# *Enhancing Natural Succession on Yukon mine tailings sites: A low input management solution*

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## Introduction

Commonly, the restoration mine tailings includes the extensive application of amendments in order to favour and allow the establishment of highly productive species: the agricultural approach. Despite vigorous and costly efforts, these attempts often beget long-term failure (Marty 2000) and can result in a stagnant plant community (Turner *et al* 1998; Withers 1999). In contrast, the aim of a low input approach is to accelerate natural succession by using ecotypically differentiated populations or adapted species that are tolerant to the site specific conditions. Using species, which have a low nutritional requirement and tolerance to potentially toxic substances for site revegetation would require fewer amendments to establish a vegetative cover, and may even allow restorationists to plant in unamended tailings (Piha *et al* 1995). Tolerant plants can modify the harsh and potentially toxic tailings conditions, thereby creating a more suitable environment for the colonization of less tolerant species. In the Yukon, adaptation to the extreme climatic conditions of the far north is also necessary. Local and native species fulfill this latter requirement, provided they can also colonize the tailings environment.

*Deschampsia caespitosa*, a circumboreal grass native to the Yukon Territory, has frequently been documented in and around mine tailings sites in Canada (e.g. Cox and Hutchinson 1979) and Europe (e.g. Von Frenckell and Hutchinson 1993). As such, this species has been the subject of numerous mine tailings revegetation projects. *Deschampsia caespitosa* has demonstrated long-term survival and seed production (over 15 years) in field plots at Nickel Rim near Sudbury, Ontario and has spontaneously colonized 1000's of hectares of barren lands around Sudbury following construction of the Super Stack in 1972 (T. Hutchinson 2005; pers comm.). In addition, many of these mine populations have demonstrated tolerance to elevated levels of numerous metals (e.g. Cu, Ni, Co, Zn, Fe, Al, Ag, Ac, and As) (e.g. Von Frenckell and Hutchinson 1993). *D. caespitosa* typically inhabits sites with poor nutrient conditions and impeded drainage (Davy 1980). In the Yukon, *D. caespitosa* is commonly found along lakeshores and riverbanks where it may experience seasonal flooding as well as periods of drought. It would seem that its natural colonizing ability in the north, its wide range of habitats, and its demonstrated metal tolerance make it a prime candidate for northern mine revegetation.

Accordingly, the intent of this project was to assess the potential of *Deschampsia caespitosa* for enhancing natural succession and revegetating Yukon mine tailings sites by using a low input approach (see Piha *et al* 1995). To assess the physical and chemical environmental conditions challenging the natural and deliberate revegetation of these tailings sites, the plant communities on and off the tailings at three mine sites in the Yukon were described and soil samples were taken. Five Yukon resident populations of *D. caespitosa* were tested for tolerance to potentially phytotoxic levels of Ni, Zn, and Cd. As well, a number of local and non-local populations of *D. caespitosa* were tested *in situ* for their ability to survive and reproduce in tailings under different soil amendments and to encourage invasion of additional species relative to chance colonization. While *D. caespitosa* was pre-selected for revegetation trials, a further goal was to locate additional candidate species for future revegetation work. This paper outlines the plant community assessment and the *in situ* revegetation trials.

### *Mine Site Description*

Three mine sites in the Yukon, Mount Skukum, United Keno Hill, and Wellgreen were selected for revegetation work based on variation in base geology, latitude, climatic conditions, and accessibility. Mount Skukum is located 100 km southwest of Whitehorse in the Wheaton River Valley (60˚14' N and 136˚26' W). Total mean precipitation at the nearest weather station in Whitehorse is 283.3 mm annually. However, Mount Skukum lies within the rainshadow of Montana Mountain and thus, precipitation in this arid region is much lower. Summer temperatures range up to 20˚C and average winter temperatures lie between -10˚ and -20˚C. The surrounding vegetation is typically white spruce and lodgepole pine forest with willow-birch shrub lands. Mineralization of Mount Skukum is chiefly gold with epithermal quartz-carbonate veins. The resulting tailings pond is approximately 12ha. To date, Mount Skukum mine is the only Yukon mine that has been acceptably decommissioned (Government of Yukon 1999). Tagish Lake Gold Corporation gained ownership in 2000 and resumed exploration in 2003.

United Keno Hill Mine is located 450 km north of Whitehorse and 300 km east of Dawson (63º 55´N and 135º 25´W). The 15,000 ha mining property lies along the broad McQuesten River valley: characterized by extensive wetlands and lakes in valley bottoms. This region is known for being both the warmest and coldest area of the territory. Summer temperatures often exceed 25˚C and winter temperatures range from -15˚C to -23˚C, with episodes commonly below -50˚C. Precipitation averages 322 mm annually. Permafrost is widespread, but discontinuous. The mineralization consists of discontinuous bands and lenses of silver deposits bottomed out in zinc. The mine is currently under the care and maintenance of the Yukon Territorial Government and a receivership company.

The Wellgreen property is located 317 km north-west of Whitehorse in the Kluane ultramafic belt (61$^{o}$28' N and 139$^{o}$32' W). The Wellgreen region hosts numerous nickel-copper-platinum group elements (PGE) with massive sulphide mineralization. Summer temperatures regularly reach 20˚C and winter temperatures rarely remain below -20˚C. Wellgreen lies within the rainshadow of the St. Elias Mountains. Precipitation is therefore low, with periodic heavy events. The Wellgreen tailings are occasionally flooded (e.g. in 2003) and there is a predominant underlying iron hard pan on the tailings. The vegetation surrounding the 7ha impoundment is primarily a dense white spruce lowland forest. Minor trenching and drilling programs in 2000, 2001 and again in 2004 were carried out by the current owner, Northern Platinum Ltd.

### *Plant Community Assessments*

Local plant communities in different seral stages were used to assess vegetation and environmental variables and to describe a successional pathway (i.e. a spatial-chronosequence) at Mount Skukum, United Keno Hill, and Wellgreen mine sites in the Yukon. Each site was divided into four habitat types: tailings, immediately adjacent shrubland, and upwind and downwind forest. In each habitat type, transects (beginning a minimum of 10 m from the edge) were set up and 1 $m^2$ quadrats were placed at 5 m intervals. At every 5 m interval two soil samples were taken and several vegetation parameters were described. The relationship between the vegetation data set and the environmental variables were analyzed statistically by canonical correspondence analysis (CCA) using CANOCO (ter Braak 1987).

