

MOSES AND OTHER EARLY COLONIZERS: PIONEERS FOR REVEGETATING MINE WASTE ROCK DUMPS AND ROCK WALLS¹

R. P. Buxton², J. Stanley, P. Alspach, C. Morgan, and C. Ross

Abstract: In the Buller Coal Field, New Zealand (41°41'S; 700–1100 m a.s.l.), the steep slopes of waste rock dumps and rock walls are difficult to revegetate using traditional techniques despite regular rainfall (6000 mm p.a.). Our goal has been to accelerate natural soil development and plant succession processes on the infertile sandstone-derived overburden. Initial trials using hydroseeding technology to apply a mixture of mosses, lichens and pioneer vascular plants achieved an average of 15% moss cover and 9.5% vascular cover within 18 months of applying the most successful treatment. This compared with 0.5% and 2.3% cover on the control plot, where no moss was applied, for moss and vascular cover respectively. Natural moss resources are limited and this would significantly limit the area that could be practically hydroseeded each year. To overcome this, a hydroseeding mixture trial was established to determine whether an effective revegetation outcome could be achieved at lower application rates on different substrates. This trial illustrated that significant moss cover can be achieved, but that there is considerable variability in cover (0.1% to 28%), depending on the aspect, rock type, slope stability, hydroseeding mixture and micro-climate. Some sub-plots suffered erosion and overall moss cover on these tended to remain unchanged. After depositing overburden, a 12-month period to allow the loose waste rock spoil to consolidate before hydroseeding is suggested. Artificial moss nurseries were also investigated as a means of increasing moss volumes to enable scaling-up for revegetation of larger areas. Results suggest that low flat covers over moss beds are more effective; being less expensive, less susceptible to wind, and promoting moss growth as well as a hooped profile alternative. The best plot in this trial yielded moss growth that was 30 times the amount of moss 'sown' after two years.

Additional Key Words: tailings reclamation, rock slopes, pit wall, plant establishment, hydroseeding, erosion.

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Introduction

Environmental rehabilitation of difficult sites is a challenge facing the mining industry worldwide. Low levels of plant nutrients and organic matter, pH extremes, heavy metals and often difficult climatic conditions all hinder revegetation of mined rock. For steep slopes of waste rock dumps and rock walls that are difficult to revegetate using traditional techniques, our goal has been to accelerate natural soil development and plant succession processes. Previous research has shown that mosses can improve germination, emergence and survival rate of juvenile vascular plants (During and Van Tooren, 1990; Sohlberg and Bliss, 1984). Following successful trials at Indonesian and New Zealand mines (Stanley et al., in press), we have developed methods for rapid establishment of mosses, lichens and other pioneer plants on bare rock surfaces, particularly on steep rock dumps and walls. These species promote slope stabilisation (Gorman et al., 2000), accelerate natural soil development, and provide microsites for the subsequent natural establishment of indigenous grasses, shrubs and trees. Research by others suggests that terrestrial mosses reduce infiltration of precipitation into tailings much more so than vascular vegetation (Kalin and van Everdingen, 1988). Therefore, establishing mosses on mine tailings might also assist in reducing acid mine drainage.

This paper presents information on using mosses to revegetate difficult, drastically disturbed surfaces. The disturbed sites on which our research was conducted were steep, boulder laden side-slopes of waste mine rock dumps and rocky pit walls adjacent to subalpine temperate rainforest and grassland.

We developed a recipe from previous research for 'seeding' mosses and other pioneer plants onto waste rock dumps. However, this recipe was based on small-scale plots and application by hand. Further experimentation was required to determine the most practical techniques for applying the moss mixture on a large-scale. Some of the questions that needed to be answered included how would hydroseeding compare with dry application; Did the technique work well on different substrates; What moss application rates gave good results? Calculations from the initial successful rate tested indicated that a shortage of moss supply would significantly limit the area that could be 'seeded' each year. Whether moss could be applied at a lower rate and still provide an effective revegetation outcome was also a question to which we had insufficient information. This paper describes the results of trials aimed at answering these questions.

Supplying sufficient quantities of mosses for revegetating large areas of disturbed land at mine sites is challenging. Complete harvesting of natural colonies of mosses ahead of mining operations is one such source. Partial harvesting, with treatments to enhance recovery, is appropriate for moss-covered areas that will not be disturbed by mining operations. However, these sources are insufficient to supply the projected needs of the large coal mining operation where our research was conducted. Nursery propagation is an obvious solution since preliminary research had shown that it was feasible to propagate mosses in a nursery and that growth was significantly improved under protective covers compared with unprotected controls. A research trial is described here that examined a range of treatments for nursery moss production.

