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Report on the Experimental Vegetation Plots Established on 3 Abandoned Toxic Yukon Mine Tailings Sites, Revisited in 2009.

By

Tom Hutchinson and Allison Hayward

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Report on the Experimental Vegetation Plots Established on 3 Abandoned Toxic Yukon Mine Tailings Sites, Revisited in 2009. Plots Set Up in 2003 – 2006

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Plate 12: 4 compost plots seeded with stratified seeds of Sheperdia in 2006. Extremely successful establishment and with other species present, including the moss Pohlia nutans. On the left is a 2006 compost plot with sweet clover as a dominant invader.

Plate 13: Compost plot at United Keno, set up 2003 with transplants of tufted hair grass (left). The plot is dominated by invading soapberry. July 2009

Plate 14: Close up of one compost plots at United Keno set up in 2005, with multiple species invasions. See plate 12 for species

Plate 15: Compost plot at United Keno, set up 2006, photographed July 2009, with sweet clover, tufted hair grass and the grass *Pohlia nutans*

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Summary

In July 2009 we re-visited the re-vegetation experiments, which had been set up on tailings in the period 2003-2006. The three experimental sites are at Mount Skukum, United Keno and Wellgreen. The experiments consisted of either seeding the tailings with various populations of the tufted hair grass and/ or with stratified (cold temperature treated) seed of the shrub soapberry, or making transplants of the same two species. The treatments included the addition of compost from the City of Whitehorse, addition of fertilizer as 7:7:7 pellets, addition of organic matter as sheep manure, peat or woody debris from on site and, in the case of Wellgreen, a lime addition to overcome the strong acidity.

The results are striking and illustrated in the Plates 1-15. Data of performance and flowering success are shown in the Tables, as are chemical analytical data in the Figures and Tables. Plots set up in 2003 provide a nucleus for effective re-vegetation, having survived for 6 years. The success of the seedings and transplants at Mount Skukum and United Keno was good, while that at Wellgreen was very poor. Wellgreen has suffered flooding with washing out of plots and washing out of the neutralizing lime. Nevertheless, in compost additions plots at Wellgreen, set up in 2005 and 2006, a small amount of re-vegetation and survival has occurred, especially in the wetter areas near the tailings pond.

The seeding and transplanting of tufted hair grass at United Keno and Mount Skukum has been successful especially in the compost addition treatments. The populations of the tufted hair grass that have naturally invaded the tailings provided seed and transplants for our experiments, which are surviving, spreading and flowering. These represent metal-tolerant populations, which are also able to tolerate drought and nutritional deficiencies. Interestingly, some Yukon populations from non-tailings non-polluted sites, such as Annie Lake Road, also showed excellent potential for tailings re-vegetation work. Some populations have survived 6 years from planting or seeding directly in the tailings with no organic or nutritional amendments. This is very promising.

The seeding of United Keno tailings with stratified seeds of soapberry (Sheperdia) was a remarkable success. The shrubs are dense and vigorous, and this shrub is a nitrogen-enhancer via microbial symbionts in the roots, but not the Rhizobium bacteria of the legumes.

The addition of 7:7:7 fertilizer by itself was always worse than compost or with no amendment. Since the sites are severely nutrient deficient, this is a bit of a surprise. We used only one type of fertilizer so clearly other experiments with a range of fertilizer treatments could usefully be done. However, the Whitehorse compost was a remarkably positive addition for long-term re-vegetation. It provided organic matter, a low supply of nutrients, an improved water holding capacity and, importantly, a source of viable seeds of weedy species, which established on the compost. Many of these were annual species that seeded themselves back in for a number of years.

The most important contribution of the compost, however, was as a seedbed for seeds blowing on to the tailings from surrounding areas. The biodiversity in the compost plots was greatly increased (see Plates) and the early stages of natural primary succession has been initiated. Roadside barley, fireweed, willow and many grasses have established. Two of the most useful colonizing species are sweet clover, which is doing astonishingly well at United Keno and alpine milk vetch. Both are perennial species and nitrogen fixers, with root nodules. The addition of compost was all that was needed to get this re-vegetation underway.

We also visited Whitehorse Copper where we observed similar invasions of fireweed, roadside barley, willow, poplar, and especially sweet clover taking place on the experimental plots. Compost was an additive there too, but we did not do these experiments.

We analyzed foliage of several species growing on the tailings at United Keno and Whitehorse Copper. Particularly at United Keno, several species showed significant heavy metal uptake into their foliage, especially of lead, zinc, and cadmium. This foliar uptake study was a preliminary one and clearly needs a thorough follow up.

In view of the constant success of the tufted hair grass (*Deschampsia cespitosa*) on the various tailings, it seems that it would be rather easy to develop an experimental nursery to grow commercial populations of this grass specifically for particular tailings sites. One could start with populations already growing on some of the tailings sites and also other Yukon populations from non-polluted locations that seem to be pre-adapted to tailings re-vegetation.

The photographs, Plates 1-15, really tell the story. Long-term, low management re-vegetation of many of the abandoned toxic mine sites can be achieved and a natural succession initiated. Some sites, such as Wellgreen, are a much greater challenge, likely because of extreme acidity and site instability. Compost is invaluable for tailings re-vegetation work and the City of Whitehorse compost seemed to provide a plethora of benefits for tailings re-vegetation. The supply is of course limited. Whitehorse is also now moving to produce more compost for sale to the public (Yukon News, June 2010). We have been impressed with the quality o the compost for our work in 2003-2006 and the helpfulness and knowledge on part of the manager.

Pre-Amble

Many abandoned mine sites in the Yukon, especially tailing deposits, have failed to re-vegetate naturally over a period of 20-60 years since abandonment. In most cases, some natural re-vegetation has occurred involving invasion by native Yukon species, which have established on parts on the tailings. Some sites have shown good re-invasion, while a few have proven very resistant to re-vegetation. The difficulties for plant establishment are often due to extreme acidity or, less commonly, to extreme alkalinity and salinity, and to the presence of high concentrations of toxic heavy metals and other elements, such as arsenic. Problems of severe summer droughts, flooding, exposure and sand blasting of vegetation by wind blown tailings all make the abandoned sites a very stressful place for plants. All are also very nutritionally deficient, lack organic matter and soil microbial flora. Amongst the most challenging sites are Venus, Arctic Gold and Silver, Wellgreen, Cyprus Anvil, United Keno Hill and Whitehorse Copper (Hutchinson and Kuja 1989).

The MERG project identified abandoned toxic mine sites as a priority, with the purpose of developing a methodology for re-vegetating them, particularly so as to prevent erosion, run-off and contamination of the watershed, for improvement of aesthetics and to reduce the risk of contamination for humans and wildlife food chains. From 2003 – 2005 I was awarded annual MERG-grants to attempt experimental re-vegetation of some of the most difficult mine sites, most of which were still nearly devoid of vegetation in 2003. The purpose of the research was to see whether the use of metal tolerant and stress tolerant vegetation might allow long-term re-vegetation of the sites with minimal long-term management requirements for repeated interventions. Alison Clark's thesis (2006) (my earlier Trent M.Sc. student) thesis was focused on this Yukon work. We established a number of vegetation trials, using both seeding and planting transplants and using a variety of amendments. The latter involved liming of the acid sites, additions of fertilizers, additions of compost from Whitehorse City Municipal compost facility, addition of organic matter including peat, sheep manure, and creation of on site woody debris barriers to encourage seed and organic matter entrapment.

We did a lot of preliminary chemical analyses of the tailings from many sites, as well as, recording which plant species had invaded and established on about 20 Yukon tailing sites. A small number of plant species had been able to invade many of the sites, though, on a site such as Wellgreen, the natural re-vegetation was very limited. We recorded the progress of our experimental plots from 2003 – 2006 and this was reported annually to MERG. Alison Clark's thesis (2006) was also provided to MERG.

The 2009 Re-Visit and Update

<u>What Was Done</u>

The three experimental Yukon mine tailings sites were all visited during the last two weeks of July 2009. These are Mount Skukum, United Keno Hill, and Wellgreen. In addition, as suggested in the proposal, we went to Whitehorse Copper to see how natural re-vegetation was occurring and to look at the re-vegetation plots set up by others in the same time frame that Alison Clark set up her experiments.

Much earlier 1986-1989, I had also carried out experiments at Whitehorse Copper, as well as, at Venus, Arctic Gold and Silver, Cyprus Anvil at Faro, United Keno Hill, and Wellgreen in the 1980's, with Alan Kuja, now of MOEE Ont., as part of the ALUR program of the Department of Indian and Northern Affairs (reports are available, Hutchinson and Kuja 1989).