### *Deschampsia ceaspitosa revegetation plots*

In June 2003, experimental plots were established in unvegetated areas of the tailings of all three sites. Four treatments were used at MTSK and UKHM: 1) no amendments (untreated); 2) compost; 3) fertilizer; and 4) compost and fertilizer (mixed). Compost was acquired from the City of Whitehorse. Due to the very acidic nature of the WG tailings an additional treatment of lime was used at this site only. Thus, the five treatments used at WG were: 1) no amendment (untreated); 2) lime; 3) lime and compost (compost); 4) lime and fertilizer (fertilizer); and 5) lime, compost, and fertilizer (mixed). A commercial dolomite lime was used and applied at a rate which, in the short term changed the pH from ~2.7 to ~5.5.

Healthy transplants of *D. caespitosa* were collected from each mine site and planted reciprocally at all sites and for all treatments. Two uncontaminated sites, Kluane and Annie Lake Road were used. As well, three populations from Ontario were brought to the Yukon and planted in each test mine site. Plants were scored at the end of the first growing season (2003) and again at the end of summer 2004. The vegetative scoring system was based on growth and visual health of the plants and is as follows: (0) dead; (1) poor growth with severe chlorosis and/or purpling and 3/4 die back; (2) better growth, but with severe chlorosis and/or purpling and 1/2 die back; (3) moderate chlorosis and/or purpling, little die back; (4) new growth, healthy; (5) lush growth without visual chlorosis or anthocyanin production (purpling foliage). The number of individual flowering stalks produced in summer 2004 was also recorded in early August. Data were analyzed with a non-parametric ANOVA, Kruskal-Wallis.

## Results of Plant Community Assessments

### *Physical and chemical analysis*

The physical and chemical analysis of the tailings are surrounding soils from all three tested mine sites are shown in Tables 1, 2).

### *Species-Environment Interactions*

Ordination summaries for each site are listed in Table 3. At each site, the selected habitat types were grouped based on environmental variables, suggesting that there was minimal overlap in physical and chemical composition among the habitats. There was, however, an overlap is species. At both MTSK and WG, the upwind forest samples were clustered the furthest away from the heavily disturbed tailings samples and generally, had the least overlap in species (Figures 1, 3).

At MTSK, the variance explained by axis 1 (24.2%) was significant according to a Monte Carlo permutation test (Table 3). Axis 1 was considered a ground cover gradient with bare and exposed tailings on the positive end, and litter and downed woody debris on the negative end. The second axis at MTSK explained a smaller proportion of the plant species distribution (15.1%). It was characterized primarily by total Al, Mg, and K on the one hand, and carbon, nitrogen, and total phosphorous on the other. This gradient was considered a chemical-nutrient gradient.

Species formed clusters around their primary habitat type. However, species such as *D. caespitosa*, *Cerastium fontanum*, *S. planifolia*, *S. pulchra*, *Aster sp*, and *Senecio leguns*, were located in the centre of the ordination, closer to the shrubland community. Their respective species scores, as well as the species, which clustered with the tailings, were highly correlated to the positive end of axis 1 (i.e. exposed conditions). Species diversity increased with increasing amounts of carbon, nitrogen and phosphorous.

At UKHM, the variance explained by axis 1 (24.2%) was significant according to a Monte Carlo permutation test (Table 3). Heavy metals such as Pb, Fe, Cd, and Zn explained most of the variation on the negative end of the gradient; base cation minerals i.e. Ca, Na, and Mg as well as nutrients such as nitrogen, phosphorous, and carbon, accounted for most of the variation on the positive end (Figure 2). The first axis was classified as a chemical-nutrient gradient. The second axis explained a smaller proportion of variance, but was characterized as a substrate gradient due to the strong influence of ground cover on one end, and lack thereof on the other.

Generally, an increase in diversity corresponded to an increase in ground cover, though species richness and heterogeneity were greatest at intermediate levels of carbon and nitrogen. Species associated with the shrubland community were affiliated with the lower and intermediate end of the nutrient spectrum. *D. caespitosa* and *H. jubatum*, along with *S. pulchra*, *P. balsamifera*, showed little affiliation with any habitat, i.e. they were habitat generalists.

The WG ordinations indicated that 24.5% of the variance was significantly explained by axis 1 (Table 3). Ni explained the largest portion of CCA axis 1 from the negative side, followed by total Mg, K and Na (Figure 3). Carbon, nitrogen, and pH influenced the positive side of the gradient. CCA axis 1 was best classified as a chemical-nutrient gradient that shifts from high nutrients and near neutral pH to low nutrients and extremely acidic pH. CCA axis 2 was explained primarily by water holding capacity, bulk density, tailings depth, and bare ground. Ground covers i.e. moss, lichen, and downed woody debris also provided some explanation for this axis. Similar to the other sites, axis two was considered a substrate-ground cover gradient.

At WG an increase in carbon, nitrogen, and pH, corresponded to an increase in diversity. Similarly, an increase in ground cover corresponded to an increase in diversity. Many of the shrubland species were strongly associated with high nutrients and also very exposed conditions. Species documented only in the upwind forest were far removed from the tailings and downwind forest communities. *D. caespitosa* and *C. aquatilis* were clumped within the tailings community, albeit their occurrences were similar, if not greater in the downwind forest.

