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Regeneration on Linear Developments Subject to Wildfires in a Zone of Continuous Permafrost

By

Catherine Jacobsen
EDI Environmental Dynamics Inc.

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EDI ENVIRONMENTAL DYNAMICS INC.
Natural Resource Consultants

REGENERATION ON LINEAR DEVELOPMENTS SUBJECT TO WILDFIRES IN A ZONE OF CONTINUOUS PERMAFROST

Prepared for:

MINING AND PETROLEUM ENVIRONMENTAL RESEARCH GROUP (MPERG)
Box 2703 (K102)
Whitehorse, Yukon
Y1A 2C6

Prepared by:

Catherine Jacobsen, M.Sc.
EDI ENVIRONMENTAL DYNAMICS INC.
407B Steele Street
Whitehorse, Yukon
Y1A 2C7

Phone: (867) 393-4882
Email: yukon@edynamics.com

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Regeneration on Linear Developments Subject to Wildfires in a Zone of Continuous Permafrost

Non-technical Summary

Seismic lines are a persistent feature in the North American boreal forest. Historically, methods of clearing seismic lines involved bulldozing linear, 6-8 m wide corridors through the landscape to allow for travel of geophysical crews and equipment. As a result, seismic lines have left a visible mark on the landscape. There is interest among First Nation and other governments, industry groups and NGO's in monitoring the long term response of vegetation to linear disturbances in order to better understand the ecological impacts of these disturbances. In order to gain a better understanding of re-vegetation on linear disturbances, it is also important to consider the influence of fire in this regeneration process. In northern boreal forests, fire is a recurring and influential factor in processes of vegetation regeneration and succession. Many vegetation species have been shown to regenerate rapidly following fire. Others, such as black spruce, regenerate after a delay of several to many years. Research into how vegetation in linear disturbances responds to wildfire contributes to our overall understanding of re-vegetation in these disturbances, and may also aid the development of Best Management Practices for seismic exploration.

The Study

The purpose of this study was to investigate the influence of fire on vegetation regeneration in several types of linear disturbances, including 30-year-old seismic lines, a one-year-old winter road leading to a test well site, and a portion of the same winter road constructed on a 30-year-old seismic line. The study took place in a black spruce-dominated forest in the zone of continuous permafrost in the area of Eagle Plains, YT. The study was conducted in the first year following a fire that burned the newly-constructed winter road and surrounding forest. The field component of the research included documenting all of the vegetation species present, and the abundance of these species, in burned and unburned linear disturbances and adjacent forests. Comparisons were made between vegetation within each type of linear disturbance and the adjacent forest, as well as between burned and unburned areas.

Results

Overall, the vegetation was highly uniform throughout the study area and among the different disturbance types. Fire had the greatest effect on vegetation, with a greater number of species present and more abundant vegetation in unburned sites. In burned sites, the dominant plant species found in the black spruce forest are re-generating rapidly across all disturbance types, likely from plants and below-ground sources that were not completely burned. This initial response suggests that vegetation characteristic of pre-fire conditions is likely to re-establish in the burned linear disturbances.

Of the three types of burned linear disturbances studied, the combined disturbance of the new winter road constructed on an existing seismic line had the greatest impact on vegetation regeneration in the first post-fire growing season. Vegetation was more abundant and a greater number of species were present in this combined disturbance type. It is possible that this disturbance did not burn as severely as

the adjacent forest as a result of having a lighter fuel load, allowing for immediate re-growth from preserved plants.

Because the study was completed in the first post-fire growing season, it was not possible to assess regeneration of black spruce, an important structural species that is not reported to begin re-establishing until several years after a burn. Similarly, it was also not possible to assess lichen regeneration, an important element of vegetation succession in black spruce forest that also re-establishes later than the first post-fire growing season. Continued monitoring will be required to understand the longer term response of vegetation to fire in linear disturbances.

ABSTRACT

With assistance from the Yukon Oil and Gas Branch, EDI Environmental Dynamics Inc. developed and submitted a proposal to the Mining and Petroleum Environmental Research Group (MPERG) to conduct a study of vegetation regeneration on linear developments subject to wildfires, specifically on and in the vicinity of the winter access road leading to test well site K-58, beginning in the first post-fire growing season. The study site was located in sub-arctic, black spruce (*Picea mariana*) dominated forest in a zone of continuous permafrost in the area of Eagle Plains, YT.