In 2009, we were able to locate all the plots, despite a lot of them having been frost-heaved or wildlife ravaged. At the Wellgreen site some plot markers had floated away in floods on the tailings. Detailed photographs were taken at all sites, some of which are included in this report, Plates 1-15. We also recorded all species present in all plots, as well as the vegetative and flowering success of all our experiments. In addition, in the compost addition plots we recorded what species had established, survived and produced viable seeds over the 6-7 year interval since we began studies. The addition of compost provided not only much needed organic matter and some nutrients, but this Whitehorse municipal compost also contained viable seeds, which germinated in 2003 – 2006. These compost-borne seeds were mainly of weedy species. In addition, a large number of species from the vegetation surrounding the tailing sites had germinated and established in our plots, notably in the compost addition plots. Finally, we paid particular attention to the fate of the seeding and planting experiments of the metal-tolerant tufted hair grass *Deschampsia cespitosa* set out 2003 – 2006. We had used transplants of *D. cespitosa* within and between sites in the Yukon, as well as collecting mature seed in 2003 – 2005 at Yukon sites and sowing this in plots with various amendments.

We collected tailings in 2009 from the sites for chemical analyses, pH, nutrient status, heavy metal and elemental content to determine the 2009 status of our sites. We also collected foliage of several species, which were growing well at some sites to determine the metal content of their foliage. This was done as an addition to our proposal and specifically in response to conversations with Yukon government personnel. They have concerns with toxicity and potential food chain effects if the vegetation on abandoned toxic mine sites were to take up metals to potentially toxic levels for grazing animals (deer, moose, rodents) and/ or pass these up the food chain to humans or predators. For example, a) toxic metal concentrations passed to moose, elk, or rabbits and they are then eaten by hunters, b) berries collected for human consumption and c) to predators such as fox, wolf, and lynx, which might suffer from food chain bio magnification.

2009 Findings

<u>Contamination on Tailings</u>

Examples of the varying success of the re-vegetation experiments are shown in the photographs from the 3 sites. (Plates 1 to 15) The results of the various treatments were very apparent. Mount Skukum and United Keno Hill tailings have allowed good vegetation establishment and persistence over the 4-6 year trial. This is in sharp contrast to the Wellgreen site where most of the vegetation plots have failed. This failure includes that of both seeding and planting even after first liming the tailings to pH 5.5 – 6.0. Wellgreen is a highly acidic site, with a very significant heavy metal and sulphide challenge (Table 1 and Figure 1). This adverse chemical environment was made worse by episodes of flooding of the site during spring run-off, and by severe summer drought conditions. None of our other sites have had this degree of flooding. The lime treatments at Wellgreen were overwhelmed by flooding by very acidic water washing the lime out, and by the high acid generation potential of tailings on the site. The site gives off a harp acid sulphur smell. Nevertheless, even on this site, we did have some success, especially with metal tolerant populations of the tufted hair grass *Deschampsia cespitosa* and with additions of Whitehorse City compost.

The obvious beneficial effect of compost is shown in Plates 3,5,9,11,14 and 15. Plates 3 and 9 illustrate the experiments using tufted hair grass as seed planted source in 2004. In contrast, when 7:7:7 fertilizer by itself was used as a treatment, it had either no positive effect or a negative one, Plates 3 and 9. This negative response to a mixed fertilizer occurred despite the fact all sites are severely deficient in nitrogen, but also, to a lesser extent, phosphorus and potassium.

For reference, the chemical analyses of the tailings are shown in Table 1. The pH of the tailings between sites differed considerably, which was one of the initial reasons for choosing them. Thus, Wellgreen tailings were around pH 4.1, while we recorded pHs as low as 2.7 when Alison Clark set up the 2003 experiments. Mount Skukum was around pH 7.1, United Keno pH 6.2 - 7.1, and Whitehorse Copper pH 7.8. At the time of A. Kuja's thesis in 1980's, Whitehorse Copper tailings were recorded at pH 9.1 (Hutchinson and Kuja, 1989. ALUR Report).

The organic content of the tailings was very low (Table 1). Mount Skukum was 16% carbon, United Keno 1.0 %, Wellgreen 4.1% (3.2% in A. Clark's thesis), and Whitehorse Copper 0.13%. This latter is basically fine sand with no organic matter.

Phosphorous was uniformly very low, at concentrations at which deficiencies would likely occur. It ranges from 2.7 ppm available phosphorous at Wellgreen to 6.7 ppm at United Keno.

Calcium and magnesium levels ranged from adequate to high for plant growth at the sites. Table 2 shows the water extractable concentrations of nutrients and metal for the sites, with the relative nutritional status for agricultural crops, noted on the table. This varied being from very low (VL) to very high (VH). Potassium, in contrast, in water extractable concentrations is low at all 3 experimental sites.

The water extractable concentrations (Table 3) of aluminum are all very high, ranging from 364 ppm at Wellgreen to 80 ppm at United Keno. All these concentrations are likely to cause aluminum toxicity and associated phosphorous deficiency to most plants. Figure 1 and Table 2 show the total (nitric acid digest) elemental concentration for the tailings collected at the various sites in July 2009, together with analyses from the Kluane

Lake uncontaminated site at Destruction Bay, where natural populations of the grass *D. cespitosa* occur. Aluminum was very high at all sites as it is in most soils. United Keno Hill tailings were exceptionally high for cadmium, ie 80 ppm, and also very high for lead, 10,016 ppm and zinc 3193 ppm. Copper was also elevated reaching concentrations that could cause phytotoxicity, but elevated lead zinc and cadmium are of greater concern for re-vegetation of United Keno Hill site. Mount Skukum was generally without high concentrations of heavy metals, though copper was at 205 ppm. Wellgreen was especially high in total nickel (1277 ppm), in total copper (768 ppm and was also elevated in arsenic, chromium, cobalt, and to a small extent cadmium. At the low pH of Wellgreen, nickel and copper can be expected to be the major phytotoxic factors.

At Whitehorse Copper, only copper was severely elevated, with 1910 ppm in the tailing samples collected. At the "reference site" of Destruction Bay, all elements were at low concentration, except for copper that occurred at 81 ppm, which is rather high for natural soil.

<u>Vegetative Metal Uptake on Tailings</u>

Because of concerns expressed to us at the Yukon Government Assessment and Abandoned Mines Unit, we analyzed vegetation growing on some of the sites to determine whether they were taking up the metals from the soil, and whether these metals might appear in the foliage in significant quantities which may pose a threat to animals grazing on them and so on up the food chain. Similarly, concerns were also raised regarding berry picking on re-vegetated sites; see Figure 2 and Table 3.

Plants growing on the United Keno site did show high levels of certain elements in their foliage. Notably, we collected naturally invading willow (Salix), trembling aspen (*Populus tremuloides*), buffalo berry (*Shepherdia canadensis*), and sweet clover (*Melilotus,* both white and yellow flowered), see Plates 8 and 15. Lead levels reached 320ppm in Shepherdia (buffalo berry) foliage at United Keno, zinc was 179ppm, while cadmium was 4ppm. Balsam poplar had foliage containing 39ppm cadmium, 42ppm lead, and 887ppm zinc. Trembling aspen foliage at the United Keno site contained very high concentrations of cadmium (49ppm), lead (96ppm) and zinc (1235ppm). Willow shrubs at the site had foliage levels of 32ppm cadmium, 68ppm lead, and 808ppm Zn. Thus, the concern regarding foliar accumulation of toxic metals at the United Keno site is a very real one. These are very high levels for foliage.

The use of non-Yukon species in re-vegetation work in the Yukon seems to be viewed unfavourably. This is rather unfortunate in that some of the very best success we have had is with sweet clover, *Melilotus alba,* which we believe came into our plots the from Whitehorse compost additions, and has survived and reproduced for 6-7 years (see plate 15). This species is also a big success on the Whitehorse Copper site, where its foliar concentrations of copper (16ppm) and zinc (37ppm) were within acceptable limits even though the site had high copper and zinc concentrations in the soil (1910ppm and 100ppm respectively) (Table 3). It appears that this species does not accumulate metal at this site. We had insufficient material from United Keno of sweet clover to determine whether it accumulated high levels there. Sweet clover is doing exceptionally well in plots at both Whitehorse Copper and United Keno, seems less of a ‘risk’ from foliar accumulation. It is now widely distributed in the Yukon as an alien invader, especially along the ditches and roadsides of major highways.