**Table 1 The mean metal content of soil and tailings samples from associated habitat types for each mine site. Values indicated are the means of a minimum of three samples and represent total concentrations, rather than extractable or available concentrations.**

| Site | Habitat Type | Ag Mg/kg | Al mg/kg | As mg/kg | Cd mg/kg | Cu mg/kg | Fe mg/kg | Ni mg/kg | Pb mg/kg | Zn mg/kg | AGP | TS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MTSK** | Tailings | <2 | 76500 | <50 | <2 | 205 | 38500 | <20 | <50 | 150 | 2.40 | 0.04% |
| | Shrubland | <2 | 52000 | <50 | <2 | 81 | 21000 | <20 | <50 | 119 | | |
| | upwind forest | <2. | 79667 | <50 | <2 | 10 | 26000 | <20 | <50 | 69 | | |
| | downwind forest | <2 | 73000 | <50 | <2 | 12 | 30667 | <20 | <50 | 86 | | |
| **UKHM** | Tailings | 113 | 12325 | 573 | 77 | 255 | 70000 | <20 | 7850 | 3500 | 0.92 | 0.56% |
| | Shrubland | 105 | 40500 | 720 | 134 | 150 | 85000 | 21 | 8200 | 5550 | | |
| | upwind forest | <2 | 18000 | <50 | <2 | 48 | 14000 | <20 | 51 | 64 | | |
| | downwind forest | 2 | 37000 | <50 | <2 | 28 | 30500 | 24 | 120 | 120 | | |
| **WG** | Tailings | <2 | 50333 | 150 | <2 | 564 | 102333 | 610 | 68 | 69 | 97.70 | 5.16% |
| | Shrubland | <2 | 23000 | <50 | <2 | 28 | 17000 | 49 | <50 | 62 | | |
| | upwind forest | <2 | 22000 | <50 | <2 | 29 | 15000 | 22 | <50 | 67 | | |
| | downwind forest | <2 | 36000 | 120 | <2 | 3100 | 220000 | 760 | 58 | 80 | | |

NOTE: MTSK: Mount Skukum Mine; UKHM: United Keno Hill Mine; WG: Wellgreen; AGP: Acid generating potential; TS: Total sulphur

**Table 2 Mean total macronutrient concentrations, pH and organic content of soil and tailings samples from associated habitat types. Nutrient values indicated are the means of three samples and represent total concentrations. Percent carbon and nitrogen, water holding capacity, and bulk density of the mean of all samples tested along transects in each habitat type**

| Site | Habitat Type | Ca mg/kg | K mg/kg | Mg mg/kg | Na mg/kg | % N | P mg/kg | % C | C:N | pH | $H_2O$ g /100g | $B_d$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MTSK** | Tailings | 33500 | 25500 | 11500 | 15000 | 0.09 | 685 | 1.64 | 18.2 | 7.1 | 35.31 | 1.38 |
| | Shrubland | 28500 | 19500 | 5800 | 12500 | 0.41 | 795 | 6.22 | 15.2 | 6.5 | 28.04 | 0.69 |
| | Upwind forest | 15500 | 18500 | 6050 | 19000 | 0.09 | 205 | 3.44 | 38.2 | 6.7 | 30.97 | 0.56 |
| | Downwind forest | 19667 | 22667 | 9900 | 21000 | 0.12 | 547 | 2.56 | 21.3 | 6.4 | 20.51 | 0.39 |
| **UKHM** | Tailings | 1975 | 3775 | 1600 | 408 | 0.02 | 185 | 0.83 | 41.5 | 6.2 | 29.06 | 1.11 |
| | Shrubland | 2950 | 13300 | 3350 | 945 | 0.08 | 465 | 1.17 | 14.6 | 7.0 | 26.38 | 1.05 |
| | Upwind forest | 24500 | 4400 | 4550 | 2950 | 0.9 | 745 | 24.8 | 27.6 | 6.0 | 31.43 | 0.39 |
| | Downwind forest | 12250 | 7650 | 6100 | 7050 | 0.45 | 645 | 20.8 | 46.2 | 4.8 | 34.6 | 0.28 |
| **WG** | Tailings | 30000 | 9000 | 14667 | 12200 | 0.29 | 503 | 3.24 | 11.2 | 2.7 | 37.81 | 1.29 |
| | Shrubland | 38000 | 4600 | 8100 | 6100 | 1.26 | 620 | 25.4 | 20.2 | 6.2 | 19.81 | 0.73 |
| | upwind forest | 34000 | 4100 | 6100 | 5900 | 0.78 | 760 | 17.4 | 22.3 | 5.1 | 32.58 | 0.43 |
| | downwind forest | 42000 | 8300 | 15000 | 7300 | 0.57 | 220 | 10.1 | 17.7 | 3.2 | 27.59 | 0.69 |

NOTE: MTSK: Mount Skukum Mine; UKHM: United Keno Hill Mine; WG: Wellgreen; %OM: percent organic matter; C.N- carbon nitrogen ration; $H_2O$: water holding capacity- grams of $H_2O$ held per 100g of soil; $B_d$: Bulk density ($g/cm^3$).

**Table 3 Ordination summaries for environmental data (CCA) from all three test mine sites. The eigenvalues for the vegetation data (DCA) are also listed.**

| | MTSK | | UKHM | | WG | |
|---|---|---|---|---|---|---|
| CCA Ordination axis | Axis 1 | Axis 2 | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| DCA eigenvalues | 0.728 | 0.500 | 0.942 | 0.586 | 0.896 | 0.515 |
| CCA eigenvalues | 0.665 | 0.436 | 0.934 | 0.638 | 0.881 | 0.497 |
| Species-environment correlations | 0.967 | 0.917 | 0.990 | 0.934 | 0.956 | 0.901 |
| Cumulative % variance of species data | 0.964 | 0.914 | 10.8 | 18.1 | 10.6 | 18.2 |
| Cumulative % variance of species-environment data | 24.2 | 40.1 | 24.2 | 40.8 | 24.5 | 41.9 |
| Sum of constrained eigenvalues | 9.617 | | 8.668 | | 8.152 | |
| Sum of all canonical eigenvalues | 2.747 | | 3.857 | | 4.01 | |
| Monte Carlo permutation test | F=3.648, p=0.001 | | F=10.263, p=0.001 | | F=2.089, p=0.001 | |

