Best wishes, Hilary, J. Ash

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The introduction of native plant species on industrial waste heaps: a test of immigration and other factors affecting primary succession

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Summary

1. Industrial waste heaps in north-west England have become colonized by interesting floras which include regionally uncommon species. However, the range of species is restricted and the vegetation remains open even after 100 years. This appears to be due to (i) the chemical and physical characteristics of the sites, and (ii) difficulties of immigration for appropriate species.

2. To test these hypotheses and to explore the improvement of such areas for creative conservation and amenity, introduction of further native species was undertaken. Several species from calcareous grassland, were successfully established on alkaline chemical waste and blast furnace slag, and species from acidic heathland on colliery shale. Some species were established on pulverized fuel ash, but the successful ones had no obvious characteristics in common.

3. This demonstrates the limitations that can be set in isolated sites by problems of immigration. When suitably adapted species are introduced, appropriate niches for their establishment appear to be available. Failure of more nutrient demanding species showed that nutrient deficiency can also be a major factor controlling colonization.

4. The results reveal some of the factors affecting primary succession. They indicate the limitations faced by species which might require to migrate in the face of climatic or other environmental changes. They also show that it is practicable to diversify the species composition of such derelict sites for creative conservation or amenity purposes.

Key-words: dispersal, introductions, industrial wastes, island biogeography, primary succession.

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Introduction

Among the many derelict waste tips ('bings') to be found in industrial areas, there are older sites in the North West of England which have become naturally colonized by an interesting flora (Greenwood & Gemmell 1978; Ash 1983). Some of this consists of pioneer ruderals, common in the surrounding areas, which can tolerate low soil fertility and extreme pH. However, there are other species with specialized soil preferences which have travelled considerable distances from habitats having similar conditions. In particular, alkaline wastes may support large populations of orchids, especially spotted and marsh orchids, *Dactylorhiza*‡ spp., and fragrant orchids (*Gymnadenia conopsea*) together with other calcicoles which are rare elsewhere in North West England because of the lack of calcareous strata. Many appear to have colonized the sites from coastal dune systems 30–40 km away (Bradshaw 1983).

Nevertheless, even after 100 years the sites are very open and have a very restricted flora. It appears that this is due to (i) the extreme soil characteristics of the sites, which limit plant growth, combined with (ii) the difficulties that appropriately adapted species have in immigration, which limit species richness. These waste heaps are in effect islands in an alien sea which has different edaphic conditions (Gray 1982).

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‡ Nomenclature follows Clapham, Tutin & Moore (1987).

Many of the sites can be considered to be *derelict land* (Environmental Advisory Unit 1985), but their developing natural vegetation gives them considerable interest. As a result many local authorities are considering the conservation of such sites for amenity and educational purposes. However, because they are still visually unattractive for most of the year and prone to 'fly-tipping' (illicit dumping) and other abuses, there is some wish to improve their appearance and species-richness, although it is recognised that some should be retained as unique examples of primary succession.

Improved growth can be achieved by applying fertilizers, but levels have to be kept very low, otherwise fertility-demanding perennial grasses will dominate and exclude the more attractive species (Ash 1983). The majority of the nearby species which are mobile and appropriately adapted have already colonized the wastes. The prospects for further colonization by well adapted species from distant, but ecologically similar areas, such as coastal dunes and limestone grassland, are poor. It would appear that the most effective improvement would be by artificial introductions, as suggested by Davis (1986).

Such introductions would be a direct test of the hypothesis that the floristic poverty is due to difficulties of immigration. At present many of the waste sites appear to fit the species–area relationships predicted by island biogeography (McArthur & Wilson 1967; Gray 1982). Similar relationships have been found for other island-like areas, including woods in Britain (Moore & Hooper 1975; Helliwell 1976), Yorkshire nature reserves (Usher 1979) and American vacant lots (Crowe 1979).

Accordingly, a series of experiments was devised which involved the introduction of a range of herbaceous species on four sites with and without fertilizer. Introduction of tree and shrub species was also attempted, but difficulties in establishment, largely unrelated to site characteristics, made the results too fragmentary to be worth reporting here. Details are, however, available (Ash 1983). The aim was to establish populations large enough to allow natural evolutionary processes to continue (Frankel & Soulé 1981).

Materials and methods

Details of the four sites are given in Table 1. The following introduction techniques were used.

