VEGETATION IMPACT ASSESSMENT AND MONITORING STUDIES, RED DOG MINE, ALASKA

SECOND ANNUAL REPORT

Prepared for

Teck Cominco Alaska Inc.
3105 Lakeshore Dr.
Building A, Suite 101
Anchorage, Alaska 99517

Prepared by

ABR, Inc.—Environmental Research & Services
P.O. Box 80410
Fairbanks, Alaska 99708

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ABR inc. *environmental research & services*

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PROJECT OVERVIEW

Mining and mill operations at the Red Dog Mine have resulted in the deposition of dust derived from many sources, including blasting, load-haul-dump activities, ore stockpiles, crushing activities, the main waste stockpile, overburden stockpile south of the tailings pond, concentrate handling and transport, and exposed mill tailings. Dust derived from mined ore is likely to be rich in metal sulfides (iron, zinc, and lead), and iron sulfate, and produces sulfuric acid during oxidative decomposition (Cox 1995). ABR, Inc.—Environmental Research & Services (ABR) was contracted by Teck Cominco Alaska Inc. (TCAK) to determine the extent to which plant communities have been affected by dust, and identify potential treatment options for mitigating impacts. The objectives of the three-year study are to (1) determine the specific cause(s) of plant mortality in affected areas; (2) identify and evaluate ameliorative treatments that may be effective in promoting recovery of the disturbed natural plant communities; and (3) establish a monitoring program to document long-term changes in the structure and composition of plant communities surrounding the mine site.

This report summarizes research efforts of Year 2 of the study, which included collecting baseline vegetation cover data for treatment blocks set up in August 2006; applying a second ameliorative treatment (triple phosphate); and comparing differences in soil characteristics between reference (untreated plots) and plots treated with dolomitic pelletized lime in 2006. These preliminary results will be used to determine whether the treatment was effective in reducing concentrations of aluminum (Al) and increasing pH, thereby increasing the neutralization potential of the soil. The long-term vegetation monitoring transects established in 2006 to monitor vegetation impacts (or recovery) of dust-affected areas were not monitored in 2007.

STUDY AREAS

Based on the site assessment of vegetation impact areas in the late June 2006 study (ABR 2007), three locations were selected for testing two ameliorative treatments: Triangle Area (E01), Red Dog Creek (E02), and Tailings Area (E03) (Figure 1). Tailings Area was referred to as Tailings Area 1 in the original site assessment. The Triangle Area is just north of the tailings dam

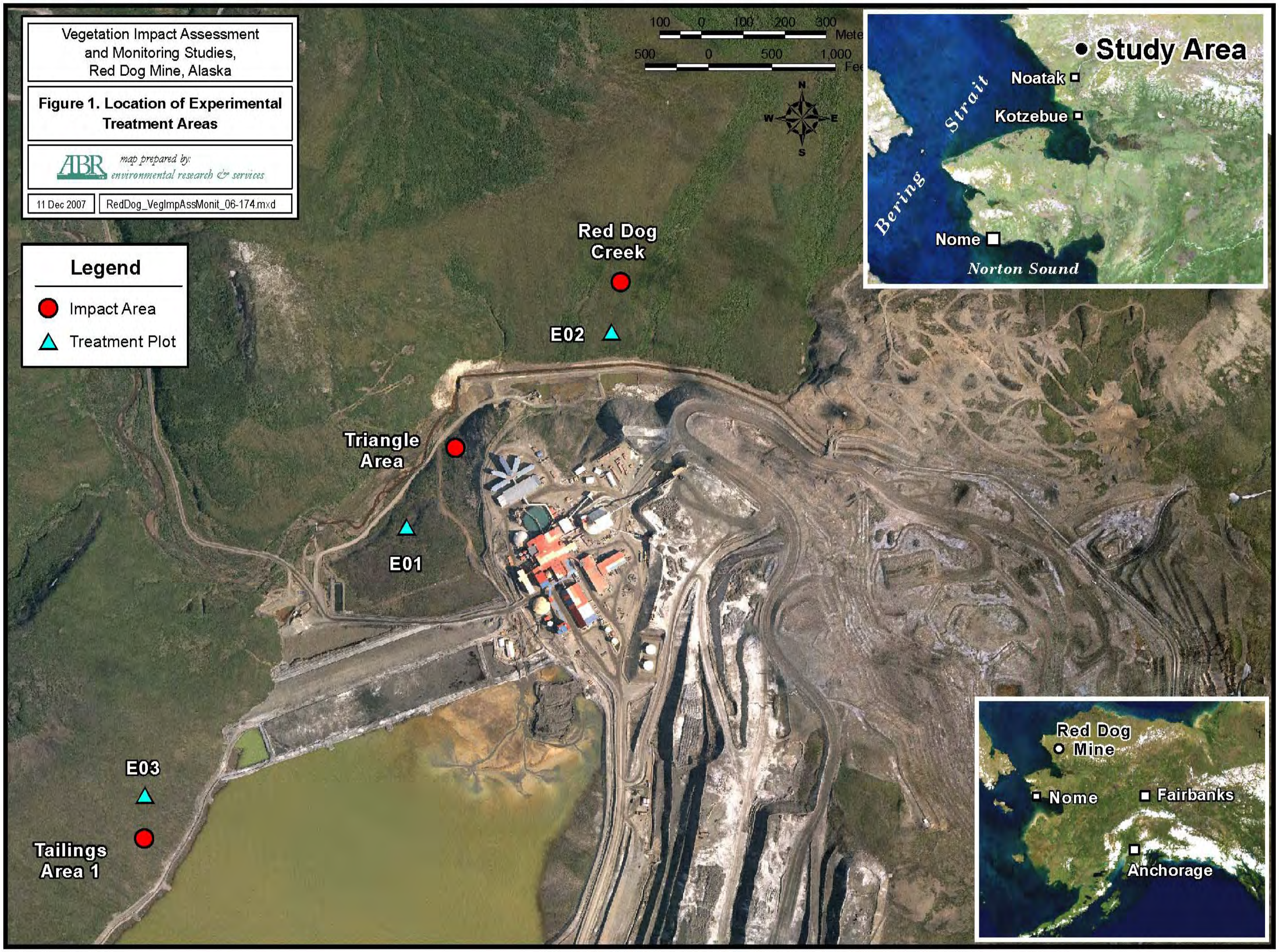

Figure 1. Locations of experimental treatment areas, Red Dog Mine, Alaska, 2007.

and has a northwest-facing slope and supports an upland low shrub community composed of *Betula nana* (dwarf birch), *Vaccinium uliginosum* (blueberry), and several species of willow (*Salix* sp.). Graminoids were dominated by *Carex bigelowii* (Bigelow sedge) and *Festuca altaica* (Altai fescue). This area is situated in the lee of both the mill and stockpile areas and has probably received fugitive dust from both concentrate loading and hauling operations (prior to upgrades to the concentrate loading facility) and the ore stockpile. The Red Dog Creek area is located along the north side of the Red Dog Creek diversion channel. Much of the area is situated on a south-facing slope and consists of a lowland shrub birch-sedge community interspersed with narrow bands of willows that have colonized hillside water tracks. This area is downwind of the mine pit and stockpiles. The Tailings Area encompasses a broad southeast-facing slope on the west side of the tailings pond. The majority of the slope consists of lowland shrub birch-sedge vegetation. Wetter inclusions support shrub birch-tussock communities. The area is directly downwind of the tailings pond and the waste rock stockpile and likely has received significant amounts of dust from intermittently exposed tailings beach sediments.

METHODS

EXPERIMENTAL DESIGN

Based on the results from the 2006 vegetation impact assessment (ABR 2007), we suspect the major impacts to vegetation in the immediate mine area are due to deposition of acid-forming dust, input of iron sulfate and zinc sulfate from fugitive dust, and reduction of soil Al to soluble forms. To identify potential treatments for reducing dust effects, we tested ameliorating the soil with additions of lime and triple super phosphate. The lime was selected to raise the pH of the soil surface, add neutralization capacity to counteract potential acidic spring inputs, and lower available Al levels (by raising surface soil pH). Triple super phosphate is being evaluated for its potential to reduce Pb concentrations. Although we do not know definitively that elevated Pb levels are responsible for vegetation impacts found in the 2007 assessment, we did find elevated Pb levels associated with some of the highest vegetation damage index rankings.

To evaluate the effectiveness of the two treatment options, we established treatment blocks 29–30 August 2006 in the Triangle Area, Red Dog Creek area, and Tailings Area (Figure 1). At each location, nine 5 × 10 m plots were established and marked with corner stakes. With the exception of the Triangle area, plots were laid out in 3 rows of 3 with a lime (L) treatment, Triple phosphate (T) treatment, and untreated, reference (R) plot randomized in each row (Figure 2). The Triangle Area plots were established in a single row, as the slope length was not sufficient for the same grid configuration as the other two sites. Each plot was photographed (in both years) and the 2007 photos are provided in Appendix A.