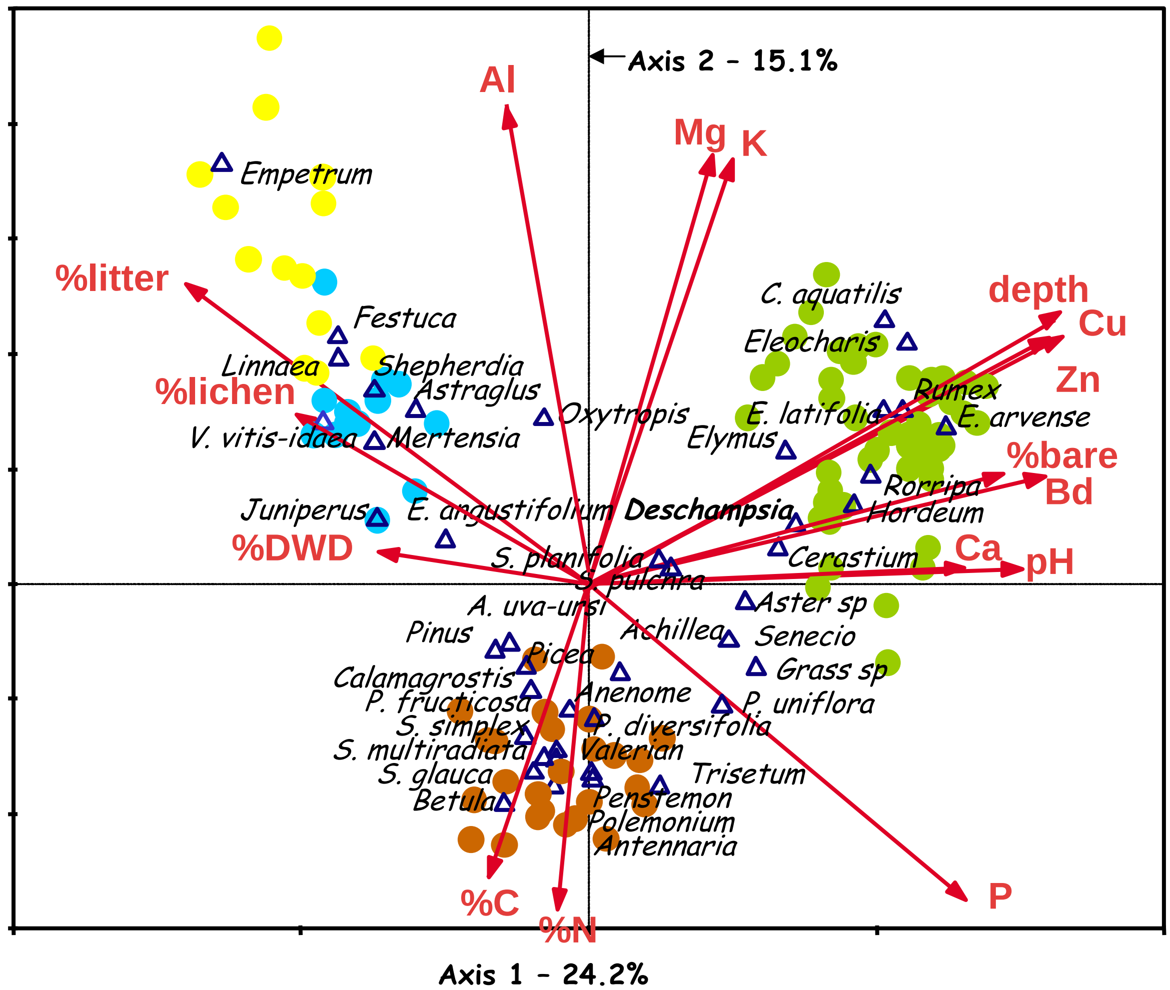


**Figure 2.2 Mount Skukum CCA ordination showing the relationships between quadrats (circles), species (triangles) and environmental variables (red arrows). The colour coding of samples is as follows: green –tailings; brown- shrubland; yellow- upwind forest; blue- downwind forest. See Table 4 for full species names. Environmental variable abbreviations are as follows: Bd- Bulk density; %bare-percent bare ground; depth-depth of tailings; % N- percent nitrogen; %C- percent carbon; pH- soil pH; %litter – relative cover of ground litter; %lichen- relative cover of lichen; %DWD-relative cover of downed woody debris. All remaining listed elements are measured in total concentration.**

