



# The importance of topography and climate on short-term revegetation of coal wastes in Spain

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## ABSTRACT

The initial colonization phase is the crucial start point for succession and therefore for restoration. However, little is known about abiotic factors that influence the early stages of revegetation dynamics on restored coal mines, particularly in a Mediterranean climate. This information is crucial for improving our ability to reclaim land despoiled by mining. Here, we characterized the short-term plant community development in the first 3 years after hydroseeding on a topographically diverse reclaimed open-pit coal mines in Spain. Topography influenced both community composition and diversity producing different trajectories between the three different aspects (north-facing, south-facing, flat). Hydroseeded species provided most of the initial vegetation cover, which brought about most of the compositional differences between these aspects. We also found that the changing climate through the growing season also influenced floristic composition and diversity. Summer drought reduced the cover of hydroseeded perennial species and allowed native species to colonize. These results emphasize the need to take topography into account when developing reclamation management plans in Mediterranean ecosystems, and an acknowledgement that climate might drive the succession in the desired direction, hence increasing success in restoring mining impacts.

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## 1. Introduction

A central issue in community ecology is to understand the factors that control the composition and abundance of species in ecological communities (Menninger and Palmer, 2006), and this must include interactions between abiotic and biotic factors (Larkin et al., 2006). Knowledge of how these processes operate is particularly important in restoration ecology, where new ecological communities need to be created on highly degraded sites (Hobbs and Norton, 1996). In such situations there are also excellent new opportunities to examine and test ecological theory (Menninger and Palmer, 2006). Here, we test the effect of a range of abiotic variables on vegetation development on reclaimed open-cast, coal mines in northern Spain.

The initial revegetation phase of any restoration scheme provides the starting point for succession; once established this vegetation will help determine the course of vegetation development at least in the short- and medium-term (Hobbs and Norton, 1996; Hobbs and Harris, 2001). However, very little is known about

early vegetation establishment during ecological restoration on coal mines in Mediterranean climates (Martínez-Ruiz et al., 2007).

Aspect and slope are two important environmental variables already identified as important in structuring community during mine restoration in Mediterranean climates (Martínez-Ruiz et al., 2007; Martínez-Ruiz and Marrs, 2007), mainly because of its effects on micro-climate and solar radiation (Bennie et al., 2006). In Mediterranean ecosystems, aspect interacts with summer drought to influence species composition, diversity and community persistence (Chiarucci and Maccherini, 2007; Valladares and Gianoli, 2007).

The coal mining operations in the northern Spain (León and Palencia) have changed markedly over the past 15 years from the traditional underground coal mines to open-cast extraction. Approximately 5000 ha of the land surface of this region is currently affected, generating localized impacts. There are, however, statutory requirements to ensure high-quality restoration (Cooke and Johnson, 2002; Moreno-de las Heras et al., 2008). The traditional way of tackling this restoration work was to use an engineering solution, where the landscape was re-modelled, the soil condition improved, and as limited recolonization processes the site was then sown with herbaceous species (González-Alday et al., 2008). However, more recently, seeds have sown using hydroseeding, although

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this approach has not always been successful and there was often failure in early establishment phase (Vandvik et al., 2005). There is therefore a need for an improved knowledge of the factors that control the composition and abundance of species during the early establishment phase, which is important to improve reclamation success in these situations.

Here, we assess the interaction of topography (aspect and slope) with micro-climate, both previously identified as important constraints in restoration schemes in Mediterranean climates (Gretarsdottir et al., 2004; Martínez-Ruiz et al., 2007; Martínez-Ruiz and Marrs, 2007) on initial vegetation development. In order to, we used a structured monitoring survey fitted into an ongoing practical land restoration scheme in Spain. The study was carried out immediately after hydroseeding a topographically diverse open-pit coal mine where the entire area of bare coal mine wastes was restored. We tested four hypotheses: (1) topography would influence revegetation dynamics, (2) growing season would also influence vegetation dynamics; this would be caused mainly by climatic variability (rainfall and temperature), (3) the species compositional differences caused by topography would occur mainly through differential colonization of native species from the surrounding area, and (4) overall species diversity would also be affected by topography and would change through time in a similar manner to community change. The ultimate aim was to provide an improved understanding of the factors controlling vegetation establishment immediately after sowing these degraded soils (Walker and del Moral, 2003), and help to create improved restoration procedures (Menninger and Palmer, 2006).