Pelletized dolomitic lime was applied to the lime treatment plots at a rate of 200 lbs/acre 29–30 August 2006. Triple superphosphate (calcium phosphate) fertilizer was applied on 30 July 2007 at a rate of 200 lbs/acre. The lime and phosphate were applied evenly throughout each plot using hand spreaders. The phosphate application was delayed because analytical results identifying lead as a potential stressor were not yet available when the lime treatment was applied in 2006.

SOIL CHARACTERISTICS

SAMPLING AND LABORATORY ANALYSIS

To establish baseline values prior to application of treatments in 2006, three soil samples were collected from each treatment plot within each block (n = 27) for analysis of selected chemical parameters and metals prior to applying the first ameliorative treatment (dolomitic lime). Each sample was a composite of three grab samples (approximately 2–5 cm below the moss layer), avoiding the plot margins and plant sampling grid transects. The samples were analyzed for total available aluminum (Al), iron (Fe), manganese (Mn), lead (Pb), zinc (Zn), and cadmium (Cd). Total nitrate (NO_3), Triple phosphate (P), potassium (K), and pH and electrical conductivity (EC) also were measured in each sample. The samples were analyzed by Colorado Analytical Laboratories, Inc., Brighton, Colorado, using standard methods (Klute 1986). Samples were again collected from the reference and lime treatment plots 23 August 2007. Since the Triple phosphate treatment only was applied in late June 2007, it will not be sampled till 2008 (final year of study). With the exception of Al and pH, soils data are summarized in Appendix B.

STATISTICAL ANALYSIS

To determine whether the lime application has had any effect on soil characteristics (after one growing season), we compared the lime treatment blocks with the untreated reference blocks

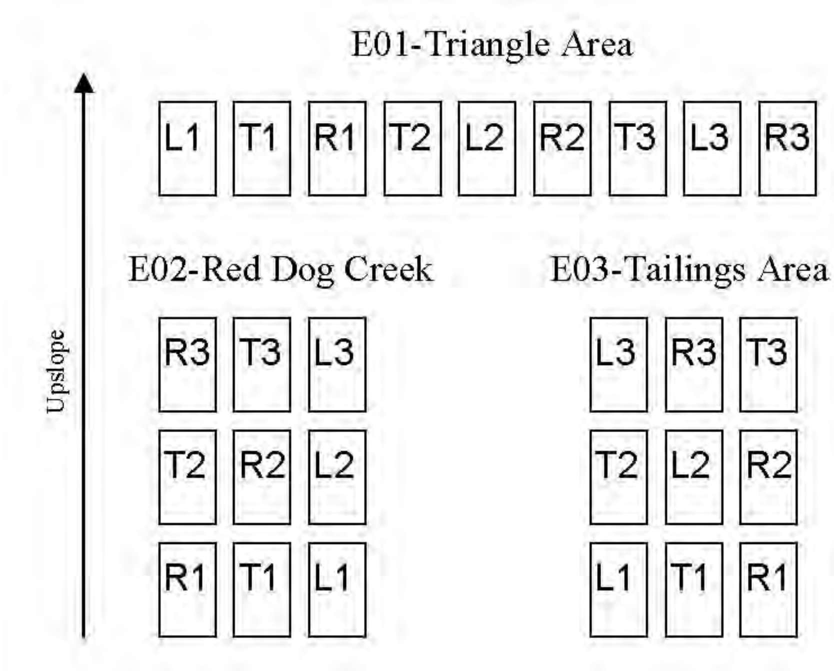

Figure 2. Ameliorative treatment plot layout at each experimental area. The treatments include lime application (L), triple superphosphate application (T), and untreated reference (R) plots. E01 was set up in a single row because the slope length was insufficient to accommodate placing plots in multiple rows.

using two-factor ANOVAs with site and treatment as factors and soil parameters as response variables. To account for departures from normality, we used a natural log (ln) transform of the Pb, Mn, nitrate (NO_3), Zn, Cd, K, and sulfate (SO_4) values. The final response variables were tested for normality using a Kolmogorov-Smirnov test and none were significantly different from normal (all $P > 0.50$). All response variables were analyzed using a two-factor ANOVA with treatment, site, and a treatment × site interaction. No interaction terms were significant in any model (i.e., all $P > 0.50$), so we removed the interaction terms and reran all models with just the main effects. A repeated measures analysis was considered for comparing differences between 2006 and 2007 in each treatment, but concerns over consistency in soil sampling between 2006 and 2007 (see Results below) suggested the comparison probably was not appropriate. ANOVA analyses were performed using SPSS (2005) statistical software.

VEGETATION SURVEY

Baseline vegetation cover in all treatment blocks was first measured 28–30 June 2007, because vegetation was too senesced to accurately determine baseline cover during the 2006 field effort in late August. Vegetation cover was sampled in each 5 × 10 m plot using the point intercept method: 100 points were sampled on a 2 × 0.025 m grid by stretching a 5 m tape measure across the plot at the 1, 3, 5, 7, and 9-m intervals, and sampling points at 25-cm intervals along the tape within the plot. A small laser-pointer mounted on an aluminum pole was used to identify a discrete sample point at each grid location. All plant species were recorded at each point, including multiple layers (canopies). This method gives a repetitive cover estimate that can exceed 100%, but generally is well correlated with biomass (Jonasson 1988). Litter and bare soil were recorded only if there was no overtopping vegetation. Mean cover by class (water, soil, litter, lichen, moss, graminoid, evergreen shrub, deciduous shrub, forb, and total live cover) was calculated for each treatment (n = 3) in each experimental block (total of 27 plots). Trace cover (those species not sampled along the transects) also was compiled for each plot. Taxonomic nomenclature follows *Flora of Alaska* (Hultén 1968). The vegetation cover data are summarized in Appendix C.

RESULTS

SOIL CHARACTERISTICS

Comparisons of soils data collected in the lime and reference plots in 2006 and again in 2007 reveal dramatic differences for some parameters, particularly for selected metals (Table 1; Appendix Figures B1 and B2). In some cases, metal concentrations are an order of magnitude higher in 2006 than 2007 (Appendix Figure B1) and the reasons are uncertain. Possible explanations include unknown differences in dust deposition between years or unexpected differences in sampling or analytical methods. We believe that soils were collected in both years according to the protocol established for the study, which stated that samples will be collected just beneath the moss mat to a depth of 5 cm. Nevertheless, because the soil sampling was conducted by different personnel, it is possible that the 2007 soil samples included soil from greater depths than those in 2006, which may have resulted in lower metal concentrations. A previous study looking at metal concentrations in soils surrounding the mine showed that Pb and Zn concentrations drop off steeply 5 cm below the surface (Figure 3) (TCAK, unpublished data). To be conservative, therefore, statistical analyses of the differences between treated and reference plots are restricted to the 2007 data.

Table 1. Mean values of selected soil chemical characteristics and metal concentrations in treatments blocks at three study areas, Red Dog Mine, 2006 and 2007.

	Triangle Area				Red Dog Creek				Tailings Area			
	Lime		Reference		Lime		Reference		Lime		Reference	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
pH	2.9	3.6	3.0	3.4	3.9	5.6	3.9	4.8	3.8	4.2	3.7	4.0
EC (dS/m)	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.4	0.4	0.2	0.4	0.4
SO_4	1,256.6	610.9	1,155.4	550.9	1,003.4	64.7	1,488.8	87.0	907.1	131.2	1,093.2	174.5
Available Metals (mg/kg)												
Al	430.7	234.6	310.0	353.4	293.3	2.3	241.3	55.1	319.3	155.2	522.0	232.7
Fe	15,633.0	504.8	19,354.3	467.1	17,958.7	304.2	13,920.2	331.7	41,064.3	574.5	27,903.6	572.8
Pb	2,925.3	310.8	2,484.9	259.8	1,180.9	36.0	1,446.3	53.9	1,852.3	24.0	1,991.3	78.2
Mn	6.3	7.9	5.5	13.7	241.5	133.5	111.5	164.7	31.2	13.8	3,881.6	18.2
Zn	6,850.4	324.2	5,851.8	327.7	25,631.2	183.5	32,496.8	167.2	8,723.3	150.7	18,065.4	120.9
Cd	6.6	6.3	4.8	4.5	37.0	2.1	77.3	2.7	8.8	2.6	19.1	1.9
Available Nutrients (mg/kg)												
NO_3	0.4	4.3	0.5	7.7	8.1	1.1	2.7	0.7	1.3	1.3	1.4	2.0
P	10.5	9.9	8.8	13.8	18.9	9.9	32.3	8.7	43.4	9.3	30.0	9.4
K	47.0	187.0	51.4	233.9	880.2	298.2	635.9	346.7	266.3	260.2	509.2	321.1