Materials and Methods

Environment

Field trials researching revegetation with pioneer species were established in the spring of 2001 at Solid Energy's Stockton Opencast Coal Mine in the Buller Coal Field, West Coast, New Zealand (41°41'S 171°52'E). The Stockton Plateau is a challenging environment. The mine extends over an altitudinal range of about 700–1100 m a.s.l. and receives over 6000 mm of annual precipitation. Rainfall is relatively evenly distributed throughout the year and evapotranspiration rates are low, so moisture deficits are generally small and brief for natural soil and vegetation. Mean annual temperature is 8.6°C, mean monthly temperatures range from 13°C in January to 4°C in July; snow lies on the ground for short periods most winters and frosts are common. The plateau is exposed and receives wind from a predominantly north-westerly to westerly and easterly direction. Fog, mist and low cloud cover are common. Bituminous coal occurs within the Brunner Coal Measures, comprising a sequence of basement Greenland Group (late Cambrian to early Ordovician) greywacke and igneous intrusions of Britannia (Devonian) granite, overlain by Kaiata Formation (Eocene) carbonaceous mudstone, which in turn is overlain by laminated and massive quartzose sandstone. Both the mudstone and sandstone contain facets of pyritic acid-forming rock. Low solar radiation, erosive rain intensities, high winds, and infertile soils and overburden materials contribute to naturally slow rates of plant colonization and growth.

Initial Hydroseeding Trial

A trial was established on steep (angle of repose), bare, rocky (sandstone) slopes of a waste rock dump at Stockton in December 2002, to compare hydroseeding with dry application of a moss mixture. The trial comprised two replicates for each of three treatments: hydroseeding¹, dry application through a blower machine, and an untreated control. The hydroseeding mixture contained fragments of locally-sourced mosses (*Campylopus clavatus*, *Polytrichum juniperinum*, *Breutelia elongata*, *Rhacocarpus purpurascens*, *Racomitrium* spp.), lichen (*Stereocaulon* sp.) and pioneer vascular species (*Raoulia* sp., *Anaphalis bellidioides*, *Nertera depressa*, *Epilobium* spp.); seeds of manuka (*Leptospermum scoparium*), and southern rata (*Metrosideros umbellata*); soil inoculum and compost. Plots were 10m x 10m, with ten sub-plots (0.5m x 0.5m) monitored on each plot.

Hydroseeding Mixture Trial

Thirty-six plots (10m × 10m) were established on bare, rocky slopes at Stockton Mine in November 2003 using a Finn Hydroseeder®¹. The hydroseeding mixture contained fragments of locally-sourced mosses, lichens and pioneer vascular species, vascular seeds, slow release fertiliser, and other hydroseeding ingredients. The 18 treatments consisted of three levels of moss × three levels of soil amendment × two levels of vascular plants (seeds and herb fragments). One complete replicate was established on coarse boulder laden sandstone that comprised the overburden rock dump slope (angle of repose). The other replicate was divided into 9 plots on a rocky granite veneer 20-30cm thick applied over sandstone, and 9 plots on a pit wall (weathered granite regolith and colluvium). Samples were collected for nutrient analysis from the three trial sites.

Twelve 0.5 x 0.5m sub-plots per plot were marked out on each plot prior to the treatment application and assessed for vegetative cover. The sub-plots had no vegetation prior to treatment, except for the granite veneer, on which the moss averaged 1.4% cover and the vascular plants averaged 0.3% cover. The sub-plots were reassessed in May and November 2004 using a vegetative cover scale (Payton et al., 1999) for moss and vascular plant cover. The data from the 36 plots were averaged over the 12 subplots, and then both moss and vascular cover scores were subjected to analysis of variance.

¹ Hydroseeding was carried out by Rural Supply Technologies Ltd.

Moss Nursery Trial

In September 2002, 80 plots (1m x 1m) were established at Stockton Mine to compare growth of six moss species under different artificial covers. Treatments included two cloth types each with two profiles (low flat vs. raised hoop). The cover (%) of each moss species sown was recorded 7, 12, 19, and 26 months after establishment, and cover scores were subjected to analysis of variance.

