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Effect of planting method on the survival of *Alnus glutinosa* and *Quercus petraea* saplings in compacted coal-mine spoils, South Wales.

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Poor vegetation performance and land degradation is a widespread problem on the reclaimed surface coalmine lands of South Wales. The 'Cradle for Nature' project is an NGO research venture that aims to determine how to achieve geoecological self-sustainability on degraded surface mine sites where the obstacles to revegetation success include extreme auto-compaction and low nutrient status of the mine-spoils. This paper deals with the first problem on degraded coal-land at Varteg in Torfaen, Wales, which had been 'reclaimed' after surface coalmining in 1963. It describes a formally established 5-year experiment designed to assess the effect of three alternative approaches to planting, namely notch planting (e.g. forestry), pit planting (e.g. parks and gardens) and trench planting (e.g. orchard terraces) on initial tree survival and growth in two species commonly used in land reclamation contexts: Alder (*Alnus glutinosa (L.) Gaertn)* and Welsh or Durmast Oak (*Quercus petraea (Matt.) Liebl)*. Results show that survival and growth rates for both species are better for trench planting and for pit planting than for notch planting.

Keywords: Land reclamation; Forest Recultivation; Self-sustainability; South Wales Coalfield.

Introduction.

Forestation is common strategy for the community-based restoration of degraded lands (Flege 2000). This report concerns the forestation of lands that have become degraded following ineffective reclamation after surface coal mining, which is a common problem in the opencast coal-mining regions of South Wales. Here, surface coalmining has been conducted sporadically since 1942, for much of this period under the direction of the National Coal Board, later British Coal Opencast Executive, and more recently, by its privatised successor companies. Despite local successes, the construction of showcase reclamation sites like Bryn Bach Parc near Tredegar (Palmer and Probert

1980) and major research, especially at the Forestry Commission's Maes Gwyn site near Neath (Bending 1993), many sites suffer from poor or declining vegetation growth, severe soil compaction and erosion (Haigh 1992). For example, in the Afon Lwyd Valley, Torfaen and Blaenau Gwent, of four major opencast coal workings, only the most recent reclamation at Garn Lakes (1996), may be counted as a success (Haigh 2000). The others Pwlldu, Waun Hoscyn, Varteg Hill, and Blaenant all display the symptoms of soil degradation. Of course, in each case, any money targeted for land reclamation is long spent and further reclamation is countenanced only in connection with funding generated by new mining activity. From the perspective of the local community, who gain little from surface mining activity besides dust, disturbance, and depreciation of the economic value of their properties, the best solution would be to cover the scars of these largely unproductive degraded lands and allow nature to restore the vegetation and soil.

The degradation of formerly reclaimed opencast coal-lands is not an officially recognised environmental problem in Wales (Haigh 1992). However, many of these lands are classified as areas suitable for environmental improvement, while recent interest in 'Carbon Offsetting' has improved attitudes towards the forestation of unproductive wasteland (Ussiri and Lal 2005). The aim of this project is research and development toward a reliable methodology for the community-based reforestation of these lands. In practice, since funds for such community works tend to be 'one-off' in character. This means that can achieve an acceptable 'natural', self-sustaining outcome, in the absence of regular investment or maintenance needs to be proven. This means creating a 'cradle for nature' , a habitat where natural processes gain sufficient strength to restore the depleted biological systems on these degraded lands and set in process a benevolent cycle of environmental improvement.

This paper concerns one part of a larger suite of experiments (Haigh 2001). This particular experiment (Cariad03) was created to test a hypothesis suggested by two decades of action research on the same site. This is that planting method plays a major role in the survival and growth of forest species. The test concerns three types of planting method. These are first, forestry industry style 'notch planting ', where the ground is opened and a young tree is heeled directly into the slot so created; second, 'parks and gardens' style 'pit' planting, where the sapling is planted into a 30-cm diameter by 30-cm deep soil pit along with the inverted topsoil; and third, contour trench planting, where the sapling, is notch planted into a trench approximately 50 cm wide by 40 cm deep , which has been back filled with the inverted soil profile. This report details the findings of a formal, 5-year, trial of 900 trees divided between two species, alder (Alnus glutinosa (L.) Gaertn.) which is commonly used on Welsh opencast sites (Hood and Moffat 1995) and (adopted here as nursemaid for) the Welsh or Durmast Oak (Quercus petraea (Matt.) Liebl.), which was a dominant species in the pre-opencast woodland on the site.