The foliar uptake studies are preliminary and opportunistic, but they clearly require a much more detailed follow up. It would be ironic if a plant species of good prospect for re-vegetation should turn out to be a risk to herbivores grazing on them on tailing sites. Buffalo berry seeded onto United Keno tailing following seed low temperature stratification to enhance its germination as done by Alison Clark, did very well over the next 5 years (see Plates 12 and 13), but seems to contain high lead levels in its foliage.

Survival and Invasion of Plant Species into the Experimental Plots at the Tailings Locations

The first experiments examined were those in plants small clones of several different *Deschampsia cespitosa* populations, which were grown from seed at Trent University or taken from the Yukon in 2003 and planted in June onto Wellgreen, United Keno, and Mount Skukum tailings. The tailings were amended immediately before transplanting with either a 10 cm depth of City of Whitehorse compost, a 7:7:7 pellet slow release fertilizer at a rate of 300 kg/hectare or, in the case of Wellgreen, a lime treatment with commercial dolomite lime to raise the pH to 5.5. A further treatment with compost plus fertilizer was used. In all cases transplants were also done without any amendments (unamended). The transplant material was collected from each of the 3 mine sites and from 3 uncontaminated sites at Kluane Lake, Minto Lake and Annie Lake Road. In addition to the Yukon plant populations, 3 additional clonal populations were raised from seed in the winter of 2002-2003 at Trent University and taken to the Yukon for transplanting in this experiment. They were grown from seeds collected at 2 Sudbury-area metal and acid contaminated sites, ie O’Donnel Roast Bed and Coniston smelter, and from an uncontaminated site referred to as Taylors, and in fact obtained from Germany. 4 clones of each of the Yukon and other populations were planted on each treatment and site

Over the years since 2003 various events, some catastrophic, have occurred to some of these transplants, notably floods and droughts at Wellgreen, animal grazing, digging and trampling notably by moose. The entire transplant experiment at Wellgreen has failed, with the lime washed out by flooding and with drought a major factor in plant deaths.

At Mount Skukum and United Keno much better and very informative results were obtained. Summary data are shown in Table 4. Note that on the compost plots at Mount Skukum not did the on-site Mount Skukum clones do well over the 6 years since planting, but also the local Annie Lake Road population did well too, suggesting a valuable pre-adaption to mine sites, see Plate 10. Compost with or without fertilizer seemed to help the Annie Lake road transplants, whereas without compost the population did not fare well. The on-site Mount Skukum population shows good adaption to this site, Table 4.

At United Keno the plants were scored on a performance scale from 0 (dead) to 5 (large, healthy and flowering). This is described in detail in Alison Clark's M.Sc. thesis and in our reports to MERG 2004-2006. The best survivorship and performance was in the compost and the compost plus fertilizer treatments, though the results were very dependent on the origin of the transplant (which was the point of doing this experiment). The 2 Sudbury area populations, together with the Taylors control and the Kluane Lake control all died or had died in all but one treatment. One control population did well, ie that from Minto Lake, which in trials at Trent University had shown strong intrinsic metal tolerance, where as the Kluane Lake population had not. The Roast Bed and Coniston transplants of *D. cespitosa* are known to be multiple metal tolerant especially to nickel and copper, and also very acid tolerant (Cox and Hutchinson 1979, 1981). The best performers on the United Keno tailings were from transplants originating from Mount Skukum, from the nearby Annie Lake Road and from United Keno itself. Unfortunately, as all transplants from United Keno in the unamended and in the fertilizer treatment were missing. Performance was reasonable to good on unamended tailings for 3 of the transplanted populations (Table 4a) with 5 out the original 8 populations still alive on these toxic tailings, with no amendments. Plants growing on compost and fertilizer achieved even better performance, with compost and fertilizer giving very good survival and performance for transplants from United Keno, Mount Skukum, and Annie Lake Road population. Fertilizer alone was generally an adverse treatment except for the Mount Skukum and especially the Annie Lake Road transplants.

This experiment shows much promise for long-term survival ie 7 seasons to date. It is also potentially very useful that Yukon *D. cespitosa* has locally adapted metal tolerant and tailings pre-adapted populations, which could be a seed resource for mine tailing re-vegetation. More details were possible with the transplants at Mt Skukum (Table 4b). All transplants in the fertilizer treatment had died and on the compost plus fertilizer treatments all transplants also died except the locals ones, from Mount Skukum itself (its origin near the mine) and from Annie Lake Road where populations grow along the roadside on the way to the mine. This population was doing especially well, with lots of flowering of the clones (Plate 10).

The best results at Mount Skukum were on the unamended tailings where 5 of the 8 populations were still alive after 7 seasons. The transplants *in situ* on the site of Mount Skukum *D. cespitosa*, which is naturally colonizing the site and flowering and spreading, are encouraging. Addition of compost seems to have helped the Annie Lake Road population, while that of Mount Skukum did as well with compost as with no amendments. Since this population has invaded the tailings just as they are, it looks as if a homegrown adapted population has evolved on this site, likely derived from the natural Yukon population of *D. cespitosa* growing along Annie Lake Road. Two commercial seed companies, ie Pickseed and Arctic Alpine Reclamation Group offer seed of *Deschampsia cespitosa* for sale for reclamation work. However, their seed has not been collected with metal contaminated sites in mind. We tested Pickseed in 2010 and it was non-tolerant. It would be easy to have *D. cesptiosa* population available that had metal and acid tolerances.

One other population did well on Mount Skukum unamended tailings, ie that from the United Keno site, where another Yukon population has evolved local tailing tolerance.

Table 5 and 6 show the occurrence and number of individuals present in July 2009 in 10 plots for the 3 treatments of unamended, compost only and fertilizer only of plant species which have either invaded the plots since August 2003 or entered as seed in the compost. Each plot was $1m^2$. Compost was applied to a depth of 5 cm, and fertilizer (7:7:7) at a rate of 350 kg/hectare. When the initial recording of the experiment was done in August 2004, no seedlings of *D. cespitosa* that has been seeded into the plots were visible. At Wellgreen, only in the compost amendment plots had *D. cespitosa* seedings survived that first year. In contrast, survival at the United Keno site was very good, both on the unamended plots and in the compost. We can now move forward 5 years to see what has happened to the *D. cespitosa* and also to see if other species have come in and survived and reproduced. These data are shown in Table 5 for United Keno and Table 6 for Mount Skukum.

12 plant species now occurring in the plots at United Keno. *Deschampsia cespitosa* continues to survive, grow and flower on the unamended tailings and even better, in terms of lowering, on the compost (Table 5). But other weedy species have arrived in the plots, notable fireweed (*Epilobium angustifolium),* fleabane (*Erigeron acris*), the salt tolerant grass Puccinellia and most excitingly, the nitrogen fixing legume alpine milk vetch (*Astragalus alpinus*) (Plates 11 and 14). The fireweed was present in large numbers in both unamended (95) and compost only plots (129), but none were present in the fertilizer plots. The fleabane was present in all 3 treatments, but much the greatest number occurred in the compost treatment, where a very large number of flowering heads occurred (Plate 11 and 14). The fireweed was less successful in flowering, but was present as small seedlings, with a few large enough to flower in 2009. In our experience with the Whitehorse City compost, plant species such as *Chenopodium alba*, *Hordeum jubatum*, *Crepis* spp., *Achillea milefolelium*, and grasses such as Agrostis, all occur as seeds. These germinate in the first year of application and these species provide biomass and organic matter to the plots (Table 5). In the United Keno treatment, several other species have invaded from sources around the site, as demonstrated in the unamended and fertilizer plots. Fireweed has come in as it always does, as has the milk vetch, and fleabane. Simply adding compost has acted as a recruitment centre for many species, creating a self-sustaining biomass over the 6-year period of the experiment. The tufted hair grass has maintained itself, despites the new species arrivals.

The unamended plots also allow recruitment but a good deal less has occurred then when adding compost (Table 5). The comparison is of 5 species in the unamended tailing plots with 125 individuals, versus 11 species in the compost with 583 individuals. The flowering success of these species is even more in favour of the compost ie 304 flowering heads in compost versus 18 in unamended.

Table 6 sites out the data for the Mount Skukum pots. The pattern of survivorship, flowering success and species biodiversity is similar to that found at United Keno; though the particular species at the sites different quite markedly. There were no legumes invading or colonizing at Mount Skukum. The tufted hair grass, which I had reported dead or absent in 2006 from the 2003 seedings, was present and doing very well in 2009. It was doing best in the unamended plots, which is a strong indicator that the locally evolved tailings population, has seeded in to the plots with 188 flowering heads, in the unamended compared with 48 in the compost plots.