Results

Initial Hydroseeding Plots

An average of 15% moss cover and 9.5% vascular cover was achieved on the best hydroseeded 100m² plot within 18 months. This compared with 0.5% and 2.3% cover on the best control plot for moss and vascular cover respectively (Fig. 1). A small number of subplots had moss covers of 40 to 50% and vascular covers of 20 to 30% in sheltered pockets of the plots. This suggests there were microsites with a total cover of 60 to 80%, which could provide important sources for further colonisation and are ecologically significant improvements over non-treated options for rehabilitation. There were no significant differences between hydroseeding and dry application, given the high level of variability between sub-plot and plot data.

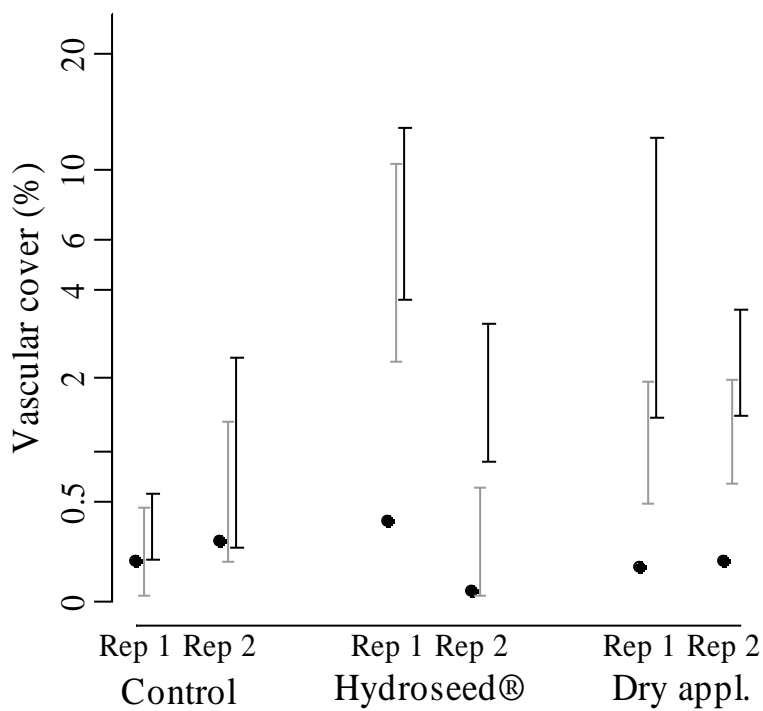
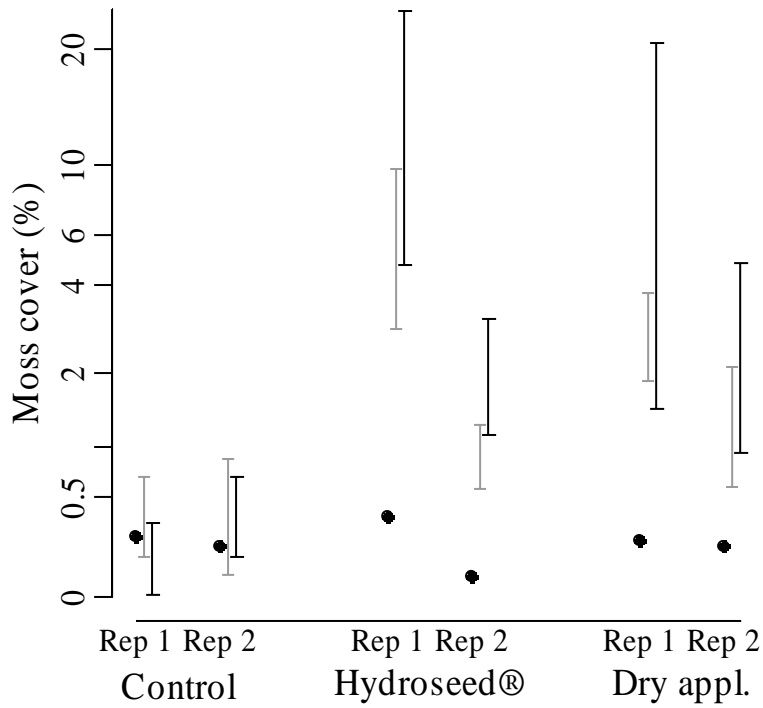


Figure 1. Moss and vascular cover as assessed from the 10 sub-plots initially (dot), in April 2003 (grey line) and May 2004 (black line) for each plot. The vertical line indicates the 95% confidence interval. Note the non-linear scale.