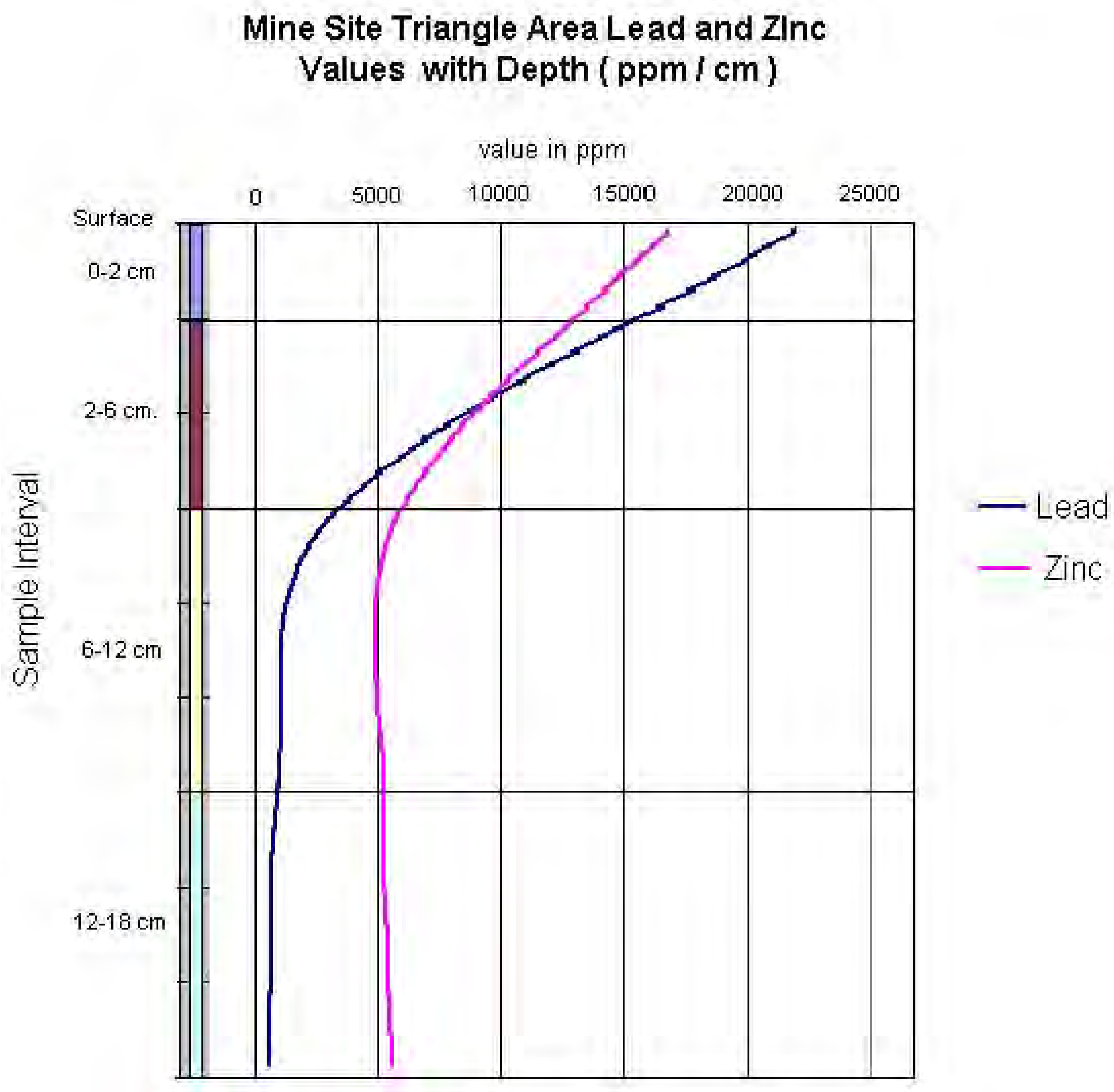

Figure 3. Soil profiles of Pb and Zn concentrations, showing steep gradient at shallow depth, Red Dog Mine (reprinted with permission from Teck Cominco Alaska Inc.).

With the exception of Al (P = 0.03), mean metal concentrations and macronutrient levels in 2007 were not significantly different between the lime and reference treatment plots at each location (Figure 4, Table 2). Given the high number of tests conducted and a P-value close to our threshold (P < 0.05), however, we are uncertain whether the differences observed are actually attributable to the treatment effect. Nevertheless, concentrations of Al were consistently lower in the lime application plots compared to the reference plots in all three locations, which suggests

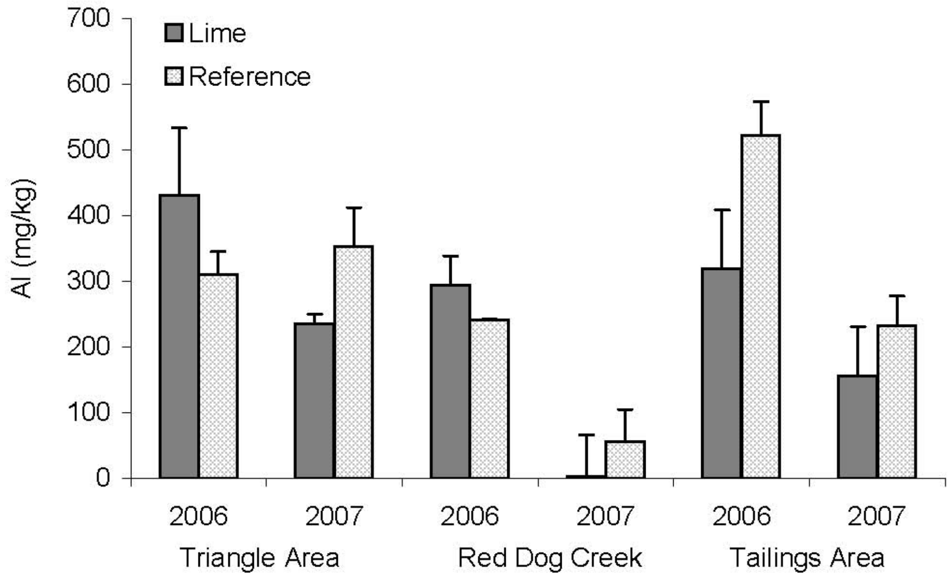

Figure 4. Comparisons of concentrations of Al in lime and reference (untreated) experimental test plots, Red Dog Mine, 2006 and 2007.

Table 2. Summary of P-values resulting from two-Factor ANOVA analyses of soil parameters by treatment and location, Red Dog Mine, 2007.

Parameter	Treatment	Location
EC	0.274	0.026
pH	0.060	<0.001
SO_4	0.372	<0.001
Al	0.030	<0.001
Cd	0.925	0.124
Fe	0.967	0.114
Mn	0.717	<0.001
Pb	0.779	0.126
Zn	0.939	0.120
NO_3	0.756	<0.001
P	0.549	0.338
K	0.264	0.107

the treatment may have had a modest effect on reducing Al concentrations. Mean soil pH increased in both the lime and reference treatments between 2006 and 2007 (Figure 5), but the increases were more modest in the reference treatment. Thus, it possible that the lime application had a real effect on increasing soil pH. Significant differences were found for several parameters when comparing results with respect to location (Table 2), which is not surprising, as the degree of vegetation impact varies considerably among the three locations. Below is a brief summary of the soil characteristics for each treatment area.

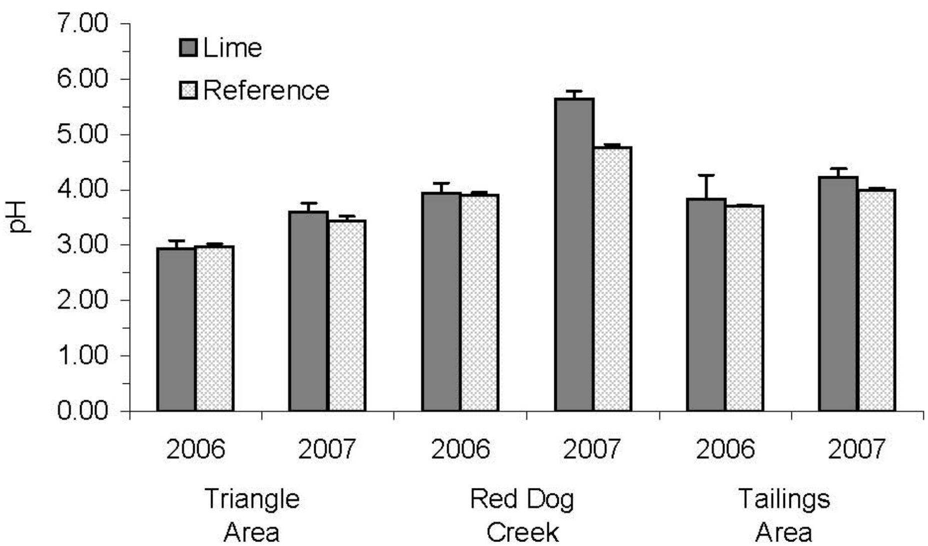

Figure 5. Comparisons of concentrations of pH in lime and reference (untreated) experimental test plots, Red Dog Mine, 2006 and 2007.