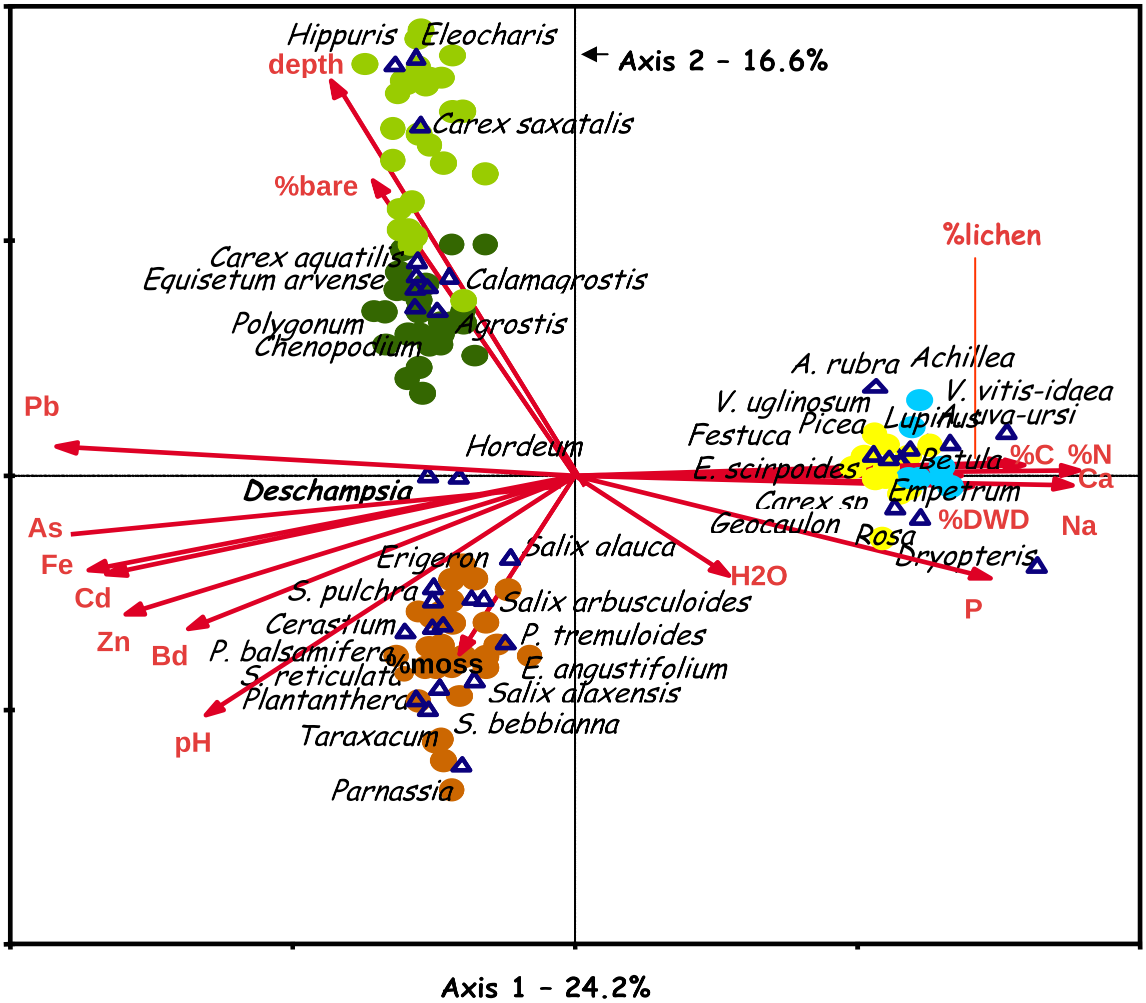


**Figure 3. United Keno Hill CCA ordination showing the relationship between quadrats (circles), species (triangles), and environmental variables (red arrows). The colour coding of samples is as follows: light green –moist tailings; dark green-dry tailings; brown- shrubland; yellow- upwind forest; blue- downwind forest. See Table 5 for full species names. Environmental variable abbreviations are as follows: H2O-water holding capacity; %bare-percent bare ground; %DWD- relative cover of downed woody debris; %lichen- relative cover of lichen; depth-depth of tailings; Bd- Bulk density; % N- percent nitrogen; %C-percent carbon; pH- soil pH. All remaining listed elements are measured in total concentration.**

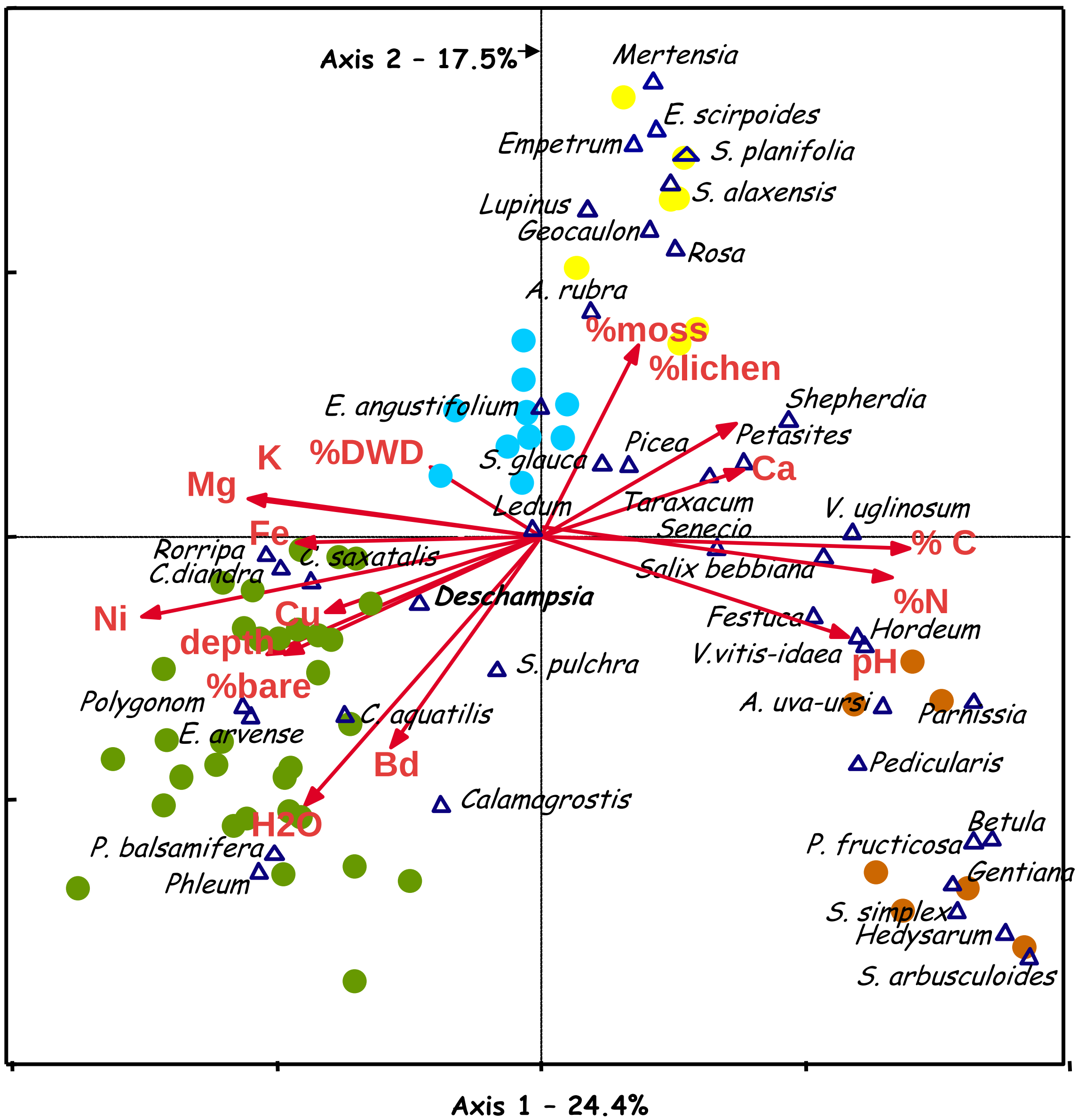


**Figure 4. Wellgreen CCA ordination showing the relationships between quadrats (circles), species (triangles) and environmental variables (red arrows). The colour coding of samples is as follows: green –tailings; brown- shrubland; yellow- upwind forest; blue- downwind forest. See Table 6 for full species names. Environmental variable abbreviations are as follows: H2O-soil water holding capacity; Bd- Bulk density; bare- percent bare ground; depth-depth of tailings; % N- percent nitrogen; %C- percent carbon; pH- soil pH. All remaining listed elements are measured in total concentration.**

## Results of Field Plots

### *Vegetative Growth in Revegetation Plots*

***Mount Skukum***

2003 vegetative score data did not show significant differences among soil amendment treatments ($X^2_{.025, 3}$=7.720, p=0.052). In general, plants grown in the fertilizer treatment performed poorer than those in the other treatments (Figure 4). There were no clear populations effects ($X^2_{.025, 7}$=10.539, p=0.160). The 2004 relative performance scores did show significant treatment differences ($X^2_{.025, 3}$=23.721, p≤0.001) but again, no population effect ($X^2_{.025, 7}$=12.156, p= 0.096) (Figure 4). There was an overall decrease in scores from 2003, but with the exception of the WG plants, individuals from all *D. caespitosa* populations survived the winter with minimal mortality, and subsequently grew during the summer of 2004.