## 2. Materials and methods

### 2.1. Site description and hydroseeding

The study site was located in 'Pozo Sell', a 10-ha reclaimed open-pit coal mine near Villanueva de la Peña, Palencia, northern Spain (1185 m a.s.l.; lat 42°50'N, long 4°38'W). The climate is sub-humid Mediterranean (M.A.P.A., 1991), with an annual mean temperature of 9 °C and average annual precipitation of 980 mm (1932–2007 means from Cervera de Pisuerga meteorological station). Rainfall is not distributed regularly throughout the year; most rain falls during spring and autumn and there is a dry season in summer. The vegetation surrounding the site consisted of a complex matrix of grasslands (*Bromus mollis*, *Vulpia myuros*, *Plantago alpina*, *Arenaria montana*), crop fields (*Avena sativa*, *Secale cereale*), remnants of natural shrubland (*Rosa canina*, *Erica cinerea*, *Cistus laurifolius*, *Juniperus communis*) and *Quercus pyrenaica* woodland (González-Alday et al., 2009).

After coal mining stopped, the open pit was filled with coal wastes from nearby mines and the surface was covered with 50–100 cm of fine-textured sediments and a layer of cattle manure (30 t ha<sup>-1</sup>). Thereafter, in October 2003 the entire site was hydroseeded by the mining company (Unión Minera del Norte S.A.). The hydroseeding slurry contained soluble chemical fertilizer (150 kg ha<sup>-1</sup>; 8N:15P:15K), and a seed mixture (210 kg ha<sup>-1</sup>) containing grasses and herbaceous legumes (81:19 by weight).

The seed mixture included *Festuca* spp., *A. sativa*, *S. cereale*, *Lolium perenne*, *Phleum pratense*, *Poa pratensis*, *Trifolium pratense*, *Lotus corniculatus*, *Medicago sativa* and *T. repens* in 9:3:3:2:2:2:1:1:1:1 proportions.

### 2.2. Vegetation sampling

Vegetation development following hydroseeding was examined in three different areas (north- and south-facing slopes (25°) and a flat area), placing in each area three permanent plots of 20 m<sup>2</sup> (n=9). Within each plot, eight 0.25 m<sup>2</sup> quadrats were positioned randomly and marked permanently on the first sampling date (January 2004). The cover (%) of all vascular plant species present in each quadrat was estimated visually by the same observer every 2 months from January 2004 to September 2006 (n=17). The use of plant cover and richness for characterize the short-term revegetation dynamics was based in previous work by Prach and Pyšek (2001) and Martínez-Ruiz et al. (2007); we accept this measure confounds density and growth. The quadrats were monitored over three growing seasons (considering growing season the period from October to September): Season 1=2003/2004; Season 2=2004/2005; Season 3=2005/2006. The seedlings started to establish in January 2004, so this date was used as the baseline.

### 2.3. Climate

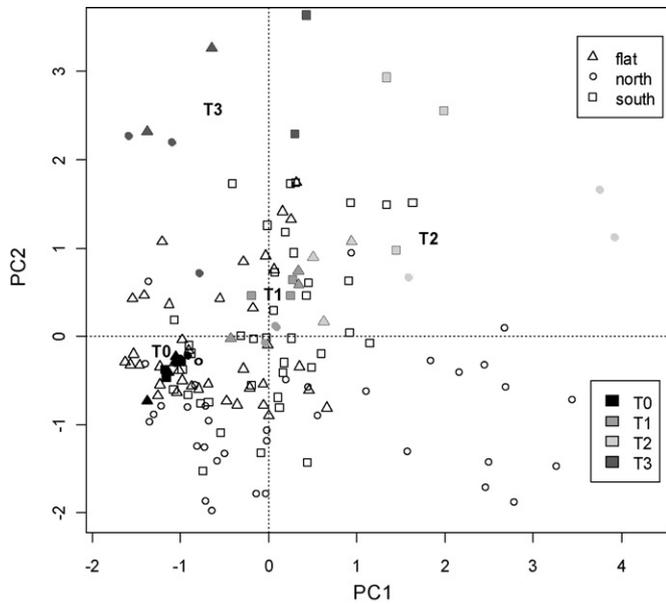
The climatic data were provided by Spanish Meteorological National Agency from the Cervera de Pisuerga meteorological station (lat 42°51'N, long 4°30'W; 1113 m a.s.l., 12 km East of 'Pozo Sell'). Average precipitation (mm) and temperature (°C) were summarized monthly over the study period, and for each of the three growing seasons.