Other species that have done well as invaders are roadside barley (*Hordeum jubatum*), the bluegrass (*Poa palustris*), and dock (*Rumex crispus*). Other perennials have taken hold, including fireweed and bearberry. 11 species are now present in the compost plots, 8 in the unamended and 3 only in the fertilizer plots. A combined total of 666 flowering heads of these species occurred in the compost plots, 537 on the unamended and only 15 on the fertilizer plots. The results are very clear.

The equivalent experiment done at Wellgreen was a total failure, though it never had a real chance as floods washed away the compost, fertilizer, lime and indeed pretty much all trace of our 2003 experiments. Our earlier reports had already indicated this (MERG 2004-2006 Clark and Hutchinson)

Other Observations of Native Plant Recruitment to our Experiments

At Mount Skukum we also recorded what species have invaded the 2003 plots set up as *D. cespitosa* transplant experiments (reported in Table 4). This is to note what has happened in addition to the transplants survival. In the unamended plots 6 species have invaded and survived as of July 2009. They have created a plant cover of 12-20% of the surface area of the plots. The dominant cover species are *D. cespitosa, Poa palustris*, and *Hordeum jubatum* (Table 7).

In the compost-amended plots the surface vegetation cover is now 60-70%, with 12 different plant species present. Almost all of these have seeded in from the surrounding area, rather than surviving from the initial compost source. While the annual Chenopodium originating in the compost is still present, and seeding itself back into the plots each year, an additional vigorous multiple species flora is now in place, including a number of perennial species (Table 7), such as yarrow, fireweed, arctic willow, bent grass, and lyme grass. The Mount Skukum site is a difficult one because of the surface evaporation leading to a surface saltpan in places. Species such as dock and lyme grass are adapted to this salinity.

In 2006 we added Whitehorse compost as a solo amendment to all 3 sites, to see if this also would invite recruitment of plants species and lead to a single one-time-only management approach. We recorded what species came into the sites in the period from August 2006, as recorded in July 2009. This represents y ears of invasion, stress and survivorship. The overall plant species that have invaded are listed in Tables 8 and 9 for United Keno and for Wellgreen where a very small amount of species had occurred. Plate 15 shows some of these 2006 plots. It should be noted that compost was added to a depth of approximately 10 cm and no seeding or plantings of any kind was done.

19 species are now present in the compost plots at United Keno with white sweet clover dominant in many plots (see Plate 15). Other species which have had done well include tufted hair grass, fireweed, roadside barley, cinquefoil, yarrow, tall dock and willow. Many of the plots had 75% - 90% vegetative cover. Many of the plants were flowering. The location where we added compost in 2006 was devoid of vegetation, but was not the absolute worst exposed part of the site. It has been strikingly successful (Table 8).

The fact some of the plant species, such as popular and willow, which have invaded this site and have taken up significant amounts of lead, zinc and cadmium into their foliage, was referred to earlier, see Table 3. Sweet clover was rather better than the other species we sampled in that it had lower foliage concentrations. The compost technique works for re-vegetating the United Keno site, as it doe at Mount Skukum too. It is a potential complication that some of the best reclamation species may present, through foliar uptake from tailings, a food chain toxicity threat.

Table 9 shows the invasions into the 2006 compost plots at Wellgreen. It was hardly a profuse re-vegetation. Many plants were present as very tiny seedlings that required one to crawl on hands and knees to see them. The plot closest to the present tailings pond had the largest plants. The invaders included a noticeable sub-set of species known for their extreme acid tolerances (eg. *Rumex acetosella, Agrostis scabra, Rumex arcticus,* and in the case of the moss *Pohlia nutans*, it is known as a species which invades acidic and metal contaminated sites, such as Sudbury, Ontario, Prescott Canes UK, and Smoking Hill N.W.T. The Juniper moss *Polytrichum juniperinum* is also frequent in acid sites, 12 species are present. Cover is generally less then 1%. Only *D. cespitosa* was flowering of these species, and then only a few individuals in the wetter plots. Compost at much higher rates of application may have success at Wellgreen. The security person on site some years ago added human sewage to the tailings in a wettish area and had a good success in re-vegetation for some years, before the flooding eliminated the experiment.

Whitehorse Copper Tailing

We visited Whitehorse Copper tailings site in late July on a very hot sunny day, which emphasized the inhospitable nature of the fine sand-like tailings. It resembled a reflective desert. Alison Clark and I had not set up experiments at this site but I was familiar with experimental plots set up in the past decade by others. The plots with vegetation in them were clearly visible. The raised berm around the into the tailings is well vegetated and has a much high clay and watering holding capacity than the tailings, which are alkaline see Table 1 and 2 for chemistry of the tailings).

In the quadrats (treatment unknown to us) of tall plants of white and yellow sweet cover (*Melilotus*) were flowering vigorously. They are very well established and successful. Also invading these plots is yarrow (*Achillea millefolium*), dandelion (*Taraxacum officinale*). Also, lots of sweet clover and purple alfalfa were flowering. These species provide a lot nitrogen fixation in the plots. We believe there the plots may have been experimentally sown with sweet clover; however, it may have come in spontaneously as it did at United Keno into our compost plots. It is a vigorous colonizer of disturbed areas.

The legumes and especially the sweet clover hold much promise for re-vegetation of sites that are not especially acidic. The genus is not native to the Yukon and our data on metal uptake into the foliage suggested that it maybe potentially for grazing animals.

Bees were very active on the sweet clover flowers and we noted moose prints all over the site, as well as, lots of rabbit activity.

Species which seemed to be naturally invading the site included couch grass (*Agropyron repens*), roadside barley, timothy grass and shrubby willows (*Salix spp*.), and in shaded areas where the tress trembling aspen (*Populus tremuloides)* and balsam popular (*Populus balsamifera)* were growing, the moss *Pohlia nutans* was again present in large amounts, as it had been at United Keno. *Pohlia nutans* is reported elsewhere as a copper and nickel tolerant species. Whitehorse Copper tailings have large copper levels.

Trees were growing well at one area of the tailings, perhaps rooted in soil beneath the tailings but in one plantation there were evenly spaced rows. The trees were 8-10m high. We took foliar samples for chemical analysis, and which confirmed that some plants growing on Yukon tailings do take up into their foliage quite elevated concentrations of heavy metals and metalloids (Table 3).

While the sweet clovers were doing well in the tree plots, they did not seem to have spread much outside the plots. Also, the number of invasive species that had appeared in the plots was very few ie dandelion, yarrow and fireweed. There is much less in terms of species biodiversity then we found with our plots at Mt. Skukum and United Keno.

Finally, I noted that dead leaves from previous years were accumulating beneath the poplar trees and on the ground of the sweet clover plots. This strongly suggests that litter decomposition is greatly reduced on the Whitehorse Copper tailings. Whether this due to lack of decomposer microbes or to dry hot conditions inhibiting litter breakdown, or whether due to copper poisoning of the microbial flora is not known. One area had a white ‘saline’ evaporative surface on the top of very clayey tailings. Elsewhere, blue tailings underlay the surface. Nothing grew in these areas.

Plate 1: Overview of Mount Skukum tailings, taken from the berm. Much of the vegetation on the site has invaded naturally, notably around the edge of the ponds and the wetter areas. July 2009.