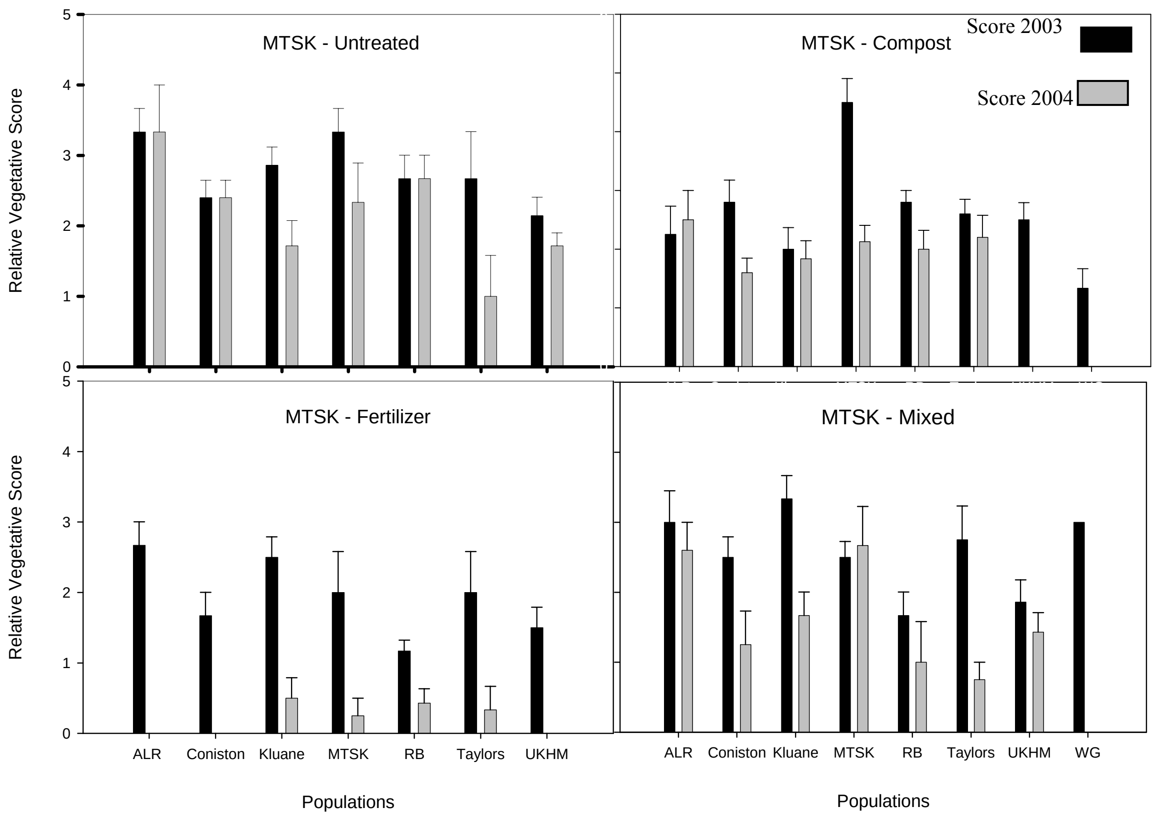


**Figure 4 Mean relative vegetative scores (scoring ranged from 0-5) of *D. caespitosa* transplanted from 8 sites for both soil amendment treatments and populations as assessed in August 2003 and 2004 at Mount Skukum mine. Bars represent standard error.**

***United Keno Hill***

Vegetative growth at the time of recording in 2003 showed that treatment had a significant effect ($X^2_{.025, 3}$=12.972, p=0.005), but that population did not ($X^2_{.025, 7}$=15.356, p=0.032) (Figure 5). In 2004, significant growth differences were found in the relative scores for both treatment ($X^2_{.025, 3}$=45,261, p≤0.001) and population ($X^2_{.025, 7}$=37.577, p≤0.001) (Figure 5). Overall, scores decreased from 2003. However, all populations had surviving individuals in each treatment.

