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Natural and man-induced revegetation on mining wastes: Changes in the floristic composition during early succession

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ABSTRACT

The performance of introduced species when interacting with colonising herbs and shrubs from the surrounding areas has become an important issue in plant ecology and restoration management. In this paper, we examined the influence of hydroseeding a commercial seed mixture on the revegetation of uranium mine wastes under a semi-arid Mediterranean climate in West-Central Spain. Eight dump slope sites differing two by two in revegetation treatment (hydroseeding or not) and aspect (north/south) were monitored annually during 3 years. There was a combined effect of treatment and aspect on the floristic composition during early succession. Particularly, hydroseeding increased differences in floristic composition between aspects, being the contribution of sown species to these differences small and short. Hydroseeding increased plant cover and diversity significantly only 2 years after its application on the north-facing slopes, favoured the perennial species (mainly hemicryptophytes), and had a different effect depending on the aspect favouring grasses and legumes on the north- and south-facing slopes, respectively. The species mixture was not suitable and the use of local seeds should be tested in future revegetation projects at this zone. The importance of improving natural colonisation for ecological restoration is emphasised.

1. Introduction

The damage to soil and vegetation caused by mining, unless prevented by careful planning, is usually extreme, because the original ecosystems have had to be grossly disturbed or buried by the mining process (Bradshaw, 2000). To achieve a successful restoration the soil has to be remediated and the vegetation re-established (Bradshaw, 1997). The presence of an initial plant cover will clearly be important in beginning the process of stabilisation and accumulation of finer material (Bradshaw, 2000; Parrotta and Knowles, 2001; Nicolau, 2002). However, in areas with a semi-arid Mediterranean climate, the low and irregular distribution of rainfall is the major factor limiting plant growth (Noy-Meir, 1973; Zohary, 1973) and vegetation cover tends to be low and sparse (Schelesinger et al., 1990).

To enhance vegetation establishment and stabilising inaccessible steep slopes, such as that caused by mining, the hydroseeding technique has become widely used (Sheldon and Bradshaw, 1977; Roberts and Bradshaw, 1985; Albadalejo et al., 2000; Brofas and Varelides, 2000). This involves spraying a homogeneous slurry of seed, fertilizer, binder and mulch

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from a high-pressure hose (Sheldon and Bradshaw, 1977). The steepness of the slopes and the nature of the surfaces prevent the use of conventional agricultural machinery of seed and fertilizer application (Hanson and Juska, 1969). However, hydroseeding represents a specialised and costly technique, which can have limitations (Roberts and Bradshaw, 1985).

The major factors affecting the success of hydroseeding, in a particular region, are technical: components used and rates of application (Sheldon and Bradshaw, 1977; Roberts and Bradshaw, 1985; Merlin et al., 1999), sowing time and prevailing weather conditions (Andrés et al., 1996; Cano et al., 2002); and intrinsic to the site: angle of slope (Leavitt et al., 2000), aspect that will affect energy relations and soil moisture (Andrés et al., 1996; Cano et al., 2002) or roughness and material hardness (Cano et al., 2002).

Under semi-arid Mediterranean conditions in Spain, soil stabilization on roadsides and mining wastes is often achieved by using commercial mixtures of non-native seeds (Andrés et al., 1996; Andrés and Jorba, 2000; Nicolau, 2002). However, the behaviour of these species in providing rapid vegetation cover of exposed substrate in a regime of scarce and markedly seasonal rainfall, and their performance when competing with colonising species invading from nearby are still poorly understood (Andrés et al., 1996). Also the capacity of species characteristic of later successional stages to displace the initial ground cover should be better understood (Marrs and Le Duc, 2000; Bakker et al., 2002). We hypothesize that the dynamics of early revegetation in such semi-arid Mediterranean conditions will be affected by both the hydroseeding of non-native species and site aspect. To understand these factors, we compared natural and man-induced community development on uranium waste dumps of differing aspect in West-Central Spain. We also investigated the effectiveness of introduced species in providing plant cover and diversity during early succession according to the aspect.