1. Seed of wild species: most of the material used was hand collected (Wells, Bell & Frost 1981; Thompson *et al.* 1981) from natural populations, tested for germination, and sown in both autumn and spring into six replicate 1-m^2 plots on each site, at a rate to give one viable seed cm^{-2}. On the alkaline sites the seeds of tall and short species were sown in two separate lots.
2. Seed of commercial grass and legume cultivars: mixtures of low and slow-growing types, sown in autumn 1980 on each site, in 0·5-m^2 plots with three fertilizer treatments each with three replicates per site.
3. Young transplants: less than 1 year old, transferred in spring either from natural sites or from nursery-grown stocks, five plants in each of six replicate 1-m^2 plots per site.
4. Litter: used on acid sites, collected in spring from *Calluna* moorland and spread by hand in a layer less than 10 mm thick, in six replicate 1-m^2 plots per site.
5. Small turves: used on alkaline sites, transferred in autumn from an unimproved limestone pasture, 25 × 25 cm, 5 cm thick, three replicate turves per site.

The species used had to be determined by availability, but were chosen to be a selection of those

Table 1. Characteristics of the waste heaps*

Substrate and situation	Age (years)	Area (ha)	Material	Surface pH	Special features
Leblanc waste					
Darcy Lever, near Bolton, Lancs SD 737074	*c.* 80	1·6	Mainly Ca hydroxide and sulphate, and cinders	8–9	Surface weathered to $CaCO_3$, high P fixation
Blast furnace slag					
Kirkless Lane, near Bolton, Lancs SD 607066	*c.* 50	10	Ca-Al silicates with calcium carbonate and hydroxide	7–8	Very stony, calcareous, high P fixation
Pulverized fuel ash					
Westwood, Wigan, Lancs SD 580044	*c.* 20	3	Coal ash from power station	6·5–7·5	Ash only 1–2 m above water table, high B
Colliery spoil					
John & Taylor tip, near Wigan, Lancs SD 554080	*c.* 40	3	Coal Measure shales and mudstones	4–5	Loose tipped, well weathered at surface

* Full details given by Ash (1983).

adapted and unadapted to the soil conditions of each type of site. As far as possible they came from populations in north-west England. All were absent not only from the sites, but also from surrounding areas.

In Methods 1, 3 and 5 half the plots were fertilized annually in spring with N, P and K at 30, 13 and 25 kg ha^{-1} respectively; in Method 2 the corresponding N:P:K application rates were 100:44:83, 50:22:42 and nil.

Plots were set up in both autumn 1979 and spring 1981. Because of the low existing plant cover (about 50%) on all wastes, no attempt was made to clear areas. The materials were applied to the surface, and seed and litter were lightly raked in. Weather conditions following the autumn sowing were average, but a 12-week drought occurred in the spring of 1980. The spring sowing had normal damp conditions.

The experiments were recorded annually and included measurements of percentage cover using a point quadrat with 100 points m^{-2}; but only survival and area covered after 6 years are given here (except in Table 4) because the critical character for this work is long-term survival and spread. Statistical analysis is not given because differences between species were large and consistent. Year of first flowering is given to indicate how quickly the species became able to spread by seed. Full records of the introductions are lodged with the Lancashire Trust for Nature Conservation and the North West Biological Data Bank, Liverpool Museum.

Results and discussion

LEBLANC WASTE

This waste heap was highly alkaline, the surface dominated by calcium carbonate, with severe deficiency of nitrogen and phosphorus, and phosphorus subject to high absorption (Gemmell 1977; Ash 1983). The existing flora was limited (Table 2) and plant cover low.

Seventeen species, out of a total of 36 introduced, became permanently established (Table 3). All species germinated; any failure occurred subsequently. The most successful were those characteristic of calcareous grassland. More nutrient-demanding species either failed to establish, even when given fertilizers, e.g. poppy (*Papaver dubium*) or only grew poorly, e.g. cowslip (*Primula veris*). The commercial cultivars only established at the highest nutrient application, and did not persist except for bird's foot trefoil (*Lotus corniculatus*). The failure of catchfly, *Silene gallica* on this and other sites, appeared to be because seedlings did not over-winter; spring sowings were successful. For those species whose establishment from seed was excellent, transplants and turves proved less successful, perhaps due to summer drought.

Eight species spread by seed, and three vegetatively, beyond the experimental plots. After 4 years yellow-wort (*Blackstonia perfoliata*) had extended over an area 16 × 25 m, and felwort (*Gentianella amarella*) after 6 years (two cycles of spread) over an area 10 × 20 m. By 1990, 11 years after introduction, both species extended all over the heap, approximately 70 × 200 m. There were no major changes to the results in Table 3; all species spreading after 6 years were continuing to do so, and some spread of *Festuca ovina* and *Sanguisorba officinalis* was observable.

