RECONSTRUCTION OF FORESTED ECOSYSTEMS ON ROCK DISPOSAL SITES AT MOUNT POLLEY MINE

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ABSTRACT

Mount Polley Mining Corporation, operated by Imperial Metals Ltd, is located in the Fraser Plateau physiographic region in central British Columbia, approximately 56 km northeast of Williams Lake and 8 km southwest of Likely. The mining method employed is open-pit mining of a gold/copper porphyry deposit. Reclamation research has been conducted since 1998 to develop innovative techniques for restoring sustainable forest ecosystems and critical wildlife habitat. In 1998 and 1999, a total of 12 treatments in triplicate were established on top of the 1,170 m dump. In 2000, an additional 12 treatments were established on the side slope of this dump. The treatments were established to evaluate the following variables, parameters and components: depth of topsoil required to meet reclamation objectives; suitability of tailings and biosolids as a growth medium; selection of tree species for reclamation objectives; interaction of vegetation competition with tree survival and growth; extent of metal uptake by vegetation; and vegetation relationships to various soil amendments. The trials were measured in 2006, and detailed statistics were generated. The analysis indicates the following: a minimum of 15 cm of soil is required to established trees; there is a significant positive response to tree growth to a soil depth of 40 cm, and thereafter no significance in growth is seen with increasing soil depth; 40 cm of soil amendments is currently meeting tree growth objectives; there is a positive response in tree and vegetation growth to biosolids amendments on the 1998 and 1999 trial, but no response in seen on the 2000 trial; tree mortality is significantly higher (α=0.05) with biosolids amendments for all trials (ammonia toxicity to the young seedlings is suspected); vegetation competition is also a significant negative factor in seedling survival and growth (vegetation growth is directly related to available soil nutrient supply); and vegetation cover and diversity increased with increase in soil amendment depth or addition of biosolids. This paper presents the 8-to-9-year results of vegetative growth of this trial, examines the effects of combinations of variables and proposes further investigation to more specifically describe the causes of the results observed.

INTRODUCTION AND METHODS

The Mount Polley project is a gold/copper porphyry deposit employing open-pit mining. The mine is located in the Fraser Plateau physiographic region in central British Columbia, approximately 56 km northeast of Williams Lake and 8 km southwest of Likely. The site is in the ICHmk3 Biogeoclimatic Subzone and dominated by the 01 site series—the climate is cool and moist. Site preparation for the mine started in the spring of 1995 when soil salvaging was initiated. The mine was commissioned in July 1997, and the research program commenced in the spring of 1998; the mine suspended operations as of September 2001, and then recommenced operations in March 2005. The objective of the reclamation research program is to develop the methods, materials and protocol for achieving specific end land use objectives for each reclamation unit.

Test plots were established in 1998, 1999 and 2000 to evaluate the following variables, parameters and components:

- The depth of topsoil required to establish a suitable medium for growth given the reclamation objectives;
- The essential ecosystem components required for re-establishing a forested ecosystem;
- The requirements for soil amendments, if any;
- The suitability of tailings solids as a growth medium;
- The suitability and practicality of re-colonization of disturbed areas by native species;
- The selection of tree species for reclamation objectives;
- The interaction of vegetation competition with tree survival and growth;
- The extent of metal uptake by vegetation; and
- Vegetation relationships to various soil amendments.

The 1998 and 1999 trials were located on top of a rock disposal site (RDS) (1,170-meter dump) near the uppermost terraces at Mount Polley and consisted of 12 treatments, most of them in triplicate. The treatment blocks are 13 m by 15 m (195 m^2) in size. Each block is separated by 3 m of non-treated area, and each treatment block was randomly selected.

The research trial for 2000 consisted of establishing 12 treatments on a Rock Disposal Site side slope between the 1,170- and 1,150-meter dump. This trial is northeast of the trial established in 1998, and is directly over the crest of the 1,170- meter dump. The slope range is from 3.5:1 to 2.5:1 (28 to 40 %) on an easterly aspect. The entire slope from the 1,170- to 1,150-meter dump has been planted within the treatment units. Due to the contouring, the slope length between treatments is variable. Each treatment is unique, with no replication, and the size of each treatment block is approximately 833 m^2. All treatments were planted at a ratio 70:30 lodgepole pine to Douglas fir at 2,000 stems/ha with one year old container planting stock. The fertilizer amendment used was RTI Bio-Paks containing 10 g/bag; the treatment is 1 bag/seedling at 16-6-8-3 NPKS. Three different seed mixtures were utilized (Table 4) and seeded at a rate of 40 kg/ha on the 1998/1999 Trials and 20 kg/ha on the 2000 Trial. Tables 1, 2, and 3 display the treatments, by Trial year, that were established on top of the 1,170-meter RDS.