Hydroseeding Mixture Trial

Nutrient analyses showed that the planting substrates are extremely infertile (Table 1). The pH values for the sandstone waste rock dump were strongly acidic, with a hint of some pyritic

material but not sufficient to be designated as acid producing rock. The pH values for the granite pit wall and granite veneer were moderately acidic with no acid-producing potential of concern. Organic matter was negligible. Levels of NO_3^- and NH_4^+ were extremely low; and biological activity was virtually non-existent. Plant-available P (Olsen et al., 1954) was very low for the sandstone waste rock dump and granite veneer, but levels for the pit wall were moderate, presumably as a result of the influence of freshly exposed granitic material containing apatite minerals. Exchangeable cations were all at very low levels for all samples.

Table 1. Nutrient analyses for the Hydroseeding mixture trial sites; means and (\pm standard errors).
*The standard test used in New Zealand agricultural fertilizer testing, based on the Olsen et al. (1954) method.

Site	pH		Total		Olsen*		Exchangeable		
	(water)	(H_2O_2)	C (%)	Total N (%)	P (mg/kg)	Ca	Mg	K	Na
							(cmol(+)/kg)		
Sandstone	4.20 (± 0.07)	3.59 (± 0.09)	2.38 (± 0.91)	0.04 (± 0.01)	4 (± 1)	0.14 (± 0.02)	0.03 (± 0.009)	0.12 (± 0.03)	0.05 (± 0.02)
Granite veneer	5.52 (± 0.04)	5.07 (± 0.10)	0.41 (± 0.11)	0.01 (± 0.003)	6 (± 0.58)	0.36 (± 0.24)	0.26 (± 0.04)	0.09 (± 0.00)	0.04 (± 0.003)
Pit wall	5.42 (± 0.08)	5.0 (± 0.18)	0.46 (± 0.18)	0.018 (± 0.005)	29 (± 4.1)	0.038 (± 0.02)	0.045 (± 0.01)	0.063 (± 0.01)	0.053 (± 0.01)

There was an overall increase in moss cover between initial assessment in November 2003 and final assessment in November 2004; however, little or no change occurred in either the moss or vascular cover over the winter months. The moss cover on the granite pit wall plots was striking (Fig. 2 and Fig. 3). Moss covers ranged from 6% to 28% (mean of 13%) in the plots containing higher soil additions after 12 months. Medium and low soil plots produced moss covers below 6%, averaging about 1.4% for both. Qualitative visual observations showed some sub-plots suffered erosion that has led to burial and loss of moss cover on many plots. Overall moss cover on eroded subplots tended to remain unchanged. No differences were found for vascular cover, other than between locations. Erosion will always be an issue as was demonstrated at the granite veneer site (Fig. 4), which had been undisturbed for several years and was less steep than the other two sites. It is possible that an extreme weather event such as those

experienced in February 2004 (200-300% normal monthly rainfall) may have been sufficient to destabilise this slope.