Vegetation cover measurements, and field observations suggested that the newly introduced species were filling vacant niches and not having a detrimental effect on the existing flora (Table 4).

BLAST FURNACE SLAG

This waste heap is very stony, highly calcareous and deficient in all major nutrients. Chlorosis was evident in the vegetation, perhaps induced by the low iron content and high levels of calcium. The flora was limited (Table 5), forming a very open community.

All species germinated and 21 out of the 41 introduced established successfully (Table 6), all being characteristic of calcareous grassland. *Gentianella amarella*, *Blackstonia perfoliata* and yellow rattle (*Rhinanthus minor*) proved particularly successful. *Rhinanthus*, an annual, spread rapidly by seed in its first seeding year (Fig. 1). Small changes in topography interfered with dispersal of the heavy winged seeds, but 2 years later the population had increased in density and spread to the limits of suitable habitat in the downwind direction.

Blackstonia, a biennial, could not show any dispersal until the second year. However, its seeds are much smaller and lighter than those of *Rhinanthus* so that its dispersal after 4 years slightly exceeded that of the annual *Rhinanthus* (Fig. 1). It was also not able, in 6 years, to extend beyond the main open area, because of the barrier of unsuitable ground. *Gentianella* established in smaller numbers and showed less mobility. However, by 1990, after 11 years, both species had passed these boundaries and had spread over a substantial area, approximately 100 × 70 m, of the site. The results were, again, not materially different from those in Table 6: all species then spreading had continued to do so, and *Carex flacca*, *C. nigra* and *Sanguisorba officinalis* were starting to spread.

PULVERIZED FUEL ASH

At the site PFA had been tipped into a mining subsidence flash. Willow scrub had developed, with large, spectacular, populations of marsh orchids (*Dactylorhiza* spp.), and a somewhat restricted range of other species (Table 7). The waste was

Table 2. Flora of Leblanc waste site before species introduction

Acer pseudoplatanus	1	*Hieracium pilosella*	3
Agrostis capillaris	3	*H. vulgatum*	4
A. stolonifera	1	*Hypochaeris radicata*	2
Angelica sylvestris	+	*Linum catharticum*	4*
Aster novi-belgii	+	*Plantago lanceolata*	2
Bellis perennis	3	*Pohlia nutans* (Hedw.) Lindb.	2
Centaurea nigra	4	*Potentilla reptans*	2
Centaurium erythraea	4	*Ranunculus repens*	+
Cerastium fontamum	2	*Rubus fruticosus* agg.	1
Chamaenerion angustifolium	4	*Rumex acetosa*	+
Cirsium arvense	1	*Salix repens* ssp. *argentea*	+*
Crataegus monogyna	2	*Sambucus nigra*	+
Dactylis glomerata	5	*Senecio jacobaea*	1
Dactylorhiza fuchsii	+*	*Solanum dulcamara*	1
D. incarnata	2*	*Sorbus aucuparia*	+
Erigeron acer	2*	*S. intermedia*	+
Euphrasia nemorosa	2*	*Succisa pratensis*	+
Festuca arundinacea	+	*Taraxacum officinale* agg.	3
F. rubra	4	*Trifolium pratense*	1
Gymnadenia conopsea	2*	*Tussilago farfara*	3
Heracleum sphondylium	1	*Vicia cracca*	1
		Bare ground	7

Values are given on the Domin scale of cover/abundance.
* Indicates that species is a colonist from a long distance (>30 km).

deficient in nitrogen, but had adequate levels of other nutrients; populations of clover (*Trifolium repens*) were spreading over much of the site.

Despite the apparently more benign soil conditions, relatively few species established (Table 8). However, the early success of lady's fingers (*Anthyllis vulneraria*) eyebright, *Euphrasia nemorosa*, and *Lotus corniculatus* was notable, while *Rhinanthus minor* did well later. By 1990, 11 years after establishment, the tree canopy had closed over most of the site and the majority of the introduced species were in decline. However, *Rhinanthus* and *Euphrasia* had spread all over the site, an area about 300 × 100 m, being particularly abundant in clearings and at the edges. Commercial cultivars of grasses showed poor survival and chlorosis occurred even when fertilizer was applied, but white clover, *Trifolium repens* and *Lotus corniculatus* thrived. It is difficult to explain the pattern of survival, but the success of the legumes, which are generally borate-tolerant (Hodgson & Townsend 1973), suggests that high levels of borate may have been important. Establishment from turves was better than from transplants. Variations in edaphic conditions between parts of the site also influenced establishment.