Table 1: Treatments Applied in the 1998 Trial

Treatment Regime	Basic prep.: Scarify top of rock disposal site	Soil added, cm	Fertilizer: tea bag	Fertilizer: Biosolids dT/ha	70:30 Lodgepole pine: Douglas-fir stems/ha	Domestic grasses Kg/ha	Native grasses Kg/ha
A control	Basic prep.	0			2000	40	
B	Basic prep.	15			2000	40	
C	Basic prep	15	1 / tree		2000	40	
D	Basic prep	15		75	2000	40	
E	Basic prep	15		150	2000	40	
F	Basic prep	25			2000	40	
G	Basic prep	15			2000		40
H	Basic prep	40			2000	40	
I_1	Basic prep	65			2000		40

Table 2: Treatments Applied in the 1999 Trial

Treatment Regime	Basic prep.: Scarify top of rock disposal site	Soil added, cm	Tailings added, cm	Fertilizer: Biosolids dT/ha	70:30 Lodgepole pine: Douglas-fir stems/ha	Domestic grasses Kg/ha
I_{2+3}	Basic prep.	65			2000	40
J	Basic prep.	15			2000	40
K	Basic prep.	25			2000	40
L	Basic prep.	40			2000	40
M	Basic prep.	20	20	75	2000	40

Table 3: Treatments Applied in the 2000 Trial

Treatment Regime	Basic prep.: Scarify top of rock disposal site	Soil added, cm	Dump fines added, cm	Fertilizer: Biosolids dT/ha	70:30 Lodgepole pine: Douglas-fir stems/ha	Dry-seeded Domestic grasses Kg/ha	Hydroseeded Domestic grasses Kg/ha
N	Basic prep.	30		50	2000	20	
O	Basic prep.	15		50	2000	20	
P	Basic prep.	0		50	2000	20	
Q	Basic prep.	0		50	2000		20
R	Basic prep.	15		50	2000		20
S	Basic prep.	30		50	2000		20
T	Basic prep.	30			2000		20
U	Basic prep.	15			2000		20
V	Basic prep.	0			2000		20
W	Basic prep.	0			2000	20	
X	Basic prep.	15			2000	20	
Y	Basic prep.	30			2000	20	
Z	Basic prep.	20	20		2000	20	

Table 4: Composition of Seed Mixtures (2007 Annual Reclamation Report, Mount Polley)

Symbios Mixture		Pickseed Mixture		Mount Polley Mixture	
Species	**% by weight**	**Species**	**% by weight**	**Species**	**% by weight**
Lupinus polyphyllus	82.5	*Elymus cinereus*	25.0	*Poa compressa*	5.0
Brachyrhizobium innoculant	0.7	*Festuca ovina*	25.0	*Trifolium pratense*	20.0
Elymus glaucus	7.1	Wild-Flowers	12.5	*Trifolium repens*	5.0
Dryas drummondii	1.4	*Dactylis glomerata*	12.5	*Festuca rubra*	20.0
Carex mertensii	6.4	*Trifolium repens* var. tahora	12.5	*Agrostis alba*	2.0
Achillea millefolium	1.3	*Poa palustris*	12.5	*Phleum pratense*	5.0
Festuca occidentalis	0.7			*Lotus comiculatus*	10.0
				Festuca ovina	8.0
				Lollum perenne	25.0

STATISTICAL ANALYSIS

The data collected in the field, which are total height, leader height, (1998, 1999, 2000 trials), calliper (2000 trial) and vigour were entered in Excel and checked for accuracy and validity. Statistics were generated in Minitab and Excel, using basic descriptive statistics, the General Linear Model for testing the difference between results of sets of unequal size, correlation and regression analysis and Chi-Square Goodness-of-Fit Test for Observed Counts analysis.