2. Methods

2.1. Site description and sampling

The study was carried out at a uranium-mine in Salamanca province, Spain (40°37′N, 6°38′W), disused 10 years ago. The climate at the site is semi-arid Mediterranean with a mean annual rainfall of 500 mm, and acute summer droughts where there is only 12% of the annual rainfall. The mean annual temperature is 12.7 °C, the mean minimum in the coldest month (January) is −0.34 °C and the mean maximum in the warmest month (August) is 31 °C (Martínez-Ruiz, 2000). The soils are slightly acidic loams (pH 5.5–6.7) overlying slate bedrock, with a predominance of dystric cambisols (Dorronsoro, 1992). The natural vegetation of the area is a 'Dehesa' formation which is a mixture of grassland, shrubby vegetation (*Cytisus multiflorus-dominated*) and woodland (*Quercus ilex* subsp. *ballota*); shrub and tree species occur at low densities (Martínez-Ruiz, 2000).

The waste generated from the uranium ore mining was heaped into different dumps at an incline angle of 37°. The waste consisted of slate bedrock fragments up to 80 cm in diameter, although there was a small amount of finer material between the larger particles (10% <2 mm). Restoration of vegetation by the mining company (E.N.U.S.A., State-owned Company of Uranium Ltd.) involved, where possible, covering the waste with a ca. 30 cm deep layer of finer textured sediments, excavated from a 10–150 cm depth from a nearby Arkoses pit, consequently this material may contain some seeds and plant remains. The cover material was a sandy-loam with loose granular structure; it had good soil aeration and low compaction, and its chemical properties (Table 1) were intermediate between the mine wastes and the Dehesa soils (Martínez-Ruiz, 2000).

The mining company applied hydroseeding in autumn 1992 to two spoil dumps (4–15 m high, and with both northern and southern slopes available), although only to some parts of the areas previously covered by the arkosic material. Two well-defined areas with comparable soil properties were distinguished on the same dump slope, one was hydroseeded the other not, both of which were in the process of revegetation. Small areas of naturally coloniser vegetation near the bases of the dumps chosen for the study provided a source of propagules.

The hydroseeding slurry contained: 450 kg ha^{-1} of short fibre mulch, 300 kg ha^{-1} of soluble chemical fertilizer (15N:15P:15K), 400 kg ha^{-1} of organic tackifier, 5000 million g^{-1} of legume inoculum and 275 kg ha^{-1} of a commercial seed mixture of grasses and legumes. About 70% of seed weight was *Festuca arundinacea*, *Lolium perenne*, *L. rigidum*, *Dactylis glomerata*, *Lupinus hispanicus* and *Medicago sativa* in a 2:1:1:1:1:1 proportion. The rest of the seed mixture comprised eight species in lower proportions: *Avena sativa*, *Agrostis stolonifera*, *Poa pratensis*, *Lotus corniculatus*, *Trifolium repens*, *Retama shaerocarpa*, *R. monosperma* and *Cytisus scoparius*. Autumnal rainfall after hydroseeding in 1992 was very low (112 mm) as well as the total rainfall during that year (304 mm). Annual rainfall registered from June of the preceding year to May of each sampling year (1994–1996) was higher for the first and third years (588 and 755 mm, respectively) than for the second one (230 mm).

Table 1 – Site soil analysis (mean of *n* = 6)

	pH (H_2O)	CEC	Organic matter (%weight)	Water-soluble	Total (mg/kg)					
				P	N	K	Zn	Cu	Pb	Cd
Waste material	3.3	8.0	0.15	0.41	290	848	137	58	42	0
Covering substrate	4.6	15.6	0.23	0.25	460	1147	30	9	12	0

Data provided by the mining company (in Martínez-Ruiz, 2000); CEC, cation exchange capacity (meq/100 g).

Eight dump slope sites of similar characteristics, except for treatment (hydroseeded/non-hydroseeded) and aspect (north/south), were monitored annually from 1994 to 1996. There were two replicates for each combination of treatment and aspect. Vegetation on the northern and southern slopes on the nearby Dehesa was also sampled during the same years, and they were used as reference sites to assess the success of revegetation of the waste materials.

Eight 0.25 m^2 quadrats were located randomly in the first sampling year across the whole of each site (100–200 m^2) and marked permanently. The sampling size was tested in pilot studies using the "pooled quadrat" method (Pielou, 1969) to encompass at least 90% of all species (Martínez-Ruiz, 2000). The cover (%) of all species present in each quadrat was estimated visually in early June of each year, and because of overlapping vegetation strata, cover values frequently exceeded 100%. 143 vascular plant species (67% annuals/biennials, 27% perennial herbs, 6% woody) from 30 families were found and species nomenclature follows Tutin et al. (1964–1980).

2.2. Statistical analyses

Diversity (H'), using the Shannon index (Shannon and Weaver, 1949) with logs to base 2, and its two components, richness (S) and evenness (J') (Pielou, 1969), were calculated.