Plate 2: Mount Skukum tailing area. Note lack of vegetation in the drier area. The plants in the mid-distance are sedges and grasses of the *Puccinellea* and *Deschampsia cespitosa*. July 2009

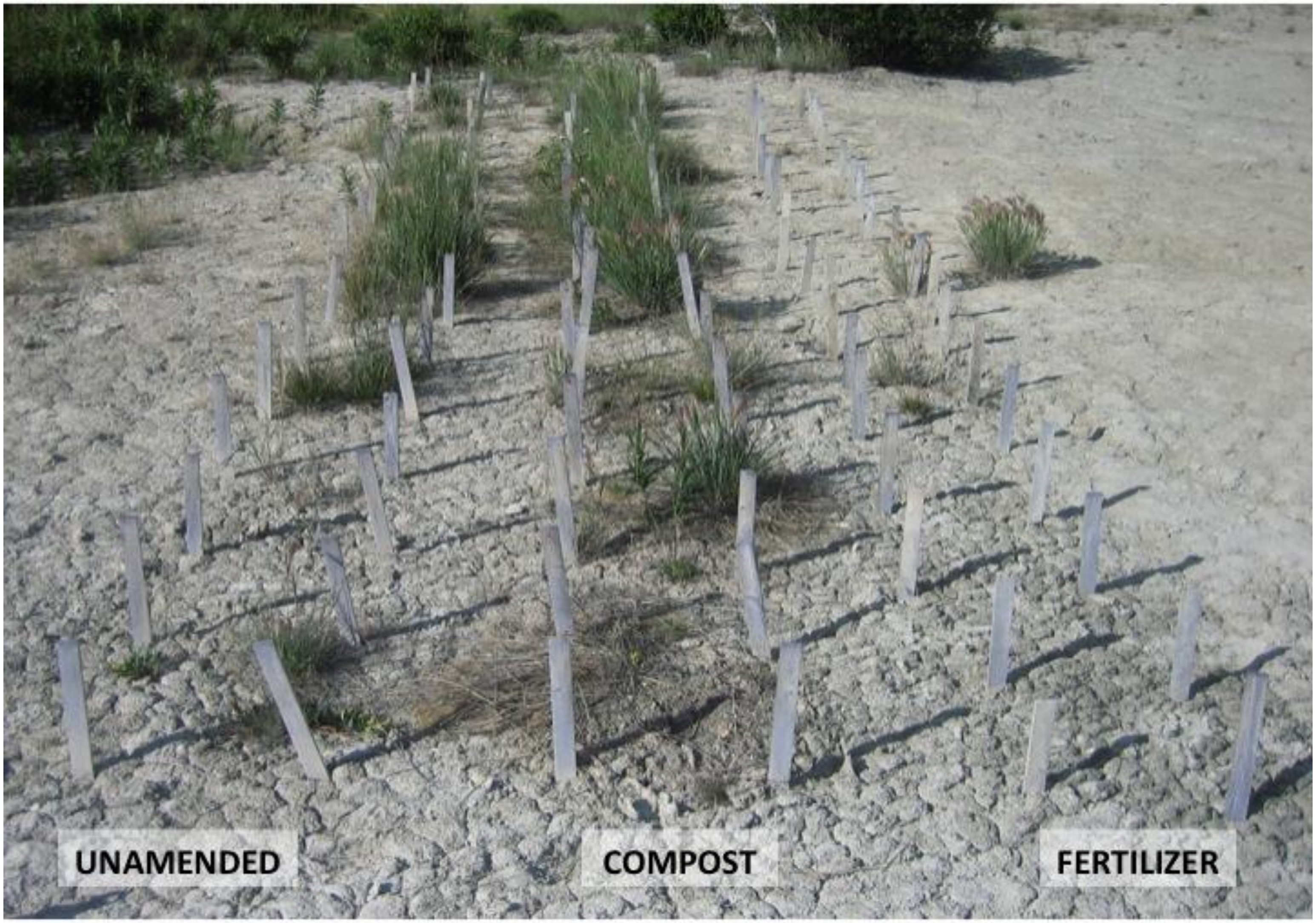

Plate 3: View of 3 rows of experiments. Left row is unamended, middle row is with compost from Whitehorse and the right one, with many frost heaved stakes, is 7: 7:7 fertilizer, all set up in 2003, photographed July 2009. Most of the grasses are tufted hair grass (*Deschampsia cespitosa*), transplanted to the site in 2003, with invaders of yarrow, roadside barley, fireweed, and ragweed also visible. Best results from compost additions, followed by no treatment. The fertilizer treatment yielded the worst results.

Plate 4: A compost plot at Mount Skukum from 2003 with Annie Lake Road transplants of tufted hair grass. The clones have established, are flowering and seeding. July 2009.

Plate 5: A compost plot at Mount Skukum with established ‘invasion’ of fireweed, roadside barley and other grasses. July 2009.

Plate 6: Compost plot from 2003 at Mount Skukum showing vigorous establishment of roadside barley and many small pale clones of tufted hair grass.

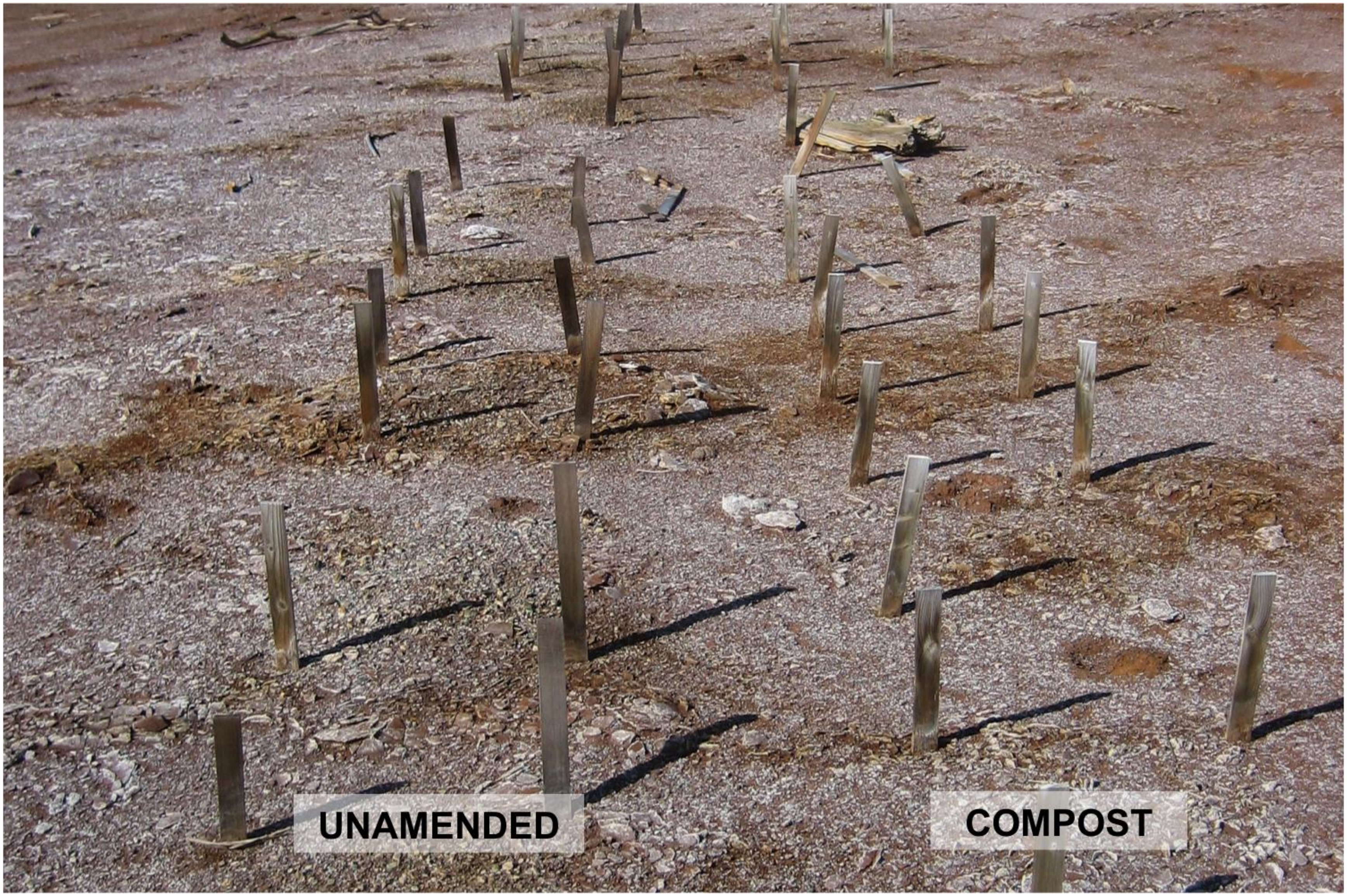

Plate 7: Wellgreen transplant experiments set up in 2003, showing the compost and unamended plots. The fertilizer and lime plots were washed away. No plants have survived or invaded in July 2009 photograph.

Plate 8: United Keno Mine site tailing, July 2009. Natural re-vegetation by willow, horsetail and the moss *Pohlia nutans*. Note nearly all the vegetation, especially the horsetail, is very chlorotic (yellow), indicating metal toxicity.