COLLIERY SPOIL

This site was not extreme, but pH, nitrogen and phosphorus levels were low. Scrub and woodland had colonized part of the site. Introduction experiments were carried out in areas with grass cover (Table 9).

Introduced species, whether by seed or transplants, did not grow well until their second year. Only a small number of plants grew, but some species were successful (Table 10). All grew better in fertilized plots, although successful species set some seed even in unfertilized plots. The litter treatments produced 19 heather (*Calluna vulgaris*) plants, but no other species, perhaps because of desiccation and removal of litter by wind. In general, species of dry heath and acidic grassland were those which established successfully. The site was destroyed in 1984.

Conclusions

ISLAND BIOGEOGRAPHY AND PRIMARY SUCCESSION

The waste heaps showed some quite unusual species assemblages. However, they do not approach the richness of other man-made sites, such as Millersdale Quarry, Derbyshire (Holliday & Johnson 1979). It has been argued that this is because of their distance from sites in which ecologically appropriate species occurred (Greenwood & Gemmell 1978; Ash 1983; Bradshaw 1983). Thus, in contrast, quarries in limestone areas are normally surrounded by floristically rich grassland which can act as a source of suitable propagules (Hodgson 1982). It is possible, however, that the paucity of species on these industrial wastes was due to the extreme edaphic characteristics of the sites. Species introduction provides a critical test of these two alternatives.

The experiments show that certain species can colonize these sites very successfully once introduced. Indeed, the rapid spread of species such

Table 3. Leblanc waste: fate of introduced species after 6 years

	Soil preferences*	Introduction method†	Year of first flowering‡	Area (m^2) and mode of spread
Species spreading beyond original plots				
Anthyllis vulneraria	L C	PT	2	2 (seed)
Blackstonia perfoliata	L C	S	3	100 (seed)
Briza media	L C	PT	2	0·2 (veget.)
Carex nigra	L C	T	7	0·2 (veget.)
Euphrasia nemorosa	L C	T	1	100 (seed)
Gentianella amarella	L C	S	3	100 (seed)
Leucanthemum vulgare	L C	P	2	2 (seed)
Prunella vulgaris	L CN	S	2	12 (seed)
Rhinanthus minor	L C	S	1	10 (seed)
Sanguisorba minor	L C	PT	2	2 (seed)
Thymus praecox	L C	T	7	0·1 (veget.)
Species growing, but not yet spreading				
Festuca ovina	L CN	T	4	
Fragaria vesca	M CN	P	2	
Helianthemum nummularium	L C	T	4	
Koeleria macrantha	L CN	T	4	
Lotus corniculatus§	M CN	S	7F	
Primula veris	M C	S	6F	
Sanguisorba officinalis	M C	S	4	
Species which died				
Agrostemma githago	M N	S	2	
Agrostis stolonifera Emerald§	M N	S	3	
Bellis perennis	M N	T	1	
Bromus sterilis	M N	S	3	
Festuca rubra Dawson§	M N	S	4	
Festuca rubra Ruby§	M N	S	4	
Filipendula vulgaris	M N	T	5	
Hieracium pilosella	M CN	T	1	
Hordeum murinum	M CN	S	2	
Papaver dubium	M CN	S	2	
Plantago lanceolata	M CN	T	2	
Poa pratensis Aquila§	M CN	S	2	
Ranunculus bulbosus	M N	T	3	
Sedum acre	L N	T	1	
Silene gallica	L N	S	2	
Trifolium repens S100§	M CN	ST	4	
Torilis japonica	M N	S	5	

* Fertility: L, low; M, medium; H, high. pH: C, calcareous; N, neutral.
† S, seed; P, transplants; T, turves; where two introduction methods are indicated both were successful.
‡ Fertilizer had no significant effect except where marked F.
§ Commercial cultivar.

as *Blackstonia perfoliata* and *Rhinanthus minor*, with no apparent effect on pre-existing species, demonstrates that there were vacant niches for appropriate species. The development of the flora has clearly, therefore, been restricted by distance from suitable source populations, even though (i) source populations were less than 40 km away, (ii) the sites were in a populated area which could have aided transport, (iii) 50–100 years had been available for immigration.

The edaphic nature of the sites was clearly also a barrier. Local species which did not colonize Leblanc waste, for instance, included common species such as creeping buttercup (*Ranunculus bulbosus*) and *Trifolium repens*, which are tolerant of soils with moderate nutrient levels, but not of soils with extreme characteristics. Some calcicole species such as *Primula veris* would only grow if given fertilizer; and dropwort (*Filipendula vulgaris*) only survived and did not spread. These edaphic characteristics are, however, known to change with time, allowing improved growth (Ash 1983).