To evaluate the significance of the temporal changes in the parameters studied, one-way analyses of variance were applied followed by Tukey's tests to enable pairwise comparisons of means ($p < 0.05$). To test the significance of differences observed in the parameters studied between treatments, aspect or species groups (taxonomical or functional) for each sampling year, paired t-tests were used. Assumptions of normality and equal variance for parametric testing had previously been checked (Sokal and Rohlf, 1996). Statistical computations were made using SPSS software V.11.5 and only significant differences included in figures.

A multivariate gradient-analysis technique (DCA) was used to investigate the way and order in which treatment and aspect contributed to determining changes in the community composition, and to identify the taxa associated with them. The plotting technique employed was an HJ-Biplot (Galindo, 1986), which is a variant of the biplot graphic display proposed by Gabriel (1971). After double-centring the data, samples and species were simultaneously represented as points on a two-dimensional scatter diagram (Golub and Reinsch, 1970; Galindo, 1986). This ordination method has provided better results than other conventional multivariate techniques (Galindo et al., 1996) in several investigations including successional studies (Rivas-Gonzalo et al., 1993; Santos et al., 1991; Martínez-Ruiz et al., 2001; Martínez-Ruiz and Fernández-Santos, 2005), because the quality of plotting, both for samples and species, seems to be superior (Galindo and Cuadras, 1986; Galindo et al., 1996). The HJ-Biplot was calculated by using the cover values of species present in more than one dump-slope-site with cover of at least 2% (80 species), and by grouping sites by age to increase the discriminating power of the analysis. For calculation of the biplots the algorithm was programmed using MATLAB, a programming environment oriented to matrices; for more details contact the author (villardon@usal.es). Besides indirect interpretation of the ordination axes, analyses of variance were performed to assess the significant influence of the variables associated with the axes on the floristic composition of the dump slopes.

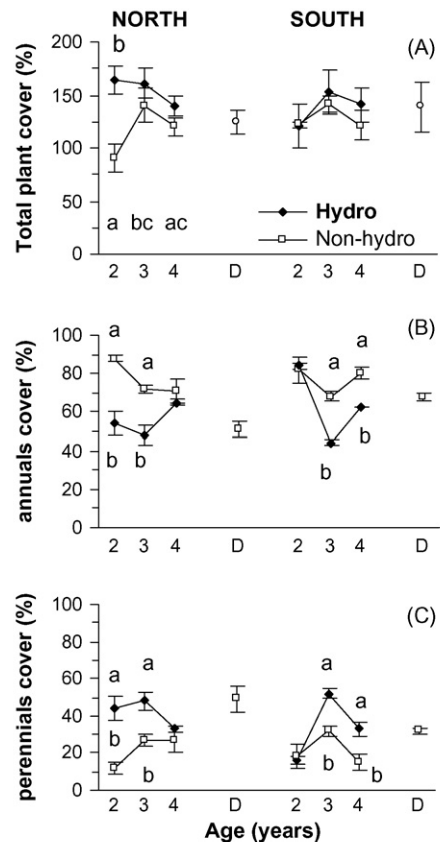

Fig. 1 – Mean value (%) and standard error of absolute total plant cover (A) and relative contribution of annual (B) and perennial (C) herbs, at different stages of revegetation (2–4 years) and in the reference community (D = Dehesa). In (A) significant differences ($p < 0.05$) between treatments and between years are included. In (B) and (C) only significant differences ($p < 0.05$) between treatments are included.

3. Results

Hydroseeding increased plant cover significantly only 2 years after its application on the north-facing slopes ($p = 0.028$; Fig. 1A). This fact masked the tendency for plant cover to increase in the second sampling year (3-year-old), as occurred in the rest of the sites but was only significant for the non-hydroseeded north-facing slope (one-way ANOVA, time, $F_{[2,5]} = 28.15$, $p = 0.011$). After 4 years vegetation cover values were similar to those found at the reference community. For both treatments, no differences in plant cover between both aspects were found for the period analysed, and also in the reference community. In both aspects, there was a higher relative contribution of annual species to the total plant cover without hydroseeding ($p < 0.05$; Fig. 1B) and of the perennial herbs on the hydroseeded areas ($p < 0.05$; Fig. 1C), except for