### 2.4. Data analysis

The climate data were analysed using descriptive statistics, whereas the vegetation dataset was analysed using both multivariate and univariate methods. Multivariate methods were used to test the first three hypotheses on community composition. Before analysis the species dataset was reduced by removing all species which only occurred in fewer than five quadrats. An initial detrended correspondence analysis (DCA) produced eigenvalues of  $\lambda_1=0.27$ ,  $\lambda_2=0.12$ ,  $\lambda_3=0.09$ ,  $\lambda_4=0.08$  and gradient lengths (GLs) of GL<sub>1</sub>=2.36, GL<sub>2</sub>=1.97, GL<sub>3</sub>=1.67, and GL<sub>4</sub>=1.48 for the first four axes. The gradient lengths suggested that linear based ordination methods were appropriate (ter Braak and Šmilauer, 2002), and these were used in all subsequent analyses. First, a principal components analysis (PCA) was carried out to describe community composition. Partial redundancy analysis (pRDA) was then used to test Hypotheses 1 and 2. For Hypothesis 1, whether topography influenced revegetation dynamics was tested by analyzing the site × time interaction; here the overall effect of time and the variation between the study plots was partialled out. Hypothesis 2, whether growing season and climatic variability (rainfall and temperature) influenced vegetation dynamics, was

**Table 1**  
Temperature and precipitation during (a) the summer, and (b) the three growing seasons studied compared to the 76-year growing seasonal mean.

	Temperature (°C)			76-Year mean	Rainfall (mm)			76-Year mean
	Growing season				Growing season			
	1	2	3		1	2	3	
(a) June–July	17	18	19	16	26	8	21	43
(b) Annual	9.3	9.4	9.3	8.9	880	543	626	988



**Fig. 1.** PCA ordination diagrams of the first two axes of plots, from the three growing seasons experiment at the 'Pozo Sell' reclaimed open-pit coal mine, Villanueva de la Peña, Palencia, northern Spain. Compositional change for the spring samplings over the course of three growing seasons is shown, where T0 indicate the first sampling date (January of 2004) and T1, T2 and T3 the spring samplings (May) for the years 2004, 2005 and 2006. The diagrams below represent the plots of each site in each growing season, whereas the arrows are the trajectories of compositional change of site plots in each season.

tested by assessing the interactions between sites, growing seasons and climatic variables (precipitation and temperature); here the effects of the successional trends of the different sites were partialled out. In these pRDA analyses, significance was assessed with randomization tests using the reduced model and 999 permutations.

Thereafter, Hypothesis 3 was tested using principal response curves (PRCs, van den Brink and ter Braak, 1999). PRC was used to test whether vegetation development would be influenced differentially by topography because of differential colonization from native species adjacent each area. In this analysis, the change in plant community composition through time in north and south sites were contrasted against the flat reference site. Month was included as a covariate to control the overall temporal trend. Both axes of the PRC analyses were inspected and significance was tested with randomization tests using the reduced model and 199 permutations stratified within month. In addition, randomization tests (999 permutations) were performed at each sampling date to evaluate the significance between sites.

**Table 2**

Summary of the partial RDA analyses of species cover during the first three growing seasons after reclamation of the 'Pozo Sell' open-pit coal mine, Villanueva de la Peña, Palencia, northern Spain. The effects of the model for each analysis are specified in variables, and the covariables indicate the conditional variables; the effects of the covariables are removed before constraining the other variables. The significance (999 permutations) and the percentage of the total floristic variation in the data accounted for by each model are reported.  $P=9$  plots;  $T$ = time;  $S$ = the three different sites (north, south, flat);  $G$ = the three growing season (1, 2, 3);  $Pr$ = precipitation;  $Te$ = temperature;  $M$ = months.