The flora of these sites is, therefore, a good demonstration of the variety of factors which can control ecosystem development in primary succession. It finds its particular analogue in new islands such as Surtsey (Fridriksson 1975), although there it has not been possible to test the restrictive factors experimentally.

Table 4. Percentage cover on seeded plots, 20 months after sowing of selected species into existing cover: Leblanc waste

Plots	'Tall species'			'Short species'		Unseeded
Fertilizer	–	+		–	+	–
Sown species*						
Bromus sterilis	10	21	*Blackstonia perfoliata*	6	7	
Rhinanthus minor	1	4	*Gentianella amarella*	9	5	
Sanguisorba officinalis	6	12	*Primula veris*	3	4	
Torilis japonica	2	12	*Prunella vulgaris*	11	23	
Existing species†						
Dactylis glomerata	16	16		9	16	16
Festuca rubra	15	19		18	29	26
Other spp.	15	16		17	16	20
Bare ground	35	6		27	0	38

* Only results for the most successful species are shown.
† Analysis of variance show no significance differences between the values for the seeded plots and the values for the unseeded plots.

Table 5. Flora on blast furnace slag site before species introduction

Agrostis stolonifera	4	*Holcus lanatus*	2
Arenaria serpyllifolia	2	*Hypericum maculatum*	2
Aster novi-belgii	1	*Linaria vulgaris*	2
Centaurea nigra	+	*Linum catharticum*	1*
Centaurium erythraea	2	*Medicago lupulina*	2
Chamaenerion angustifolium	2	*Plantago lanceolata*	1
Cirsium arvense	3	*Ranunculus acris*	+
Dactylis glomerata	1	*Reseda lutea*	1*
Dactylorhiza majalis ssp. *praetermissa*	1*	*R. luteola*	1*
Equisetum arvense	2	*Rubus fruticosus* agg.	2
Festuca rubra	5	*Silene vulgaris*	+
Heracleum sphondylium	2	*Taraxacum officinale* agg.	2
Hieracium pilosella	2	*Tragopogon pratensis*	+
H. sabaudum	+	*Trifolium pratense*	3
H. vulgatum	4	*Tussilago farfara*	2
		Bare ground	8

Values are given on the Domin scale of cover/abundance.
* Indicates that species is a colonist from a long distance (>30 km).

METHODS OF INTRODUCTION

Industrial activity continues to produce completely new habitats, such as quarries and gravel pits. Some are being allowed to become areas for wild life. While this can be brought about by natural colonization processes, diversity will develop only slowly. The experiments show that introduction of appropriate native herbaceous species into these industrial waste habitats is not difficult. It is significant that there are some alkaline sites where *Blackstonia* has overcome restrictions to immigration and has become a conspicuous feature, for instance, the Witton lime beds, Cheshire (Ash 1983).

The species most likely to succeed on a particular waste are those from communities of natural habitats with similar soil condition, e.g. calcareous grassland species are likely to succeed on blast furnace slag and Leblanc waste. Unfortunately, for PFA it is difficult to predict tolerance to toxic elements such as boron; suitable species will only be found by experiment (e.g. Hodgson & Buckley 1975). On all wastes, commercial cultivars, usually selected for fertile soils, showed lack of success in this study unless the soil nutrient status was upgraded. Which species or populations survive is, however, the outcome of a very complex set of ecological interactions including the effects of climate during establishment, and it may never be possible to predict exactly what will happen.

Seed was the most successful introduction technique and had the advantages of easy handling and ready availability, as well as ensuring a wide genetic base. Most species did equally well from autumn and spring sowings, the exceptions being winter annuals, e.g. sterile brome (*Bromus sterilis*) which