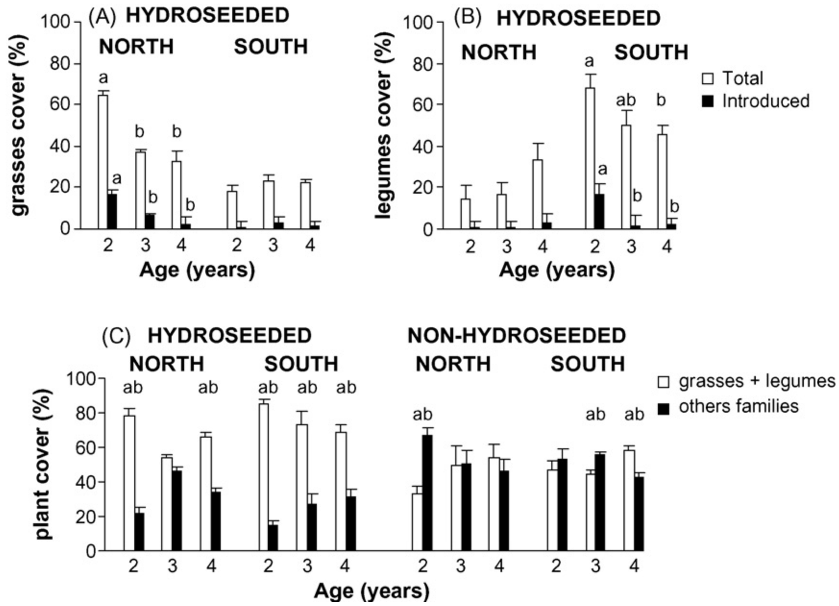

Fig. 2 – Temporal changes with hydroseeding in grasses (A) and legumes (B) relative cover (%) as a function of aspect, and contribution of the introduced species (mean value ± S.E.). (C) Relative cover of 'grasses + legumes' in comparison with 'others families' as a function of treatment and aspect. Differences between the total and introduced species cover of grasses and legumes (not shown in the (A)) were always significant ($p < 0.05$). In (A) and (B) only significant differences ($p < 0.05$) between years are included. In (C) only significant differences ($p < 0.05$) between species groups are included.

the fourth year of revegetation on the north-facing slopes and for the second year on the south-facing ones.

Woody species only represented a small fraction (2–6%) of the total plant cover. For both treatments, the relative contribution of annual and perennial herbs to the total plant cover did not differ according to the aspect, as in the reference community.

Hydroseeding favoured the grass cover on the north-facing slopes (Fig. 2A) and the legume cover on the south-facing ones (Fig. 2B), the differences between slopes being significant in the second and third years ($p < 0.01$). In particular, 2 years after hydroseeding, sown species constituted 17% of the total plant cover, which was mainly due to the grasses *Festuca arundinacea, Lolium perenne* and *Dactylis glomerata* on the north-facing slopes, and to the legume *Lupinus hispanicus* on the south-facing ones. Later, their contribution to the total plant cover significantly decreased (Fig. 2A and B), as well as the total cover of grasses and legumes on the northern and southern slopes respectively (one-way ANOVA, time: sown grasses, $F_{[2,5]} = 76.33$, $p = 0.003$; total grasses, $F_{[2,5]} = 11.33$, $p = 0.04$; sown legumes, $F_{[2,5]} = 281.33$, $p < 0.001$; total legumes, $F_{[2,5]} = 9.68$, $p = 0.049$). With hydroseeding the higher contribution to the total plant cover was due, in both aspects, to the group 'grasses + legumes' (71% mean value), whereas without hydroseeding the contribution of other families was higher (52% mean value) ($p < 0.05$; Fig. 2C). For example, *Compositae* were more competitive reaching around 26% (mean value) of the total plant cover in contrast with 17% on the hydroseeded areas.

Hydroseeding only produced a significant increase in diversity values in the second year on the northern slopes ($p = 0.04$; Fig. 3A), due to a significant increase in species richness