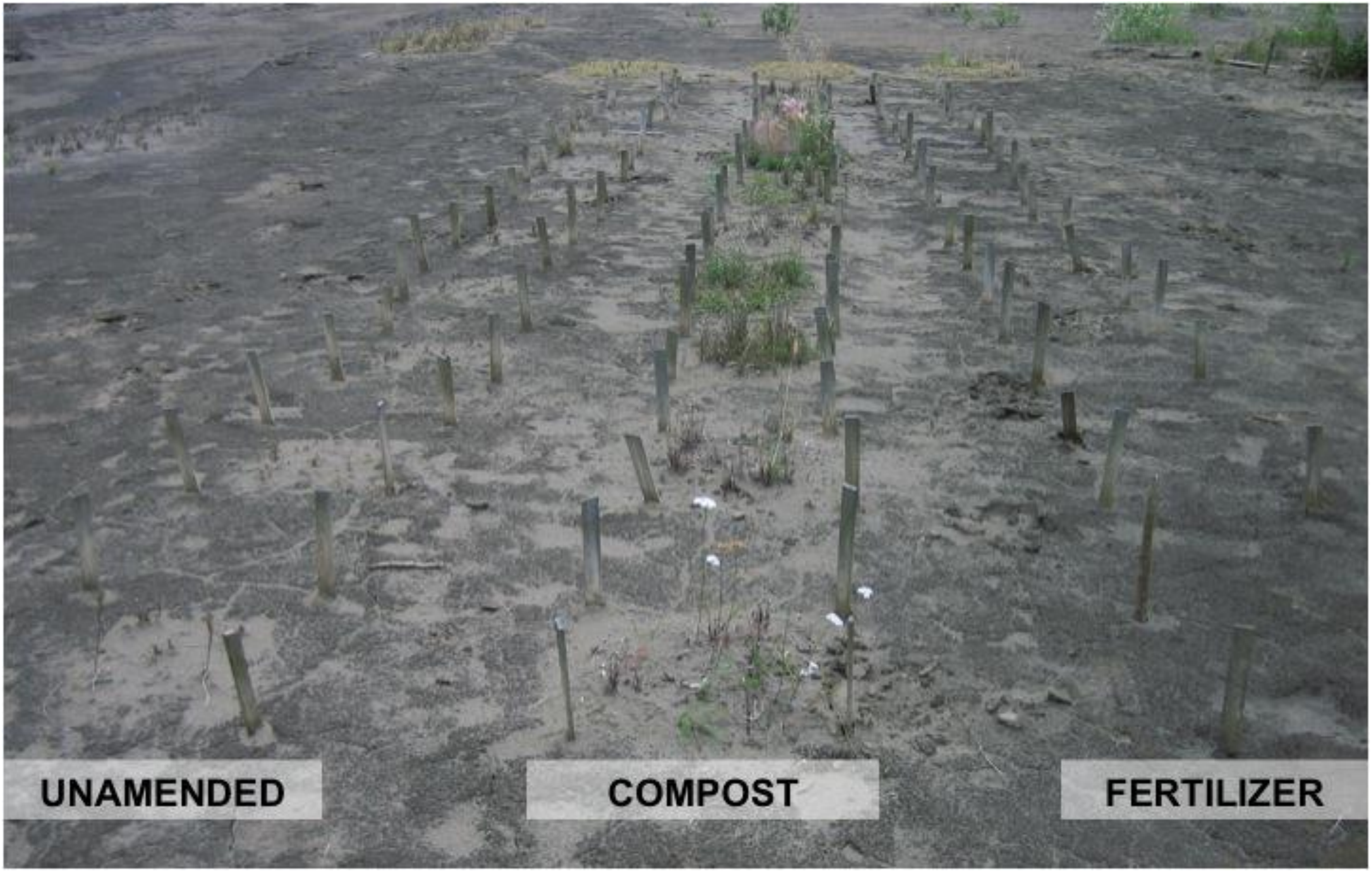

Plate 9: United Keno mine tailing experiment in foreground. Set up 2003, photographed July 2009. Left to right rows are treatments a) unamended b) compost c) fertilizer 7:7:7. Some *Deschampsia cespitosa* is surviving in the unamended and in the compost plots, but very few in the fertilizer. In addition, a great variety of local invaders have come in to the compost plots. 3 plots in mid range are *Deschampsia cespitosa* seedling plots, and the compost plots of 2006 in the background show vigorous invasions by sweet clover and Sheperdia.

Plate 11: United Keno compost plot set up 2003, with very successful invasions of many species, including cinquefoil, roadside barley, fleabane, Poa grass and notably the legume alpine milk (*Astragalus alpine*), a nitrogen fixer.

Plate 12: 4 compost plots seeded with stratified seeds of Sheperdia in 2006. Extremely successful establishment and with other species present, including the moss *Pohlia nutans*. On the left is a 2006 compost plot with sweet clover as a dominant invader

Plate 13: Compost plot at United Keno, set up 2003 with transplants of tufted hair grass (left). The plot is dominated by invading Sheperdia. July 2009

Plate 14: Close up of one compost plots at United Keno set up in 2005, with multiple species invasions. See plate 12 for species

Plate 15: Compost plot at United Keno, set up 2006, photographed July 2009, with sweet clover, tufted hair grass and the grass *Pohlia nutans*

Table 1: pH, cation exchange capacity, organic matter, and available nutrients in tailing soil

Site	pH	Cation Exchange Capacity	Organic Matter	Phosphorus (ppm)	Potassium (ppm)
United Keno	7.50 ± 0.00	7.57 ± 0.32	0.97 ± 0.07	5.33 ± 0.33 VL	15.67 ± 0.82 VL
Whitehorse Cooper	7.80 ± 0.12	24.13 ± 0.32	0.13 ± 0.03	4.33 ± 0.33 VL	67.33 ± 1.33 L
Wellgreen	4.10 ± 0.06	23.77 ± 0.18	4.60 ± 0.10	2.67 ± 0.67 VL	50.00 ± 1.00 L
Site	Magnesium (ppm)	Calcium (ppm)	Sodium (ppm)	Aluminum (ppm)	
United Keno	175.00 ± 10.40 H	1200.00 ± 50.33 H	6.67 ± 0.33 L	79.67 ± 0.88	
Whitehorse Copper	476.67 ± 6.67 H	3990.00 ± 61.10 H	5.00 ± 0.00 L	107.67 ± 2.96	
Wellgreen	141.67 ± 4.41 VL	956.67 ± 53.83 VL	16.00 ± 0.00 L	363.67 ± 6.57	

Table 2: Total metals and metalloids in tailing soil in 2009 (ug/g D.wt). Italics represent data collected by Clark 2007.

Site	Aluminum	Arsenic	Cadmium	Chromium	Cobalt	Copper
United Keno	1417 ± 57	75 ± 3	80 ± 2	12 ± 0	5 ± 0	243 ± 5
Whitehorse Copper	8140 ± 59	12 ± 0	1 ± 0	17 ± 0	32 ± 0	1910 ± 10
Wellgreen	8170 ± 335	183 ± 2	4 ± 0	158 ± 5	52 ± 1	748 ± 7
Destruction Bay	13667 ± 33	8 ± 0	1 ± 0	49 ± 1	16 ± 0	81 ± 2
Mount Skukum	*76500* ± *2828*	*<50*	*<2*			*205 24*
SSite	Lead	Molybdenum	Nickel	Selenium	Zinc	
United Keno	10017 ± 243	1 ± 0	10 ± 1	1 ± 0	3193 ± 64	
Whitehorse Copper	26 ± 1	20 ± 2	16 ± 0	1 ± 0	100 ± 0	
Wellgreen	36 ± 2	1 ± 0	1227 ± 7	33 ± 2	81 ± 2	
Destruction Bay	16 ± 1	1 ± 0	43 ± 1	1 ± 0	109 ± 2	
Mount Skukum	*<50*		*<20*		*150 21*	

±

Table 3: Total metal concentration (ug/g dry weight) in leave tissue of various species growing on the mine tailings of Whitehorse Copper and United Keno, in 2009.