Table 6. Blast furnace slag: fate of introduced species after 6 years

	Soil preferences*	Introduction method†	Year of first flowering‡	Area (m^2) and mode of spread
Species spreading beyond original plots				
Anthyllis vulneraria	L C	PT	1	25
Blackstonia perfoliata	L C	S	3	>100 (seed)
Briza media	L C	T	3	0·1 (veget)
Euphrasia nemorosa	L C	T	1	4 (seed)
Gentianella amarella	L C	S	3	10 (seed)
Leucanthemum vulgare	L C	P	3	4 (seed)
Linum catharticum	L C	T	2	10 (seed)
Rhinanthus minor	L C	S	1	>100 (seed)
Sanguisorba minor	L C	PT	2	2 (seed)
Species growing, but not yet spreading				
Carex flacca	L C	T	3	
C. nigra	L C	T	4	
Festuca ovina	L CN	T	7	
Festuca rubra Dawson§	M N	S	–	
Festuca rubra Ruby§	M N	S	–	
Filipendula vulgaris	M N	T	–	
Fragaria vesca	M CN	P	3	
Galium verum	L C	T	–	
Helianthemum nummularium	L C	T	4	
Koeleria macrantha	L CN	T	4	
Lotus corniculatus	M CN	S	7	
Primula veris	M C	S	–^{F}	
Prunella vulgaris	L CN	S	4	
Sanguisorba officinalis	M C	S	5	
Ulex europaeus	L CNA	T	–	
Species which died				
Agrostemma githago	M N	S	2	
Agrostis stolonifera Emerald§	M N	S	3	
Bellis perennis	M N	T	1	
Bromus sterilis	M N	S	3	
Hieracium pilosella	M CN	T	2	
Hordeum murinum	M CN	S	2	
Leontodon hispidus	M N	T	3	
Lotus corniculatus§	M CN	T	3	
Papaver dubium	M CN	S	1	
Poa pratensis Aquila§	M CN	S	3	
Ranunculus bulbosus	M N	T	2	
Sedum acre	L N	T	2	
Silene gallica	L N	S	2	
Taraxacum officinale	M N	T	1	
Thymus praecox	L C	T	3	
Torilis japonica	M N	S	3	
Trifolium repens S100§	M N	S	4	

* Fertility: L, low; M, medium; H, high. pH: C, calcareous; N, neutral; A, acidic.
† S, seed; P, transplants; T, turves; where two methods indicated, both were successful.
‡ Fertilizer had no significant effect except where marked ^{F} (species died without fertilizer).
§ Commercial cultivar.

required autumn sowing for flowering the following summer.

Transplants showed variable success and large numbers would have been needed to ensure a population of sufficient size to guarantee the long-term survival of the species. The method would be preferred only in special circumstances. It has been used successfully for the rare tufted saxifrage (*Saxifraga cespitosa*, Parker 1981). Limestone grassland turves showed promise, but are rarely available in sufficient quantity. Moorland litter showed promise on acid sites, but needs further trials. The method has been very successful for restoring moorland in the uplands (Environmental Advisory Unit 1988).

In all cases suitably adapted species were established without fertilizer applications, although a low rate was beneficial to the growth and appearance of some species.

Because of lack of previous work, a wide variety of material and a range of different methods were

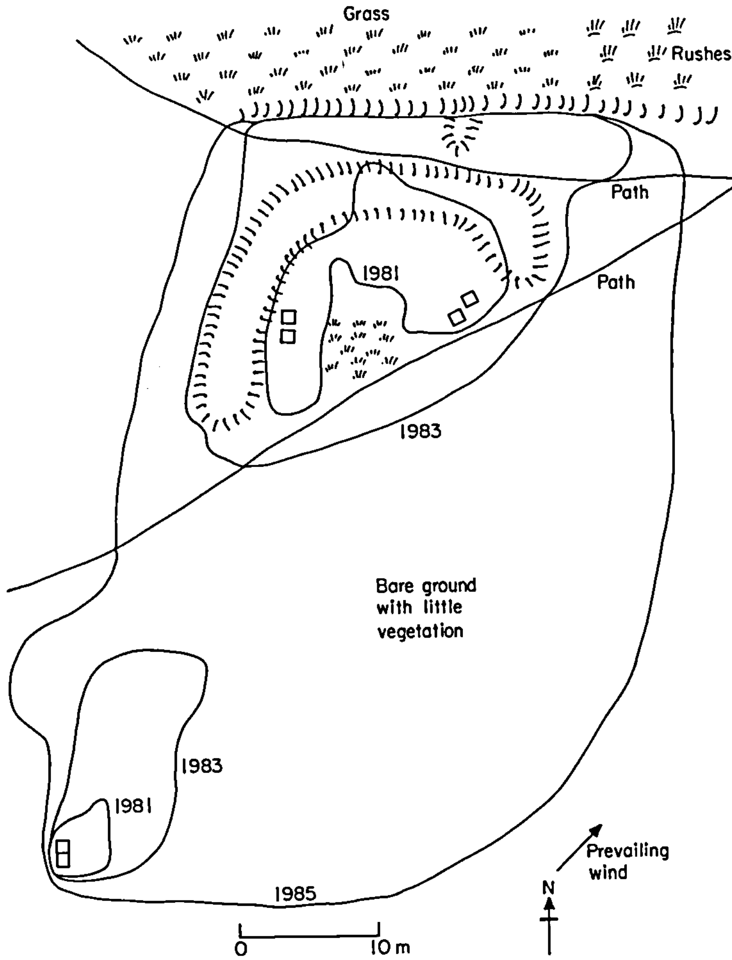

Fig. 1. Spread of *Rhinanthus minor* on blast furnace slag waste heap at Kirkless Lane, in 1981, 1983 and 1985, from sowings made in the autumn of 1979 (by 1990 the *Rhinanthus* covered an area of 100 × 70 m); □ plots where original sowings were made.

