RE-CREATING WOODLAND AND HEATHLAND ON SLATE WASTE IN WALES[1]

Julie C. Williamson, Edwin C. Rowe, John R. Healey, Davey L. Jones, Peter J. Holliman and Mark A. Nason[2]

Abstract. We report on ecological restoration at Penrhyn, Europe's largest slate quarry, which lies adjacent to Snowdonia National Park and a Site of Special Scientific Interest. Broadleaf woodland and heathland were targeted, to provide wildlife corridors to adjacent habitats of high conservation value. Young tree seedlings (six species) of local provenance were planted into slate pockets amended with nutrients (readily available mineral NPK or an organic mix of biosolids and paper sludge with an estimated five-year impact) and water retentive materials (clay overburden or polyacrylamide gel). Applying mineral NPK increased tree basal area by 70% in the first 18 months. The organic mix gave an increase of 130 % in tree basal area, promoted water retention and stimulated nutrient cycling. Both N-fixing tree species and non-fixers responded to fertilization and small-seeded species responded more than large-seeded ones. Tree basal area increased by 50% in the clay treatment compared with trees planted in bare slate ± gel.

The transfer during quarrying of heath vegetation with associated peat to a site designated for restoration proved effective in establishing key heathland subshrubs. Bilberry re-sprouted easily from buried shoots whilst heather turf died, but within one year a flush of heather seedlings had germinated from the seedbank in the transferred peat. Three years on, there was complete ground cover of target heathland species, provided that sheep were excluded. Grazing by rabbits was beneficial in reducing grass and increasing heather cover. Where availability of heathland topsoil was limited, heathland brash was applied to clay-covered slate. Germination of heather proved slow and sparse, with no germination of bilberry.

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[2]Julie C. Williamson is Senior Scientific Officer, Institute of Environmental Science, University of Wales Bangor, Gwynedd, WALES, LL57 2UW.
Ed C. Rowe is Senior Scientific Officer, IES, UWB, WALES.
John R. Healey is Lecturer, School of Agricultural and Forest Sciences, UWB, WALES.
Davey L. Jones is Lecturer, School of Agricultural and Forest Sciences, UWB, WALES.
Peter J. Holliman is Lecturer, Department of Chemistry, UWB, WALES.
Mark A. Nason is Scientific Officer, IES, UWB, WALES.

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Seed rain and litter deposition from re-created islands of vegetation will accelerate natural colonization. Trials at Penrhyn Quarry have demonstrated pragmatic and inexpensive technologies to achieve this, largely using on-site by-products and local wastes.

Additional Key Words: substrate amendments.

Introduction

Quarries and minesites are examples of extreme disturbance. Frequently, soil-forming material is scarce and ecological restoration is the only viable option. Ecological restoration is '*the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structure, regional and historical context and sustainable cultural practice*' (SER, 1996). We report on ecological restoration at Penrhyn, Europe's largest slate quarry, which lies adjacent to Snowdonia National Park in North Wales, and the Glydeiriau and Cwm Idwal Site of Special Scientific Interest. The blocky nature of the slate waste tips (slate is extremely resistant to weathering) and the lack of topsoil make the re-vegetation of these waste tips by natural means very slow; one hundred year-old waste tips are only sparsely colonized by trees and woody shrubs. Major constraints to plant establishment here were assumed to be low nutrient availability, low water-holding capacity and grazing pressure from sheep and rabbits. Management of these key-limiting factors should differ according to the habitat being created; in the case of Penrhyn, broadleaf woodland and heathland were targeted for re-creation. The principal aims of the study were to:

- Create wildlife corridors that connect re-created quarry habitats to adjacent areas of semi-natural heath and woodland habitats of high conservation value.
- Improve the visual impact of waste tips.
- Identify cost-effective methods of plant establishment.
- Promote industry uptake of research findings by disseminating information in a Best Practice Manual.

Methods

Broadleaf Woodland Creation

Three approaches were tested at Penrhyn, using seeds collected from local provenance, often from trees within the quarry:

- Pocket planting of young trees on flat benches, incorporating water retention and nutrient delivery regimes.
- Fertilizing naturally established trees.
- Use of 'fillers' on blocky slopes for planting young trees.