Site	Species	Aluminum	Arsenic	Cadmium	Chromium	Cobalt	Copper	Lead	Molybdenum	Nickel	Selenium	Zinc
Whitehorse Copper	Trembling Aspen	66.67	<0.5	0.50	2.33	1.00	12.67	<5	5.33	2.67	2.10	60.33
	Balsam Poplar	46.67	<0.5	0.87	3.00	1.00	15.00	8.67	3.00	2.67	1.35	59.33
	Willow	30.00	<0.5	4.55	<1	<1	11.50	<5	4.00	1.50	0.80	74.00
	Sweet Clover	30.00	<0.5	0.50	<1	<1	15.67	<5	8.00	2.33	1.00	37.33
United Keno Hill	Trembling Aspen	30.00	11.95	48.90	<1	<1	7.50	95.50	<1	1.50	<0.5	1235.0
	Balsam Poplar	16.67	3.43	38.93	1.33	<1	4.00	42.00	<1	1.33	0.53	887.33
	Buffalo Berry	50.00	25.30	4.15	1.50	<1	13.50	320.5	<1	2.00	<0.5	179.00
	Willow	30.00	6.40	32.20	< 1	< 1	7.00	68.00	<1	< 1	0.90	808.00

Table 4: Performance of transplants of the tufted hair grass, *Deschampisa cespitosa* grown on Yukon mine tailings with various amendments. **(A)** United Keno Hill Mine and **(B)** Mount Skukum. Planted as clones in 2003 and recorded in July 2009

(A) At United Keno	Amendment			
Origin of Transplants	**Unamended**	**Compost**	**Fertilizer**	**Fertilizer and Compost**
Taylors (German Source)	1.5	0.0	0.0	0.0
Sudbury Roast Bed	0.0	1.5	0.0	0.0
Coniston (Sudbury Area)	0.0	0.0	0.0	0.0
United Keno Mine	-	1.5	-	3.0
Mount Skukum	2.6	1.8	2.0	4.0
Alnnie Lake Road	1.8	3.0	4.0	4.0
Minto Lake	2.7	4.0	1.0	2.0
Kluane Lake	1.0	0.0	0.0	0.0

(B) At Mount Skukum	Amendment							
Origin of Transplants	**Unamended**		**Compost**		**Fertilizer**		**Fertilizer and Compost**	
	Rating	Flowering	Rating	Flowering	Rating	Flowering	Rating	Flowering
Mount Skukum	12	30	11.5	31	0	0	5	0
Annie Lake Road	3	0	6	11	0	0	12	28
United Keno Mine	10	19	0	0	0	0	0	0
Kluane Lake	0	0	0	0	0	0	0	0
Sudbury Roast Bed	1	0	0	0	0	0	0	0
Coniston (Sudbury Area)	3	4	1	0	0	0	0	0
Wellgreen	0	0	0	0	0	0	0	0

Table 5. United Keno Hill Mine: Occurrence of the various plant species in the *Deschampsia cespitosa* seeded plots at United Keno Hill. Plots established in 2003 and surveyed in July 2009. 10 plots of $1m^2$ were used for each treatment.

	Total survivors in 10 plots			Flowering heads in 10 plots		
Species Present	**Unamended**	**Compost**	**Fertilizer**	**Unamended**	**Compost**	**Fertilizer**
Deschampsia cespitosa	10	11	2	7	19	0
EpilobiumAngustifolium	95	129	0	2	1	0
Erigeron acris	13	78	3	4	263	0
Hordeum jubatum	6	14	0	4	29	10
Crepis tectorum	1	1	0	1	0	0
Astrogalus alpinus	0	210	0	0	0	0
Agrostis spp.	0	0	0	0	0	0
Taraxacum officinale	0	1	0	0	0	0
Salix arctica	0	1	0	0	0	0
Puccinellia spp.	0	22	0	0	0	0
Achillea millefolium	0	8	0	0	5	0
Potentilla norvegica	0	8	0	0	7	0
Number of species	5	11	2	5	6	1
Number of Individuals	125	583	5	18	304	10

Table 6: Mount Skukum: Occurrence of the various plant species in the *Deschampsia cesptiosa* plots at Mount Skukum. Plots established in 2003 and recorded in July 2009. 10 plots of $1m^2$ were used for each treatment.

	Total survivors in 10 plots			Flowering heads in 10 plots		
	Unamended	**Compost**	**Fertilizer**	**Unamended**	**Compost**	**Fertilizer**
Deschampsia cespitosa	36	27	12	128	48	12
Rumex crispus	6	11	0	6	6	0
Hordeum jubatum	16	15	1	40	40	1
Elymus trachycaulus	4	0	0	110	110	0
Salix arctica	1	0	0	0	0	0
Polygonum bistorta	6	1	0	0	0	0
Agrostis scabra	6	2	0	8	0	0
Poa palustris	31	50	2	85	458+	2
Erysimum cheiranthoide	0	1	0	0	0	0
Epilobium angustifolium	0	17	0	0	10	0
achillea millefolium	0	11	0	0	15	0
Taraxacum officinale	0	1	0	0	0	0
Arctostaphyles una-uni	0	1	0	0	0	0
Number of species	8	11	3	6	6	3
Number of Individuals	106	137	15	537	666	15

Note: Wellgreen: Total failure in all 10 plots for each treatment of the seeded *Deschampsia cespitosa* plots irrespective of the treatment ie unamended, limed, compost, fertilizer, and lime and fertilizer

Table 7: Mount Skukum: Survival and performance of plant species following 2 treatments ie compost and/ compost plus fertilizer (6 plots) versus unamended. The plots had *Deschampsia cespitosa* clones transplanted into them. This table records those other plants species now present, which had originated from the surrounding and from the compost.

Compost 6 plots 60-75% plant coverage	**Unamended** 3 plots 12-20% plant coverage	**Common Name**
Chenopodium alba	-	Pigweed
Hordeum jubatum	*Hordeum jubatum*	Roadside Barely
Deschampsia cespitosa	*Deschampsia cespitosa*	Tufted hair
Epilobium angustifolium	-	Fireweed
Achillea millefolium	-	Yarrow
Polygonum buxiforme	-	Bistorta
Agrostis scabra	*Agrostis scabra*	Bent grass
Poa palustris	*Poa palustris*	Poa grass
Descuranea sophia	-	Tansy mustard
Salix arctica	-	Arctic willow
Elmus trachycaulus	*Elmus trachycaulus*	Lye grass
-	*Rumex crispus*	Dock

Table 8: Tailing vegetation in the compost plots at United Keno Hill Mine. Compost added 2008, recorded July 2009.

Latin Name	**Common Name**
Deschampsa cespitosa	Tufted hair grass
Epilobium angustifolium	Fireweed
Hordeum jubatum	Roadside barley
Crepis tectorum	Hawks beard
Potentilla norvegica	Cinquefoil
Poa alpina	Alpine bluegrass
Erigeron acris	Fleabane
Astragalus alpina	Milk vetch
Salix arctica	Dwarf willow
Melilotus alba	Sweet clover
Taraxacum officianle	Dandelion
Agrostis tenuis	Bent grass
Salix - shrub	Shrub willow
Senecio atsopurpuneus	Ragwort
Rubus ideaus	Raspberry
Plantago major	Plantain
Pohlia moss	Pohlia moss
Rumex crispus	Tall Dock
Achillea millifolium	Yarrow

Table 9: Survival on plots at Wellgreen tailings sites. The plots consisted of Whitehorse City compost addition to depth of 5 cm made in 2006. Recorded July 2009. Note: Where no compost had been added there were no invasions.

Species Present		**Number of Plots**
Latin Name	**Common Name**	
Deschampsia cespitosa	Tufted hair grass	13
Rumex achicella	Sheep sorrel	3
Epilobium angustifolium	Fireweed	7
Pohlia nutans *	Nodding pholia moss	5
Hordium jubatum	Roadside barley	1
Polytrichum juniperinum	Juniper moss	1
Chenopodium alba	Fat hen	1
Salix spp.	Willow	3
Populus balsumifera	Balsam poplar	1
Poa protensis	Swamp bluegrass	2
Agrostis scabera	Redtop	9
Rumex arctica	Arctic dock	1

* Known for metal tolerance

Note: Plot #1 was further from water and 13 was almost in the pond. The success of the 'invaders' increased in the wetter sites. *Deschampsia cespitosa* was much the most successful, with some flowering. Very large number of tiny seedlings and success in the hoof prints of moose. The *Epilobium* was preset in good numbers as tiny purple seedlings.

