercus* seedlings and acorns. In each experiment, acorn emergence and seedling survival and growth were monitored. Shrubs enhanced seedling survival and growth and acorn emergence, in comparison with open spaces. Seedling survival was <20% in open areas and >90% under shrubs after the first summer. Acorn predation was a limitation, but not seedling herbivory. Seedling survival and growth were greater for *Q. pyrenaica* than *Q. petraea*, while *Q. petraea* showed better acorn emergence and survival of emerged acorns. The use of shrubs as nurse plants to improve environmental conditions is promising for the effective reintroduction of late successional species in reclaimed mined sites. The best results are obtained through *Q. pyrenaica* seedlings under shrubs. This avoids problems such as acorn predation and germination failure. The ontogenetic stage and the stress tolerance of the target species should be taken in consideration in order to increase the effectiveness of this restoration technique.

1. Introduction

Facilitation in plant communities encompasses non-trophic, beneficial interactions between organisms (Brooker et al., 2008). In the last years, facilitation is achieving its own field of research, due to its contribution to our understanding of ecological systems, ecosystem restoration and its potential evolutionary impacts among other topics (Brooker and Callaway, 2009). However, there are still a lot of uncertainties about how facilitative interactions work (Brooker et al., 2008), especially in novel ecosystems created due to restoration of man-made impacts (Hobbs et al., 2009).

The plant–plant interaction outcome is a complex process which depends on many factors, such as species identity, environment and the life stage of the interacting organisms among others (Gómez-Aparicio et al., 2004; Prévosto et al., 2012). Conceptual models explaining facilitation (see Bertness and Callaway (1994) for the stress-gradient hypothesis, and Maestre and Cortina (2004) or Michalet et al. (2006) for the hump-shaped hypothesis) do not still represent the reality of the processes properly (Brooker et al., 2008; López et al., 2013). Although it is still not clear when neighbour effects will be positive, they are more probable in limiting habitats such as drylands (Brooker et al., 2008), or when the site is further from the species niche optimum (Gross et al., 2010; Liancourt et al., 2005), like in new-ecosystems such as reclaimed mines. In fact, facilitation processes enable the creation of new niche spaces in stressful environments for species establishment (Bruno et al., 2003).

Recent studies have suggested that facilitation processes can be a tool to enhance plant restoration in disturbed environments, where harsh environmental conditions or herbivory are major constraints (Brooker et al., 2008). The usage of shrubs as restoration tools under the Mediterranean conditions of the

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Iberian Peninsula is well-known (e.g. Castro et al., 2002; Gómez-Aparicio et al., 2004, 2008). Indeed, this has been the topic of two meta-analyses and a review already (Gómez-Aparicio, 2009; Padilla and Pugnaire, 2006; Verdú et al., 2012). However, although some progress have also been achieved by testing facilitation processes as restoration technique in traditional anthropogenic systems, such as grasslands or croplands (Cuesta et al., 2010; Pueyo et al., 2009; Soliveres et al., 2013), more knowledge is needed in more drastically man-disturbed ecosystems, such as open-cast mines. An efficient use of facilitation in restoration projects requires more accuracy about the results of particular target and nurse species interactions under specific problematic conditions. Thus, widening the range of species and environments considered in the facilitative restoration experiments seems necessary.

Coal mining is an extended activity in Northwest Spain (Alday et al., 2011a), where *Quercus petraea* at its southernmost distribution limit and *Quercus pyrenaica* almost endemic of Iberian Peninsula (do Amaral Franco, 1990) are major forest species. The restoration of these native forest species in mined sites is very important for the provision and maintenance of ecological functions, biodiversity and landscape values (Alday et al., 2011b). In recent times, the most common mine restoration approach within this region has been to reshape the mined landform, improve the baseline soil-forming materials, and then introduce herbaceous seeds by hydrooseeding (González-Alday et al., 2008). However, the recovery in these mine sites of late-successional broadleaf species present before the mining operations, such as *Q. petraea* and *Q. pyrenaica*, is a hard task (Alday et al., 2014). It is well known that in Mediterranean ecosystems, forest species regeneration suffers from two major constrains: (i) summer drought (Pugnaire et al., 2011), being increased in reclaimed mined sites by a lack of soil structure such as in forest systems (Alday et al., 2012), and (ii) herbivory, which can occur through trampling and browsing by livestock and wild ungulates, but also by means of acorn predation for *Quercus* species (see Gómez et al., 2003; Smit et al., 2008). In order to overcome these two constraints, facilitation mediated by shrubs has been proposed for the reforestation of Mediterranean systems (Castro et al., 2006; Gómez-Aparicio et al., 2004; Rey et al., 2009), which could also be implemented for mining sites (see Alday et al., 2014). Facilitation mediated by shrubs can help to reduce summer drought stress (Smit et al., 2008), improving soil properties (Pugnaire et al., 2004), and providing protection against herbivory (Smit et al., 2006). Thus, in the present study we assessed the influence of nurse shrubs during two growing seasons on reforested seedlings and acorns of two *Quercus* species (*Q. petraea* and *Q. pyrenaica*) in a reclaimed open-cast coal mine. The aim of the experiment was to identify the effectiveness of using native colonizer shrubs as nurse plants to reintroduce the two main tree species present before the mining operations. It must be considered that in these mined sites the summer drought effects are increased by the lack of developed soil, restricting the development of *Quercus* species. Moreover, herbivory usually reduces the establishment success of these species. Therefore, the use of shrubs as nurse plants might help to decrease these constrains. Here, our hypotheses were: (1) the effect of shrubs and enclosures would be positive for the survival of the two *Quercus* species seedlings; (2) shrubs and enclosures would also be beneficial for seedling growth; (3) acorn emergence and subsequent seedling survival of the two *Quercus* species would be positively affected by shrubs and mesh protection in the mine as by mesh protection in the forest microhabitat; and (4) different patterns between species for the studied parameters would expect to be found according to their different ecological requirements.