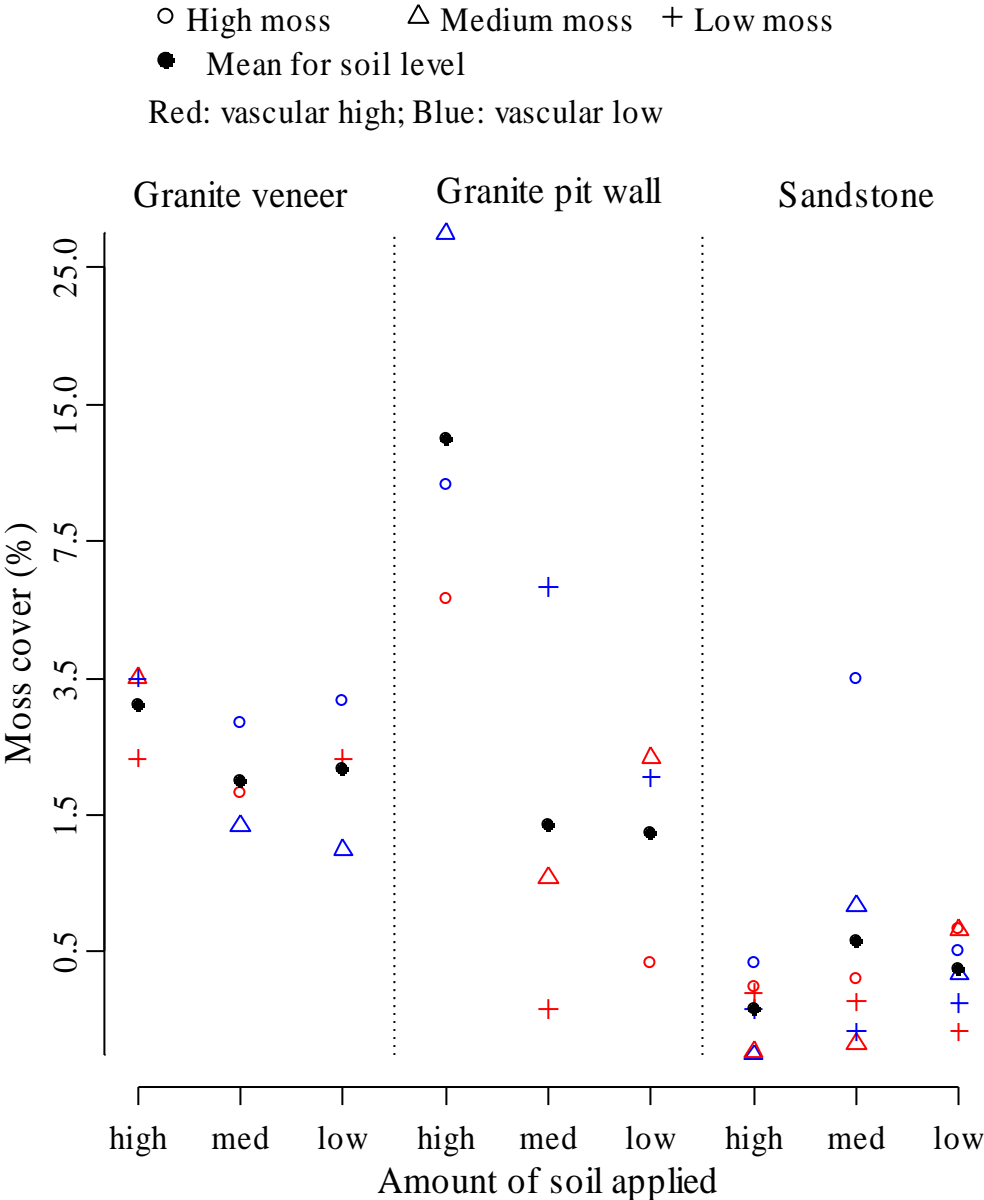


Figure 2: Average moss cover for each plot, distinguished by location, soil, moss and vascular treatments, assessed 12 months after trial establishment. The high cover on some of the pit wall plots is significant. Note the non-linear scale.



Figure 3. Moss cover on the granite pit wall 12 months after application in the hydroseeding mixture trial, on a plot that was treated with a mixture containing high soil additive levels. The footprint (bottom left) shows the fragile nature of this surface. Note the untreated slope behind with no vegetation.

Results for the granite veneer were less successful, averaging 2.4% moss cover after 12 months. The sandstone site had very little moss establishment (averaging <1%) because of the very coarse boulder laden material, the infertile nature of the materials and instability (erosion) of the angle-of-repose surface. Overall, the difference between plots consisting of varying soil levels was not significant.



Figure 4. Erosion runnel on the granite veneer site with adjacent moss growing in the protection provided by a large boulder.

Moss Nursery Trial

Mean cover of the six moss species sown differed considerably after 26 months (Fig. 4). Clearly, *Campylopus introflexus* (15% cover) and *Racomitrium lanuginosum* (11%) did not perform particularly well, whereas *Racomitrium pruinosum* (71%) and *Breutelia elongata* (39%) achieved significant cover. *Polytrichum juniperinum* (28%) and *Rhacocarpus purpurascens* (21%) were between these extremes. For the better performing species the volume of moss harvested was 10.6 and 2.8 times (for *R. pruinosum* and *B. elongata* respectively) the quantity of moss applied 2 years previously. The type of protective cover, whether cloth type or profile, did not significantly affect either the moss cover values or volume harvested, although harvested volume may have been greater under low flat profiles (P=0.10).