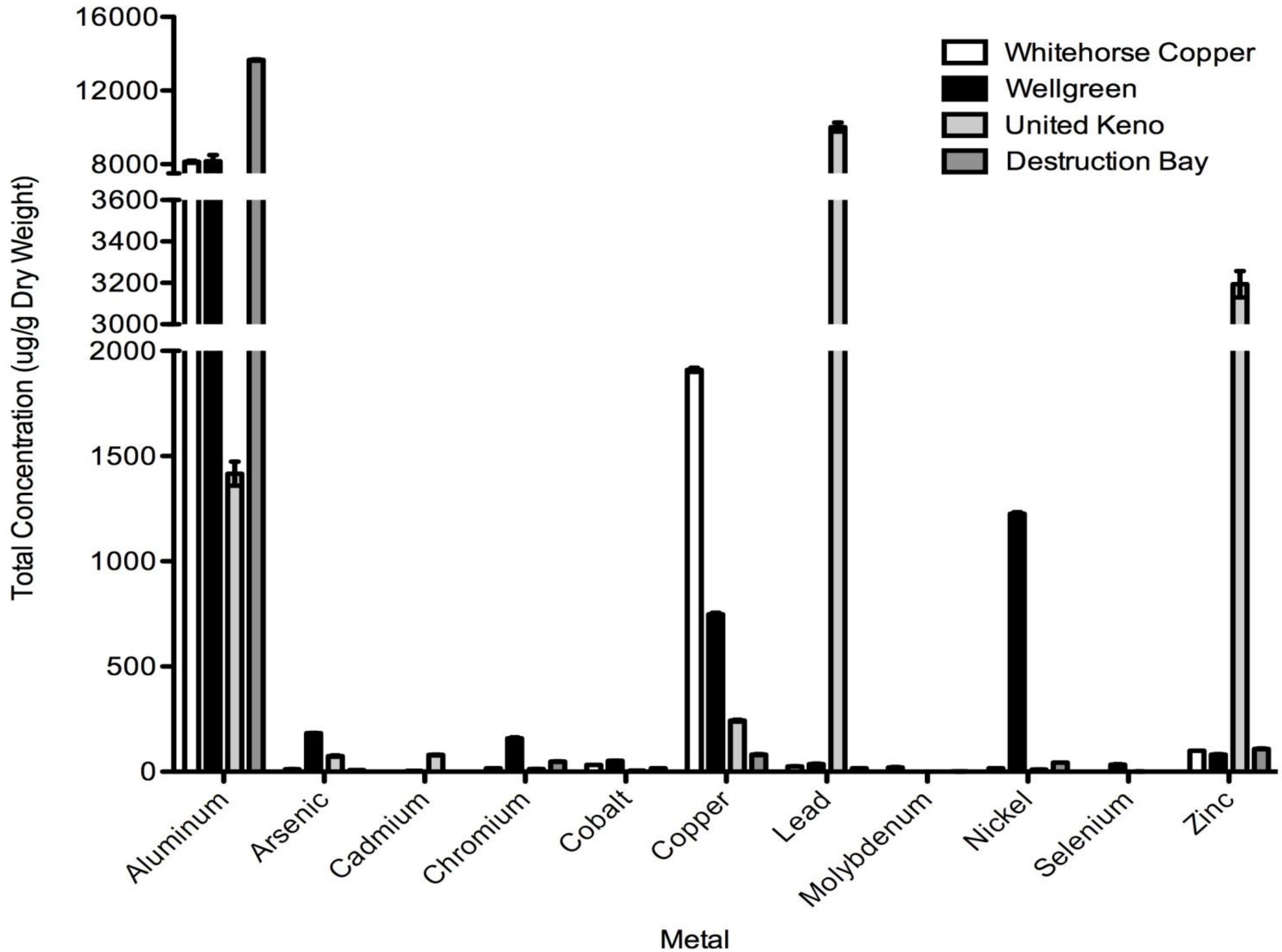

Figure 1: Total metal content of tailing soils from Whitehorse Copper, Wellgreen, and United Keno, and from uncontaminated soil of Destruction Bay.

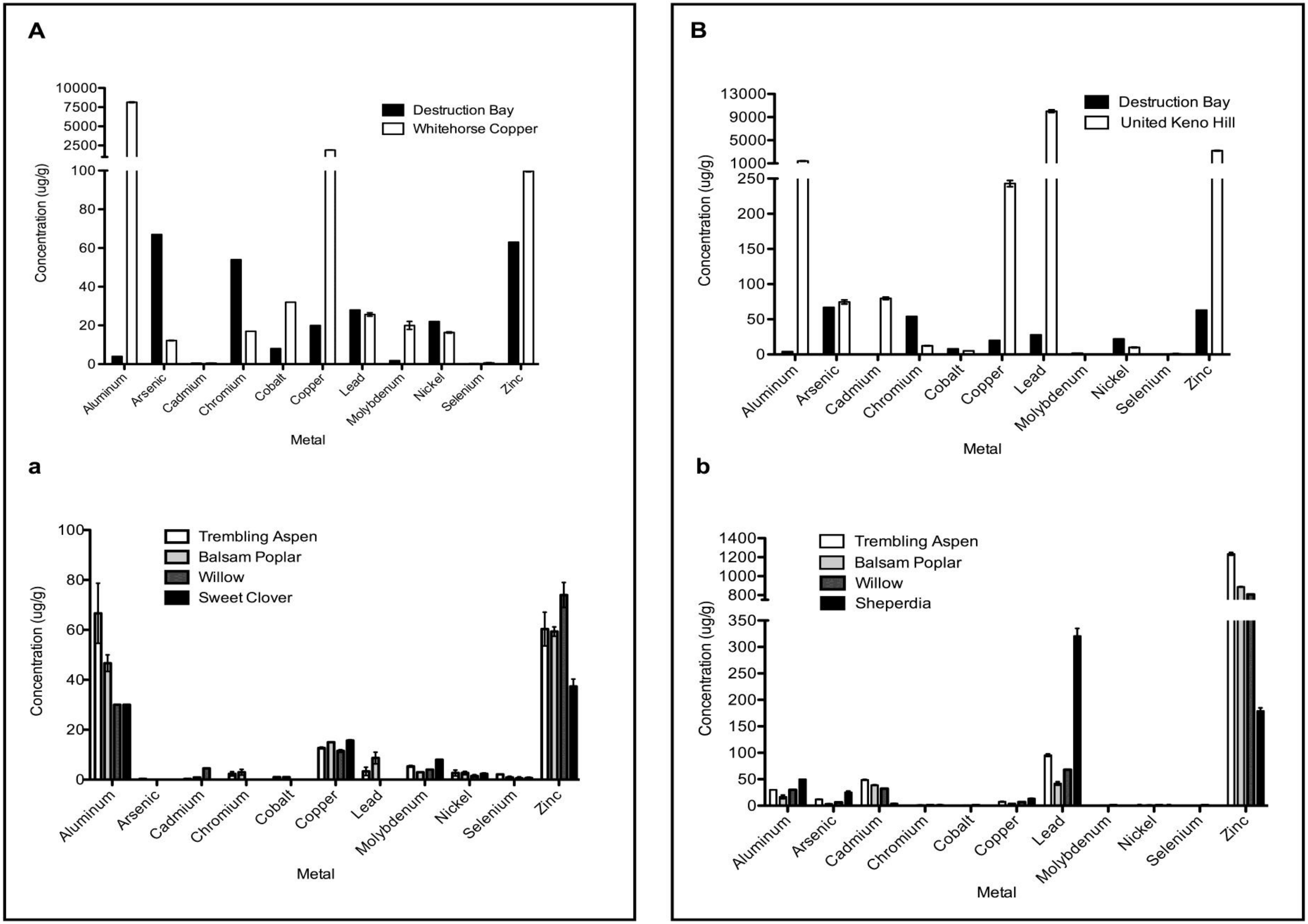

Figure 2: Figure 2: Total metal content in the soil (upper-case letter) and in the leaves of invading plants (lower-case letter) from Whitehorse Copper (A) and United Keno (B) in ug/g dry weight.

References

1) Arctic Seed Ltd. Company profile, seed catalogue. 2008. www.aaseed.com/cata/catalogue.html

2) Bush, E.L. and S.C.H. Barrett. 1993. Genetics of mine invasions by *Deschampsia cespitosa* (Poaceae). Can. J. Bot. 71. 1336-1348

3) Clark, A. 2005. Enhancing natural succession of Yukon mine tailings sites: a low-input management approach. M.Sc. Thesis. Trent University, Canada.

4) Clark, A. and T.C. Hutchinson. 2003-2006. Reports for MERG on tailings re-vegetation work in the Yukon.

5) Cox, R.M. and T.C. Hutchinson. 1980. Multiple metal tolerances in the grass *Deschampsia cespitosa* (L) Beau. from the Sudbury smelting area. New Phytol 84 631-647

6) Cox, R.M. and T.C. Hutchinson. 1979. Metal co-tolerances in the grass *Deschampsia cespitosa*. Nature. 279: 231-233

7) Hutchinson, T.C. and A. Kuja. 1989. The use of native and agricultural plant species to re-vegetate Northern mine tailings. Arctic Land Use Research Program (ALUR). Department of Indian and Northern Development. 43pp.

8) Mining Environmental Research Group. 2003. Examination of re-vegetational methodologies for dry stack tailings in Northern environments. Prepared by Access Counseling Group. 17pp. Government of the Yukon.