

A COENOCLINE OF WOODY COLONIZER SPECIES IN RECLAIMED SURFACE COAL MINES IN SPAIN

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Abstract: In this study, we combined the analysis of a coenocline with HOF modelling of species behaviour to describe colonization patterns of woody species on reclaimed coal wastes in northern Spain. We hypothesize that fine-scale variation in abiotic factors along the forest-mine gradient affects colonization pattern of woody species. To understand these factors, we analysed changes in the abundance of the main woody colonizers according to the distance from the forest-mine border. Our results showed how the primary coenocline extracted from DCA1 reflected a gradient in environmental conditions influencing the species composition of woody plant communities, from the more shade, moist and dense forest on acid and rich soils to the open, dry and oligotrophic grassland. The colonization pattern of woody species is affected by the fine-scale variation in abiotic factors, such as the increase in pH, P, light, and the decrease in K, N, C/N, organic matter and soil moisture, from the forest to the mine. Most species HOF modelled showed monotone responses with decreasing trends along the environmental gradient from the forest to the mine, being *Quercus petraea* the species clearly dominant in the forest. On the contrary, *Cytisus scoparius* and *Genista florida* colonize intensely the mine area, reaching the maximum abundance around 14 and 11 m of distance to the forest boundary, respectively. We conclude that the composition of woody species in the forest is not a good predictor of the colonizing intensity, not even of the species composition in the mine area.

Keywords: Mediterranean deciduous forests, extraction of soils and minerals, spontaneous succession, reclamation of industrial and polluted areas.

Introduction

In northern Palencia, Spain, as in other areas in the world, opencast coal mining plays an important role in the dynamics of landscape fragmentation (Hardt & Forman 1989). As a result, a spatial variation in the physical and biological structure of plant communities is produced, since the restored coal mines become scars healing in a forest matrix (Gómez-Milder 2006). The process is strongly affected by interactions between the forest matrix and the initial patch of herbaceous vegetation (López-Barrera et al. 2007), but also by the new environmental gradient emerged (Williams-Linera 1990) from the forest to the open mined area. In this study, the combined analysis of a coenocline with HOF modelling of species behaviour is used for describing colonization patterns of woody species on reclaimed coal wastes in northern Spain. We hypothesize that fine-scale variation in abiotic factors along the forest-mine gradient affects colonization pattern of woody species. To understand these factors, we analysed changes in the floristic composition and in the abundance of the main woody colonizers according to the distance from the forest-mine border.

Materials and methods

This study examines three close sites, all surface-mined for coal, in the province of Palencia (El Sestil; 1110 m a.s.l.; 42°47'N, 4°50'W). The climate is sub-humid Mediterranean (MAPA, 1991); with a rainy season in autumn and spring and dry season in July through August. The area surrounding the sites is forested with relatively diverse vegetation associated to the sessile oak (*Quercus petraea*) forests. Study sites were reclaimed around 15 years before our autumn 2005 sampling (see Gómez-Milder 2006).

A total of 23 transects 74 m long, extending 63 m onto the mine site and 11 m into the forest, were laid out perpendicular to the forest-mine boundary (Hardt & Forman 1989). Nineteen 2x2 m plots, centered at 4 m intervals along each transect were sampled. Within each 2x2 m sample plot, the number of individuals of all woody plants was censused; only 19 species were recorded through the study. Separate stems at ground level were recorded as individuals. Soil was sampled to a depth of 15 cm with a soil auger (diameter 3 cm) at one random point near each of the established 2x2m plots. The 23 soil samples from the same position along transects were bulked and composited by position; hence there were 19 soil samples to evaluate potential differences in soil characteristics along the forest–mine gradient.

DCA was used to extract the primary ordination axes or coenocline. Later, sample ordination scores were tested for a significant correlation with the explanatory variables by means of Kendall's τ . The explanatory variables considered in this study were soil parameters (pH, organic matter, N, P, K and C/N) and the unweighted Ellenberg indicator values (Ellenberg et al. 1991) for light (L) and soil moisture (F), calculated by averaging the available indicator values for the species present in each plot. Species responses along the DCA1 coenocline were modelled by Huisman-Olf-Fresco models (Huisman et al. 1993), which are a means of describing species responses, which may result from both environmental conditions and intra- and inter-specific interactions. The AIC statistics (Akaike 1973) was used to select the most appropriate response model for each species; smaller values indicate better models. DCA was carried out using the CANOCO 4.5, with standard options and no downweighting of rare species, and HOF models using the GRAVY package implemented in the R software environment (v. 2.4.1). Correlation analyses were carried out using STATISTICA software v. 5.1.

Results and discussion

The eigenvalues (λ) for the first four DCA axes were 0.85, 0.40, 0.29 and 0.22, respectively. The Kendall's τ coefficient indicated a highly significant negative correlation ($p < 0.001$) between plot scores along DCA1 and their belonging to the forest or mine area ($\tau = -0.72$), and with their distance to the forest boundary ($\tau = -0.59$). This suggests a gradient strongly associated with environment type (Kollman & Schill 1996), which influences the species composition of woody plant communities (Fig. 1b), although modified by the effect of the distance from a propagules source (Müller et al. 2007). The plots in the forest and those in the mine area but close to the forest boundary cluster together on the right of the diagram, whereas plots in the open mine area cluster on the left (Fig. 1a). Species composition gradually changes from the forest to the mine (Fig. 1b); from those exclusive of the forest (Erar, Livu, Prsp, Masy, Vamy, Vila) to those more abundant in the open mine area (Cysc, Gefl).