Seeds from alder (*Alnus glutinosa*), birch (*Betula pubescens x B. pendula*), *gorse (Ulex europaeus*), oak (*Quercus petraea*) and rowan (*Sorbus aucuparia*) were treated, germinated and grown-on in a purpose-built nursery at Penrhyn. Hardwood cuttings from local willow *(Salix caprea x S. cinerea*) were also used.

Pocket planting (Fig. 1) entailed digging into consolidated slate waste to a depth of 15 cm to give a volume of about three litters. Soil amendments that deliver nutrients and water were then mixed with the excavated slate and used to backfill the hole around the young tree. The pocket material sustains tree development whilst the roots explore the slate waste to find deeper fines in which to anchor and draw moisture in the longer term.

The slate pockets were amended with nutrients, either mineral NPK fertilizer (15:10:10) or an organic mix of biosolids and paper sludge with an estimated five-year impact, and water retentive materials (clay overburden or polyacrylamide gel) in a fully factorial design. The biosolid - paper mix was combined to give a gross C:N ratio of 15 - 20 (Table 1) and a mineral-N delivery in the first year equivalent to that of the mineral fertilizer, using published mineralization data for biosolids (WRc, 1985). This amounted to equal proportions, on a wet weight basis. The biosolids were obtained from a rural area with little industrial effluent input so that heavy metal concentrations in amended slate were extremely low and at most, 200 times less than EU permitted limits.

All plantings were protected against sheep and rabbits with meter-high, barbed-wire fencing buried and weighted with boulders at ground level.

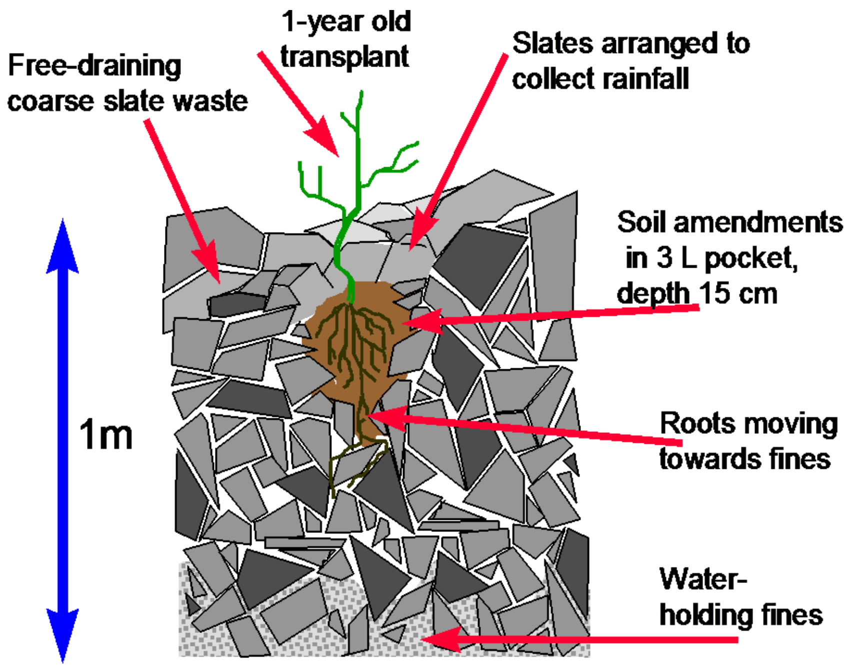

Figure 1. Schematic diagram showing the pocket planting design, which promotes transplant growth, water, capture and soil formation.

Table 1. Selected nutrient concentrations and application rates of amendments to slate waste used for tree establishment.

	Total C %	Total N %	Total P %	Gross C:N	Total N applied to planting pocket, kg N ha^{-1}
Biosolids-paper mix	29.2	2.01	0.95	15	4000
NPK fertilizer	na†	15	4.4	na	550

† not applicable

Heathland Creation

Three approaches were tested at Penrhyn:

- Direct transfer of heathland turf (vegetation mosaic with associated topsoil).
- Planting heather plugs.
- Seeding using harvested heather (*Calluna vulgaris*, *Erica cinerea* and *Erica tetralix*) sprigs or seed heads.

Heathland topsoil with *in situ* vegetation was dug to a depth of 50 cm from its donor site and taken immediately to the recipient site where it was stored in small mounds for up to seven days before spreading. No special effort was made to position vegetation upright during spreading. The heathland establishment study tested effects of fencing, coir netting, planting heather (principally *Calluna vulgaris*) plugs, and peat topsoil transfer in various combinations.

