Forest edge shape influence in woody species colonization: application in coal wastes restoration

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Abstract: Edge shape influence and ecological implications between two vegetation patches with high contrast were analyzed: grassland surged in a reclaimed opencast coal mine (Palencia, Northern Spain), and the adjacent sessile oak forest. To that purpose, woody species colonization and browsing traces were measured in 23 transects, that were laid out perpendicular to the forest-mine boundary and classified attending to their shape (concave, convex, and straight). The results obtained showed that reclaimed coal mines were colonized from the forest edge by few woody species, whose colonization intensity decreased as distance to the edge increased and differed depending on the edge shape (being more intense in concave edges than in convex edges). Woody species predominating in the forest were *Quercus petraea* and *Rosa canina* and in the mine *Cytisus scoparius* and *Genista florida*. The highest browsing intensity and frequency was concentrated in the initial meters of distance to the forest, being highest in convex edges, on the contrary to other author's results. In general, edge shape seems to be the main factor affecting natural woody colonization of the mine area. Therefore, planting trees and shrubs along the forest edge to produce concavities, and accentuate those less marked, could favour forest revegetation in the reclaimed mine.

Keywords: Mediterranean deciduous forests, woody plants colonization, fragmentation, edge shape, browsing, spontaneous succession

Introduction

Boundaries between different ecosystems or landscape elements have important consequences for many ecological processes, as they mediate the rates of flow of organisms and matter. How edges mediate these fluxes is determined by edge permeability. Edge permeability, determined by different forest edge types, has major implications in terms of forest conservation and regeneration, as for wildlife management (López-Barrera 2004; López-Barrera et al.,2005).

Edge shape can be widely varied (Forman & Moore 1992) and affects doubtless ecological processes and dynamics (Forman & Moore 1992; Forman 1995). Among other aspects, it can determine patch expansion or contraction (Forman & Godron 1986), because patch shapes interdigitate with adjacent patch shapes, and interact significantly with the orientation of directional forces in the landscape, such as wind and species dispersal from source areas. Therefore, edge characteristics have a strong potential to be used in the restoration of degraded areas. Taking advantage of ecotone location and creation of new ecotones we can collaborate with nature in its own recovery (Martín-Ovelleiro 2001). Therefore, these new area of knowledge can offer strong possibilities for landscape conservation (Murcia 1995) and management of degraded areas due to coal mining as in Northern Palencia.

In this paper we will examine the woody colonization of mines in Northern Palencia (Spain) to evaluate the ecological significance of edge shape between two patches with contrasting vegetation (grassland and forest). We hypothesize that: (1) edge shape affects distance and colonization intensity; (2) Species composition of the colonizing stems reflects the species composition of the forest edge; and, (3) herbivore browsing is concentrated along the edge of the patch and plays a key role in determining colonization patterns.

Materials and methods

The study was carried out in an opencast coal mine reclaimed approximately 15 years before our autumn 2005 sampling (see Gómez-Milder 2006). 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 mine is forested with relatively diverse vegetation associated to the sessile oak (*Quercus petraea*) forests.

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 to the forest-mine area (Hardt & Forman 1989). For each transect the shape of the forest-mine edge was recorded as concave (5 transects), convex (4 transect) or straight (14 transects) in relation to the forest, assuming that a convex edge is a projection of the forest vegetation into the grass-vegetated mine. Nineteen 2x2 m plots, centered at 4 m intervals along each transect, were sampled, recording the number of individuals of all woody plants, and the number of individual stems with browsing traces. Separate stems at ground level were recorded as individuals.

Statistical analysis consisted of: basic data description, analysis of variance and regressions to emphasize the differences with statistical significance. Analysis of variance and correlations were calculated using SPSS v.11.5.1 package. To fit the best models to describe the influence of distance and edge shape on the colonization intensity we calculated regressions (GLM models) using the R package (R Development Core Team; http://www.r-project.org/).

Results and discussion

The natural colonization of the mine area by woody species present in the forest edge is relatively scarce for an area reclaimed approximately 15 years before sampling. Only 12 woody colonizing species were censured, as in a previous study in a nearby similar area (Vergel-Otero 2002), opposite to the 22 found by Hardt & Forman (1989) in a similar study in the United States. Moreover, only six of woody colonizers accounted for more than 2% of all colonizing individuals and they were taken into consideration in the data analysis (*Cytisus scoparius*, *Genista florida*, *Quercus petraea*, *Rosa canina*, *Rubus ulmifolius* y *Crataegus monogyna*). Colonization scarcity could be due to the intrinsic characteristics of the species, but also to a low nutrient availability in the soil (Bradshaw et al. 1982) or its barely depth. On the other hand, the success in the woody species establishment depends on a good germination and pre-reproductive mortality that, at the same time, are strongly determined by abiotic factors variability (Williams-Linera 1990). However, it is possible that the species that are active colonizers of the mine have the broadest niche widths, due to their tolerance to different light regimes and their persistence under deep shadow as subordinate woody species in either rich or poor forest soils (Lawesson & Oksanen 2002).

