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COLONIZATION OF SPOIL BENCHES OF AN OPENCAST LIGNITE MINE IN NORTHWEST SPAIN BY AMPHIBIANS AND REPTILES

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Abstract

Colonization by reptiles and amphibians of the spoil benches of the Meirama opencast lignite mine in northwest Spain was studied over the 10 years following the start of the revegetation process. At Meirama, spoil benches are initially fertilized and hydroseeded with a pasture mix, but are subject to little subsequent management and are gradually colonized by scrub vegetation characteristic of the region. Herpetofauna censuses were carried out (1) yearly on a single 2 ha plot over the 6 years following hydroseeding, and (2) in a single year on ten 2 ha plots which had been hydroseeded between 0 and 10 years previously. In addition, censuses were carried out on three undisturbed 'control' plots close to the mine. Fifteen species (nine amphibians and six reptiles) were detected in one or more of the spoil-bench plots. Recolonization is particularly rapid after the first 2–3 years post-hydroseeding, and is clearly closely related to habitat development due to revegetation and natural succession. The first reptile species to colonize the study plots was Podarcis bocagei *(first year), and the first amphibians* Alytes obstetricans *and* Rana perezi *(second year). Species composition was most similar to that in control plots in the oldest (ten-year-old) spoil plots. Copyright © 1996 Published by Elsevier Science Limited*

Keywords: amphibians, reptiles, colonization, disturbed land, restoration, opencast mining.

INTRODUCTION

Opencast lignite mines generate large quantities of spoil, which is generally spread out to form 'spoil benches', either on already-mined areas or on adjacent terrain. Initially, spoil benches lack both vegetation and soil (in both the pedological and biological senses; see Bradshaw, 1983). The establishment of biotic communities on such sites thus constitutes an interesting example of primary succession. As pointed out by Bejcek (1988), spoil benches present a number of advantages for the study of such processes. First, they often cover large areas. Second, climate, topography and substrate characteristics tend to be highly homogeneous. Third, the start of the succession process can be precisely dated.

Studies on the colonization of mine spoils by vertebrates have mainly been on birds (e.g. Dorsch & Dorsch, 1969; Giller, 1976; Bejcek & Tyrner, 1980; Bejcek & Stastny, 1982) or mammals (e.g. Verts, 1957; Sly, 1976; Hansen & Warnock, 1978; Bejcek, 1988; Halle, 1993), and there have been very few on reptiles and amphibians (though see Nichols & Bamford, 1985; Twigg & Fox, 1991; Halliger, 1993).

In the work reported here, we censused reptile and amphibian populations on spoil benches of the Meirama opencast lignite mine in northwest Spain. Sampling was carried out on benches of between 0 and 10 years of age, thus allowing analysis of changes in herpetofauna composition over the first 10 years of community development.

STUDY AREA

The Meirama lignite mine, in operation since 1980, is situated in the region of Galicia in northwest Spain (La Coruña Province, 43° 12′ N, 8° 26′ W). The climate in this region is Humid Oceanic, characterized by mild temperatures which differ relatively little between the coldest and hottest months, and by high precipitation which is relatively well distributed throughout the year. There are about 180 cloudy days and about 2000 h of sunshine per annum (Pérez-Alberti, 1982; Pérez-Alberti & Guitián-Rivera, 1984). The Meirama mine has its own weather station, 900 m from the study site and at similar altitude (219 m a.m.s.l.). Mean monthly precipitation at this station (20 years' data) ranges from 35·9 mm (July) to 220·5 mm (December), and mean annual precipitation is 1471 mm. Monthly mean temperatures (10 years' data) range from 7·5°C (January) to 18·7°C (July), and annual mean temperature is 12·6°C.

In terms of Rivas Martínez's (Rivas Martínez, 1987) phytoclimatic zonation of the Iberian Peninsula, the study area falls within the Atlantic Superprovince of the

Eurosiberian Region; climax vegetation is *Quercus robur* woodland. The mine is surrounded by a mosaic of habitats including cropland, meadows and small villages (these generally being delimited by hedges of *Rubus*, *Crataegus*, etc.), interspersed with areas of scrub (dominant species: *Ulex europaeus*, *Cytisus striatus* and *Erica cinerea*), tree plantations (*Pinus pinaster* and *Eucalyptus globulus*) and seminatural woodland (*Quercus robur*, *Castanea sativa*, together with introduced pine and eucalypt). The valley bottoms are largely occupied by croplands and meadows, while scrub and woodland communities are more frequent on higher ground. Streams and drainage ditches are numerous, and typically support riparian communities dominated by *Alnus glutinosa* and *Salix atrocinerea*.

