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Shrub-induced understory vegetation changes in reclaimed mine sites

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ABSTRACT

Despite advances in post-mine sites reclamation methods in the recent years, restoration treatments are not always successful in creating self-sustaining ecosystems. Occasionally, vegetation remains in a state of arrested succession where conditions are hostile for many late-successional target species. An in-depth study of the environmental factors that control vegetation dynamics on reclaimed mined sites may, therefore, improve the methods for late-successional species introduction, rehabilitating the landscape effectively. In this context, using 12 reclaimed mines in northern Spain colonized mainly by two leguminous shrubs (*Cytisus scoparius* and *Genista florida*) we explored: (i) how organic-matter thickness, bryophyte cover and plant diversity and cover attributes change across a gradient of dominant shrub cover/volume, and (ii) how the understorey plant species were associated with these shrub canopies. We hypothesized that shrub growth modified the micro-climatic conditions and influenced the understorey plant species either by facilitation or competition. The results reveal an important positive effect of shrub volume on micro-environmental conditions, such as organic matter-thickness and bryophyte cover, creating environmental heterogeneity underneath larger shrub canopies. At the same time, the shrub volume gradient was also associated with species composition; there was a shift in plant composition from a greater abundance of annual, light-demanding species and legumes in open conditions towards water-requiring, shade-adapted, and broad-leaved species under greater shrub volumes. In contrast, there were no shrub effects in diversity and evenness. The analysis of individual species indicates that 18 out of the 40 most frequent species showed a significant association with shrub volume. Assessment of the species optima associated with shrub colonization allows the development of new species mixtures that are tailored to individual site conditions to favour desired plant communities. Moreover, it seems that shrubs acted as ecosystem engineers in these reclaimed mined sites. Natural shrub encroachment has been shown in this study as one means through which these ecosystems can be modified to create heterogeneity in micro-environmental conditions and hence inducing greater overall diversity.

1. Introduction

Open-cast mining is a major environmental disturbance that often leaves the landscape with no vegetation and very poor soil-forming material for subsequent ecosystem development (Herath et al., 2009). As a consequence, open-cast mining rehabilitation is presented as an ideal model system for the study of ecosystem development starting from near point zero (Hüttl and Weber, 2001; Marrs and Bradshaw, 1993). In the search for appropriate restoration strategies of these sites, a key focus has been the identification of mechanisms that both facilitate and prevent vegetation establishment and development (Pallavicini et al., 2013). Recently, a number of studies have identified that, after initial reclamation activity, vegetation remains in early-successional stages or in a state of arrested succession where conditions are hostile for the colonisation of many late-successional target species (Boyes et al., 2011). An in-depth study of the mechanisms and environmental factors that control vegetation dynamics of such ecosystems may, therefore, advance the reclamation methods in order to rehabilitate the landscape quickly and effectively (Alday et al., 2010; Martínez-Ruiz and Marrs, 2007).

In northern Spain, particularly in the provinces of León and Palencia, open-cast coal mining has caused an extensive impact on the landscape, affecting ca. 5000 ha of land (Alday et al., 2011a). Over the last 20 years, there has been much progress in post-mining restoration and reclamation methods, especially focusing

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on plant community establishment such as top-soiling, improvement of seed mixtures or tree seedling establishment protocols (Alday et al., 2012; Martínez-Ruiz et al., 2013). However, not all areas subjected to some form of reclamation treatment were always successful in creating self-sustaining ecosystems. Alday et al. (2011b) found that the establishment of plant species over raw coal wastes was very slow even after 40 years, producing unstable communities. Therefore, there are still many questions unresolved in relation to the drivers structuring these plant communities. For example, it has been observed that vegetation development in these reclaimed sites is often accompanied by an increase of shrub density and encroachment (Alday et al., 2011b,c, c). These processes have been linked to alterations in the spatial pattern of soil resources and ecosystem function (Schlesinger and Pilmanis, 1998). However, the effects of shrub colonization can vary widely from drastic reductions in plant biomass and species richness (Archer, 2010) to just the opposite trends, depending on the species and climate involved (Eldridge et al., 2011). Nevertheless, although this process has been studied in large-scale environments (Pugnaire et al., 2011) or in several degraded ecosystems with secondary succession arrested (Gómez-Aparicio et al., 2004; Stradic et al., 2014), its possible translation and influence on small-scale processes in reclaimed mines are still little explored.