Site Description

The Cariad03 Test plots are located on a terrace bench exposed to the south and west, at about 370 metres above msl. (51044'40"N 0305'20"W: British National Grid: SO 255057). Average rainfall (1971-2000) was 1543 mm/year at Cwmavon Reservoir, 800m to the north on the nearby Afon Lwyd Valley floor (SO 269070) and evaporation is estimated at 472 mm/year on rough grazing land (Faber Maunsell 2006 p19).

The site was created in 1963 after the closure of the Waun Hoscyn Extension (Varteg Hill) Opencast Coal-mine. Officially reclaimed, the site was apparently reseeded, although revegetation has been poor and local testimony has it that the topsoil set aside for the area containing the Cariad03 Test Plots was never applied. After >40 years, the site exhibits a thin organic layer of ~ 5cm above a very dense layer of compacted and weathered mine-spoil (commonly 1.5 – >1.7 gm.cm3 cf. Haigh and Sansom 1999, Moffat et al. 2001), which has very low nutrient status and poor water holding capacity (Harmers Ltd. 2009). Vegetation on the site varies from a patchy grass and lichen sward on higher areas to Juncus reeds and moss in hollows.

The site lies immediately to the south and west of an area currently scheduled for opencast coal-mining by the Glamorgan Power Company, who, in 2004, launched a proposal to extract 350,000 tonnes from a 60m deep pit covering 14 hectares (Hawkesworth and Hawkesworth 2006). The area adjacent to the Cariad Test plots is scheduled to be reclaimed as acid moorland grassland, pretty much its current state, but further north as forest with gorse.

The site adjoins the Varteg Waste (SO 258 055) which is recognised as a non-statutory "Site of Importance for Nature Conservation" or "SINC". This is a location recognised under Policy E5 of the Torfaen Local Plan "as being of national or local nature conservation interest" and that should be "safeguarded against development that would have an unacceptable impact upon the ecology" (Hawkesworth and Hawkesworth 2006 v1, p9)

Soil tests show the site to have moderate pH with occasional hotspots of high acidity and elevated levels of metals with, or border-line, contamination. Tests of surface waters found them to be pH 6.8-7.3 (EC 237-277 muS/cm), although spring water could be acidic (pH 3.0). Surface runoff samples from February 2006 contained somewhat elevated levels of iron (ca. 0.2 mg/l), manganese (0.015-0.064 mg/l), nickel <0.008 mg/l) and arsenic (<0.008 mg/l) (Faber Maunsell 2006).

Method.

This experiment (Cariad03) was set out as a classic Latin Square of nine plots, three each of notch planted, pit-planted and trench planted trees. Random number tables were used to determine the location of 281 oak trees in the matrix of 675 alders. Trees were planted as root trainers and each soil plug was supplemented by a handful, 0.5kg, of spent mushroom compost.

Results and Analysis.

In both species, the notch-planted trees suffered greatest mortality, rising to 75% in the notch planted alders. In general, trench planted trees had a slightly higher survival rate than the pit planted. However, there was a far greater mortality among alders than the oaks.

Alnus glutinosa	Year	1	2	3	5
	Notch	89	71	40	**34**
	Pit	96	91	50	**50**
	Trench	100	96	65	**50**
Quercus petraea	Notch	91	84	76	**72**
	Pit	93	93	92	**88**
	Trench	100	97	95	**94**

Table 1. Survival rates (%) by planting method and year of record for (Alder) Alnus glutinosa and (Oak) Quercus petraea.

Table 1 displays survival rates across the five years of record. The main difference between the two species was high mortality in year three of the experiment (2005-2006) (Figure 1 and Figure 2).