The study examined vegetation composition and abundance, as well as soil and permafrost conditions, in four types of linear disturbances, including: 1) burned 30+ year old seismic lines; 2) a burned one-year-old winter road; 3) the same burned one-year-old winter road constructed on an existing, 30+ year old seismic line, and; 4) unburned 30+ year old seismic lines. A total of 73 ($200m^2$) paired vegetation plots were completed within each of the above linear disturbances and adjacent forests.

Overall, the vegetation was highly uniform among all types of linear disturbances and undisturbed sites in the study area. Differences in species composition and abundance were most pronounced between the burned and unburned sites, with a greater number of species present and higher vegetation cover in unburned sites. Of the three types of linear disturbances sampled, the combined disturbance of the burned one year old winter road constructed on a 30+ year old seismic line demonstrated the most notable differences in vegetation composition and abundance in comparison with the adjacent forest. In contrast, species composition and abundance in the burned winter road and burned 30+ year old seismic line were more similar to that in adjacent, burned forests.

No trends in soil moisture were detected among the various disturbance types. Depth to permafrost was slightly lower in all three linear disturbances, but this difference was not significant. Depth of organic soil was significantly lower in the combined disturbance of the burned one year old winter road constructed on a 30+ year old seismic line, and was significantly higher in the burned winter road, when compared to adjacent, burned forests. Moss depth was significantly higher in unburned than burned sites.

In the first post-fire year, this recent burn appears to be the dominant factor affecting vegetation composition and abundance in the study area. Re-vegetation is occurring rapidly on linear disturbances, with the dominant vascular plant species in the unburned, undisturbed forest re-generating across all disturbance types. Because the study was completed in the first post-fire growing season, it was not possible to assess regeneration of black spruce, an important structural species that is not reported to begin to regenerate until several years after a burn. Similarly, it was also not possible to assess lichen re-establishment, an important element of vegetation succession in black spruce forest that also re-establishes later than the first post-fire growing season. Continued monitoring will be required to understand the longer term response of vegetation to fire in linear disturbances.

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1.0 INTRODUCTION

Seismic lines are a persistent feature in the North American boreal forest. Historically, methods of clearing seismic lines involved bulldozing linear, 6-8 m wide corridors through the landscape to allow for travel of geophysical crews and equipment. As a result, seismic lines have left a visible mark on the landscape. There is interest among First Nation and other governments, industry groups and NGO's in monitoring the long term response of vegetation to linear disturbances in order to better understand the ecological impacts of these disturbances, and to develop Best Management Practices to support long term re-vegetation.

In northern boreal forests, fire is a recurring and influential factor in processes of vegetation regeneration and succession. Fire impacts successional patterns and processes at multiple scales. At the landscape level, fire-induced deforestation is considered to have been responsible for a major shift from boreal forest to arctic tundra over the last 3000 years B.P. in sub-arctic Canada (Arsenault and Payette, 1992; Arsenault and Payette, 1997; Sirois and Payette, 1989). Landscape changes in the form of an increased transition of spruce-dominated stands to shrub-dominated landscapes in regions of continuous permafrost have also been observed and are predicted to continue in response to climate warming (Camill, 1999; Landhausser and Wein, 1993).

At the stand level, studies of post-fire regeneration of sub-arctic black spruce forests have identified several stages of development, marked largely by colonization and changes in the composition and abundance of lichen and moss species. Seminal studies of post-fire regeneration completed in the 1970's and 1980's indicate that vegetation is otherwise largely homogeneous, with no measurable differences in stages of development following a burn. Dominant vascular plants (shrubs and herbs) re-sprout and rapidly achieve pre-fire abundance and frequency. Black spruce seedling recruitment begins following a delay of 4 to 14 years, and spruce trees penetrate the canopy in a period beginning 15-20 years after a burn (Black and Bliss, 1978; Morneau and Payette, 1988; Sirois and Payette, 1989). More recent studies of post-fire vegetation regeneration in the far north suggest, however, that black spruce may decrease in abundance and range, and tall shrubs may increase in abundance and range, in response to a warming and drying climate (Landhausser and Wein, 1993).