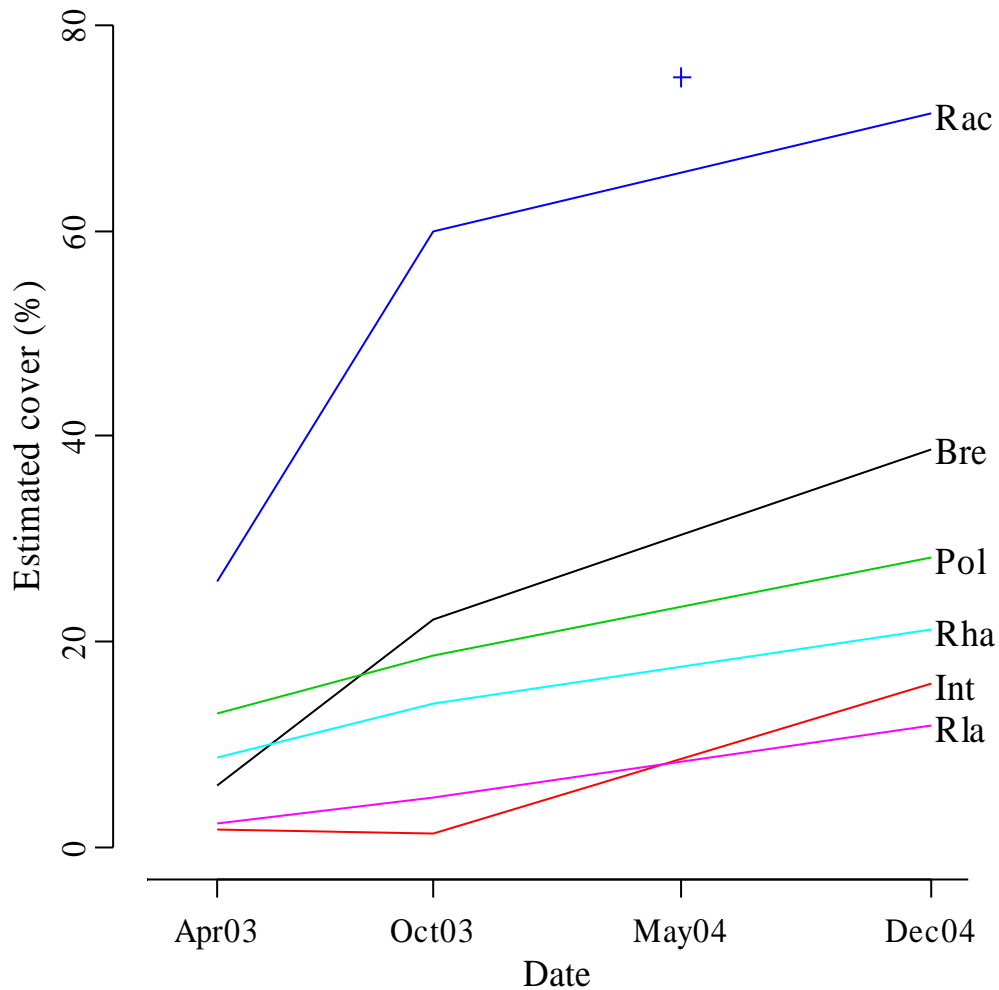


Figure 5. Mean moss cover (%) of the promulgated moss for each species from the first assessment (April 2003) to the last (December 2004). Only the *Racomitrium pruinosum* plots were assessed in May 2004 (indicated by the + symbol). Abbreviations are: Bre *Breutelia elongata*, Int *Campylopus introflexus*, Pol *Polytrichum juniperinum*, Rha *Rhacocarpus purpurascens*, Rla *Racomitrium lanuginosum* and Rac *Racomitrium pruinosum*.

Discussion

Success of hydroseeding

The initial hydroseeding trial demonstrates that, on a micro-site level, mosses and other colonizing plants can be successfully ‘seeded’ onto boulder laden waste rock dump slopes. Stabilizing vegetation covers that aid the establishment of vascular plants and plant successional processes, can be reached within 18 months. Similar results were achieved for both dry application and hydroseeding. However, hydroseeding is a more successful method

of revegetation when seeding with early colonizers than is dry seeding. Hydroseeding is less affected by wind and achieves a more uniform cover of well-mixed seeding ingredients.