Table 7. Flora on PFA site before species introduction

Agrostis capillaris	2	*H. vulgatum*	1
Aster novi-belgii	+	*Holcus lanatus*	5
Betula pendula	5	*Hypochoeris radicata*	2
Calluna vulgaris	1	*Leontodon autumnalis*	2
Centaurium erythraea	3	*Lupinus polyphyllus*	2
Cerastium fontanum	1	*Luzula campestris*	2
Chamaenerion angustifolium	4	*Polytrichum juniperinum*	5
Cirsium arvense	1	*Rhododendron ponticum*	2
Cytisus scoparius	+	*Rumex acetosa*	+
Dactylis glomerata	4	*Sagina procumbens*	1
Dactylorhiza fuchsii	2	*Salix caprea*	6
D. incarnata	2*	*S. cinerea*	6
D. majalis ssp. *praetermissa*	4*	*S. repens*	+*
D. majalis ssp. *purpurella*	2*	*Solidago canadensis*	+
D. hybrids	2	*Taraxacum officinale* agg.	1
Deschampsia flexuosa	1	*Trifolium pratense*	5
Epipactis palustris	1	*T. repens*	5
Equisetum arvense	3	*Tussilago farfara*	3
Festuca rubra	3	*Vicia cracca*	+
Hieracium sabaudum	2		
		Bare ground	6

Values are given on the Domin scale of cover/abundance.
* Indicates species is a colonist from a long distance (>30 km).

Table 8. PFA: fate of introduced species after 6 years

	Soil preferences*	Introduction method†	Year of first flowering‡	Area (m^2) and mode of spread
Species spreading beyond original plots				
Anthyllis vulneraria	L C	PT	1	10 (seed)
Euphrasia nemorosa	L C	T	1	20 (seed)
Lotus corniculatus	M CN	PT	3	10 (seed)
Prunella vulgaris	L CN	S	3	1 (seed)
Rhinanthus minor	L C	S	1	3×10^4 (seed)
Sanguisorba officinalis	M C	S	6	1 (seed)
Trifolium repens S100§	M N	S	3	considerable (seed & veg)
Species growing, but not yet spreading				
Filipendula ulmaria	M CN	T	–	
Lotus corniculatus§	M CN	S	3	
Species which died				
Agrostemma githago	M N	S	2	
Agrostis stolonifera Emerald§	M N	S	3	
Bellis perennis	M N	T	1	
Blackstonia perfoliata	L C	S	4	
Briza media	L C	P	4	
Bromus sterilis	M N	S	3	
Carlina vulgaris	L C	T	3	
Carex flacca	L CN	T	4	
Festuca ovina	L CN	T	3	
Festuca rubra Dawson§	M N	S	3	
Festuca rubra Ruby§	M N	S	3	
Fragaria vesca	M CN	P	4	
Galium verum	L C	T	2	
Gentianella amarella	L C	S	4	
Helianthemum nummularium	L C	T	4	
Hordeum murinum	M CN	S	2	
Koeleria macrantha	L CN	T	2	
Leontodon hispidus	M N	T	1	
Leucanthemum vulgare	L C	P	3	
Linum catharticum	L C	T	3	
Medicago lupulina	M N	T	3	
Papaver dubium	M CN	S	1	
Plantago lanceolata	M CN	T	2	
Poa pratensis Aquila§	M CN	S	3	
Primula veris	M C	S	3	
Ranunculus bulbosus	M N	T	1	
Sanguisorba minor	L C	P	4	
Silene gallica	L CN	S	2	
Taraxacum officinale	M N	T	1	
Thymus praecox	L C	T	2	
Torilis japonica	M N	S	3	

* Fertility: L, low; M, medium; H, high. pH: C, calcareous; N, neutral; A, acidic.
† S, seed; P, transplants; T, turves; where two methods used, both were successful.
‡ Fertilizer had no significant effect.
§ Commercial cultivar.

employed. It was, therefore, not possible to study the details of the behaviour of individual species and causes of failure. This must await further work. The crucial point, however, is that the results owe nothing to human assistance after the initial inoculation.