RESULTS AND DISCUSSION

Detailed analysis is presented in Mount Polley's 2007 Annual Reclamation Report. In the 2006 data (collected in the spring of 2006) for the 1998 trial (9 years from seed), certain trends are evident, and the following can be concluded:

- Trees have a high mortality (64 to 77%), poor vigour and growth (<20% of observed maximum total height) with negligible leader growth when planted directly into waste rock with no soil amendments (TR A).
- Trees on the biosolids treatments (TR D, E) have a significantly higher mortality rate.
- Tree survival is adequate (>80%) with 15 cm of soil amendment.
- Douglas fir and lodgepole pine have the same mortality rate.
- The addition of fertilizer (TR C) had no effect on seedling survival rate.
- Douglas fir and lodgepole pine tree growth and mortality respond similarly to the differing treatments of varying soil depths, changing soil amendments and revegetation techniques.

- A comparison between comparable treatments indicates that lodgepole pine is currently more vigorous than Douglas fir.
- Initially, Douglas fir was less vigorous as its growth was stunted; however, once a critical height (±1 meter) was reached, the growth increment showed a marked improvement. This is a reflection of Douglas fir seedling susceptibility to frost and the significance of cold air pounding on high elevation sites.
- Biosolids amendments make a significant improvement to all characteristics of tree growth. To date, no significance is observed between 75 or 150 dT/ha biosolids amendments.
- There is a significant trend of improved growth, survival and vigour with increasing soil depth up to 40 cm; but to date, no significance is observed when increasing soil depth past 40 cm.
- Currently, the tea bag amendment (TR C) showed no significant difference in growth characteristics from other 15 cm soil amendment treatments. A positive response to fertilization was initially indicated (Reclamation Report 2000), but recent data show that the tea bag fertilizer effect lasted only two growing seasons and resulted in a 50 to 100 mm advantage in total height at that time. This previously positive response is not seen at this juncture; in fact tree growth of Douglas fir is not significantly different in total height. The leader growth is significantly lower in the fertilized 15 cm soil amendment treatment compared to the non-fertilized one (TR B). For lodgepole pine, the fertilized treatment had significantly lower total growth and leader growth. It may be hypothesized that fertilization of young seedlings results in initial top growth at the expense of root growth, leaving the seedling root mass insufficient for sustainable growth in later years.
- No significant difference is observed between treatments with native species or domestic species of forbs and grasses.

For the 1999 trial data collected in the spring of 2006 (8 years from seed), certain trends are evident, and the following can be concluded:

- Tree mortality is higher for the 1999 trial, especially for Douglas fir. As climate conditions during the initial growing season were more favourable in 1999, it may be postulated that seedling stock handling may have been a major contributor to seedling mortality.
- TR M consisted of a 50:50 mixture of mineral soil and tailing material (40 cm total) mixed with biosolids (75 T/ha.). An immediate and vigorous flush of herbaceous vegetation growth occurred due to a postulated excessive nutrient flush. This resulted in seedling mortality and reduced growth from excessive herbaceous competition. Currently, the seedling survivors are few, but these have now overcome vegetation competition and have reached a free to grow stage.
- On TR M Douglas fir has made a significantly better growth response over TR K with 25 cm and TR L with 40 cm soil amendments. But for lodgepole pine on this treatment no significant difference in response has been seen over other treatments.
- Trends seen in 1998 are repeated in 1999 (growth improves with increasing soil cover up to 40 cm).

For the data of the 1998 trial the leader height was subtracted from the individual trees' total height to obtain the trees' height at tree-age 8 years. This data manipulation allows the comparison of the variable total height of Trials A thought M for the 1998 and 1999 trials combined. The trends of significantly improved seedling survival, vigor and improved seedling growth are seen with increasing depth of soil amendment to a limit: no significance is currently seen past a soil depth of 40 cm. A regression analysis of soil depth vs. total tree height indicates a significant relationship for both species; for Douglas fir the $r^2 = 0.83$, and for lodgepole pine $r^2 = 0.67$ (see Figure 1). It is also confirmed that there is significant gain in seedling growth on the biosolids treatments compared to non-biosolids, but no significant difference between the 75 T/ha or 150 T/ha rates of biosolids application.