The hydroseeding mixture trial has illustrated that high moss cover can be achieved, but that there is considerable variability, depending on the aspect, rock type, slope stability, mixture of pioneer plants, and micro-climate. Moss cover after 12 months varied from plot averages of 0.1% to over 25% for one plot on the granitic pit wall. Even though there were some large erosion runnels on the pit wall, the treatments containing more soil averaged 12% moss cover. No treatment plot on either of the other two sites averaged over 5% moss cover. Differences in the physical properties of the growing media are likely to affect growth, i.e., the weathered granite regolith and colluvium on the pit wall was much finer and more soil-like than either the granite veneer (intermediate physical condition) or sandstone waste rock dump (coarse, bouldery and steep). As both the pit wall and veneer were granite-based media, a closer look at the nutrient analyses may be of value. For most of the initial nutrient measures the variations within sites were similar to that among sites, and it is unlikely that these could explain the differences between sites with respect to moss growth. For four variates, the variation among sites was higher than that within sites. These were, in decreasing magnitude of the ratio of among:within site variances, pH (water), exchangeable Mg, pH (peroxide) and Olsen P. For both pH measures the granite veneer and pit wall were similar, but the sandstone waste rock pile was more acidic by about 1 pH unit. For exchangeable Mg the granite veneer site was about an order of magnitude higher than the other two sites; Olsen P was five or six times higher at the pit wall than the other two sites (29 *cf* ~5 mg/kg). Earlier small-scale trials also recorded good moss growth on granite sites. Gordon et al. (2001) found that total bryophyte cover in Arctic heath almost doubled with additions of phosphorus (5kg ha⁻¹ yr⁻¹), and *Polytrichum juniperinum* cover, which increased in response to nitrogen or phosphorus alone, had a greater than additive response to the combination of these nutrients. They suggest that these two nutrients may be co-limiting. The addition of soluble phosphate to limestone soils in a greenhouse study (Tyler et al., 1995) improved bryophyte establishment and the resulting biomass after 12 months was 7 times greater than in untreated soil. However, this and other studies (Virtanen et al., 2003) show bryophyte species often have individualistic responses to nutrient treatments.

The reduced growth of moss (and somewhat better growth of vascular species) over the winter months has been noted in the other trials, although it is unclear whether this is due to

the beneficial effect of the initial fertiliser leaching out, or the climatic conditions of winter *per se*.

When this trial was established, it was realised that its scale would lead to large background variability between subplots that would make interpretation difficult. Nevertheless, it was considered worthwhile to establish larger plots with necessarily few replicates for the experience that would be gained by scaling up to practical revegetation levels. These initial assumptions have proven to be valid.

Slope stability

The erosion experienced in the hydroseeding mixture trial suggests that slopes should be allowed to stabilise for a period of time before hydroseeding moss. We suggest a 12-month consolidation period before hydroseeding. This presents us with a dilemma, as one of the objectives of hydroseeding moss and other colonising plants is to promote surface consolidation and reduce erosion. Gorman et al. (2000) found that increased vegetative groundcover resulted in reduced erosion on fly ash veneer on abandoned mined land. Of the three vegetation types tested, they found that mosses or fungi appeared to provide better erosion protection than grass-legume cover. Perhaps the erosion in our trial occurred before the moss was able to establish and the surface needs to consolidate for a short period of time before moss treatments are applied. The most suitable length of time for slopes to stabilise before hydroseeding is uncertain, but our observations suggest about 12 months after waste rock dump slopes are formed. The time to stabilise before hydroseeding moss onto the site needs to be balanced against the potential of the moss to assist in the stabilisation. A shorter consolidation period might be a practical compromise, or it may be more effective to applying two hydroseeding treatments – one initially and one after 12 months.

Reshaping of the rock dumps to reduce the length and angle of slopes may also lessen the erosion and instability. In addition, there is great potential in the establishment of micro-topographic humps and hollows to provide plants with shelter and protection (Fig. 4).

Nursery production

The results support the use of artificial moss nurseries as a means of increasing moss volumes for seeding mixtures. Low flat covers, being less expensive, less susceptible to wind, and at least as effective as the hooped profile in promoting moss growth, are preferable. After two years the best plot in this trial yielded moss growth that was 30 times the quantity of moss sown. This target is realistic, given that this trial did not establish as quickly as an earlier one, possibly due to a better water supply for the latter.

Acknowledgments

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