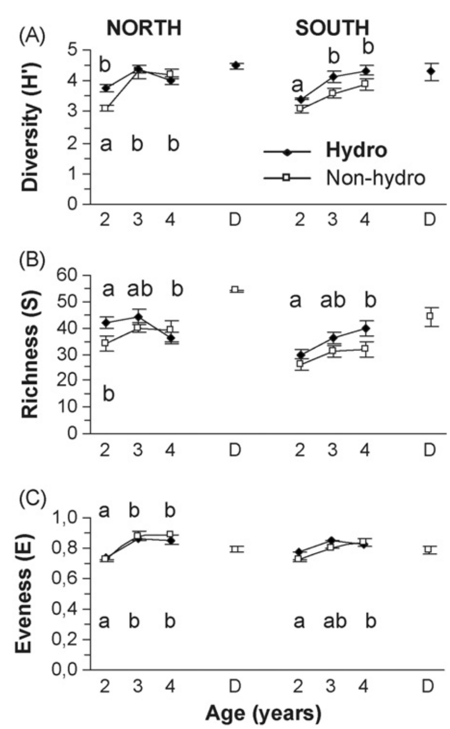

Fig. 3 – Mean value and standard error of Shannon diversity index (A) and its two components: richness (B) and evenness (C), at different stages of revegetation (2–4 years) and in the reference community (D = Dehesa). Significant differences ($p < 0.05$) between treatments and between years are included in every figure.

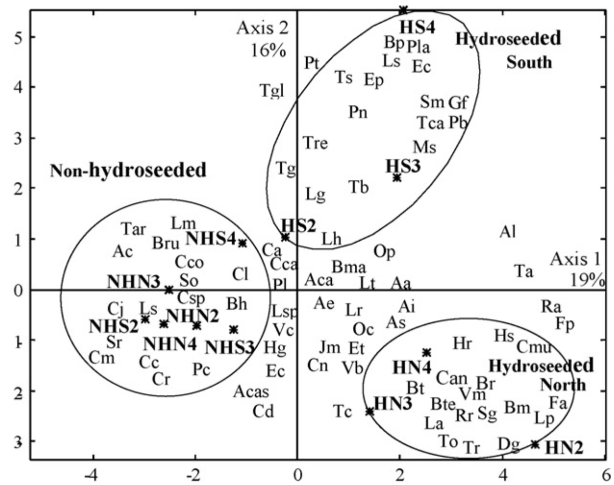

Fig. 4 – DCA ordination of sites and species in the first two dimensions obtained by HJ-Biplot analysis. Sites identified by treatment (NH, non-hydro; H, hydro), aspect (N, north; S, south) and age (years after revegetation). Species listed by first letter of genus and first or two first letters of species name (see Table 3 for species identification).

Table 2 – Three-way ANOVA with the coordinates of dump slopes sites in the first two HJ-Biplot axes and the explanatory variables

Source of variation	d.f.	Mean square	F-value
With the coordinates of axis 1			
Treatment	1	50.03	105.66**
Aspect	1	0.88	1.86
Age	2	3.87	8.17
Treatment × aspect	1	3.52	7.43
Treatment × age	2	0.88	1.85
Aspect × age	2	0.51	1.08
Error	2	0.47	
With the coordinates of axis 2			
Treatment	1	1.29	2.86
Aspect	1	22.61	50.35*
Age	2	3.69	8.22
Treatment × aspect	1	17.18	38.27*
Treatment × age	2	1.49	3.32
Aspect × age	2	1.66	3.69
Error	2	0.45	

* $p < 0.05$.
** $p < 0.01$.

($p = 0.008$; Fig. 3B) since evenness was about the same in both aspects (Fig. 3C). Only three exotic sown species (*F. arundinacea*, *L. hispanicus* and *Trifolium repens*) contributed then to the increase in richness, since the native sown species *D. glomerata* and *L. perenne* were also present in the non-hydroseeded areas. For the rest of the years, no differences between treatments in diversity and its components were found. Except for the hydroseeded north-facing slopes, diversity and its components increased with time although differences were not always significant (Fig. 3A). Diversity values after 4 years and for the reference community were about the same.

The first two axes of the DCA explained 35% of the variation (Fig. 4). Axis 1 reflected a highly significant gradient associated with treatment (Table 2), with the hydroseeded sites on the left hand area of the diagram and the non-hydroseeded sites on the right hand area. Axis 2 showed a significant gradient associated with aspect (Table 2) only apparent within the hydroseeded sites (treatment × aspect interaction). Species associated with different combinations of treatment and/or aspect for the period analysed are given in Table 3 . The number of perennial herbaceous species (all of then hemicryptohytes) was higher on both northern and southern hydroseeded slopes than without hydroseeding, and woody species were excluded from non-hydroseeded slopes. Grasses and legumes were more abundant after hydroseeding, being grass and legume number higher on the north- and south-facing slopes, respectively. Without hydroseeding, however, species from other families especially *Compositae* were more numerous than grasses and legumes.