Regeneration of linear disturbances in sub-arctic boreal regions must be considered in this context of fire, compounded by climate change, as a significant influence on the dynamics of vegetation regeneration. A number of studies have addressed the re-vegetation of seismic lines and other linear disturbances in the boreal forest and arctic tundra, without considering the influence of fire (see for example Magnusson and Stewart, 1987; Raynolds and Felix, 1989). Two recent studies have looked at post-fire re-vegetation of linear disturbances in black spruce forests in permafrost regions (Nowak, Kershaw and Kershaw, 2002; Seccombe-Hett and Walker Larson, 2004).

An opportunity to build on these studies of the interactions of fire with linear disturbances arose following the consecutive occurrence of winter road construction and wildfire in an area of past seismic disturbance in Eagle Plains, Yukon Territory. During late winter (February – April) 2005, Devon Energy Corp. constructed a 9.82 km long by 8 m wide ice/snow access road off of the Dempster Highway, approximately 33.5 km southwest of Eagle Plains (Figure 1). The winter road was used to access the K-58 test well site (UTM: 08 413100 7335136). A portion of the road (6.29 km) was constructed on two existing, 30-year-old seismic lines, while the remainder (3.53 km) was newly cut. During the summer of 2005, a wildfire burned the winter access road, well site and surrounding area.

With assistance from the Yukon Oil and Gas Branch, EDI Environmental Dynamics Inc. developed and submitted a proposal to the Mining and Petroleum Environmental Research Group (MPERG) to conduct a study of regeneration on linear developments subject to wildfires, specifically on and in the vicinity of the winter access road leading to test well site K-58, beginning in the first post-fire growing season.

The purpose of this study was to assess the impacts of former and recent linear developments in sub-arctic boreal conditions in a zone of continuous permafrost, and to investigate the effects of wildfires on these developments, including effects on vegetative re-growth, permafrost and soil conditions. More broadly, an additional goal of the study was to contribute to scientific understanding of the dynamics of succession on linear disturbances in order to contribute to the ongoing development of Best Management Practices in seismic exploration.

2.0 METHODS

2.1 Study Area

The study site was located in sub-arctic, black spruce (*Picea mariana*) dominated forest in a zone of continuous permafrost in the area of Eagle Plains, YT. The region is classified as part of the Taiga Cordillera Ecozone. This ecozone is characterized by a mean annual temperature of -6.5°C, with a summer mean of 10°C and a winter mean of -23.5°C. Mean annual precipitation ranges from 400 to 450 mm. The vegetation is dominated by open, often stunted stands of black spruce and tamarack with secondary amounts of white spruce. Ground cover includes dwarf birch, willow, ericaceous shrubs, cottongrass, lichen, and moss. Relief is low and the elevation ranges from 300 to 600 m above sea level. Wetlands cover 25-50% of the land area and consist of peat plateau bogs, palsa bogs, and ribbed and horizontal fens. Wildlife characteristic to the area includes caribou, moose, grizzly and black bear, wolf, red fox, snowshoe hare, spruce grouse, beaver, raven, osprey, and waterfowl (Environment Canada, 2005).

The study area encompassed the abovementioned winter access road leading to the K-58 test well site (UTM: 08 413100 7335136), including portions of the road constructed on existing seismic lines (cut in 1968 and 1972), and the newly winter cut road, both of which burned in 2005 (Figure 1). A burned portion of the seismic line not subject to road construction was also included in the study, as well as an unburned section of the same 1968 seismic line outside of the reach of the 2005 fire.