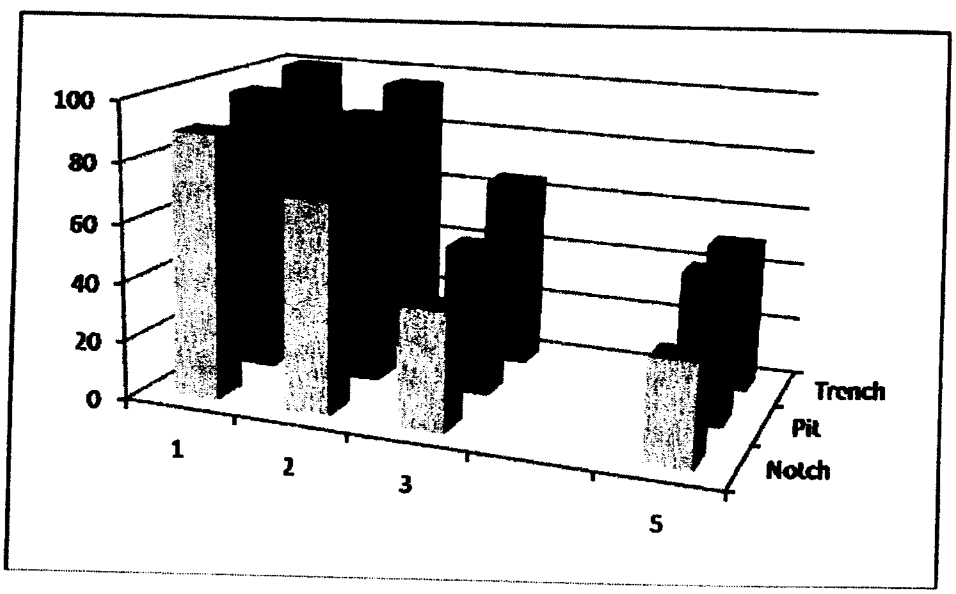

Figure 1. Survival Rates of *Alnus glutinosa* by planting method (2003-2008)

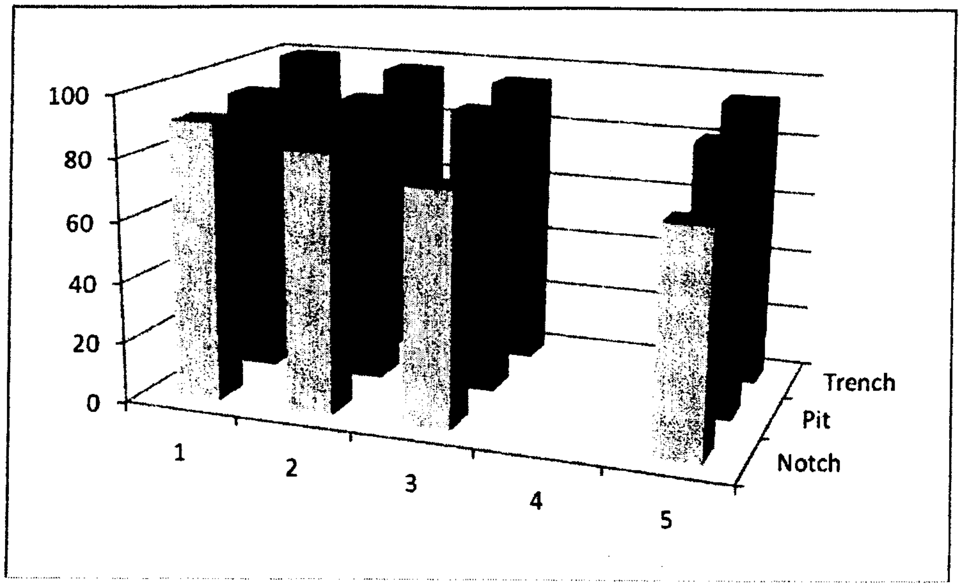

Figure 2. Survival rates of *Quercus petraea* by planting method (2003-2008)

Table 2 displays a statistical analysis of these results using Fisher Exact Test. In both species, there are significantly better survival rates from trench and pit planting versus notch planting, In Alder, early differences in survival rates between pit and trench planted trees disappear by year 2. In the case of Oak (Quercus petraea), the relative survival of trench versus notch planting increases progressively through the 5 years of observation while in Alder (Alnus glutinosa), these benefits decline after Year 2