The Kendall's τ coefficient also indicated a highly significant positive correlation ($p < 0.001$) between plot scores along DCA1 and organic matter ($\tau = 0.56$), potassium ($\tau = 0.57$), nitrogen ($\tau = 0.41$), C/N ratio ($\tau = 0.59$), and unweighted average Ellenberg value of soil moisture ($\tau = 0.51$); whereas pH ($\tau = -0.64$), phosphorus ($\tau = -0.40$) and unweighted average Ellenberg value of light ($\tau = -0.80$) were negatively correlated ($p < 0.001$) with DCA1. Therefore, variations in the species composition and number of colonizing stems produced along DCA1 (primary coenocline) can be caused by changes in soil conditions (Chen et al. 1992) and light (Rodríguez et al. 2007). Thus,

colonization is not only determined by distance itself, but it is also a result of the existing gradient of these parameters (soil conditions and light) that runs perpendicular to the boundary, from the forest to the mine.

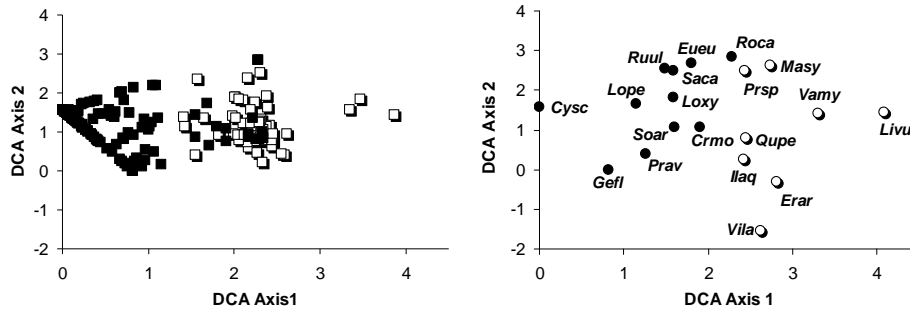


Figure 1. DCA ordination of (a) 437 plots (19 plots for each of 23 transects), full and empty symbols refer to plots belonging to mine area or forest edge, respectively; and (b) 19 woody species, listed by first two letters of genus and species name. Species codes: *Crataegus monogyna* (Crmo), *Cytisus scoparius* (Cysc), *Erica arborea* (Erar), *Euonymus europaeus* (Eueu), *Genista florida* (Geff), *Ilex aquifolium* (Ilaq), *Lonicera periclymenum* (Lope), *L. xylosteum* (Loxy), *Ligustrum vulgare* (Livu), *Malus sylvestris* (Masy), *Prunus spinosa* (Prsp), *Prunus avium* (Prav), *Quercus petraea* (Qupe), *Rosa canina* (Roca), *Rubus ulmifolius* (Ruul), *Salix caprea* (Saca), *Sorbus aria* (Soar), *Vaccinium myrtillus* (Vamy) and *Viburnum lantana* (Vila).

Most of the species HOF modelled (Qupe, Roca, Ruul, Crmo, Eueu, Ilaq, Soar) showed monotone responses with decreasing trends (HOF model II; Fig. 2) along the environmental gradient from the forest to the open mined area. Species of this group had high abundances in the forest, but as distance to the forest boundary increased the number of colonizing stems decreased, at a higher rate in the first meters of distance to the forest boundary. *Quercus petraea*, belonging to this group, is the dominant species in the forest. As a late successional and forest specialist species probably shows lower acclimation potential to increasing light conditions (Strauss-DeBenedetti & Bazzaz 1991), which reduces its ability to establish in open spaces even if acorns managed to arrive. However, light is not the only factor determining this pattern, edaphic factors also have an important influence on forest regeneration (Jose et al. 1996).

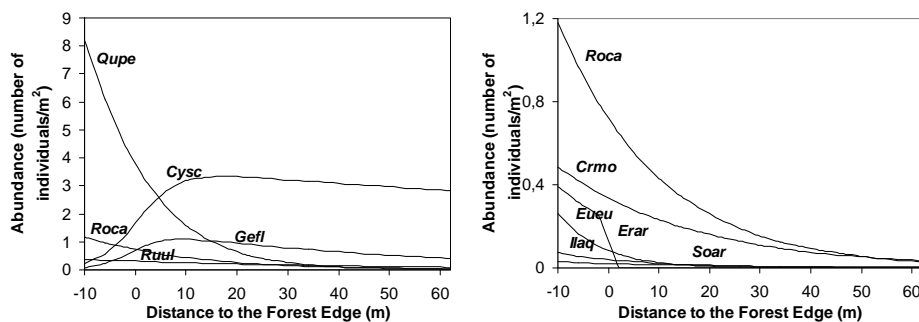


Figure 2. HOF-derived response curves showing the response of the most common species, relative to the environmental gradient from the forest to the mine. Graphs separated for clarity. For species codes see Fig. 1

On the contrary, species not especially abundant in the forest such as *C. scoparius* and *G. florida* colonize more intensely the mine area, probably because they are adapted to lower soil moisture and nutrients, and higher light-availability conditions (Jose et al. 1994). The rest of species, with a not very high abundance in the forest, do not colonize intensely the mine area.

Conclusions

The composition of woody species in the forest is not a good predictor of the colonizing intensity, not even of the species composition in the mine area. It is necessary to consider the spatial pattern of recruitment in order to gather accurate information about the biotic and abiotic factors limiting plant regeneration in Mediterranean ecosystems.

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