Applying heathland seed-bearing material, often harvested as part of firebreak management, has been used effectively to establish heather over large areas (EAU, 1988). Seed-material, chiefly heather sprigs, was dried, finely chopped and spread over slate waste clad with boulder clay at two rates (0.2 and 0.4 kg m^{-2}), with and without a mulch of bark peelings.

Permanent quadrats (2m x 2m) were surveyed after one and three years using a pin-frame technique to measure plant cover and seedlings of target ericoid species were also counted within each quadrat. The Joint Nature Conservation Committee defines vegetation with >25% ericoid cover as heathland and this criterion was used in our assessment of 'success' of heathland establishment.

Soil Analyses

Soil total C and N were determined by combustion in a high-frequency induction furnace (Leco, Michigan, USA). Microbial N was determined by chloroform fumigation extraction followed by colorimetric determination of ninhydrin-reactive N (Joergensen and Brookes, 1990). Soil respiration was derived from CO_2 evolution measured by infrared gas analyzer. Soil microbial diversity was derived from phospholipid fatty acid (PLFA) signatures (Frostegard et al., 1993). Relative abundance was calculated for 14 indicator PLFAs, specific to soil bacteria, fungi and actinomycetes, within the entire microbial biomass (Frostegard and Baath, 1996).

Results and Discussion

Broadleaf Woodland Creation

Applying mineral NPK increased tree basal area by 70% in the first 18 months (Table 2). The biosolids-paper mix gave an increase of 130 % increase in tree basal area. Both N-fixing tree species and non-fixers responded to fertilization, and small-seeded species responded more than large-seeded ones. Tree basal area increased by 50% in the clay treatment compared with trees planted in bare slate ± gel (Table 3).

Table 2. Effects of fertiliser treatments on the basal area of five woody species, 18 months after planting out.

	Species					
	Alder	Birch	Gorse	Oak	Rowan	Mean
Seed size	small	small	large	large	large	
N_2 fixer	yes	no	yes	no	no	
Fertilizer treatment	Basal area (mm^2)					
No fertilizer	44	5	33	6	5	19 a†
N.P.K fertilizer	52	26	50	11	28	33 b
Biosolid-paper mix	70	41	59	10	37	43 c
Mean	55 a	24 b	47 a	9 c	23 b	32

† Main effects labeled with the same letter were not significantly different ($P < 0.05$).

The biosolids-paper amendment also stimulated nutrient cycling as measured by soil quality indices (Table 4) and soil microbial diversity. An active microbial biomass is important for maintaining the nutrient capital of the system in the longer term and provides a strong argument for adding organic matter with some relatively available N and P (Sopper, 1993).

Table 3. Effects of water-holding treatments on the basal area of five woody species, 18 months after planting out.

	Species					
	Alder	Birch	Gorse	Oak	Rowan	Mean
Water-holding treatment	Basal area (mm^2)					
No amendment	42	21	44	8	18	27 a†
Boulder clay	74	33	59	11	32	42 b
PAM gel	49	18	38	8	20	27 a
Mean	55 a	24 b	47 a	9 c	23 b	32

† Main effects labeled with the same letter were not significantly different ($P < 0.05$).

Table 4. Effects of fertiliser treatment on the soil microbial biomass (mg N kg^{-1}), basal respiration (mg C kg^{-1} h^{-1}) and microbial diversity (from Simpson's Index) under five woody species, 18 months after planting out.

Fertilizer treatment				P value
	No fertilizer	Biosolids-paper mix	NPK	
Microbial biomass N	21 a†	135 b	29 a	< 0.001
Respiration	0.40 a	3.29 b	0.44 a	< 0.001
Microbial diversity	4.3 a	6.8 b	5.3 a	0.036

† Main effects labeled with the same letter were not different ($P < 0.05$).

<u>Heathland Creation</u>

The treatment which resulted in the greatest ericoid cover after 3 years, approaching that of 85 year-old heathland, was fenced against sheep, with peat topsoil transfer (Fig. 2 and Fig. 3). Rabbit fencing appeared to be counter-productive, resulting in the dominance of graminoids.

However, unfenced plots retained many bare patches, indicating that protection from sheep is necessary at least initially. Planting heather did not result in increased heather cover, and is thus not considered a viable method, particularly in view of its high cost.