E01—TRIANGLE AREA

Mean soil pH in 2007 was comparable between the lime treatment and reference (3.6 and 3.4, respectively, and both treatment and reference were higher than in 2006 (2.9 and 3.0, respectively) (Figure 5, Table 1). Although the differences in mean Al concentrations were not determined to be significant, they were lower in the lime treatment (234.6 mg/kg) than in the reference (353.4 mg/kg) (Figure 4, Table 1,). For several of the other metals, values were higher in the lime treatment than they were in the reference, although the differences were not significant. The most striking differences between 2006 and 2007 were for Fe and Zn, which were up to 38-fold higher in 2006. The macronutrients NO_3 and K were higher in 2007, which supports the idea that perhaps soil from lower in the profile was included in the samples. As excess metal concentrations decrease, nutrient availability typically increases.

E02—RED DOG CREEK

Similar to the Triangle Area, levels of Fe and Zn were considerably higher in 2006 compared to 2007, with levels 15–140-fold higher in 2006. Unpredictably, Fe, Mn, Zn, and Cd concentrations were higher at the Red Dog Creek site than in the Triangle Area in 2006, despite a higher degree of vegetation impact (in terms of lower vegetation cover) in the Triangle Area (Appendix Tables C1 and C2). In contrast to the Triangle Area, levels of K were higher in 2006 than 2007. Soil pH increased from 3.9 in 2006 to 4.8–5.6 in 2007. Similar to the Triangle Area, Al values were lower in the lime treatment (2.3 mg/kg) than in the reference plots (55.1 mg/kg) plots in 2007.

E03—TAILINGS AREA

The Tailings Area samples exhibit high variability, both between years and between baseline values of the reference and treatment plots. Similar to the other treatment areas, metal concentrations were much higher in 2006 compared to 2007. In addition, the reference and treatment plots in 2006 differed widely in concentrations of Fe, Mn, Zn, and Cd prior to lime application. For Fe, mean concentrations were 41,064 mg/kg and 27,903 mg/kg in the lime treatment and reference (no treatment), respectively, in 2006. These results suggest that dust is not uniformly deposited. Previous sampling efforts at the mine have encountered similar variability, particularly when the terrain contains a high degree of microtopographic variation (Jeff Clark, pers. comm.). The microtopography of the Tailings Area (Appendix A, Figures A19–A27) may in part account for the high degree of variability found in samples collected from what is a relatively small area. With respect to the other parameters measured, pH only was moderately higher in 2007 compared to 2006 and levels of P were lower in 2007 than 2006. Similar to the other two treatment areas, mean concentration of Al was lower in the lime treatment (155.2 mg/kg) than in the reference (232.7 mg/kg) (Figure 4).

BASELINE VEGETATION COVER

E01—TRIANGLE AREA

Vegetation in the Triangle Area is severely impacted, evidenced by a high cover of litter and relatively low percentages of mean total live vascular cover (TLVC) (9–12.7%) for all three treatment blocks (Appendix Figures A1–A9, Appendix Table C1). The cover (up to 15.7%) is primarily composed of deciduous shrubs (*Vaccinium uliginosum*, *Salix planifolia pulchra* [hereafter referred to as *S. pulchra*], and *Salix chamissonis*). Grasses and sedges such as *Calamagrostis canadensis*, *Festuca altaica*, and *Carex bigelowii* occur in 3 of the 9 plots, with no mean cover exceeding 10%. Evergreen shrubs, forbs and nonvascular plants (lichens and mosses) are absent except in trace amounts.

E02—RED DOG CREEK

Vegetation in the Red Dog Creek Area is moderately impacted with a mean TLVC ranging from 88.7–107% (Appendix Figures A10–A18, Appendix Table C2) for all three treatment blocks. Mean cover of bare ground (including litter) ranges from 33.7–43%. The majority of the vegetation cover is provided by deciduous and evergreen shrubs. The most common species include *S. pulchra*, *V. uliginosum*, *Betula glandulosa*, *Ledum palustre decumbens*, and *V. vitis-idaea*. Forbs (*Rubus chamaemorus* and *Petasites frigidus*), grasses (*Arctagrostis latifolia*) and sedges (*C. bigelowii*) account for less than 5% of the mean TLVC. Mosses and lichens are mostly absent.

E03—TAILINGS AREA

Vegetation in the Tailings Area is moderately impacted with a mean TLVC (72.3–81%) falling between that of the Triangle Area and the Red Dog Creek Area (Appendix Figures A19–A27, Appendix Table C3). The majority of the cover (36.7–40%) is provided by deciduous shrubs such as *S. pulchra*, *V. uliginosum*, and *B. glandulosa*. Mean cover of graminoids (primarily *C. bigelowii*, *Eriophorum vaginatum*, and *C. atrofusca*) is highest at this site and ranges from 18–26.3%. Evergreen shrubs and forbs also are present. The Tailings Area is the only site where live mosses were sampled.

DISCUSSION AND CONCLUSIONS

The soil properties of the treatment blocks described in this report represent only one growing season following lime treatment; thus, the results are preliminary. In addition, as a result of the high variability associated with the soils data between 2006 and 2007 and between treatment blocks in 2006 (prior to treatment application), it is not yet possible to determine whether applying lime has had a measurable effect on improving soil properties for plant growth. The treatment may have had a moderating effect on Al concentrations and pH (as intended), but the absence of direct comparisons between 2006 and 2007 makes it difficult to determine whether the differences observed are attributable to the ameliorating effects of the lime or are merely a reflection of interannual variation. Since we are likely to see a more significant change in soil properties than vegetation response two years following treatment application, more effort will be made in 2008 to control sampling depth (to minimize variability attributable to sampling method) and to account for site heterogeneity when collecting soil samples for analysis (to minimize variability due to non-uniform deposition of dust).

The vegetation cover measured in late June 2006 represents the baseline conditions for each treatment area, and will be used to determine whether the lime and triple phosphate treatments have an effect on plant growth and vegetation recovery. Since there is typically a lag in vegetation response following improved soil characteristics, we are uncertain the degree to which the treatments will increase vegetation cover and species diversity over the course of the three-year study. Vegetation response may be further delayed as a result of low precipitation in 2007; total rainfall from May–September was only 9.9 in, which is close to the 15-yr low (9.2 in). The 15-yr average is 13.4 in. The low precipitation could have an effect on both plant growth and the solubility of the treatments, particularly the triple phosphate added in late June. In addition, if mine dust load levels have not been notably reduced, the ameliorative treatments may be largely ineffective. Several dust control measures have been implemented, however, and preliminary results show that levels of total suspended particles (TSP) were lower in 2006 compared to 2005 (TCAK 2007). Efforts to reduce dust emissions include installing baghouses over the gyro and jaw crushers and ore stockpile, and investigating techniques for reducing dust emissions from roads, waste dumps, tailings pond beaches, and stockpiles. Baghouses are fabric dust collectors; dust-filled air passes through fabric bags that filter the dust particles. Vegetation cover will be sampled again in mid-August 2008 to compare with baseline measurements. Evidence of vegetation recovery in treatment areas will include the presence of seedlings in barren areas (particularly in the Triangle Area), reduced cover of litter (and bare ground), and increases in vegetation cover for some lifeforms. The most likely increases in vegetation cover will occur in graminoids and forbs, as they have faster growth rates than deciduous and evergreen shrubs and are likely to respond more rapidly to improved soil conditions.

The long-term monitoring transects established in 2006 will be monitored again in 2009 and compared with initial vegetation cover measurements. The placement of transects was designed to account for various landscape characteristics that affect the distribution and rates of dust accumulation, including wind shelter, snow accumulation areas, slope and aspect, and plant community structure. This monitoring effort will document natural recovery of plant species within the affected area in response to efforts to reduce fugitive dust emissions from mine facilities.

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APPENDIX A. PHOTOGRAPHIC LOG OF TREATMENT BLOCKS, RED DOG MINE, 2007

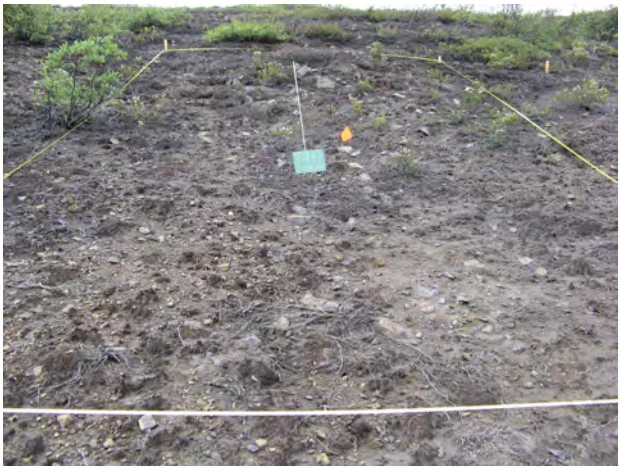

Figure A1. Lime (L) treatment plot (rep 1), Triangle Area (E01), 28 June 2007.