Woody colonization intensity decreases as distance to the forest edge increases (Fig. 1a), as found by other authors (Hardt & Forman 1989; Vergel-Otero 2002), being the logarithm model the best fitted. This is likely due to particular characteristics of ecotones, such as: higher humidity, diversity and richness of edafic fauna, higher biological activity which generates a higher rate of organic matter degradation, higher rate of soil formation and stabilization, etc. (Jordana et al. 1996), that generate an increase in biomass and shrub density in the forest edge. However, trends differ depending on the species studied, possibly due to their expansion mechanisms (Hardt & Forman 1989). *Q. petraea* (ANOVA: d.f. = 15; F = 11,31; p<0,001) is only found colonizing the initial 5 meters of distance to the forest edge. *C. scoparius* colonization trend increases up to 13 m of distance to the edge and afterwards it starts decreasing; this particular trend impedes finding differences with statistical significance depending on the distance to the edge (ANOVA: d.f. = 15; F = 1,23; p=0,25). The other four species show a soft decreasing trend as distance to the forest edge increases; Of these four species, *G. florida* (ANOVA: d.f. = 15; F = 2,68; p<0,001) is the one that accounted for the higher presence of colonizing individual stems in the areas that are farther away from the forest edge.

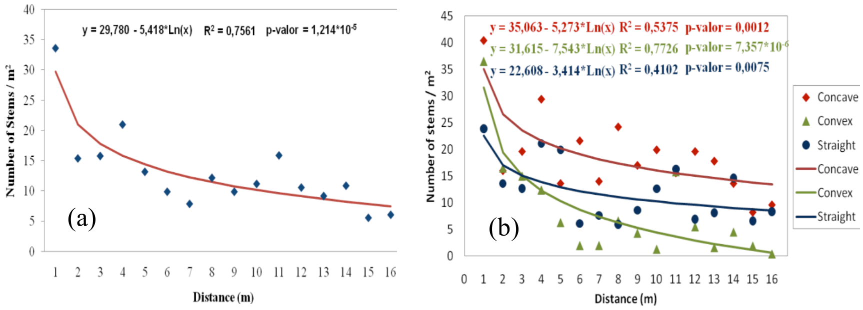

Figure 1. (a) Woody colonization intensity as a whole depending on the distance to the forest edge and the best model fitted; (b) Expression of the best adjustment for woody colonization intensity in the three types of forest edge shape depending on the distance to de forest edge.

Colonization intensity also differs depending on the type of edge (Fig. 1b); in concave edges intensity is higher, being least in convex edges and straight edges occupy an intermediate position. The same results were found by Hardt & Forman (1989). In concave edges microclimatic conditions are better (Forman 1995) than in convex edges, because they are exposed on three sides to climatic harshness. Moreover, the results obtained suggest the existence of a decreasing trend as distance to the forest edge increases, having found statistical significance for concave and straight edges, and probably significant for convex edges. The logarithm model is the expression of the best adjustment for the three types of forest edge shape (Fig. 1b), decreasing colonization in a more intense way in the first 5 m of distance to the forest edge.

In the forest edge the woody species most affected by browsing were *Quercus petraea* which accounted for 97% of all individuals affected, and *Vaccinum myrtillus* that accounted for 2%. In the mine, however, *Q. petraea* (67%) and *Crataegus monogyna* (28%) were the species with the higher number of individual stems with traces of browsing. Therefore, the species with the higher percentage of individual stems affected by browsing, in all the area sampled was *Quercus petraea*. The highest browsing intensity and frequency was concentrated in the initial metres of distance to the forest edge, possibly due to herbivores that tend to feed themselves in the proximity of the edge (Hardt & Forman 1989), but it was higher in convex and not in concave edges, unlike other authors findings (Hardt & Forman 1989; Vergel-Otero 2002).

Conclusions

We conclude that only a few woody species coming from the forest edge are active colonizers of the mine. Moreover, woody colonization intensity decreases as distance to the forest edge increases, with higher colonization occurring in concave edges, lower in convex edges and intermediate in straight edges. Hence, it seems that the main factor that determines mine colonization is edge shape. Therefore, planting trees and shrubs along the forest edge to produce concavities, and accentuate those less marked, could favour forest revegetation in the reclaimed mine.

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