The herpetofauna of northwest Spain, and particularly the amphibian fauna, is rich by comparison with other areas of the Iberian Peninsula. The most abundant species are largely Iberian endemics or taxa of Boreal origin; very few of the Peninsula's typically Mediterranean species are present (Bas, 1984; Galán & Fernández-Arias, 1993; Balado *et al.*, 1995). In the course of twenty years of fieldwork in the area of Meirama mine, I have recorded 59% (13) of Iberia's 22 species

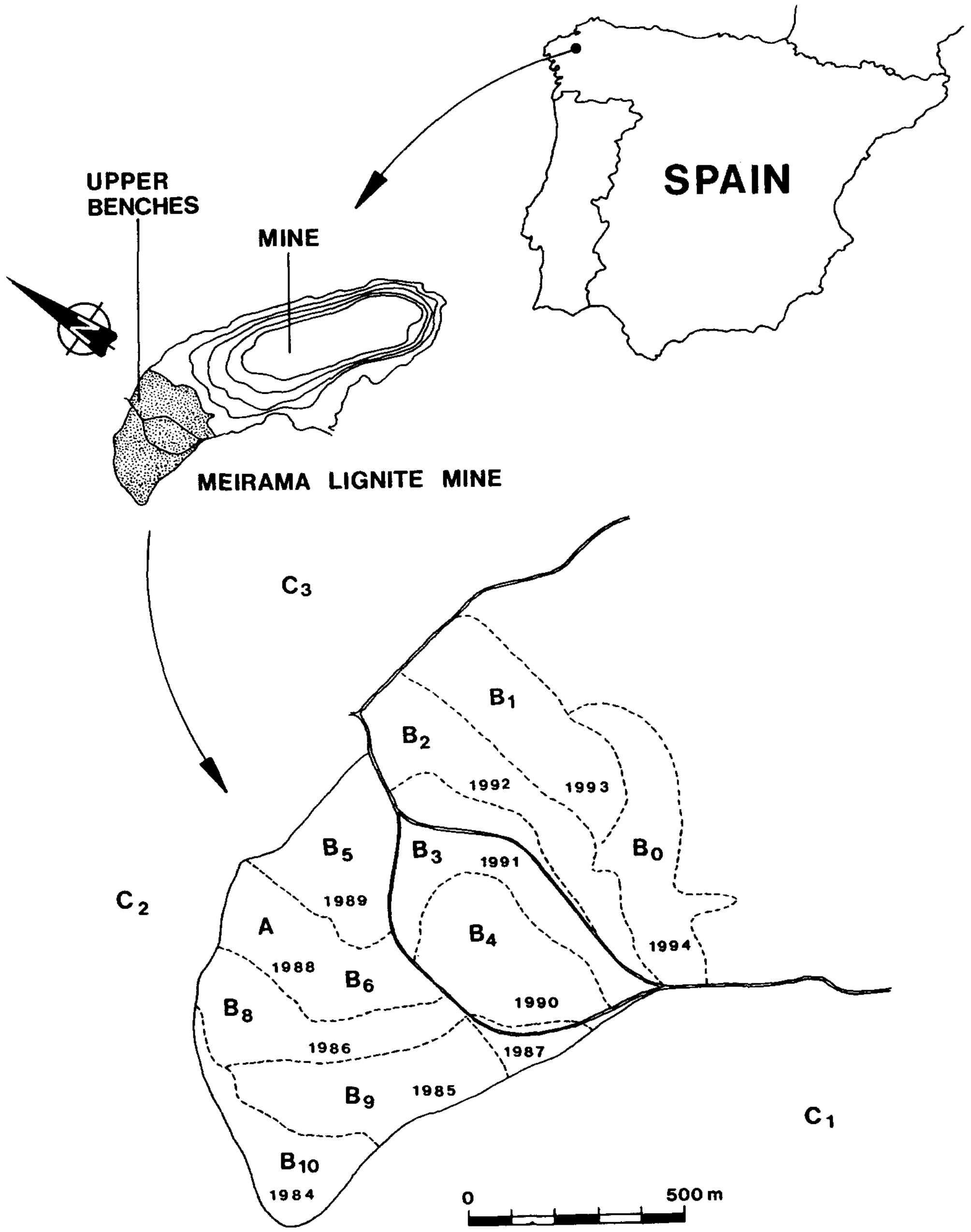

Fig. 1. Top — Map of the Meirama lignite mine showing its location in the Iberian Peninsula. Bottom — Map of the upper spoil benches showing the areas hydroseeded each year between 1984 and 1994, and the location of the eleven spoil-bench plots (A and B) and the three control plots (C). The seven-year-old bench was not studied in view of its small area. Tracks but not water bodies (drainage canals and ponds) are shown.

of amphibian, and 26% (10) of Iberia's 38 species of reptile.