Testing for effect of	Variables	Covariables	Variance	Pseudo-F	P (999)
Plot	$P$		17%	3.56	<0.001
Time	$T$	$P$	8%	15.23	<0.001
Different trend among sites (Hyp1)	$S \times T$	$P+T$	5%	2.80	0.013
Site specific growing season effects (Hyp2)	$G \times S$	$S \times T+P+T$	17%	7.22	<0.001
Site specific precipitation effects (Hyp2)	$Pr \times S \times T$	$S \times T+P+T$	6%	1.90	0.010
Site specific temperature effects (Hyp2)	$Te \times S \times T$	$S \times T+P+T$	12%	4.55	<0.001
Total explained by plot and time	$P \times T$		30%	3.33	<0.001

Hypothesis 4, that overall species diversity paralleled community change, was tested using generalized linear mixed models (GLMMs). GLMMs were used to derive responses between the diversity variables (species richness and Shannon–Weiner diversity index) and interactions between site, growing season and time. Site (north, south, flat), growing seasons (1, 2, 3) were treated as categorical fixed factors, time as a continuous factor, and time nested within plot were included as random factors to account for temporal and spatial autocorrelation (Pinheiro and Bates, 2000). Model simplification for hierarchical data followed Crawley (2007) using the Bayesian information criterion (BIC, Venables and Ripley, 2002; Pinheiro and Bates, 2000). Models were fitted using the Laplace method, the log-link function and a Poisson error distribution for count data and the logit-link and a Binomial error distribution for the diversity data (Crawley, 2007). As the conclusions from both species richness and Shannon–Wiener index were similar, only the species richness results are presented here.

All statistical analyses were implemented in the R software environment (Version 2.7.2; R Development Core Team, 2008), using the LME4 package for GLMM (Bates et al., 2008) and the VEGAN package for both multivariate analyses and the calculation of diversity indexes (Oksanen et al., 2008).

### 3. Results

#### 3.1. Climate

The climate data observed during the three growing seasons was extremely variable and atypical for the study area. In all three growing seasons the site was warmer and drier than the 76-year growing seasons mean (Table 1). These differences were especially important during early summer (June, July) with higher temperatures and lower rainfalls than average, producing summer droughts over the study period.

#### 3.2. Community description

One hundred and five vascular plant species were recorded over the three growing seasons. All the hydroseeded species were common most of them with cover values greater than 5%, especially during the first and second growing seasons. The cover of 16 species characteristic of the reference community, including *B. mollis*, *V. myuros*, *A. montana* and *Minuartia mediterranea* all increased over the study period. At the same time, 22 species, including *Inula montana*, *Agrostis castellana* and *Thymus vulgaris* were found only once, and this usually occurred in the third growing season.

In terms of community composition, the first two axes of the PCA explained 64% of the variation of the data (Fig. 1). The primary floristic gradients reflected the effects of both time and environment (sites). The starting positions are all located in the lower left quadrant of the plot, whereas the first and second growing sea-

son spring plots are located at the central and right area and third spring plots are near the top. This indicates temporal trajectories diagonal to the PCA axis 1 (50% variance). The second PCA axis (14% variance) mainly reflects differences in sites (environments), with north-facing plots having lower scores, and south- and flat-plots with progressively greater scores, indicating the effect of topography on revegetation.

3.3. Hypotheses 1 and 2: Does topography and growing season influence revegetation dynamics?

Both hypotheses were tested using multivariate pRDA (Table 2). Hypothesis 1 tested the effect of topography (north, south and flat aspects) on its own. The effect of topography on compositional trends through time accounted for 5% of the variance in the data and was statistically significant ( $p < 0.02$ ), so this hypothesis was accepted. Hypothesis 2 tested whether revegetation dynamics varied with growing season and climate variability (precipitation and temperature). When the effects of growing season were added to the model the effect was significant ( $p < 0.001$ ) and the explained variance increased to 17%. When the two climate variables related to growing season (precipitation and temperature) were tested they were also significant ( $p \leq 0.010$ ), explaining 6% and 12% of the variance in the data, respectively. Thus, Hypothesis 2 was also accepted, although there are potentially important interactions between sites and growing seasons. As 30% of the total variance in the data is explained by the differences among plots and sampling dates (model  $P \times T$ ; Table 2), clearly other unmeasured environmental factors are important in influencing revegetation.

3.4. Hypothesis 3: Are compositional differences among topographies caused mainly by native species?

This hypothesis was tested using PRC; the PRC model accounted for 28% of the variation in species composition and was significant (pseudo- $F = 3.96$ ,  $p = 0.005$ ). PRC graphs were plotted for axes 1 and 2 in order to visualize and interpret the effects of site (environment) and growing seasons on species composition through time; in both the successional trends of north and south sites were compared to the flat site as the reference  $x$ -axis (Fig. 2). The first and second PRC axes were statistically significant (199 permutations,  $p < 0.05$ ).