Figure A2. Triple phosphate (T) treatment plot (rep 1), Triangle Area (E01), 28 June 2007.

Figure A3. Control (R) treatment plot (rep 1), Triangle Area (E01), 28 June 2007.

Figure A4. Triple phosphate (T) treatment plot (rep 2), Triangle Area (E01), 28 June 2007.

Figure A5. Lime (L) treatment plot (rep 2), Triangle Area (E01), 28 June 2007.

Figure A6. Control (R) treatment plot (rep 2), Triangle Area (E01), 28 June 2007.

Figure A7. Triple phosphate (T) treatment plot (rep 3), Triangle Area (E01), 28 June 2007.

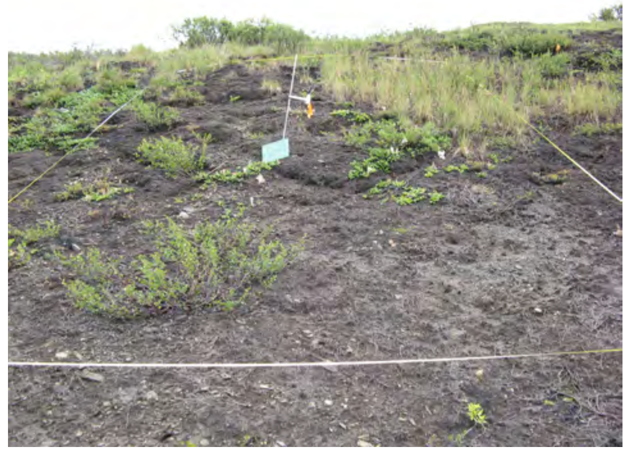

Figure A8. Lime (L) treatment plot (rep 3), Triangle Area (E01), 28 June 2007.

Figure A9. Control (R) treatment plot (rep 3), Triangle Area (E01), 28 June 2007.

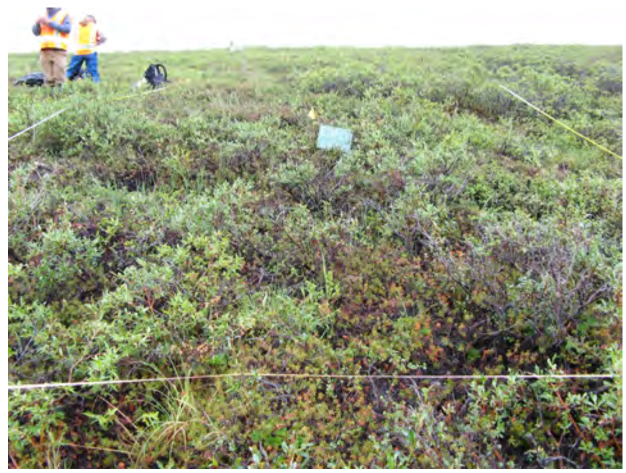

Figure A10. Lime (L) treatment plot (rep 1), Red Dog Creek Area (E02), 28 June 2007.

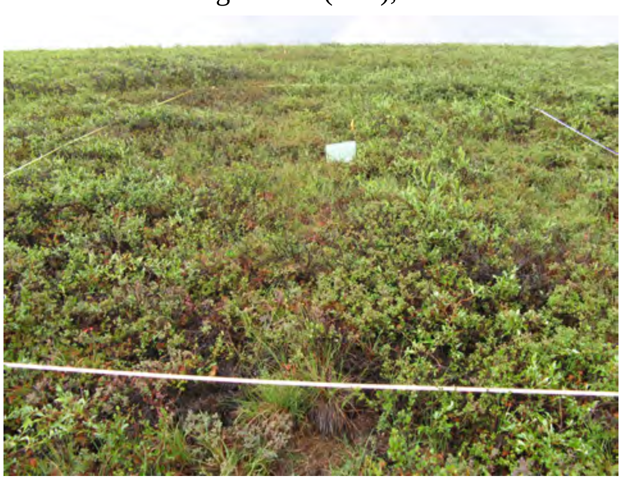

Figure A11. Triple phosphate (T) treatment plot (rep 1), Red Dog Creek Area (E02), 28 June 2007.

Figure A12. Control (R) treatment plot (rep 1), Red Dog Creek Area (E02), 28 June 2007.

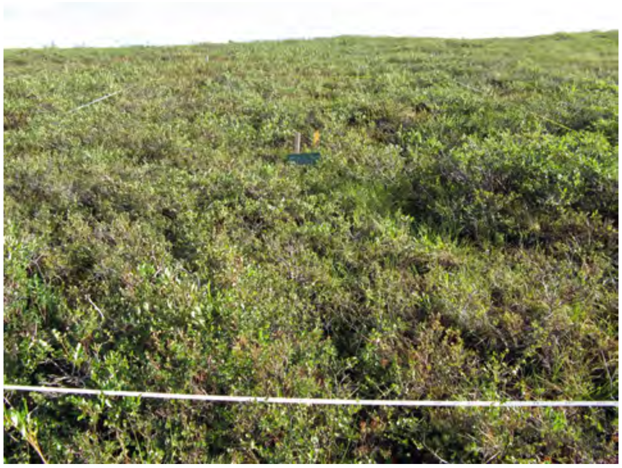

Figure A13. Lime (L) treatment plot (rep 2), Red Dog Creek Area (E02), 29 June 2007.

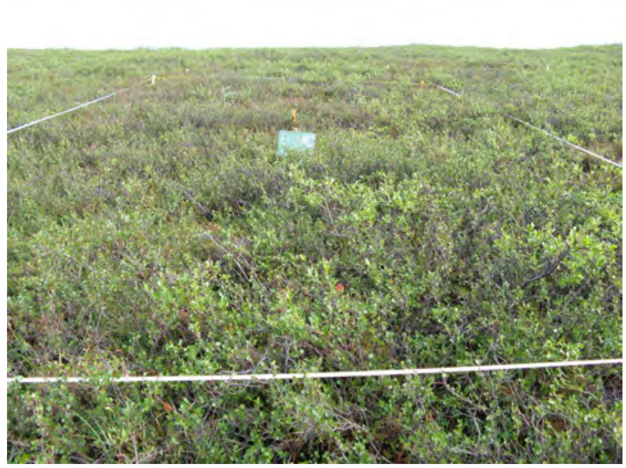

Figure A14. Control (R) treatment plot (rep 2), Red Dog Creek Area (E02), 29 June 2007.

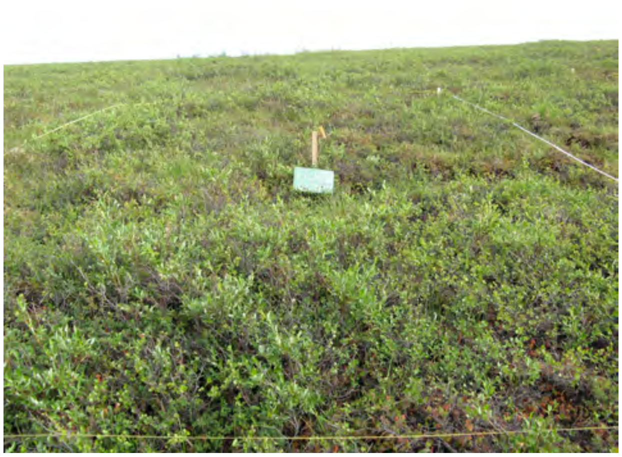

Figure A15. Triple phosphate (T) treatment plot (rep 2), Red Dog Creek Area (E02), 29 June 2007.

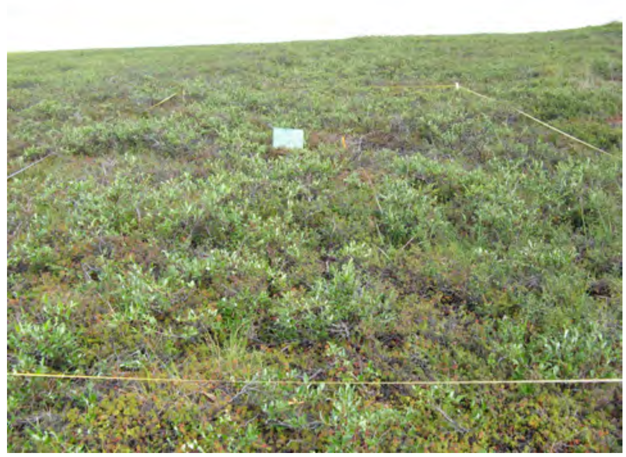

Figure A16. Lime (L) treatment plot (rep 3), Red Dog Creek Area (E02), 29 June 2007.