The Meirama mine generates about 12 million tonnes of spoil per annum, and the spoil benches now cover an area of over 200 ha. The spoil material largely comprises granodiorites, schists and various types of clay (particularly kaolinitic clays). Before laying out onto benches, the spoil materials are broken up and mixed.

The present study was carried out on a series of spoil benches in the western part of the mine (the 'upper benches'), covering a total area of about 60 ha (Fig. 1). The benches studied ranged from 0 to 10 years old (1994-1984). About 1-3 months after laying out, all benches are hydroseeded with a pasture mix (150 kg/ha of *Lolium perenne*, 10%; *L. multiflorum*, 20%; *Dactylis glomerata*, 20%; *Festuca arundinacea*, 10%; *F. rubra*, 5%; *Poa pratensis*, 5%; *Trifolium repens*, 20%; *T. pratense*, 5%; *Vicia sativa*, 5%) and fertilized (about 100 kg/ha N, 100 kg/ha K and 100 kg/ha P); subsequent management is minimal.

MATERIALS AND METHODS

Study design

The development of reptile and amphibian communities on the spoil benches was investigated on the basis of (1) censuses carried out on a single 2 ha plot

Table 1. Hydroseeded species (colum 1) and principal native species colonizing spoil benches 5+ years old (columns 2, 3 and 4) at the Meirama mine. Nomenclature follows Castroviejo *et al.* (1986–1993) and Niño *et al.* (1994)

Hydroseeded species	Principal species in grassland	Principal woody species in scrub	Aquatic and wet-ground species
Dactylis glomerata	*Agrostis capillaris*	*Adenocarpus complicatus*	*Alisma plantago-aquatica*
Festuca arundinacea	*Agrostis curtisii*	*Calluna vulgaris*	*Alnus glutinosa*
Festuca rubra	*Anthemis nobilis*	*Cytisus scoparius*	*Alopecurus geniculatus*
Lolium multiflorum	*Anthoxantum amarum*	*Cytisus striatus*	*Apium nodiflorum*
Lolium perenne	*Anthoxantum odoratum*	*Daboecia cantabrica*	*Betula alba*
Poa pratensis	*Avena barbata*	*Erica ciliaris*	*Callitriche stagnalis*
Trifolium pratense	*Bellis perennis*	*Erica cinerea*	*Caltha palustris*
Trifolium repens	*Briza media*	*Rubus lusitanicus*	*Carex paniculata*
Vicia sativa	*Bromus diandrus*	*Rubus ulmifolius*	*Epilobium tetragonum*
	Bromus hordeaceus	*Ulex europaeus*	*Frangula alnus*
	Centaurium erythraea	*Ulex gallii*	*Galium divaricatum*
	Coleostephus myconis	*Ulex minor*	*Glyceria fluitans*
	Conyza canadensis		*Juncus bufonius*
	Cynosurus cristatus		*Juncus conglomeratus*
	Danthonia decumbens		*Juncus effussus*
	Echium rosulatum		*Lythrum junceum*
	Festuca arundinacea		*Mentha aquatica*
	Festuca rubra		*Myosotis scorpioides*
	Festuca stricta		*Polypogon monspeliensis*
	Holcus lanatus		*Polypogon viridis*
	Hypochoeris radicata		*Potamogeton polygonifolius*
	Jasione montana		*Ranunculus flammula*
	Juncus bufonius		*Ranunculus omyophyllus*
	Leontodon taraxacoides		*Ranunculus repens*
	Lolium multiflorum		*Salix atrocinerea*
	Lotus corniculatus		*Schoenus nigricans*
	Lotus uliginosus		*Scirpus fluitans*
	Lupinus luteus		*Scirpus lacustris*
	Medicago lupulina		*Typha latifolia*
	Mentha rotundifolia		
	Ornithopus perpusillus		
	Ornithopus pinnatus		
	Parentucellia viscosa		
	Poa pratensis		
	Poa trivialis		
	Pseudarrhenatherum longifolium		
	Ranunculus repens		
	Rumex angiocarpus		
	Sanguisorba minor		
	Trifolium dubium		
	Trifolium pratense		
	Trifolium repens		
	Vicia sativa		
	Vulpia bromoides		
	Vulpia myurus		

(plot A, comparable with B_6) over the 6-year period 1988 (2 months after the spoil bench had been hydroseeded) to 1994, and (2) censuses carried out in 1994 on ten 2 ha plots (plots B_0–B_{10}) on benches ranging in age from 0 to 10 years (the 7-year-old bench was not studied because it covered an area of less than 2 ha) (Fig. 1). Plots were selected at random from a map, and delimited with wooden stakes.