The PRC diagram from axis 1 (Fig. 2a) illustrated that during the first months the north and south curves stayed close to the zero line control of the flat site, and showed no significant difference from it ( $p > 0.05$ ). At the end of first growing season during the dry period (July–September 2004) the north and south curves start to deviate from the flat site and the north site deviated the most ( $p < 0.05$ ). These differences were maintained throughout the second growing season, until the next dry period when all sites converged to a similar species composition (September 2005,  $p > 0.05$ ). During the third growing period the north and south sites reversed, with the north site becoming more similar in composition to the flat site than the south one. This reversal reflects the influence of climatic variability in the revegetation trajectories of each site and in the subsequent growing seasons (Hypothesis 2). In this analysis the site responses were associated positively with *T. repens* and *L. perenne*, which had the highest positive weights, followed by *T. pratense* (Fig. 2a) and five hydroseeded species (*L. corniculatus*, *S. cereale*, *A. sativa*, *P. pratense* and *Festuca* spp.) which were also positive values, but were much lower. The cover of these species was favoured in the north site, especially during second growing season. Species with negative weights were mainly native species (*Anthemis arvensis*, *Arenaria* spp.) and some ruderals as *Malva sylvestris* or *Capsella bursa-pastoris* (Fig. 2a).

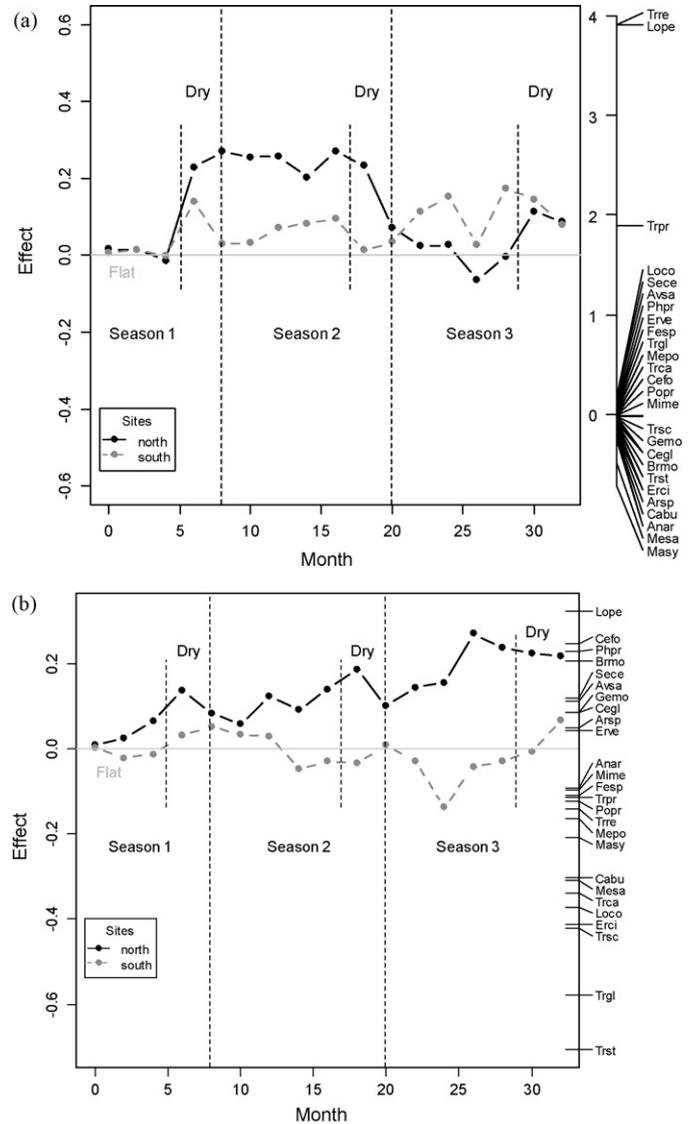
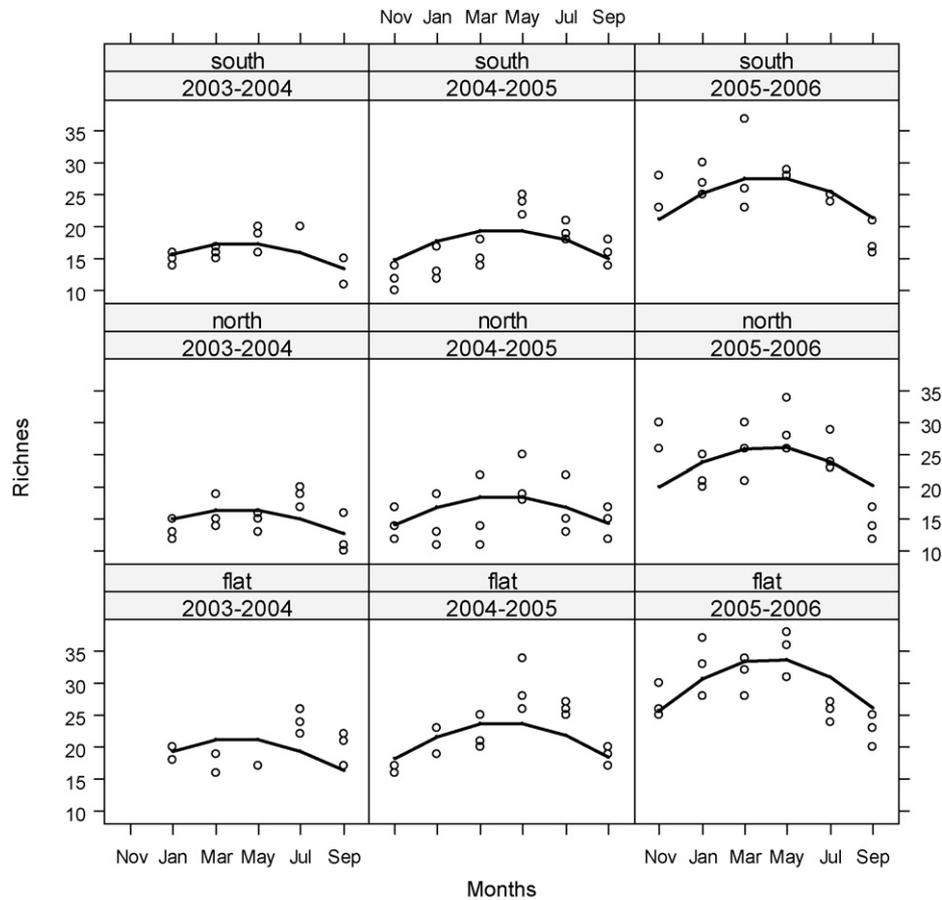