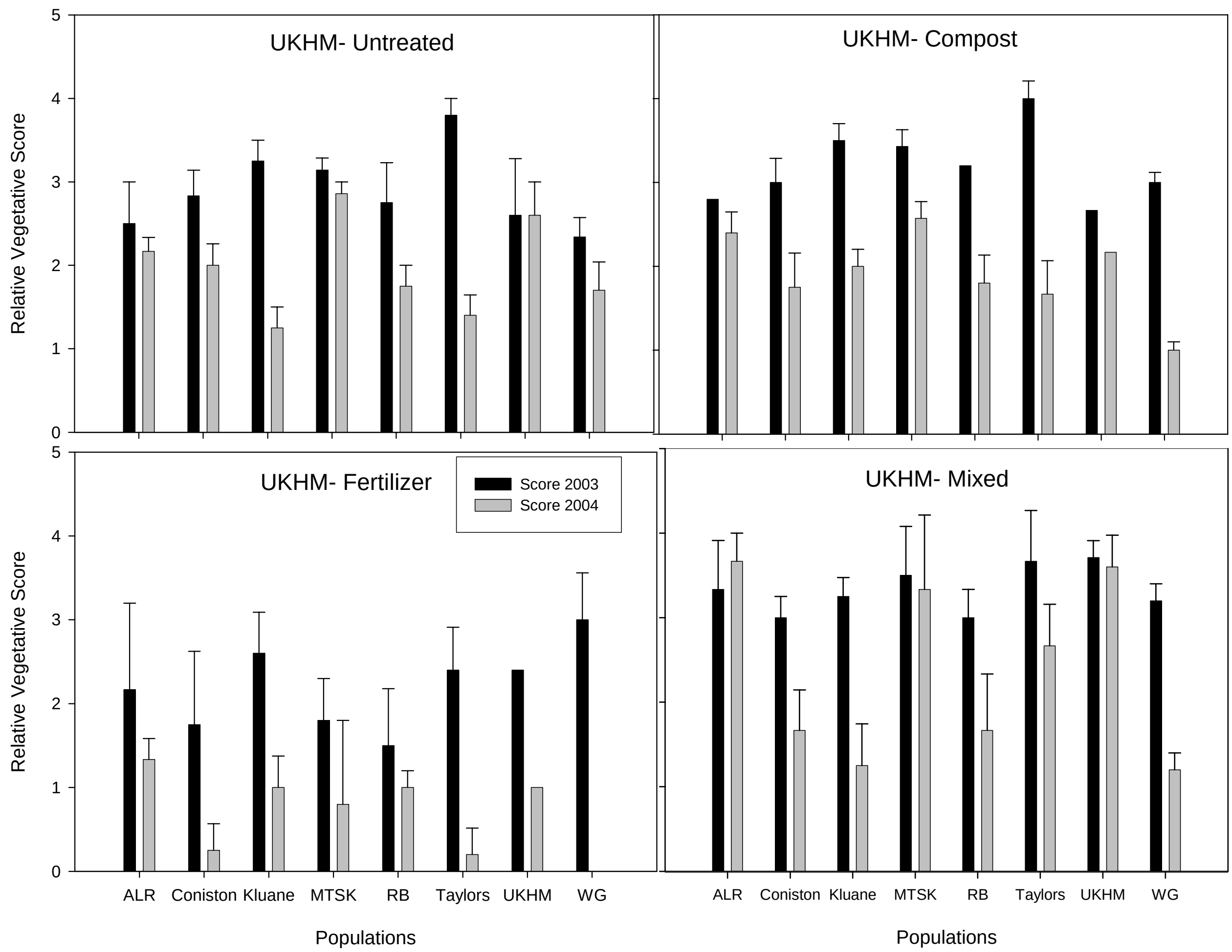


**Figure 5 Mean relative vegetative scores (scoring ranged from 0-5) of *D. caespitosa* transplanted from 8 sites for both soil amendment treatments and populations as assessed in August 2003 and 2004 at United Keno Hill mine. Bars represent standard error.**

***Wellgreen***

For 2003, Kruskal-Wallis tests revealed a non-significant treatment effect ($X^2_{.025,\,4}$=4.653, p=0.325), but a significant population effect ($X^2_{.025,\,6}$=28.523, p≤0.001). Overall, plants growing on the lime amendment performed the poorest (Figure 6). Kluane plants scored significantly higher values ($p<0.05$) than all other populations except for WG, which in turn, scored significantly higher than remaining populations except for the Sudbury RB population ($p<0.05$). Again in 2004, treatment revealed a non-significant effect ($X^2_{.025,\,4}$=7.040, p=0.134) while a significant population ($X^2_{.025,\,6}$=22.803, p=0.001) effect was found. Nonetheless, all populations tested had some surviving individuals for the first two years. At WG, the two local populations and the two Sudbury area ones performed and survived the best.

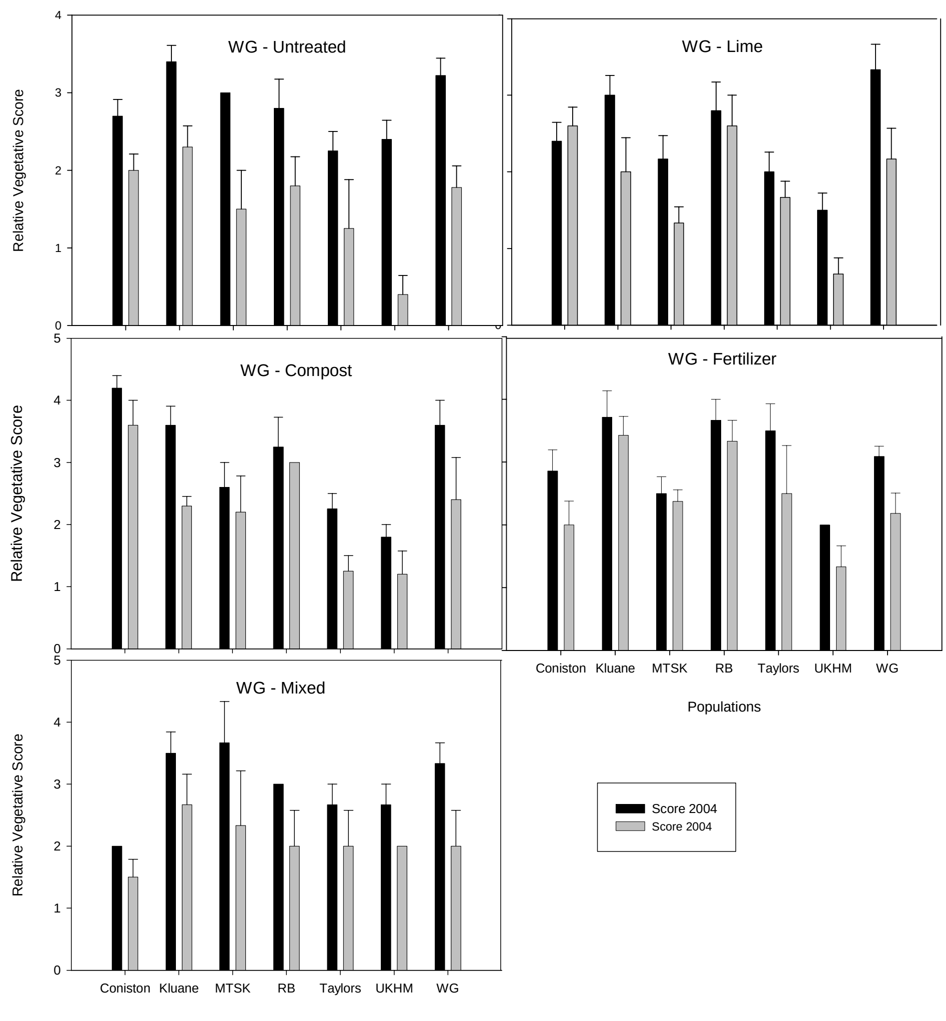


**Figure 6 Mean relative vegetative scores (scoring ranged from 0-5) of *D. caespitosa* transplanted from 7 sites for both soil amendment treatments and populations as assessed in August 2003 and 2004 at Mount Skukum mine. Bars represent standard error.**