In addition, censuses were carried out in 1994 on three randomly selected 2 ha 'control' plots (plots C_1, C_2 and C_3) located outside, but within 1 km of, the limits of the mine, in order to obtain information on the reptile/amphibian species composition of undisturbed plots of the same size. For most analyses, C_1 was used as the control for B plots (since both C_1 and the B plots are basically flat), whereas C_2 and C_3 were used as controls for plot A (since C_2, C_3 and A are slightly sloping, with westerly aspect). All three control plots are at a similar altitude to the spoil-bench plots, and have similar habitat characteristics to the older spoil-bench plots (i.e. grass/scrub mosaic with scattered trees and small watercourses). All plots were characterized in terms of vegetation (see below).

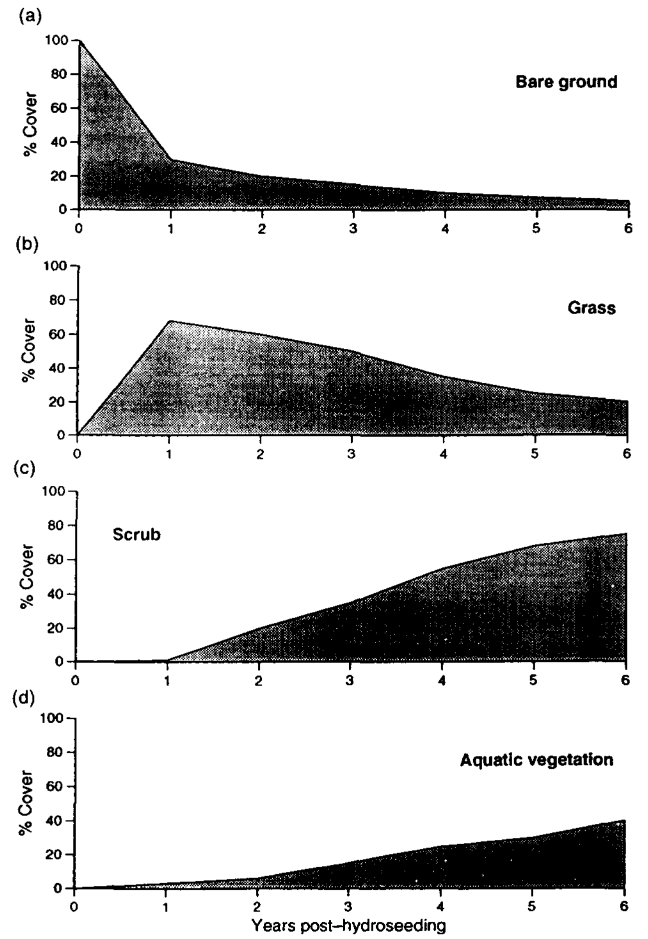

Fig. 2. Changes over time in the mean percentages of plot area occupied by (a) bare ground (i.e., vegetation cover less than 20%), (b) grasses, and (c) scrub. Also shown is the change over time in the mean percentage of water-covered area occupied by emergent vegetation. Means are for plot A in that year of study and the corresponding B plot (see text).

Finally, a complete checklist of reptile and amphibian species present in the study area (the As Encrobas Valley, A Coruña) was drawn up on the basis of the author's 20 years of fieldwork in this area.

Herpetofauna censuses

All censuses were carried out by the author. Each census (i.e., each year for plot A, or each plot for the B plots) was based on a total of 30 h of searching (3 h per month) over the period February to November inclusive. During each 3 h session, the plot was exhaustively searched on foot, with examination of all potential reptile/amphibian microhabitats (vegetation, streams, ditches, pools, under stones, etc.). All adult or subadult reptiles/amphibians detected were, where possible, captured by hand or with a net; eggs and larval forms were not counted. Only captured individuals were included in the count, and all such individuals were marked for subsequent recognition by a system of clipping of the toes (amphibians and saurians except *Anguis*) or of the ventral scales (ophidians and *Anguis*); individuals were thus counted only once within each census. In all censuses, care was taken to ensure that all microhabitat types were subject to similar search effort. In the summer months, part of the search session was carried out at night, in order to ensure efficient sampling of amphibians.