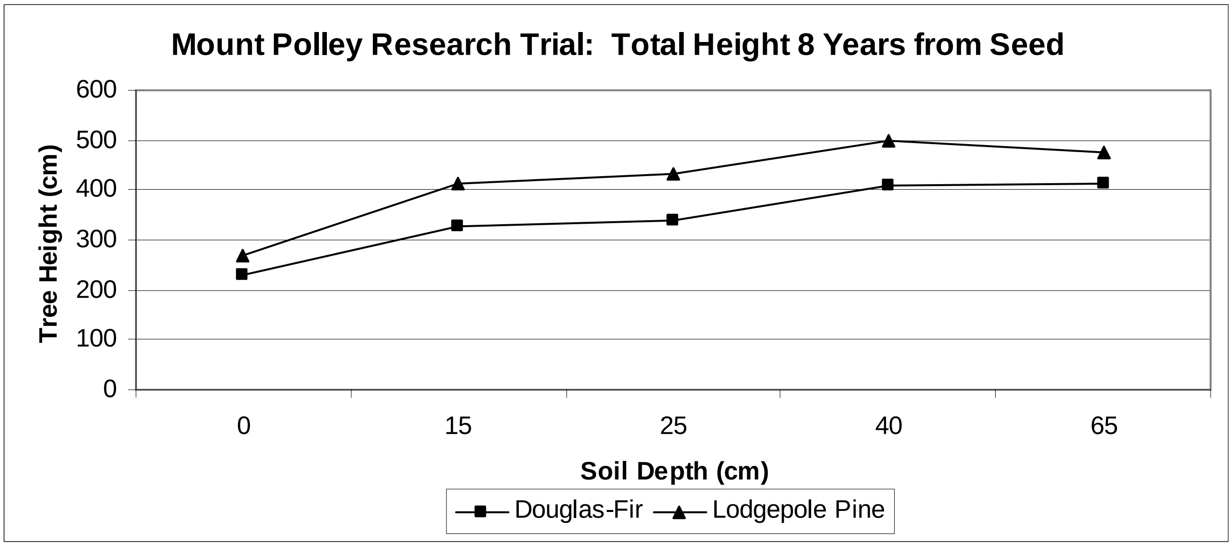

Figure 1: Total Tree Height (1998-1999 Trial) vs. Soil Depth

For the 2000 trial, measured in the fall of 2006 (8 years from seed), certain trends are evident. and the following can be concluded:

- The mortality on the biosolids Treatments (N,O,P,Q,R,S) is very high (Fd-87.7%, Pl-57.1%) in comparison to the paired non-biosolids Treatments (T,U,V,W,X,Y) (Fd-15.5%, Pl-5.2%)—see Figures 2 and 3.
- The hydroseeded Treatments' (Q,R,S,T,U,V) mortality rates (Fd-54.4%, Pl-35.7%), are slightly higher, but not significantly so, than those of the paired dry-seeded Treatments (N,O,P,W,X,Y) with mortality rates of Fd-37.6%, Pl-22.6%;.
- Douglas fir had a high mortality rate (47%) while lodgepole pine had a moderately high mortality rate (29%);.
- Soil amendments of 15 cm in depth are sufficient to establish seedlings with adequate survival and growth.
- Biosolids amendment on the waste dump with no other soil amendments (TR P, Q) had a poor survival rate (Fd-75%, Pl-64%), but the survivors have adequate growth. The growth and performance of trees on biosolids/waste rock is not significantly different from other soil amendment cover treatments.
- Trees planted directly into waste rock (TR V, W) have significantly poorer growth than all other treatments.
- Biosolids treatments with soil amendment, paired with corresponding non-biosolids treatments show no significant response in tree growth. This result is at odds with the 1998/1999 trial.

- Trees planted on biosolids placed on top of waste rock significantly responded in growth over trees planted only on waste rock.
- Hydroseeding significantly improved tree growth when no other soil amendment was present. Hydroseeding combined with either the biosolids and/or soil amendment significantly reduced tree growth.
- The maximum soil amendment for the 2000 trial is 30 cm: there is an apparent, but not statistically significant, trend in increasing seedling survival, vigour and growth. To date, no significance is seen between the 15 cm and 30 cm soil amendments.