Alnus glutinosa		Pit	Trench
Y5: 2008 *Y3: 2006* *Y2: 2005* *Y1: 2004*	Notch	Y5: 0.162 (p=0.001) Y3: 0.247 (p<0.0005) Y2: 0.247 (p<0.0005) *Y1: 0.115 (p=0.016)*	Y5: 0.159 (p=0.001) Y3: 0.222 (p<0.0005) Y2: 0.322 (p<0.0005) Y1: 0.220 (p<0.0005)
Y5: 2008 *Y3: 2006* *Y2: 2005* *Y1: 2004*	Pit		Y5: 0.002 (p=1.000) *Y3: 0.026 (p=0.622)* *Y2: 0.096 (p=0.054)* Y1: 0.130 (p=0.008)
Quercus petraea		Pit	Trench
Y5: 2008 *Y3: 2006* *Y2: 2005* *Y1: 2004*	Notch	Y5: 0.090 (p=0.011) Y3: 0.213 (p=0.005) *Y2: 0.149 (p=0.067)* *Y1: 0.045 (p=0.599)*	Y5: 0.285 (p<0.0005) Y3: 0.261(p<0.0005) Y2: 0.223 (p=0.003) Y1: 0.186 (p=0.018)
Y5: 2008 *Y3: 2006* *Y2: 2005* *Y1: 2004*	Pit	*(Nb. Results below the p= 0.05 threshold of significant are in italics)*	*Y5: 0.106 (p=0.203)* *Y3:0.054 (p=0.556)* *Y2: 0.085 (p=0.316)* Y1: 0.151 (p=0.041)

Table 2. Fisher Exact Test and phi coefficient of differences in mortality on the Varteg (Cariad03) Test Plot by Species and Year of Record.

.Discussion

Tree mortality in these compacted mine-spoils was closely related to the degree of soil loosening around their roots. The less compacted the soil is in the rooting zone, the more likely are the trees to survive (Moffat and Bending 2000, Sinnett et al. 2008). Unfortunately, these coal spoils suffer autocompaction through the accelerated weathering of the fragile, clayey shale minestones that make up much the bulk of the spoils. This means that any loosening tends to be short term – but hopefully persistent enough to allow tree roots to penetrate the material and begin the processes of biological soil aggregation (Haigh 2000). Of course, tree survival is affected by many factors, which include NPK deficiency and a lack of organic matter, which reduce both water storage and nutrient uptake (Lunt and Hedger 2003). However, the benefits of these treatments were both sacrificed for this experiment in order to isolate, as far as possible, the effects of planting method.

It was not possible, however, to control for the vagaries of climate. The Varteg Test area is an exposed, south-facing hillside. In the year's following planting, both species of tree suffered serious problems due to wind-burn, frost and summer soil-moisture deficits. However, alders suffered the highest mortality and their selective disappearance suggests that moisture deficiency was a key factor in mortality since, as a nitrogen fixer, this species is relatively tolerant of low soil fertility. In addition, by 2006, these alder saplings were much larger than the oaks and supported a far greater leaf area, which could have made them more vulnerable to moisture deficiency. The key year for mortality was 2005-2006. In this period, rainfall was 1309mm (85% of normal), which is not hugely deficient. However, its distribution may have influenced mortality, there was much rain in March and May, which would have helped the trees leaf and grow but very little rain (>43 mm/month) in June, July and only one very heavy storm in August. MORECS evaporation data for the same period was relatively high (>50mm/month) (Smart and Simpson 2006).

Conclusion

This project aims to re-establish a self-sustaining ecological system on land where reclamation after surface coal-mining has not been successful. This paper explores three planting methods available for community-based afforestation of degraded lands whose characteristics include very high soil densities. The test involved planting two common land reclamation species, alder (Alnus glutinosa) and Welsh oak (Quercus petraea) in a formal Latin-square-based trial of three planting methods: notch planting, pit planting and trench planting. Mortality records collected in the first, second, third and fifth years after planting, show that survival rates start and remain significantly lower for notch-planted trees, while those that are pit-planted and trench planted fare much better. Survival rates tend to be higher for trench planted than pit planted trees but the difference is not significant for either species apart from the first year of record. However, one concludes that providing a loosened, lower density rooting substrate significantly improves the survival rates of trees planted in compacted Welsh surface coal-mine spoils.

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