The spatial pattern of colonization by *Podarcis bocagei* was studied in greater detail. Over the period 1989–1992, censuses of this species were carried out in 50×50 m (0·25 ha) plots together covering the entire upper spoil bench area revegetated up to that time.

Characterization of plots

All plots were characterized in terms of basic habitat characteristics. Plot A was characterized in each year of study. To this end, the proportions of plot area occupied by (a) bare ground, (b) grasses, (c) scrub, (d) open water and (e) emergent aquatic vegetation were estimated. This was done at the height of the growth period, in June. Because of the extensive network of drainage ditches in the study area, nearly all plots (except plot B_8) contained significant areas of aquatic habitat.

RESULTS

Vegetation development

Within 3 or 4 months of hydroseeding, the sown species expand to cover a large proportion of the seeded area. From the second year onwards, various scrub species become established from seed or vegetative expansion from adjoining areas, especially *Cytisus striatus*, followed by *Ulex europaeus* and then *Adenocarpus complicatus*. Gradually, these scrub species displace the underlying grassland communities which also change, as native species gradually displace the seeded species (Table 1). From about the fourth year onwards, scrub communities typically occupy > 50% of ground area (Fig. 2).

Aquatic microhabitats (drainage ditches and seasonal pools) are likewise rather rapidly colonized by plants (Table 1). Communities dominated by *Alnus glutinosa* and *Salix atrocinerea* develop along the banks of the larger drainage ditches, while *Salix atrocinerea* and *Betula alba* subsp. *celtiberica* become established around the larger and more persistent pools.

Colonization by reptiles and amphibians

Of the 23 amphibian and reptile species previously recorded in the area of Meirama mine, 21 were recorded in the present study (all except *Chioglossa lusitanica* and *Coronella girondica*). Fifteen species (71% of those detected in control plots) were recorded from spoil-bench plots (maximum age 10 years) (Tables 2 and 3). The proportion of amphibian species (9 out of the 13 species present in the region) did not differ significantly from the proportion of reptile species (6 out of the 10) ($X^2 = 0{\cdot}66$; d.f. $= 1$; $p = 0{\cdot}42$).

Herpetofauna species richness increased steadily with time since seeding (Tables 2–3). The results for the B plots and plot A show close agreement, particularly as regards the year of first appearance of each species. Note, however, that species richness in the 8-year-old B plot was markedly lower than in the 6-year-old B plot; this is probably attributable to the fact that plot B_8 is atypical in the absence of drainage ditches or seasonal pools; thus, for example, *N. natrix* was not detected in this plot. In addition, this plot contains large amounts of iron pyrites (iron sulphide), provoking high substrate acidity; colonization of this plot by native plant species thus lagged behind that of other areas of similar age. The poor development of vegetation cover on this plot may explain the absence of species such as *Coronella austriaca* and *Vipera seoanei*, despite the fact that these species were detected on other younger plots (Table 2).

Early-colonizing amphibian species were *Alytes obstetricans* (found from the second year onwards and occurring even on non-vegetated substrates) and *Rana perezi* (again found from the second year onwards, in drainage ditches). *Discoglossus galganoi* was detected from the third year onwards, in grassy sites.

Only one reptile species, *Podarcis bocagei*, was an early colonizer, individuals being found on non-vegetated sites within the first year. Apart from *Natrix natrix* (detected in drainage ditches from the third year onwards), other reptile species only appeared when the scrub layer was well developed (from the fourth year onward). Some species (such as *Anguis fragilis*) were not detected until the sixth year, by which time the vegetation

Table 2. Number of individuals in the 1994 herpetofauna censuses of the B plots, ranging in age from 0 to 10 years. Results for the control plot C_1 are also shown