It is noteworthy that only half of the sown species were found through the study. The exotics *L. hispanicus* and *M. sativa* were especially present on hydroseeded south-facing slopes and *F. arundinacea* on the hydroseeded north-facing ones. The native species *D. glomerata*, *L. perenne* and *L. rigidum* were present in all sites over all the ages, as were several native non-introduced species (underlined species in Table 3), whereas *T. repens* was only present for 2 years after hydroseeding on the north-facing slopes. The most active colonising species of the dumps was the leguminous shrub *Cytisus multiflorus*, an endemic species in the study area, where it is more competitive than the sown *C. scoparius*.

4. Discussion

Our results showed relatively small and short positive effect of hydroseeded species in providing plant cover and diversity with respect to native species, and differences in their performance according to the aspect under semi-arid Mediterranean conditions. The south-facing slopes experienced the more unfavourable growth conditions, because of its lower capability to conserve soil moisture (Cano et al., 2002; Tormo et al., 2006). Thus, the positive effect of short fibre mulch accompanying hydroseeding on plant establishment by conserving soil moisture (Sheldon and Bradshaw, 1977; Luken, 1990) was evident on the northern slopes only, and shorter than expected because of lower precipitation than usual just after the sowing time (Andrés et al., 1996; Cano et al., 2002).

The failure of a high percentage of species is usually observed in soil reclamation in which commercial seeds of non-native species are hydroseeded (Andrés et al., 1996; Andrés and Jorba, 2000). Species originating from more temperate or northern areas cannot grow well in a semiarid region and under very special habitat conditions (Wali, 1999). This was the case for the introduced species, *Avena sativa*, *Agrostis stolonifera* and *Poa pratensis*, which were replaced by the natives *A. sterilis*, *A. castellana* and *P. bulbosa*. Commercial seeds perform worse than the native ones (Pinaya et al., 2000; Tinsley et al., 2006) even in the case of species widely used for reclamation, such as *Lolium* and *Festuca* spp. or *Dactylis glomerata* (Andrés and Jorba, 2000; Cano et al., 2002). But also the toxicity

Table 3 – Family, life cycle and life form of main species for different treatments and/or aspects; underlined species were present in all sites all the years

Code	Species name	Family	Life cycle	Life form	year 2	year 3	year 4
With hydroseeding on northern slopes							
Bm	*Briza maxima*	G	A	T	+	+	+
Br	*Bromus rigidus*	G	A	T	+	+	•
Bt	*Bellardia trixago*	Scro	A	T		+	+
Bte	*Bromus tectorum*	G	A	T	+	+	+
Can	*Crucianella angustifolia*	Rub	A	T		+	
Cmu	*Cytisus multiflorus*	L	W	P	+	+	•
Dg	*Dactylis glomerata*	G	P	H	•	+	+
Fa	*Festuca arundinacea*	G	P	H	•	+	
Hr	*Hypochoeris radicata*	C	P	H	+	+	+
Hs	*Holcus setiglumis*	G	A	T	+	+	
La	*Lathyrus angulatus*	L	A	T	+	+	•
Lp	*Lolium perenne*	G	P	H	•	+	+
Rr	*Raphanus raphanistrum*	Cru	A	T		+	
Sg	*Senecio gallicus*	C	A	T	+	+	
To	*Trisetum ovatum*	G	A	T	+	+	
Tr	*Trifolium repens*	L	P	H	+		
Vm	*Vulpia myuros*	G	A	T		+	
With hydroseeding on southern slopes							
Bp	*Biserrula pelecinus*	L	A	T	+	+	•
Ec	*Eryngium campestre*	Umb	B	G	+	+	
Ep	*Echium plantagineum*	Bor	B	H	+	+	+
Gf	*Gaudinia fragilis*	G	A	T		+	+
Lg	*Logfia gallica*	C	A	T	+	+	+
Lh	*Lupinus hispanicus*	L	A	T	+		
Ls	*Lavandula stoechas*	Lab	W	Ch		+	+
Ms	*Medicago sativa*	L	P	H			+
Pb	*Poa bulbosa*	G	P	H		+	•
Pla	*Plantago lanceolata*	Plant	P	H		+	•
Pn	*Petrorhagia nanteuilli*	Car	A	T	+		+
Sm	*Sanguisorba minor*	Ros	P	H	+	+	•
Tb	*Tolpis barbata*	C	A	T	+	+	+
Tca	*Trifolium campestre*	L	A	T		+	+
Tg	*Trifolium gemellum*	L	A	T	+		+
Tre	*Trifolium retusum*	L	A	T	+	+	•
Ts	*Trifolium striatum*	L	A	T	+	+	+
With hydroseeding indifferent to aspect							
Al	*Anthyllis lotoides*	L	A	T	+	+	•
Fp	*Filago pyram idata*	C	A	T		+	+
Ra	*Rumex acetosella*	Pol	P	H	+	+	+
Ta	*Trifolium angustifolium*	L	A	T	+		+
Without hydroseeding							
Ac	*Anthyllis cornicina*	L	A	T	+	+	
Bh	*Bromus hordeaceus*	G	A	T		+	
Bru	*Bromus rubens*	G	A	T		+	+
Cc	*Carduus carpetanus*	C	P	H	+		
Cco	*Carlina corymbosa*	C	P	H	+		
Cj	*Chondrilla juncea*	C	B/P	H	+	+	+
Cl	*Corrigiola litoralis*	Car	A/B	T	•	+	+
Cm	*Chamaemelum mixtum*	C	A	T	+	+	+
Cr	*Coronilla repanda*	L	A	T	+	+	+
Csp	*Conyza* sp.	C	A	T		+	+
Lm	*Logfia minima*	C	A	T	+		
Ls	*Lotus subbifolius*	L	A	T	+	+	•
Pc	*Plantago coronopus*	Plant	P	H	+	+	+
So	*Sonchus oleraceus*	C	A/B	T/H	+	+	
Sr	*Spergularia rubra*	Car	A	T	•	+	+
Tar	*Trifolium arvense*	L	A	T	•	+	+
Indifferent to treatment prefering northern slopes							
Acas	*Agrostis castellana*	G	P	H	+	+	+