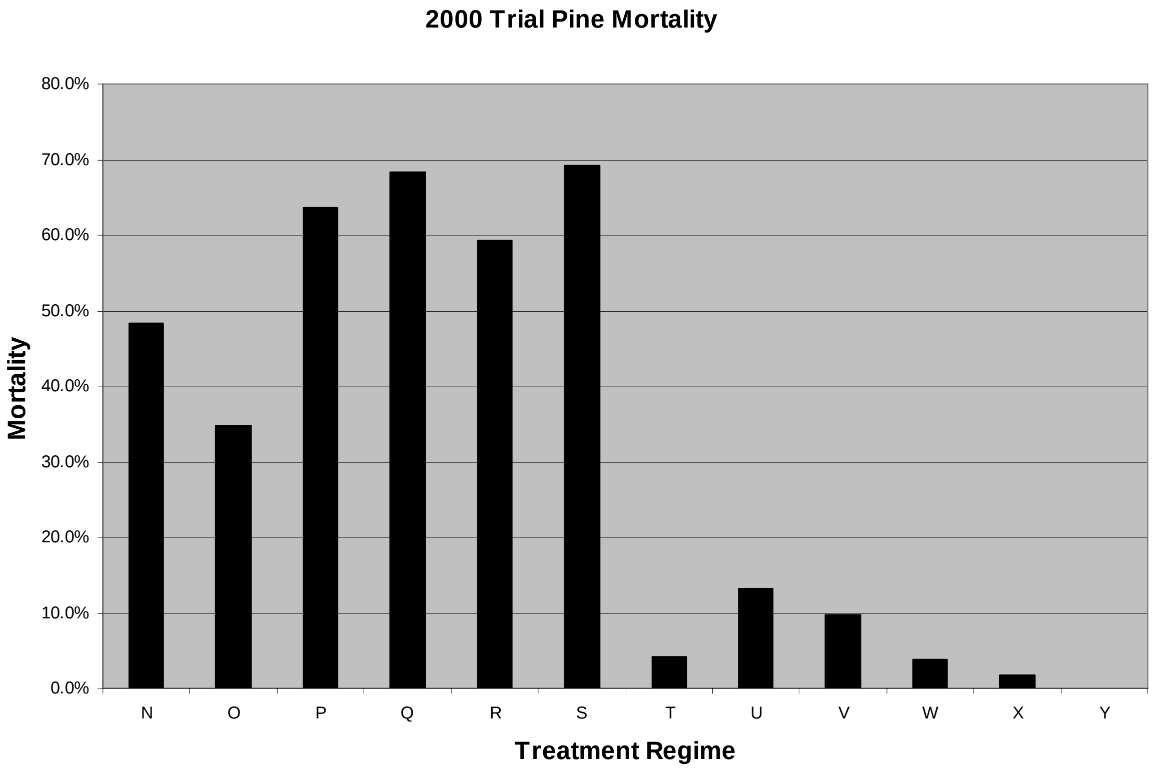

Figure 2: Pine Mortality Histogram (2000 Trial), Biosolid Treatments N through to S (50 dT/ha.), Non-Biosolid Treatments T through to Y. Comparable treatments are in mirror image. Comparable Treatments: N to Y, O to X, P to W, Q to V, R to U and S to T.