Amphibians											
Years of hydroseeding	1994	1993	1992	1991	1990	1989	1988	1986	1985	1984	Control C_1
Plot age in 1994	0	1	2	3	4	5	6	8	9	10	
Salamandra salamandra	—	—	—	—	—	—	—	2	1	3	3
Triturus boscai	—	—	—	—	—	1	—	2	2	—	18
Triturus helveticus	—	—	—	—	—	—	—	—	—	—	15
Triturus marmoratus	—	—	—	—	1	2	—	5	4	5	7
Discoglossus galganoi	—	—	—	2	3	1	8	7	10	6	9
Alytes obstetricans	—	—	3	5	16	11	15	9	12	9	7
Bufo bufo	—	—	—	—	—	—	1	—	3	1	5
Bufo calamita	—	—	—	2	5	8	13	1	7	4	8
Hyla arborea	—	—	—	—	—	—	—	—	—	—	1
Rana perezi	—	—	6	9	15	21	19	—	9	5	10
Rana iberica	—	—	—	—	—	—	—	—	—	1	7
Rana temporaria	—	—	—	—	—	—	—	—	—	—	3
No. of species	0	0	2	4	5	6	5	6	8	8	12
No. of individuals	0	0	9	18	40	44	56	26	48	34	93
Reptiles											
Years of hydroseeding	1994	1993	1992	1991	1990	1989	1988	1986	1985	1984	Control C_1
Plot age in 1994	0	1	2	3	4	5	6	8	9	10	
Anguis fragilis	—	—	—	—	—	—	1	1	2	1	6
Lacerta schreiberi	—	—	—	—	1	1	2	1	3	2	3
Podarcis bocagei	—	2	7	32	19	17	9	5	16	13	25
Chalcides striatus	—	—	—	—	—	—	—	—	—	—	2
Coronella austriaca	—	—	—	—	—	1	1	—	1	1	2
Natrix natrix	—	—	—	—	1	2	1	—	2	1	4
Natrix maura	—	—	—	—	—	—	—	—	—	—	1
Vipera seoanei	—	—	—	—	2	1	3	—	1	2	2
No. of species	0	1	1	1	4	5	6	3	6	6	8
No. of individuals	0	2	7	32	23	22	17	7	25	20	45

cover tends to be a scrub/grass mosaic with relatively high herb species diversity.

The diurnal activity of *Podarcis bocagei*, and its heliothermic habit, facilitated a more detailed study of its colonization of the study area B_3–B_{10}. This species rapidly expanded over most of the area during this period, starting from peripheral sites adjacent to undisturbed terrain (Fig. 3). The plots remaining uncolonized in 1992 were mostly occupied by topographically simple grassland offering few microhabitats suitable for this species. Plots occupied by *P. bocagei* in 1989/90 but not in 1992 were mostly plots in which scrub species had become dominant over the intervening period.

DISCUSSION

The sequential bench formation and revegetation of the Meirama mine spoils leads to the development of a range of plant and animal habitats. The development of these habitats is ultimately dependent on edaphogenesis in the surface layers of the spoil (González-Sangregorio *et al.*, 1991; Gil-Sotres *et al.*, 1992; Gil-Sotres *et al.*, 1993; Leirós *et al.*, 1993; Trasar-Cepeda *et al.*, 1993; Varela *et al.*, 1993; Seoane-Labandeira, 1994). Colonization of the Meirama mine spoils by native plant species is very rapid, and such species typically account for more than 75% of cover from about the sixth or seventh year onwards (Blanco *et al.*, 1991; Galán, unpublished data). The unusual rapidity of these processes at Meirama compared with other lignite mines is probably attributable to the absence of toxic components in the spoil (Leirós *et al.*, 1989; Leirós *et al.*, 1993; Seoane-Labandeira, 1994), and a high rainfall.

The establishment of animal communities on mine spoils is typically dependent on the establishment of native plant communities (Brenner *et al.*, 1983; Majer, 1989; Viert, 1989). This has been clearly demonstrated for birds and mammals (e.g. Brenner, 1978; Brenner & Kelly, 1981; Bejcek, 1988) and for invertebrates (e.g. Neumann, 1971; Majer, 1983; Burbidge *et al.*, 1992).

Clearly, some species are more effective pioneer colonists than others (see Sly, 1976; Ranta & As, 1982; Hingten & Clark, 1984). In studies of colonization of mined areas in western Australia by ants, it has been shown that the pioneers are often the same species, regardless of the mine's location or substrate characteristics, and that these species are generally relatively uncommon in adjoining undisturbed habitats (Woodroff & Majer, 1981; Majer *et al.*, 1984; Majer, 1985, 1989). Similarly, the pioneer colonists identified in the present study (*Podarcis bocagei, Alytes obstetricans, Rana perezi*) are also typical pioneers of other de-vegetated sites (such as quarries, gravel pits, embankments

Table 3. Number of individuals in the herpetofauna censuses of plot A, carried out yearly between 1988 (2 months after hydroseeding) and 1994 and results for the control plots C_2 and C_3