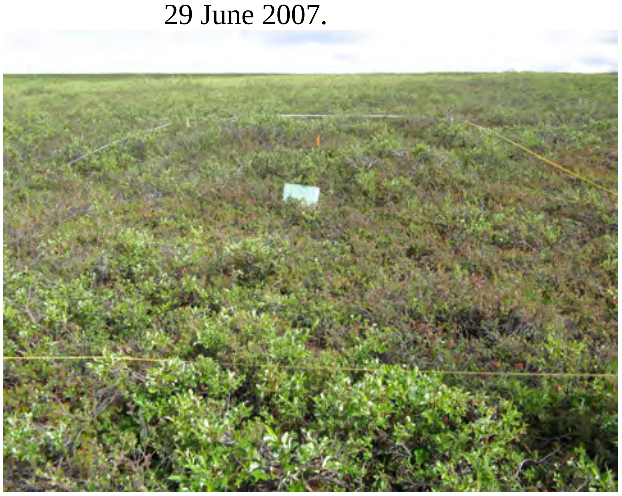

Figure A17. Triple phosphate (T) treatment plot (rep 3), Red Dog Creek Area (E02), 29 June 2007.

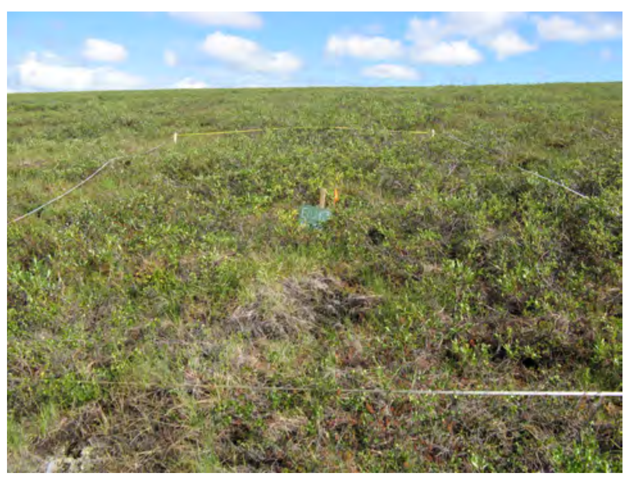

Figure A18. Control (R) treatment plot (rep 3), Red Dog Creek Area (E02), 29 June 2007.

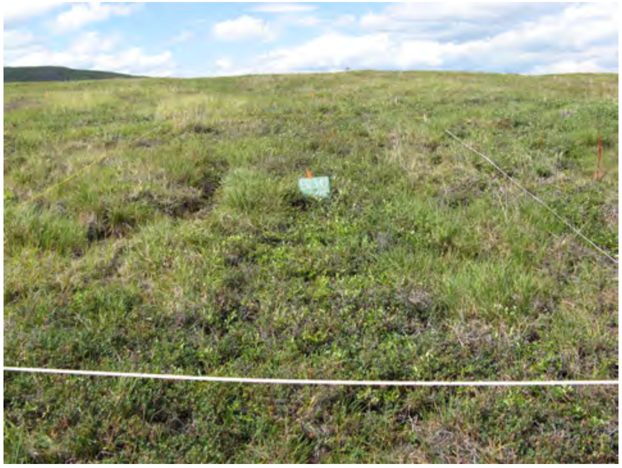

Figure A19. Control (R) treatment plot (rep 1), Tailings Area (E03), 29 June 2007.

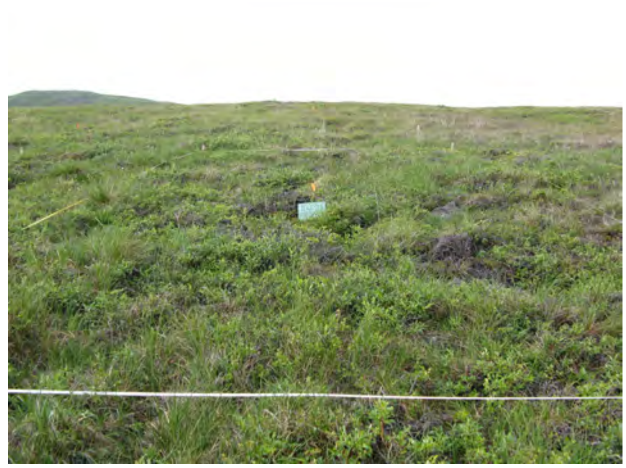

Figure A20. Triple phosphate (T) treatment plot (rep 1), Tailings Area (E03), 29 June 2007.

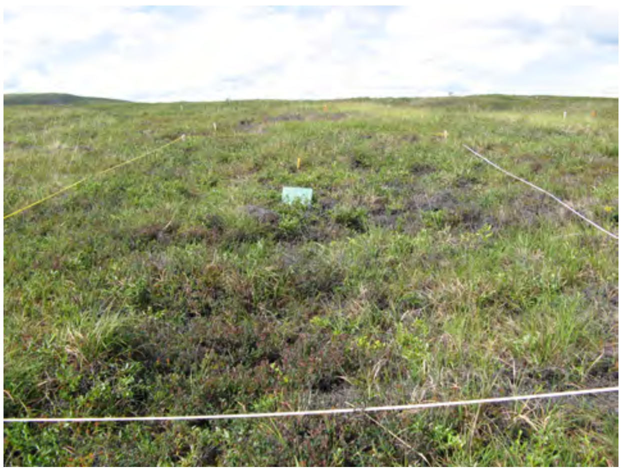

Figure A21. Lime (L) treatment plot (rep 1), Tailings Area (E03), 29 June 2007.

Figure A22. Control (R) treatment plot (rep 2), Tailings Area (E03), 29 June 2007.

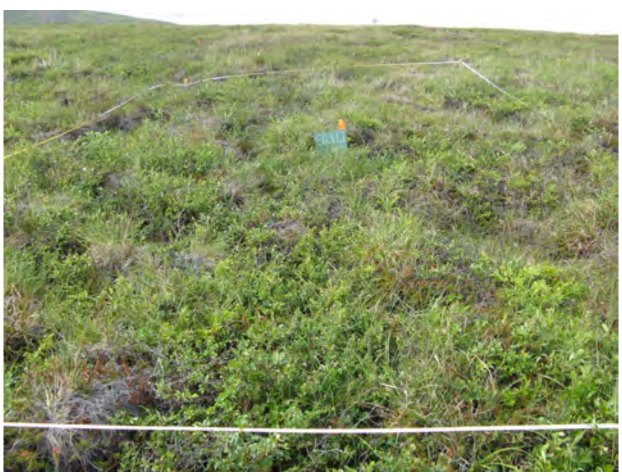

Figure A23. Lime (L) treatment plot (rep 2), Tailings Area (E03), 29 June 2007.

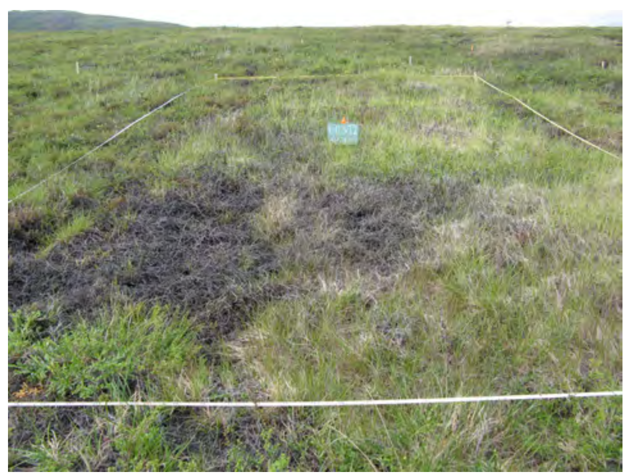

Figure A24. Triple phosphate (T) treatment plot (rep 2), Tailings Area (E03), 29 June 2007.

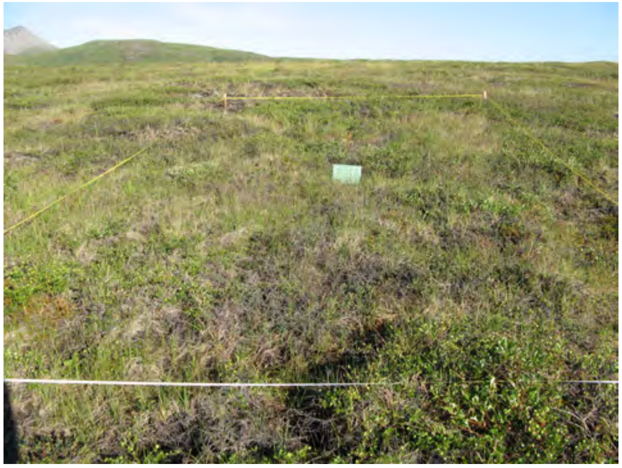

Figure A25. Triple phosphate (T) treatment plot (rep 3), Tailings Area (E03), 30 June 2007.