In general, shrubs influence the establishment of associated understorey plants through modifying micro-environmental conditions (Pajunen et al., 2012; Palaniappan et al., 1979). On one hand, shrubs may promote islands of fertility around them (Pugnaire et al., 1996) and facilitate plant establishment and subsequent growth (Schlesinger and Pilmanis, 1998) by accumulating water, soil nutrients and organic matter under their canopies whilst also providing protection from herbivores (Pajunen et al., 2012; Palaniappan et al., 1979). In contrast, established shrubs can also play the opposite role and exclude understorey species either by allelopathy or by reducing the amount of solar radiation or available water (Fargione and Tilman, 2003). This decrease in soil radiation may also influence regeneration processes on seed-dependent species, because dormancy breakage and seed germination is modulated in some species by daily soil temperature fluctuation produced by solar incidence (Santana et al., 2013). Micro-environment modification can also be associated to the proliferation of bryophytes in moist sites (Hettenbergerová et al., 2013), which could also exclude the establishment of new seedling (Lloret, 1994). There has been several studies during the last years addressing (i) the changes in spatial patterns of micro-environmental conditions beneath shrubs (e.g. Pugnaire et al., 1996; Giladi et al., 2013), (ii) the facilitative effects of shrubs on stressful systems (Holzapfel and Mahall, 1999) and (iii) differing response of contrasting functional groups to shrubs (Butterfield and Briggs, 2011). However, there is a lack of similar studies over coal mining reclamation areas, being of fundamental importance for developing future reclamation plans and ecosystem engineering techniques. Further efforts are needed in order to disentangle possible impacts of shrub canopies on diversity and to identify species and functional groups suitable for each specific condition.

In this context, we explored the relationships between shrub canopies and understorey plant species with the objective of designing improved and more effective restoration strategies. Here, we analyzed the shrub canopy impact on reclaimed coal mines in northern Spain. In these mined sites, shrub colonization was produced mainly by two non-thorny, leguminous shrubs with similar vertical structure: *Cytisus scoparius* and *Genista florida* (Alday et al., 2011a). Previous studies on these sites have demonstrated that these shrubs have an important effect on herbaceous richness and biomass accumulation patterns of different functional plant species groups (Pallavicini et al., 2013). However, the individual species responses to shrub interactions and the micro-scale changes produced by shrubs are unexplored, and these are fundamental for gaining knowledge about species performance and restoration of mined land. Here, therefore, we hypothesized that shrub growth, measured as above-ground volume, modified the micro-climate under the canopy and/or the spatial distribution of resources, and hence influenced understorey plant species either by facilitation or competition. Specifically, we asked the following questions: (i) What was the impact of natural leguminous shrub development on ecosystem properties such as organic-matter thickness, bryophyte cover and plant species diversity and cover? And (ii) How were the understorey plant species and their functional groups associated with shrub canopies? It was expected that this approach would lead to identify shrub-ecosystem effects and plant-shrub interaction patterns that might inform reclamation work in similar areas.

2. Materials and methods

2.1. Site description and selection

The study was conducted into the 'Guardo-Cervera' coal basin in the north-west of the Palencia province, northern Spain (42°48′–42°50′N, 4°44′–4°53′W). Within this basin, 12 mines relatively close together (within 16 km^2) were selected for the study, thus minimizing geographical and climatic variability. All selected mines were reclaimed using the same methodology and had a similar successional stage; i.e. age since reclamation from 17 to 25 years (8 years span), in order to reduce the possible effect of vegetation age influencing the results. For more details in age assignment and vegetation change through time see Alday et al. (2011a). The 12 study sites ranged from 1 to 3 ha, and have been restored using a combination of topsoil addition, containing a very poor seed bank (González-Alday et al., 2009), followed by hydroseeding with a grassland species mixture including grasses and legumes (81:19 by weight; 200 kg ha^{-1}), such as *Lolium perenne*,*Lotus corniculatus*, *Medicago sativa*, *Phleum pratense*, *Poa pratensis*, *Trifolium pratense* and *Trifolium repens*. The altitude range was also relatively small (1165–1419 m a.s.l.). The climate is sub-humid Mediterranean with an annual mean temperature of 9 °C, an average annual precipitation of 980 mm, and with a pronounced dry season in summer (July–August). The soil covering the reclaimed mines had little edaphic structure; it had a clay loam texture, a mean pH of 5.8 ± 0.24 and organic matter content of $7.56\% \pm 0.50$. There were few differences between the mines at the time of sampling in soil physical-chemical properties or micro-nutrients concentrations (Alday et al., 2011a). The natural vegetation surrounding these mines is a mosaic of *Quercus pyrenaica* and *Q. petraea* woodland, and remnants of natural shrublands, dominated by *G. florida* and *C. scoparius* (Alday et al., 2011a).

The 12 reclaimed mines had a patchy natural colonization of *C. scoparius* and *G. florida*, producing a shrub abundance gradient that ranged from 36% of mine cover to 80% on 25 years old mines. Both species have a ballistic type seed-dispersal mechanism (Malo, 2004; Alday et al., 2011b), that favours the seed dispersal on mined sites from the forest border. Simultaneously, in these areas both species are grazed, in low-intensity, freely by animals (e.g. deer, cattle and horses); therefore, a zoochory seed-dispersal mechanism is also common. At the same time, both species are non-thorny leguminous shrubs, with similar vertical structure and capable of actively fix the atmospheric nitrogen (Talavera et al., 1999). They prefer sunny sites to growth and are good colonizers of degraded areas (Oria de Rueda, 2003). Therefore, both species are considered into the same functional group sharing common