Fig. 2. Principal response curve diagrams, showing the effect of sites (environments) on species composition through three growing seasons: (a) PRC axis 1, (b) PRC axis 2. The responses of the most common species are shown on the right. Values deviating from the reference values of 0 (flat reference site) indicate site effects. Species codes: *Anthemis arvensis* = Anar; *Arenaria* spp. = Arsp; *Avena sativa* = Avsa; *Bromus mollis* = Brmo; *Capsella bursa-pastoris* = Cabu; *Cerastium glomeratum* = Cegl; *Cerastium fontanum* = Cefo; *Erodium cicutarium* = Erci; *Erophyla verna* = Erve; *Festuca* spp. = Fesp; *Geranium molle* = Gemo; *Lactuca serriola* = Lase; *Leontodon taraxacoides* = Leta; *Lolium perenne* = Lope; *Lotus corniculatus* = Loco; *Malva sylvestris* = Masy; *Medicago polymorpha* = Mepo; *Medicago sativa* = Mesa; *Minuartia mediterranea* = Mime; *Phleum pratense* = Phpr; *Poa pratensis* = Popr; *T. campestre* = Trca; *T. glomeratum* = Trgl; *T. pratense* = Trpr; *T. repens* = Trre; *T. scabrum* = Trsc; *T. striatum* = Trst; *Secale cereale* = Sece.