ENVIRONMENTAL CHANGE AND NATURE CONSERVATION

At the moment there is increasing concern over the cumulative effects of global climatic change and other human impacts on the survival of species. In the past the major response to environmental change has been by migration (Huntley & Webb 1989), which was possible, except for narrowly adapted species, over the continuous land surfaces which were available. However, even then local discontinuities were sufficient to prevent the migration of large numbers of species. There is little evidence for any contribution to survival from evolution (Bradshaw & McNeilly 1991).

The present work confirms that there are now

Table 9. Flora on colliery spoil site before species introduction

Agrostis capillaris	6	*Plantago lanceolata*	+
Aira praecox	1	*P. major*	+
Anthoxanthum odoratum	1	*Poa pratensis*	1
Betula pendula	4	*Pohlia nutans*	2
Chamaenerion angustifolium	2	*Potentilla anserina*	+
Cirsium arvense	1	*Prunella vulgaris*	+
C. vulgare	+	*Ranunculus repens*	+
Crepis capillaris	+	*Rubus fruticosus* agg.	3
Dactylis glomerata	+	*Rumex acetosa*	+
Epilobium montanum	2	*R. acetosella*	1
Equisetum arvense	2	*Sagina procumbens*	+
Festuca rubra	1	*Salix caprea*	2
Heracleum sphondylium	1	*Senecio jacobaea*	+
Hieracium sabaudum	2	*S. viscosus*	1
H. vulgatum	+	*Silene vulgaris*	1
Holcus lanatus	5	*Trifolium medium*	1
Hypochoeris radicata	1	*T. pratense*	2
Leontodon autumnalis	1	*T. repens*	1
Lotus corniculatus	2	*Vicia cracca*	1
Luzula campestris	1		
		Bare ground	5

Values are given on the Domin scale of cover/abundance.

Table 10. Colliery spoil: fate of introduced species after 4 years*

	Soil preferences†	Introduction method‡	Year of first flowering
Species spreading beyond original plots			
Agrostis capillaris Highland§	LM A	S	–
Anthoxanthum odoratum	LM A	P	2
Calluna vulgaris	L A	L	3
Festuca longifolia Scaldis§	LM NA	S	–
Galium saxatile	L A	S	5
Lotus corniculatus (native)	LM NA	P	2
Lotus corniculatus§	M NA	S	2
Potentilla erecta	L A	S	3
Prunella vulgaris	LM NA	S	2
Trifolium repens S100§	M N	S	1
Species which died			
Deschampsia flexuosa	L A	S	–¶
Juncus squarrosus	L A	S	–
Molinia caerulea	L A	S	–¶
Nardus stricta	L A	S	–¶
Poa pratensis Aquila§	M CN	S	2
Poa annua	M N	S	2
Stellaria holostea	M NA	P	–

* Site destroyed 1984.
† Fertility: L, low; M, medium; H, high. pH: C, calcareous; N, neutral; A, acidic.
‡ S, seed; P, transplants; L, moorland litter.
§ Commercial cultivar.
¶ No germination in the field, poor germination in greenhouse trials.

major limitations to immigration, which can prevent species occupying habitats to which they are well adapted. If climatic or other changes begin to have major effects, it may therefore be necessary to assist the migration of species into areas that have become more favourable to them than those they used to occupy.

At the present time, there is still a continuing production of damaged and degraded land requiring restoration. Minimal intervention and reliance on natural colonization is an attractive and economical option for establishing vegetation (Environmental Advisory Unit 1985). However, since vegetation development can be restricted by problems of species availability, the principle of introducing native species must also be considered.

There has recently been considerable interest in re-introducting native species for habitat creation (Buckley 1989). In consequence, native species are increasingly being introduced into country parks, private gardens, etc., sometimes sown in cleared areas, often laboriously transplanted into species-poor fertile grassland (e.g. Kelcey 1977; Emery 1986; Baines & Smart 1991).

The extension of such principles to the reclamation of difficult areas of derelict land does not, however, appear to have been tried. Although some sites should be preserved unaltered as examples of primary succession, in others introduction is valid. With due attention to ecological principles, it appears not to be difficult to establish native species on impoverished wastes. Reclamation can thereby be done very cheaply, which is important in the context of present financial stringencies (Ash 1983; Bradshaw 1984). It would also counteract the decline of at least some native plants, particularly those of impoverished habitats: an important present day problem in Britain (Nature Conservancy Council 1984).

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