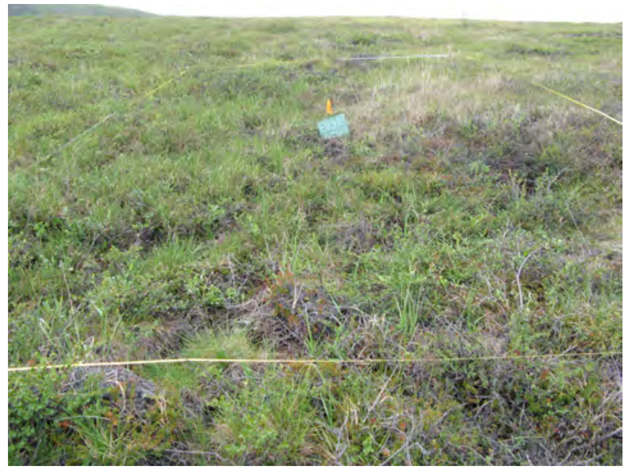

Figure A26. Control (R) treatment plot (rep 3), Tailings Area (E03), 29 June 2007.

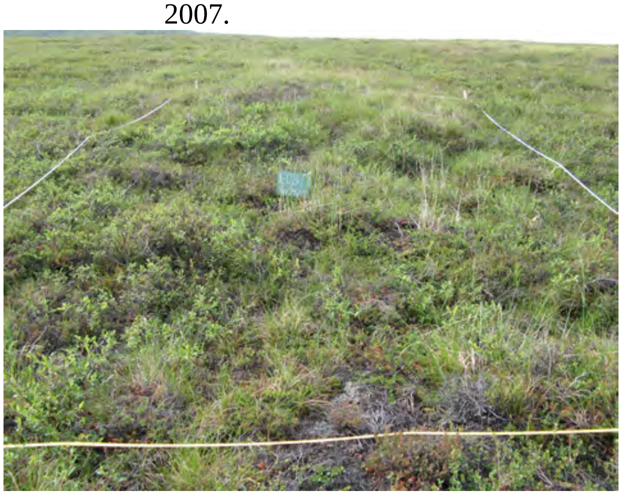

Figure A27. Lime (L) treatment plot (rep 3), Tailings Area (E03), 29 June 2007.

APPENDIX B. SUMMARY OF SOIL CHARACTERISTICS IN TREATMENT BLOCKS, RED DOG MINE, 2007

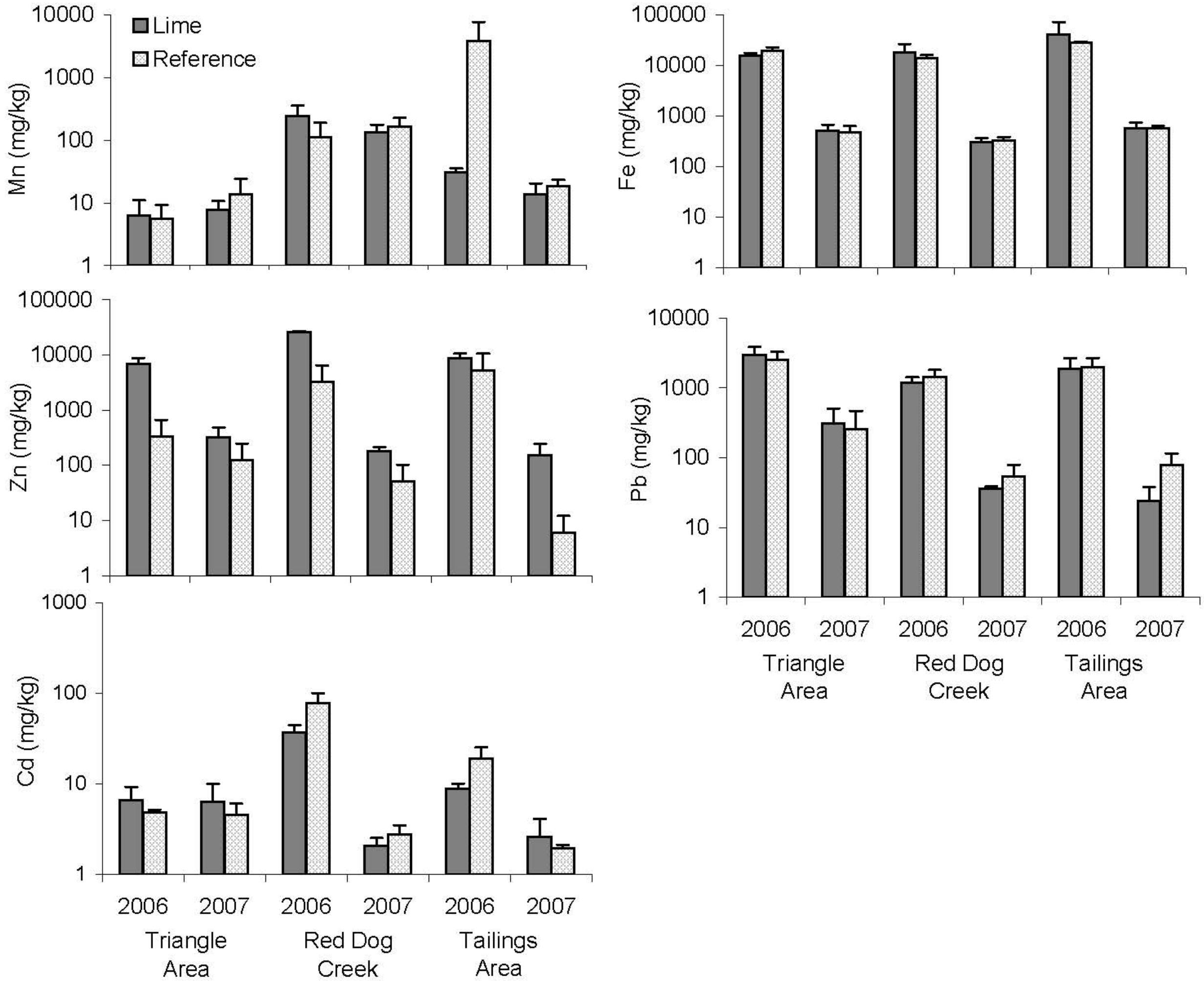

Figure B1. Comparisons of selected metals in lime and reference (untreated) experimental test plots, Red Dog Mine, 2006 and 2007.