On axis 2 (Fig. 2b) the curve for south site stayed close to the flat site indicating similar community composition, whereas the north site started deviating from the flat site at the second sampling date, and this deviation in species composition increased through the second and third growing seasons. In this analysis (Fig. 2b), the main weights were negative and composed mainly of native species (e.g. *Trifolium striatum*, *Trifolium glomeratum*, *Trifolium scabrum*, *Erodium cicutarium*, *Trifolium campestre*) and two hydroseeded species (*L. corniculatus*, *M. sativa*). These species were important in differentiating the north site from the reference site (flat) and especially from the south site, because south site had



**Fig. 3.** Species richness per plot through the three growing seasons (03/04, 04/05, 05/06) in each of the three sites (north, south and flat). The fitted line represents the minimal adequate GLMM (Table 3), some of the variance in the data originates from random variables included in the model.

the least native species cover. The broad pattern that emerges is that the first PRC axis explained 16% of the variance in the data, and demonstrated compositional differences caused mainly by hydroseeded species, whereas the second PRC axis explained 5% of the variance in the data and showed the compositional differences were caused by native species. Hypothesis 3 is therefore not supported as the main differences were produced by hydroseeded species and not by native ones.

**3.5. Hypothesis 4: Are changes in overall diversity affected by topography and do they mirror community composition?**

Species richness ranged from 10 to 37 species per plot. The GLMM analysis showed that the trend in species diversity was

not influenced by the interactions between sites, growing seasons and time (Table 3 and Fig. 3). In each season, species richness showed the same trends, richness increased to a peak in early spring (March–May), and decreased thereafter in the dry season (June–September). There were important differences between sites and growing seasons (main effects; Table 3), with greater values on the flat site in each growing season followed in order by the south and north sites. Species richness increased in each growing season; season 3 had greater values than the other two (Table 3 and Fig. 3).

**4. Discussion**

**4.1. Hypotheses 1 and 2: Does vegetation success vary with topography and season?**

Plant community composition was affected by topography; different successional trajectories were found on the three aspects through the three growing seasons. The flat and south sites maintained a similar species composition, whereas the north site diverged from them in two different ways: (a) there was a greater development of hydroseeded species during the second growing season, and (b) the north site maintained a greater cover of these hydroseeded species. These results may be caused by a combination of two factors. First, by the differential success of hydroseeding species in relation to aspect; in Mediterranean areas moister north-facing slopes tend to have a greater proportion of perennial species than drier aspects (Madon and Médail, 1997; González-Alday et al., 2008), and in our study many of these perennials were hydroseeded species. Second species colonization from the surrounding species

**Table 3**  
The relationship between species richness at 'Pozo Sell' reclaimed open-pit coal mine, Villanueva de la Peña, Palencia, northern Spain in relation to environmental variables derived using generalized linear mixed modelling (GLMM). The minimum adequate model is presented ( $\Delta BIC = 122.03$ ): the intercept refers to the flat site in Season 1, and the magnitude of the effects is calculated as the estimated difference from the intercept.

Parameters	Estimate ( $\pm SE$ )	z-Value	p-Value
Intercept	2.81 (0.07)	38.98	<0.001
Season 2	-0.14 (0.09)	-1.42	0.154
Season 3	0.30 (0.14)	2.20	0.028
North	-0.25 (0.06)	-4.03	<0.001
South	-0.19 (0.06)	-3.13	0.002
Time	0.05 (0.01)	3.52	<0.001
Time <sup>2</sup>	-0.01 (0.001)	-4.08	<0.001

pool, which was more prevalent in the south and flat sites, might have been a biotic feedback effect with seedling establishment of autochthonous species reduced through competition from the greater abundance of hydroseeded species (Matesanz et al., 2006; González-Alday and Martínez-Ruiz, 2007). Colonizing seedlings and juveniles are very sensitive to such biotic competition (Harper, 1977).

Growing season also affected community composition on all three aspects, the most likely cause is the variability of precipitation and temperature. Since, the greatest changes in composition were found during dry periods of each growing season supports this hypothesis. During the dry season growth and development are very limited, the probability of survival is reduced, and there is therefore, a strong selection pressure allowing the survival of well-adapted species (Caccianiga et al., 2006). Annuals escape the dry summer as seed, whereas perennials must use resources to survive (Clary, 2008). The drier conditions on the south and flat aspects clearly reduced the cover of hydroseeded perennial species (Joffre and Rambal, 1993), and this favoured colonization of the newly created gaps by autochthonous species (Holl, 2002; Martínez-Ruiz et al., 2007).