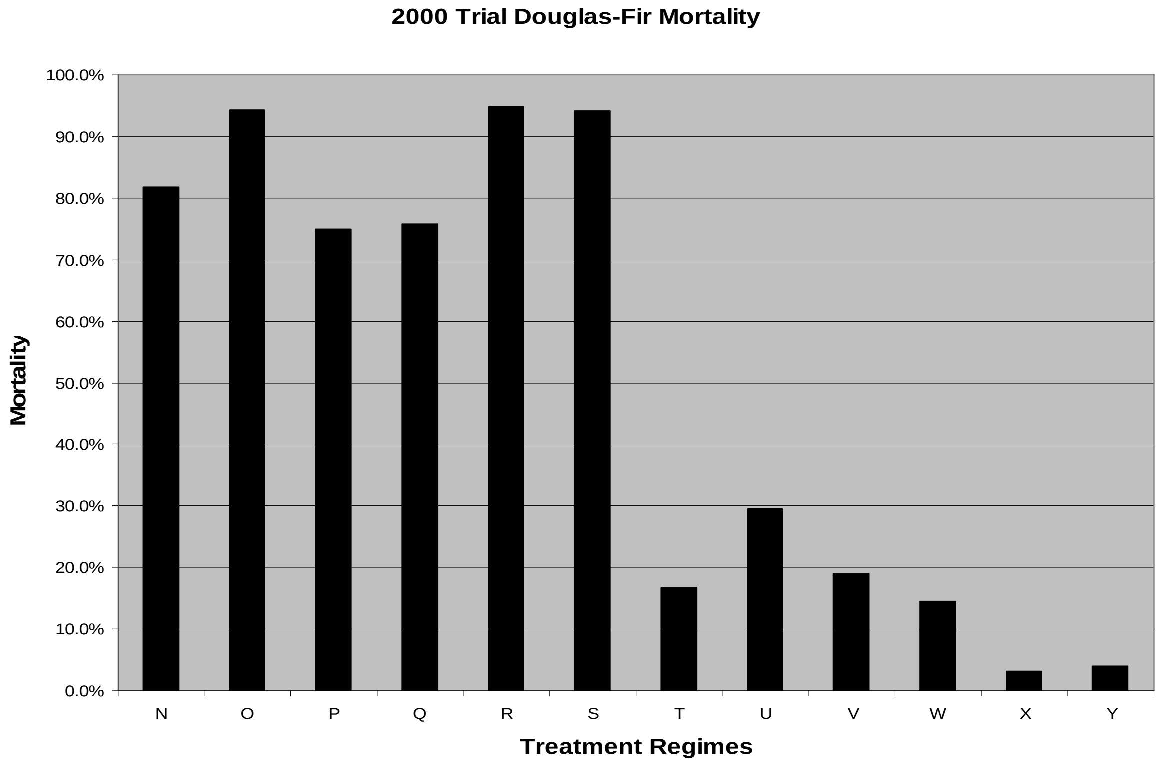

Figure 3: Douglas-fir Mortality Histogram (2000 Trial), Biosolid Treatments N through to S (50dT/ha.), Non-Biosolid Treatments T through to Y. Comparable treatments are in mirror image. Comparable Treatments: N to Y, O to X, P to W, Q to V, R to U and S to T.

Vegetation

A Vegetation Assessment was completed on the 1998/1999 trials (TR A to M) on July 11 to13, 2006 by Black Sheep Consulting. The standardized Northern Interior Vegetation Management Association (NIVMA) methodology is utilized (NIVMA, 2002). Diversity is measured by the number of species noted in the survey, and total cover refers to total vegetation ground cover. No estimate is made of vegetation biomass. Based on personal observation, the diversities of vascular and nonvascular plants are fewer in composition and less in cover to similar stands disturbed by harvesting or fire. From Table 5 (below), the following trends become evident:

- TR A with no soil amendments has both a low vegetation cover and diversity. This corresponds to a high seedling mortality and poor growth.
- There appears to be a minor trend of increasing cover and diversity with increasing soil amendments: the vegetation cover is substantially less on 15 cm of soil than on treatments with thicker soil amendments.
- Vegetation responded with increased cover and growth with biosolids amendments.
- There is a trend towards a higher mortality with increasing vegetation cover.
- Native grass seeding did not increase cover or overall diversity. Ingress of native plants and shrubs occurred on most treatments and are likely due to the soil seed bank source and by-chance airborne seeding. The ingress of native plants is likely to continue.

Table 5: Mean Total Vegetation Cover and Species Diversity by Treatment

Treatment Regime	% Vegetation Cover	Vegetation Diversity	% Fd Mortality	% Pl Mortality
A	21	8	64	77
B	50	20	15	5
C	37	13	5	10
D	88	18	12	19
E	83	17	6	28
F	42	14	6	0
G	55	12	18	4
H	66	17	13	3
I	95	18	17	10
J	92	19	42	32
K	90	18	30	10
L	95	18	39	39
M	98	18	83	78

CONCLUSION

There is a positive response seen in tree growth (height, leader growth, and calliper) and vigour with most biosolids amendments and increasing soil depth for all trials. To date, there is no differentiation between the 40 and 65 cm soil depth or the differing biosolids treatments in tree growth. We can conclude that mortality is high for trees grown directly onto the waste dump and 15 cm of soil is sufficient to establish tree seedlings. Soil amendments of 40 cm in depth are currently meeting tree growth expectations as indicated by site index determinations. Soil amendments of 15 cm in depth plus 75 dT/ha biosolids or greater are currently meeting growth expectations on the 1998 trial; however, no significant response is seen from biosolids mixed with soil on the 2000 trial. In the 2000 trial, biosolids directly mixed with waste rock shows a significant response over waste rock alone. We have shown that reclamation treatments are available that can meet our early growth projections and therefore our short-term management objectives. Longer-term monitoring is required to see if a treatment or multiple treatments can meet our longer-term objectives.