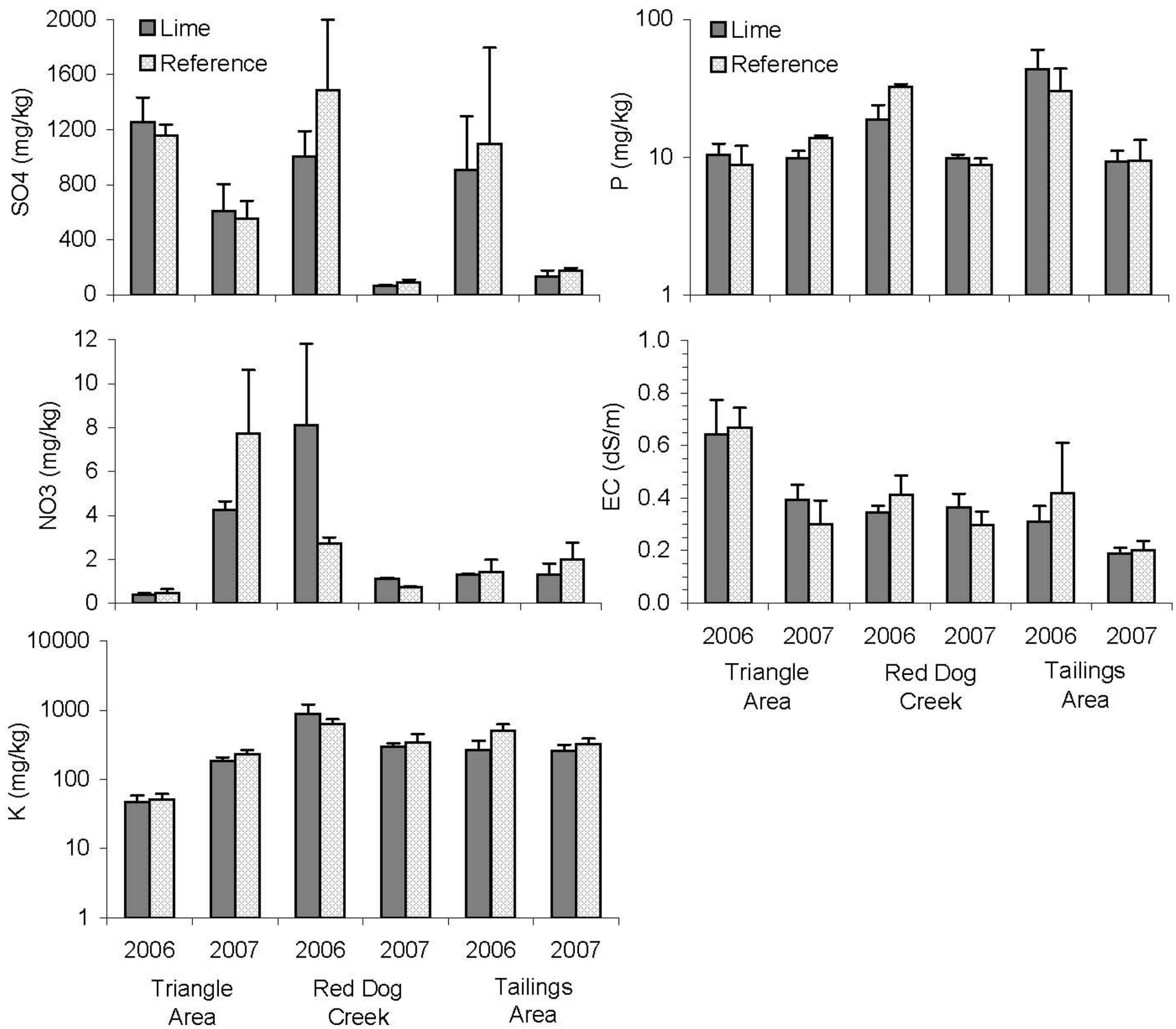

Figure B2. Comparisons of electrical conductivity (EC), selected nutrients, sulfate (SO_4), and potassium (K) in lime and reference (untreated) experimental test plots, Red Dog Mine, 2006 and 2007.

APPENDIX C. SUMMARY OF VEGETATION COVER AND SPECIES COMPOSITION OF TREATMENT BLOCKS, RED DOG MINE, 2007

Table C1. Percent cover of vegetation in E01-Triangle Area, 2007.

	Lime Application				Triple Phosphate Application				Reference (untreated)			
	L1	L2	L3	Mean	T1	T2	T3	Mean	R1	R2	R3	Mean
Bare Ground	97	96	88	93.7	97	93	76	88.7	96	93	88	92.3
Litter	22	34	54	36.7	32	33	39	34.7	38	47	44	43.0
Soil	75	62	34	57.0	65	60	37	54.0	58	46	44	49.3
Total Live Cover	5	7	15	9.0	3	11	43	19.0	4	14	20	12.7
Total Live Vascular Cover	5	7	15	9.0	3	11	43	19.0	4	14	20	12.7
Deciduous Shrubs	5	3	15	7.7	3	11	33	15.7	4	14	18	12.0
Betula nana			6	2.0			3	1.0	2		8	3.3
Salix chamissonis			2	0.7	2	1	10	4.3	1		1	0.7
S. planifolia pulchra	2	2		1.3		8		2.7	1	11	1	4.3
S. phlebophylla											tr	
S. reticulata			2	0.7								
Spiraea beauverdiana	1			0.3						2		0.7
Vaccinium uliginosum	2	1	5	2.7	1	2	20	7.7		1	8	3.0
Evergreen Shrubs											tr	
Vaccinium vitis-idaea											tr	
Forbs											tr	
Cochlearia officinalis											tr	
Minuartia arctica											tr	
Graminoids		4		1.3			10	3.3			2	0.7
Calamagrostis canadensis		1		0.3								
Carex atrofusca												
C. bigelowii		3		1.0								
Festuca altaica							10	3.3			2	0.7

Table C2. Percent cover of vegetation in E02-Red Dog Creek, 2007.

	Lime Application				Triple Phosphate Application				Reference			
	L1	L2	L3	Mean	T1	T2	T3	Mean	R1	R2	R3	Mean
Bare Ground	44	39	46	43.0	30	40	42	37.3	35	19	47	33.7
Litter	44	39	45	42.7	30	38	42	36.7	35	19	47	33.7
Soil												
Water			1	0.3		2		0.7				
Total Live Cover	92	88	86	88.7	109	95	82	95.3	108	134	79	107.0
Total Live Vascular Cover	92	88	86	88.7	109	94	82	95.0	108	134	79	107.0
Deciduous Shrubs	50	48	33	43.7	60	50	34	48.0	62	71	44	59.0
Betula nana	14	13	9	12.0	15	9	7	10.3	24	32	7	21.0
Salix planifolia pulchra	15	17	15	15.7	20	16	6	14.0	24	13	26	21.0
Vaccinium uliginosum	21	18	9	16.0	25	25	21	23.7	14	26	11	17.0

Table C2. Continued.

	Lime Application				Triple Phosphate Application				Reference			
	L1	L2	L3	Mean	T1	T2	T3	Mean	R1	R2	R3	Mean
Evergreen Shrubs	39	35	50	41.3	37	32	40	36.3	41	49	29	39.7
Empetrum nigrum	2	tr	2	1.3	1		tr	0.3			1	0.3
Ledum decumbens	24	19	19	20.7	15	17	26	19.3	24	27	20	23.7
Vaccinium vitis-idaea	13	16	29	19.3	21	15	14	16.7	17	22	8	15.7
Forbs		2	2	1.3		1	4	1.7		5		1.7
Boykinia Richardsonii	tr				tr							
Petasites frigidus	tr											
Rubus chamaemorus		2	2	1.3		1	4	1.7		5	tr	1.7
Graminoids	3	3	1	2.3	12	11	4	9.0	5	9	6	6.7
Arctagrostis latifolia	3	1	tr	1.3	3	1		1.3	1		2	1.0
Calamagrostis canadensis											tr	
Carex bigelowii	tr	2	1	1.0	9	10	4	7.7	4	9	4	5.7
Poa arctica											tr	
Poa glauca	tr											
Total Nonvascular Cover						1		0.3				
Unknown lichen						1		0.3				

Table C3. Percent cover of vegetation in E03-Tailings Area, 2007.

	Lime Application				Triple Phosphate Application				Reference			
	L1	L2	L3	Mean	T1	T2	T3	Mean	R1	R2	R3	Mean
Bare Ground	52	43	33	42.7	37	55	51	47.7	46	54	34	44.7
Litter	51	42	30	41.0	36	55	51	47.3	45	53	33	43.7
Soil	1	1	3	1.7	1			0.3	1	1	1	1.0
Total Live Cover	75	79	89	81.0	90	53	74	72.3	76	62	103	80.3
Total Live Vascular Cover	73	76	89	79.3	89	53	74	72.0	73	61	103	79.0
Deciduous Shrubs	50	30	39	39.7	47	24	39	36.7	38	33	49	40.0
Betula nana	15	7	14	12.0	7	10	28	15.0	2	22	22	15.3
Salix planifolia pulchra	13	19	15	15.7	38	2	3	14.3	9	1	5	5.0
Vaccinium uliginosum	22	4	10	12.0	2	12	8	7.3	27	10	22	19.7
Evergreen Shrubs	6	25	18	16.3	7	4	16	9.0	14	15	34	21.0
Empetrum nigrum		3	tr	1.0		tr	3	1.0	1	tr	3	1.3
Ledum decumbens	4	16	9	9.7	5		4	3.0	7	4	20	10.3
Vaccinium vitis-idaea	2	6	9	5.7	2	4	9	5.0	6	11	11	9.3
Forbs		1	1	0.7								
Petasites frigidus			1	0.3								
Polygonum bistorta						tr					tr	
Rubus chamaemorus		1		0.3	tr						tr	
Rumex arcticus										tr		

Table C3. Continued.

	Lime Application				Triple Phosphate Application				Reference			
	L1	L2	L3	Mean	T1	T2	T3	Mean	R1	R2	R3	Mean
Graminoids	17	20	31	22.7	35	25	19	26.3	21	13	20	18.0
Arctagrostis latifolia	1	2	tr	1.0	1	tr		0.3		2	Tr	0.7
Calamagrostis canadensis		4	2	2.0	tr	14	8	7.3		tr	1	0.3
Carex atrofusca										4		1.3
C. bigelowii	16	11	27	18.0	34	10	11	18.3	20	7	18	15.0
Eriophorum vaginatum		3	1	1.3							1	0.3
Hierochlöe pauciflora							tr					
Poa arctica		tr	1	0.3	tr	1		0.3	1	tr		0.3
Total Nonvascular Cover	2	3		1.7	1			0.3	3	1		1.3
Unknown moss	2	3		1.7	1			0.3	3	1		1.3