Table 3 (*Continued*)

Code	Species name	Family	Life cycle	Life form	year		
					2	3	4
Cd	*Cynodon dactylon*	G	P	H	+	+	+
Tc	*Taeniatherum caput-medusae*	G	A	T	+	+	
Indifferent to treatment prefering southern slopes							
Pt	*Polycarpon tetraphyllum*	Car	A	T	+	+	
Tgl	*Trifolium glomeratum*	L	A	T	•	+	+
Indifferent to treatment and aspect							
Aa	*Anthemis arvensis*	C	A/B	T	+	+	+
Aca	*Aira caryophyllea*	G	A	T	+	+	+
Ae	*Arrhenaterum elatius*	G	P	H	+		
Ai	*Andryala integrifolia*	C	B/P	H	+	+	+
As	*Avena sterilis*	G	A	T		+	+
Bma	*Bromus madritensis*	G	A	T		+	
Ca	*Convolvulus arvensis*	Con	P	H	+		
Cca	*Crepis capillaris*	C	B/P	H	+	+	+
Cn	*Chamaemelum nobile*	C	P	Ch		+	+
Ec	*Evax carpetana*	C	A	T	+	+	
Et	*Eryngium tenue*	Umb	A	T	+	+	+
Hg	*Herniaria glabra*	Car	P	Ch		+	
Jm	*Jasiona montana*	Cam	A/B	T	+	+	+
Lr	*Lolium rigidum*	G	A	T	+	+	+
Lsp	*Lactuca* sp.	C	B	H		+	+
Lt	*Leontodon taraxacoides*	C	P	H	+	+	+
Oc	*Ornithopus compressus*	L	A	T	+		
Op	*Ornithopus perpusillus*	L	A	T		+	+
Pl	*Plantago lagopus*	Plant	A	T	+		+
Vc	*Vulpia ciliate*	G	A	T	+	+	+
Vb	*Vulpia bromoides*	G	A	T	+		+

Presence of each species in each sampling year (2–4 years after revegetation) is symbolised by '+', and full dot emphasises year in which their cover was higher. Abbreviations. Family: Bor, *Boraginaceae*; C, *Compositae*; Cam, *Campanulaceae*; Car, *Caryophyllaceae*; Cru, *Cruciferae*; G, *Gramineae*; L, *Leguminosae*; Pla, *Plantaginaceae*; Pol, *Polygonaceae*; Ros, *Rosaceae*; Rub, *Rubiaceae*; Scro, *Scrophulariaceae*. Life cycle: A, annual; B, biennial; P, perennial; W, woody. Life form: Ch, chamephyte; G, geophyte; H, hemicrytophyte; P, phanerophyte; T, terophyte.

of fertilizers (e.g. high conductivity and nitrogen concentration) and inhibition by stabilizers (Sheldon and Bradshaw, 1977; Roberts and Bradshaw, 1985) as well as water deficit (Bewley and Black, 1994) are well-known factors responsible for poor plant establishment on hydroseeded slopes. The most severe effects of soluble fertilizer were observed on grass and legume seedling establishment when soil moisture was low (Roberts and Bradshaw, 1985).