2. Materials and methods

2.1. Site description and mine restoration treatment

The experiment was located in a 7 ha reclaimed open-cast coal mine near Guardo, Palencia, Northern Spain (latitude 42°48′N, longitude 4°52′W, ca. 1200 m a.s.l.). The climate is sub-humid Mediterranean (Alday et al., 2011a), with an annual mean temperature of 9.3 °C and average annual precipitation of 977 mm (1971–2007 temperature means and 1932–2007 precipitation means from Guardo meteorological station). Rainfall is not distributed regularly throughout the year, with a pronounced dry season in summer (July and August). In addition, precipitations of the study years were rather different. Precipitation from September 2010 to June 2011 reached 778.2 mm (80.2 mm in July–August), whereas only 567.8 mm were registered from September 2011 to June 2012 (26.5 mm in July–August). The vegetation surrounding the mine consisted of broad-leaved woodlands dominated by *Q. pyrenaica* and *Q. petraea*, and some shrubs such as *Cytisus scoparius* and *Genista florida*.

The open-cast mine was reclaimed in October 2000, using a combination of topsoil addition with a very poor seed bank (González-Alday et al., 2009), followed by hydroseeding with a grassland species mixture (for further reclamation details see Alday et al., 2011a). The reclaimed area had a patchy natural colonization of shrubs, mainly *C. scoparius* and *G. florida*, being grazed freely by animals (deer, wild boar, cattle and horses). The current soil texture is described as clay loam with a pH of 6.5 and with an effective depth of 10–15 cm (López-Marcos, 2012).

2.2. Experimental design and data collection

2.2.1. Seedlings experiment

The experimental set-up in the mine area consisted of four main-plots (30 m × 30 m, flat area): two fenced main-plots and two no-fenced main-plots with shrub/open subplots into each one, to asses the combined influence of nurse shrubs and grazing upon *Quercus* seedlings. The treatments were: (a) no-grazing and no-shrubs (fenced open areas with no shrub cover, OF); (b) no-grazing and shrub cover (fenced areas under shrubs, SF); (c) grazing and no-shrubs (no-fenced open areas, ON); (d) grazing and shrub cover (no-fenced areas under shrubs, SN). The species used as nurse shrubs were two natural mine sites colonizers, i.e. *C. scoparius* and *G. florida*, with similar vertical structure (mean height 222 ± 6.6 cm). Both species are non-thorny leguminous shrubs, 2–2.5 m tall, capable of actively fixing the atmospheric nitrogen (Talavera et al., 1999). At the same time, both species are considered into the same functional group sharing common characteristics (i.e. structure and leaf phenology), and they usually co-exist in the mined areas where they regenerate very mixed. As a consequence and based on the methodology carried out in studies using similar functional group species (Gómez-Aparicio et al., 2004), they were not differentiated in the experiment. The enclosures consisted of wire mesh (2 m high, mesh hole: 5 cm width × 15 cm length) fixed through poles and were constructed to prevent ungulates and rabbits grazing the sub-plots.

Within each main-plot, ten sub-plots (five under shrubs and five in open areas) were allocated randomly ca. 4 m apart from each other (each sub-plot ca. 2 m × 2 m; when sub-plots were under shrubs they gathered 2–3 shrubs). For example, in a fenced main-plot five OF sub-plots and five SF sub-plots were located, whereas in a non-fenced main plot five ON sub-plots and five SN sub-plots were set. In each sub-plot 10 tagged seedlings (one-year-old) of each species (400 seedlings of *Q. petraea* and *Q. pyrenaica* in total) were planted in March 2011. Seedlings (Cordillera Cantábrica Provenance), grown in cylindrical pots (type: S.L 35, 235 cm^3, 16 cm