The mixture of soil, tailings, and biosolids appears suitable as a growth medium, but greater refinement in the prescription is required for the seeding rate and the selection of more non-competitive grass/forb species. The trial on the side slope of the RDS appears to react similarly to the top of the site. It is evident that growth on these sites requires a minimum of soil amendment for successful growth. The optimal combination of soil and amendments can only be determined when nutrient and moisture requirements of the forest reach a maximum, usually at 45 years of age (see Figure 4) (Kimmins, 1987).

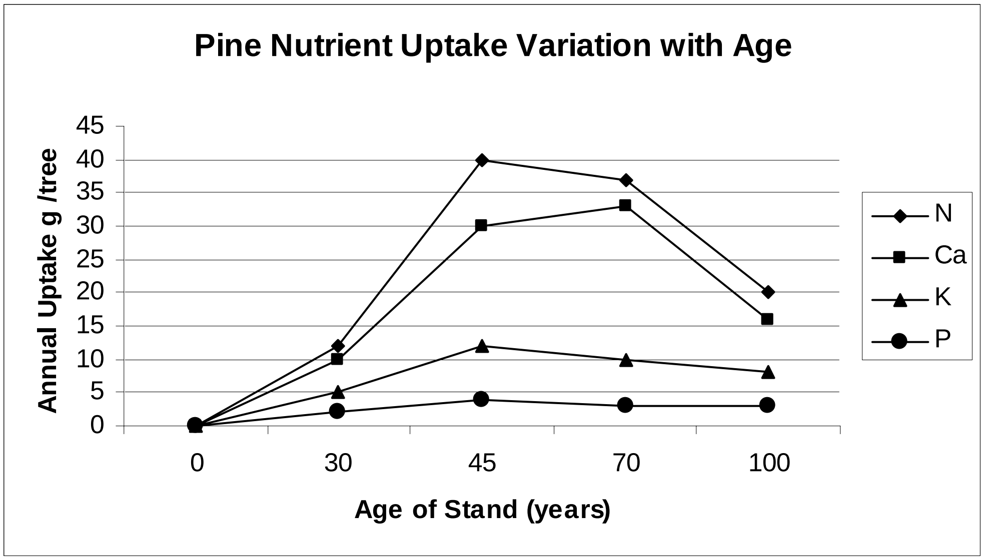

Figure 4: Nutrient Uptake Variation with Age in Pine

Vegetation competition is a significant factor in seedling survival: seedling growth and vegetation growth are directly related to available soil nutrient supply; mortality is directly related to vegetation cover. Vegetation cover is directly influenced by seeding rate and method, biosolid amendments, and fertilization. The diversity and cover of vascular and non-vascular plants are directly proportional to soil depth (related to available soil moisture capacity). Mortality on biosolids treatments is higher, more so for lodgepole pine. This may be due to herbaceous vegetation competition, but ammonia toxicity to the young seedlings is suspected. Ammonia toxicity occurs when the free ammonia ion (NH_3^+) is released when urea-N fertilizer (or possibly biosolids) converts to the ammonium form (NH_4^+). Early successional tree species such as *Pinus contorta* and *Pseudotsuga menziesii* are NH_4^+ sensitive as their predominant nitrogen source for early succession is NO_3^- (nitrate). NH_4^+ becomes the increasingly predominant nitrogen source in soils of natural ecosystems as they progress though succession. (Britto and Kronzucker, 2002). Ammonia toxicity from biosolids was noted at Bunker Hill in Idaho's Coeur d'Alene River Basin (Jenness, 2001). The biosolids used on the 2000 trial came out of winter storage and may have been stored under anaerobic conditions which favour the accumulation of NH_4^+ in the material.

For reclamation to be successful, there must be careful integration of all phases and aspects of reclamation: the quality of the soil salvage material; soil placement; amelioration considerations; revegetation composition and rate; and seedling quality and handing (Bloodgood et al., 1995). Research at Mount Polley indicates that initial forest regeneration is possible. The long-term sustainability of maturing forest ecosystems requires ongoing observation at sites in various climate zones to further this science and experience in reclamation prescriptions. We can look forward to future assessment over the years of stand growth and diversification at Mount Polley to inform the industrial and ecological professions regarding the goal of reconstruction of forested ecosystems.

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