### *Floral Production*

**Table 4 Mean number of flowers produced in each treatment for transplants from 8 sites to 3 host sites in 2004 with standard error in parentheses. *Significant difference (P<0.05) among populations when treatments are pooled is shown. **Significant difference (P<0.05) among treatments when populations are pooled.**

| | | ALR | Coniston | Kluane | MTSK | RB | Taylors | UKHM | WG | Mean(**) |
|---|---|---|---|---|---|---|---|---|---|---|
| **MTSK** | untreated | 7.66 | 5.80 | 3.43 | 6.83 | 8.00 | 2.33 | 4.86 | 0 | 4.86 (a) |
| | compost | 7.25 | 3.00 | 2.50 | 6.00 | 5.20 | 2.20 | 0 | 0 | 3.27 (a) |
| | fertilizer | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 (b) |
| | Mixed | 9.00 | 0 | 3.33 | 6.33 | 0 | 0 | 0.86 | 0 | 2.44 (c) |
| | Mean(*) | 5.98 | 2.20 | 2.32 | 4.79 | 3.30 | 1.13 | 1.43 | 0 | |
| **UKHM** | untreated | 4.33 | 3.67 | 1.50 | 3.71 | 0.80 | 3.40 | 4.40 | 0 | 2.73 (ab) |
| | compost | 10.80 | 0.75 | 2.00 | 10.14 | 2.80 | 0 | 9.67 | 0 | 4.52 (ab) |
| | fertilizer | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| | Mixed | 21.67 | 1.67 | 4.25 | 24.33 | 6.00 | 2.33 | 13.60 | 0 | 9.23 (a) |
| | Mean(*) | 9.20 (a) | 1.52 (b) | 1.93 (b) | 9.54 (ab) | 2.40 (b) | 1.43 (b) | 6.91 (ab) | 0 | |
| **WG** | untreated | . | 1.90 | 8.75 | 0.00 | 9.00 | 0.75 | 0.60 | 4.56 | 3.65 |
| | Lime | . | 6.80 | 3.33 | 1.33 | 8.40 | 1.33 | 1.83 | 2.83 | 3.70 |
| | compost | . | 19.20 | 10.20 | 5.60 | 4.00 | 0.75 | 5.00 | 5.40 | 7.16 |
| | fertilizer | . | 2.29 | 20.00 | 6.50 | 11.67 | 7.33 | 1.00 | 9.27 | 8.29 |
| | Mixed | . | 1.25 | 14.67 | 8.33 | 7.33 | 6.33 | 10.33 | 4.67 | 7.56 |
| | Mean(*) | . | 6.29 | 11.39 | 4.35 | 8.08 | 4.12 | 3.75 | 5.34 | |

## Conclusions

The plant community descriptions and site assessments showed that while both the site-specific environmental variables (Tables 1, 2) and plant communities clearly differed among and within sites, there was an overlap in species colonizing the tailings. CCA constructed an axis, which represents a chemical-nutrient gradient (i.e. C, N, P), as well as one embracing a ground cover gradient at each site (Figures 1, 2, 3). The pre-selected habitats (i.e. tailings, shrubland, upwind and downwind forest) and their associated species clustered separately in the CCAs. Nevertheless, some species such as *Deschampsia caespitosa* and *Salix sp*. were shown to be primarily habitat generalists. This supports our choice of *Deschampsia* as a candidate species due to its ability to tolerate a wide range of environmental criteria. Additional species also emerged, which while not found on the tailings may well be capable of tolerating the stress and disturbance of the tailings conditions, owing to their strong affiliation with low nutrients and/or exposed conditions, or, in some cases, their correlation to elevated metal concentrations. Some of these species are candidates for field research in 2005.

The analyses of tailings revealed elevated concentrations of heavy metals such as Cu, Cd, Ni, Fe, Pb, and Zn, as well as potentially toxic elements such as Al and As and low amounts of some essential plant nutrients (i.e. nitrogen and phosphorous). The fact that metal tolerance has been shown in numerous *D. caespitosa* populations from the Yukon (data not shown), Ontario, and Europe (Von Frenckell and Hutchinson 1993) and that this species has naturally colonized a wide variety of tailings sites implies that elevated metal concentrations alone will not hinder revegetation efforts. The results of the field study also support this conclusion.

The field study demonstrated that transplants of Yukon and Sudbury area populations of the native grass *Deschampsia caespitosa* are capable of establishing and reproducing in each of the tested mine sites irrespective of soil amendment and even in unamended tailings. Local populations performed the best at both MTSK and WG. In contrast, however, the top performing populations at UKHM were not local to the site. Instead, the two populations from the MTSK region i.e. MTSK and Annie Lake Road (ALR) attained the highest relative scores.

In terms of plant nutrients, nitrogen and carbon were important in plant community development. Both of these variables explained a large portion of their respective axes in the CCAs and they were associated with later seral and more diverse plant communities. This suggests that the addition of organic matter will promote succession on the tailings. Growth and reproduction of the *D. caespitosa* transplants was improved by the compost amendment at all three sites.

The compost would have improved water retention and supplied nutrients. It was difficult, however, to assess the importance of adding nutrients for this species. A negative NPK fertilizer response was seen at Mount Skukum and United Keno Hill, while fertilizer was beneficial at Wellgreen. In nature, *D. caespitosa* is commonly found inhabiting areas with lower nutrient levels, as was the case in this study. Northern plant species are often adapted to infertile environments and show minimal response to nutrient application (Chapin 1980). In addition, transplants in unamended plots tended to outperform those in fertilizer plots. This adverse response to fertilizer, therefore, may have been the result of fertilizer burn in plants adapted to poorer nutrient conditions.

The use of *D. caespitosa* in a revegetation programme at the tested sites, and likely at other tailings sites in the north, will contribute to a low input management solution. The plant community assessments revealed that *Deschampsia* is either associated with lower nutrients or is a habitat generalist. Multiple populations of this species from mine and non-mine environments have shown the ability to grow and reproduce, even in unamended tailings. In addition, this species is typically found in the vicinity of these mine sites, which would assist in the continued colonization and reproduction through genetic exchange and increase the likelihood that the appropriate pollinators and dispersers are present (Marty 2000). Of course, these trials need to be extended over several years to determine that their success is long-term.

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