This detailed study over the 3 years has indicated that extreme events, such as the prolonged drought in the second growing season impacted on the north site, making it more similar to the flat site, rather than south sites by reducing the cover of hydroseeded species. Thus micro-climatic effects during the growing season are likely to be important environmental drivers of change in the early phases of reclamation of herbaceous communities under Mediterranean conditions (Clary, 2008).

The large amount of unexplained variance detected in these analysis suggests that there are other important unmeasured environmental factors that influence the community compositional change at the more local scale; for example, physico-chemical substrate characteristics (Whisenant, 2002; Marrs, 2002), or the role of soil micro-organisms (Allen et al., 2002). The community dynamics of these developing ecosystems clearly involves interactions between many drivers, both biotic and abiotic (Davy, 2000), and further investigations of these additional processes and their interactions are needed.

#### 4.2. Hypothesis 3: Are compositional differences during the early phases of revegetation caused mainly by native species?

Surprisingly, the compositional differences between sites were not caused mainly by native species as we had originally hypothesized. The reason is that hydroseeding species provided most of the initial vegetation cover especially at the north site (González-Alday et al., 2008). This study confirmed that the cover of hydroseeded species was greater during the first three growing seasons.

Nevertheless, the cover of native species, increased continually through the three growing seasons on all aspects. This increase may be due to either (a) an increase in colonization rates from the surrounding vegetation, i.e. there is a greater probability of success with time (Holl, 2002), (b) an increase of plant growth of the established species (Jochimsen, 2001), or (c) a superior ability of native species to establish in disturbed sites because populations are adapted to these local environments (Urbanska, 1997). Here, we found an increasing number of species characteristic of the surrounding vegetation through time (e.g. *A. arvensis*, *Cerastium fontanum*, *B. mollis*, *V. myuros*, *M. mediterranea*, *T. campestre* or *T. striatum*), and importantly for restoration, that the ongoing succession the vegetation is moving in the desired direction, especially on the south and flat sites which had the lowest cover of hydroseeded species.

The spontaneous processes of colonization have been used as an important restoration practice in central Europe (Prach and Pyšek, 2001; Kirmer and Mahn, 2001). Here, spontaneous colonization, being not massive, helps to redirect successional processes towards natural community. Therefore, could be interesting to consider spontaneous revegetation potential in reclamation programs.

#### 4.3. Hypothesis 4: Are changes in overall diversity affected by topography and do they mirror community composition?

The lack of interaction between sites, growing seasons and time in species richness produced stable patterns in every growing season, which reflects the annual cycle of species composition change in Mediterranean ecosystems (Madon and Médail, 1997; Blondel and Aronson, 1999). Richness increased in autumn and spring, the periods when most seedling emergence occurs (Lloret et al., 2004), but reduced in summer probably because of limited water availability (Piñol et al., 1995). This result is consistent with the annuals acting as re-selected ruderals at the local scale in areas of annual seasonality (Clary, 2008), and Grime's (2001) proposal that much of primary succession should be characterized by stress tolerators.

Particularly noteworthy is the consistent increase in species richness through the three growing seasons. This might be expected, because as time since reclamation increases there is a greater chance of the arrival of new species (Begon et al., 2006). At the same time, however, there was an effect of aspect aspect-related plant community variation also affected species diversity (Hutchinson et al., 1999); the lowest richness values were found at the north site, suggesting a reduction through biotic competition between hydroseeded and native species (Begon et al., 2006).

## 5. Conclusions

The results of this study demonstrate that the short-term vegetation establishment can influence the successional development of reclamation schemes. For Mediterranean ecosystems, it is essential when planning restoration projects to accept that differences by topography will affect the outcome of succession. In particular, it will influence the persistence of hydroseeded species, and this in turn will influence the colonization of native species from the surrounding vegetation.

In a Mediterranean climate the variability of precipitation and temperature through the growing season is also important. The disturbance produced by summer drought can have a considerable effect on the floristic composition and diversity during reclamation. It produced conditions that allowed other species to colonise and redress the balance with the introduced perennial hydroseeded species. Clearly this impact may change if drought increases under new climate scenarios (Rambal and Debussche, 1995).

At the same time, this study showed that the combination of compositional responses to sites, growing seasons and climate variability create complex compositional patterns, which limits the predictability of succession even in adjacent locations. Further investigation is needed to assess the importance of other environmental abiotic factors at more local (plot level) or general scales (site level), during the short- and long-term time scales, as well as the factors that may limit native species colonization processes and recruitment.

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