On the other hand, in the study area, there was a high capacity of species from surrounding plant communities to displace the initial vegetation, maintaining high diversity in the developing plant community, as found in the 'Dehesa' pasture (reference community). The adjacent natural seed source present in remnant patches of natural vegetation and even as dormant seeds or plant remains contained in the arkosic material, together with the initial availability of suitable microsites (Martínez-Ruiz, 2000), allowed numerous species to establish and coexist (high richness and evenness values), improving natural colonisation of the dumps (Martínez-Ruiz et al., 2001; Martínez-Ruiz and Fernández-Santos, 2005). In such circumstances, the initial amelioration (fertility, moisture) at the soil surface after hydroseeding could also help to increase diversity (at the second year after revegetation on the north-facing slopes), since none of introduced species became invasive (Luken, 1990).

These results emphasize the possibility of conserving biodiversity by improving natural colonisation (Bradshaw, 1997), although it may cost something to initiate and it needs nurturing (Bradshaw, 1996, 2000) or providing suitable substrate (Martínez-Ruiz and Marrs, 2007) in some situations. Communities assembled from large species pools were inherently more resistant to invasions from exotic species (Law and Morton, 1996) and possessed greater drought resistance and exhibited both faster drought recovery and less annual variation in biomass production than species-poor communities (Tilman and Dowing, 1994; Tilman, 1996). Hence, the importance of biodiversity conservation as an objective of ecological restoration programs.

In spite of the short-term persistence of non-native introduced species in the study area, hydroseeding as a whole modified the composition of the developing plant community at early succession (2–4 year after revegetation), having a different influence according to the aspect. Hydroseeding favoured perennial herbaceous species (in number and cover) on both north- and south-facing slopes. All of them were hemicyptophytes, including five of hydroseeded species (*Dactylis glomerata*, *Festuca arundinacea*, *Medicago sativa*, *Lolium perenne*, and *Trifolium repens*). Hemicryptophythes have been shown to be important in colliery spoil reclamation (Down, 1973; Prach et al., 1997). They often have long tap roots enabling them to extract water from depth during summer drought. Nevertheless, annual species are well represented in the study area because of their character of stress-tolerators rather than ruderals in xeric habitats (Madon and Médail, 1997). It is also known that their cover varies from year to year in relation to rainfall, and can be strongly reduced by drought (Madon and Médail, 1997), as occurred in the second sampling year (3 years after revegetation), which was drier than two others.

On the other hand, hydroseeding increased differences in floristic composition between both aspects, not evident without hydroseeding (Fig. 4), favouring grasses on the northern slopes and legumes on the southern ones, both in number and cover. However, the contribution of native species to the total plant cover, particularly relevant for the rosette forming *Compositae*, progressively increased as in the long-term vegetation dynamics in the study area (Martínez-Ruiz and Fernández-Santos, 2005). Therefore, it is expected that the long-term development of these plant communities will not be markedly affected by hydroseeding application, not even on the north-facing slopes (Martínez-Ruiz, 2000).

We conclude that the commercial seed mixture used by the mining company to revegetate the spoil heaps was not suitable for the study area, and the cost of introducing herbaceous cover was not justified because poor vegetation cover was the final outcome. If the introduced species were also natives, they rapidly established and persisted through time (Tinsley et al., 2006). Thus, the use of locally collected seeds should be tested in future field experiments, which will be possible since, at the moment, there are companies in Spain that specialise in supplying local indigenous seeds of a wide variety of plant species.

On the other hand, our results emphasise the importance of improving natural colonisation (Prach and Pyšek, 2001) by providing suitable substrate for the restoration of similar semi-arid ecosystems if a seed bank or an adjacent seed source is present in remnant patches of natural vegetation (Martínez-Ruiz and Marrs, 2007). The result would be more diverse vegetation, dominated by annual species, capable of responding to year-to-year variation in weather conditions (Madon and Médail, 1997) that characterises those environments (Martínez-Ruiz and Marrs, 2007). Definitively, the knowledge about spontaneous vegetation succession derived from previous studies carried out at this uranium mine (Martínez-Ruiz et al., 2001; Martínez-Ruiz and Fernández-Santos, 2005) should be integrated into future restoration programs. Indeed, as Bradshaw (1983, 1996) noted: 'restoration is an acid test of our ecological understanding'.

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