Amphibians									
Years of census	1988	1989	1990	1991	1992	1993	1994	Control C_2	Control C_3
Plot age	0	1	2	3	4	5	6		
Salamandra salamandra	—	—	—	—	—	—	—	—	2
Triturus boscai	—	—	—	—	—	—	—	3	15
Triturus helveticus	—	—	—	—	—	—	—	—	9
Triturus marmoratus	—	—	—	—	—	1	1	5	3
Discoglossus galganoi	—	—	—	2	6	4	5	9	3
Alytes obstetricans	—	—	7	12	11	18	24	4	7
Bufo bufo	—	—	—	—	—	—	—	5	6
Bufo calamita	—	—	—	—	5	7	10	—	—
Rana perezi	—	—	3	8	15	20	17	15	27
Rana iberica	—	—	—	—	—	—	—	8	3
Rana temporaria	—	—	—	—	—	—	—	3	9
No. of species	0	0	2	3	4	5	5	8	10
No. of individuals	0	0	10	22	37	50	57	52	84
Reptiles									
Years of census	1988	1989	1990	1991	1992	1993	1994	Control C_2	Control C_3
Plot age	0	1	2	3	4	5	6		
Anguis fragilis	—	—	—	—	—	—	2	4	1
Lacerta lepida	—	—	—	—	—	—	—	2	—
Lacerta schreiberi	—	—	—	—	1	1	1	8	5
Podarcis bocagei	—	3	9	21	26	16	12	11	15
Chalcides striatus	—	—	—	—	—	—	—	—	3
Coronella austriaca	—	—	—	—	—	1	1	2	1
Natrix natrix	—	—	—	1	—	2	1	1	2
Natrix maura	—	—	—	—	—	—	—	2	—
Vipera seoanei	—	—	—	—	1	3	1	1	1
No. of species	0	1	1	2	3	5	6	8	7
No. of individuals	0	3	9	22	28	23	18	31	28