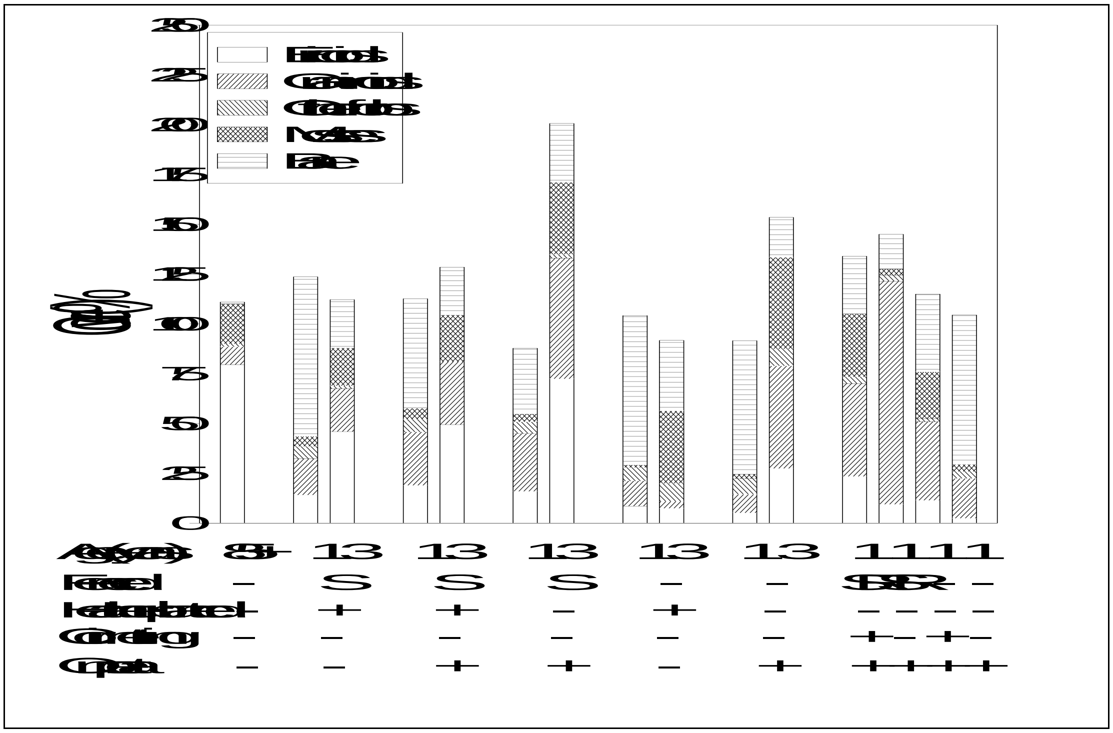

Figure 2. Cover of different plant groups following heathland restoration treatments.
S = fenced against sheep; SR = fenced against sheep and rabbits. Cover >100% = overlapping leaves.

A major factor limiting the success of applying heathland seed-bearing material was windblow. Roughness of the clay surface, imparted by the many large boulders, helped reduce windblow and provided a range of microclimates suitable for establishment of young ericoid seedlings. However, germination of heather was slow and sparse (range of 2 - 23 seedlings per 4 m^2 plot), with no germination of bilberry (*Vaccinium myrtillus*). Pywell et al. (1996) found that the woody stems of the harvested material provided suitable microsites for the germination and survival of heathland species, acting as a mulch and conserving moisture on skeletal mineral wastes. It would therefore seem critical that the windblow problem is addressed at Penrhyn. The process of drying the seed-bearing material prior to application was believed to cause dormancy, which explained the slow germination. Another experiment was set up subsequently using fresh seed heads stripped from the woody material and applied with a tackifier, and it is hoped that this procedure will overcome both dormancy and windblow effects.

Figure 3. Re-created heathland from transferred heathland turf, fenced against sheep, three years after transfer. Here the most abundant ericoid is *Calluna vulgaris*; there is some *Erica tetralix* (e.g. mid-field) and a heathland tussock grass, *Carex echinata*.

Conclusions

The essence of ecological restoration is to create islands of vegetation from which seed rain and litter deposition will lead to accelerated natural colonization and connectivity to adjacent undisturbed habitats of high conservation value. Trials at Penrhyn have demonstrated pragmatic and inexpensive technologies to achieve this, largely using on-site by-products, local wastes and plant material of local genetic provenance.

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