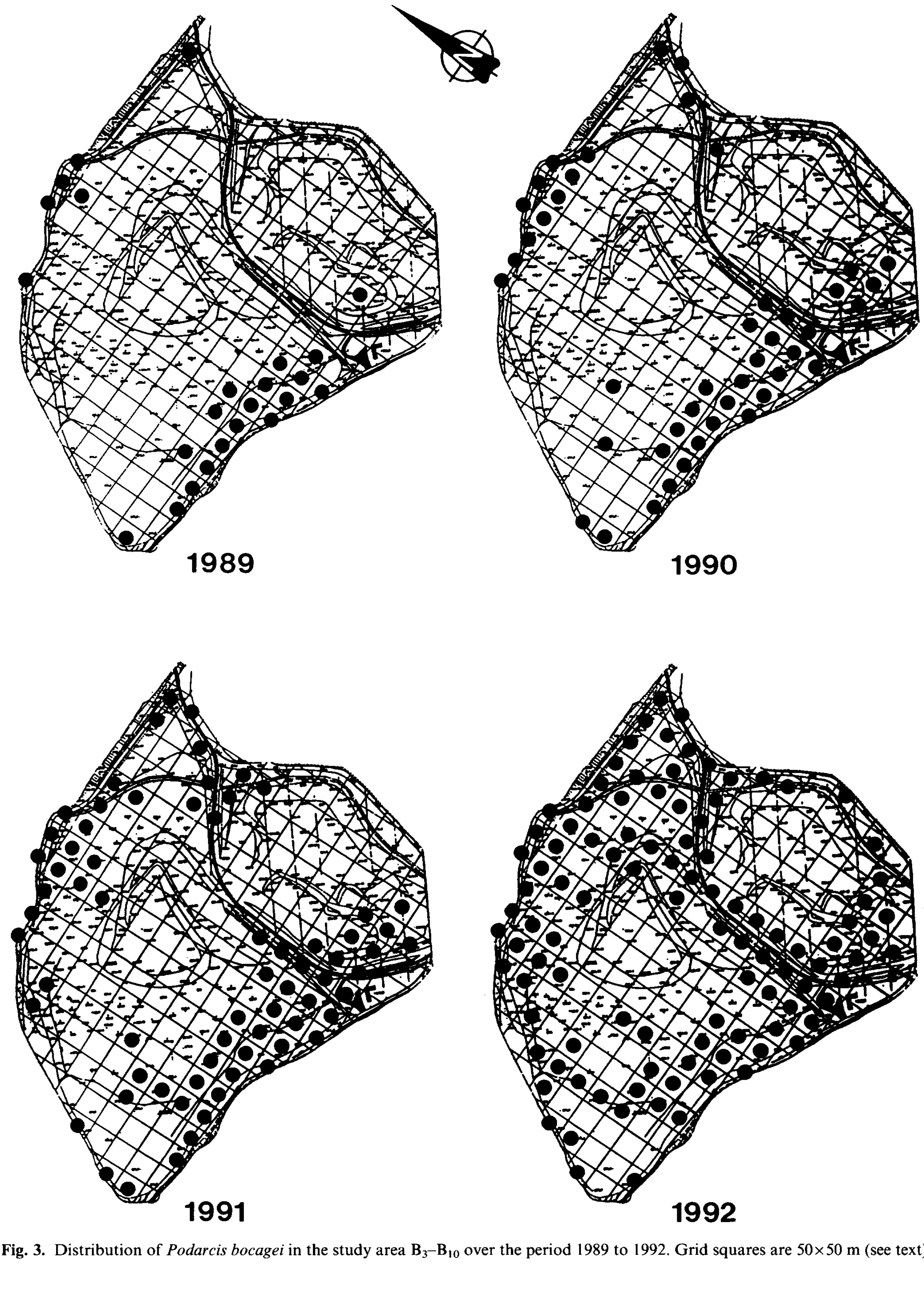

Fig. 3. Distribution of *Podarcis bocagei* in the study area B_3–B_{10} over the period 1989 to 1992. Grid squares are 50×50 m (see text).

and fire-breaks) and are frequently observed on sites severely degraded by fire or erosion (Galán, unpublished observations). In eastern England, the otherwise scarce *Triturus cristatus* is a colonist of brick-clay workings, presumably because of the suitable breeding areas (B. N. K. Davis, personal communication). *P. bocagei* was detected within one year of hydroseeding in both census series. This species occurs in many habitat types but is most frequent in sites where scrub or woodland vegetation alternates with bare ground (Arnold & Burton, 1978; Pérez-Mellado, 1981; Galán, 1986, 1994; Domínguez & Salvador, 1989; Galán & Fernández-Arias, 1993).

Following colonization by these pioneer species, others arrive in rapid succession, and high levels of species diversity (both for amphibians and reptiles) are soon reached. A clear correspondence is apparent between the increase in herpetofauna diversity and the development of vegetation-related habitats and microhabitats.

The first individuals of all amphibian species detected within the first three years were juveniles. In monthly censuses of a pool of about 0·25 ha in area (not part of any of the plots) I did not detect evidence of breeding by any amphibian species until the fifth year, when I found eggs and larvae of *Discoglossus galganoi* and *Bufo calamita*. However, juveniles of both species had been found on the site from the third year onwards so, it seems possible that the individuals which bred in the fifth year were those which had arrived as juveniles two years previously.

In some circumstances, habitat disturbance may cause an increase in herpetofauna abundance and diversity with respect to predisturbance conditions. In the present study, the appreciable differences in species composition between the control plots and the oldest revegetated plots suggest that more than 10 years are required for herpetofauna communities to attain predisturbance characteristics. Two species (*Chioglossa lusitanica* and *Coronella girondica*) were not detected in any plots, possibly because of their rarity in the study area but more likely because of their very specific habitat requirements (streambeds in mature deciduous woodland, and dry rocky slopes, respectively).

Similar results (involving revegetated sites of between 5 and 32 years of age) have been obtained in previous studies of isopods, diplopods and carabid beetles (Neumann, 1971), thysanopterans (Stannard, 1967), reptiles and amphibians (Nichols & Bamford, 1985), birds (Nichols & Watkins, 1984) and small mammals (Hingten & Clark, 1984). Results of this type are probably attributable to the fact that, in many animal communities, there are likely to be species which require microhabitats that arise only after a very long period, such as fallen tree trunks. Halliger (1993), for example, has suggested that copper mine spoils in Australia probably require at least 80 years for full re-attainment of pre-disturbance species diversity.

In some cases, species diversity may never return to pre-disturbance levels, as has been reported for the soil microfauna of revegetated mine spoils in New Mexico (Parker *et al.*, 1984). This is particularly likely to occur in 'malleable' ecosystems, i.e., ecosystems which may stabilize in any of various equilibrium states (Majer, 1989). At the Meirama mine, spatial heterogeneity in the physicochemical properties of the spoil leads to associated heterogeneity in vegetation type and thus herpetofauna habitat; reptile and amphibian species characteristic of different successional stages may thus co-exist, to some extent independently of the time since revegetation started.

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