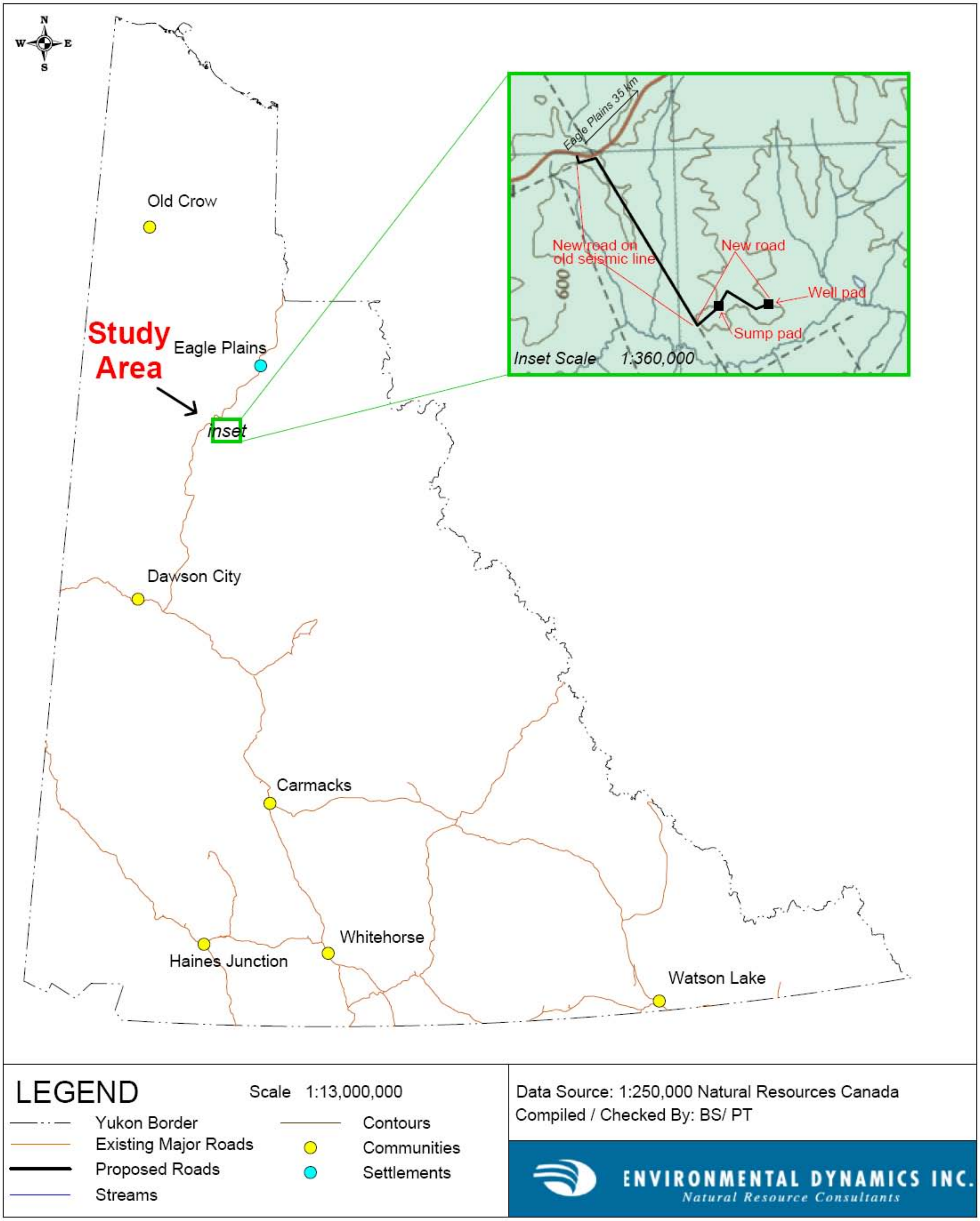


Figure 1. Study Area.

(UTM: 08 407073 7340841). Tan additional seismic line located parallel to the K-58 winter road was also sampled. Cut in 1972, this seismic line contained both unburned and burned sections resulting from the 2005 fire (UTM: 08 407466 7336721). Appendix 3 shows the locations of the seismic lines included in the study and the K-58 winter road.

2.2 Study Design and Sampling

The study examined vegetation composition and abundance, as well as soil and permafrost conditions, in four types of sites encompassing three forms of linear disturbance. These sites included: 1) burned 30+ year old seismic lines (CLB); 2) a burned one-year-old winter road (WRDB); 3) the same burned one-year-old winter road constructed on an existing seismic line (CLRDB), and; 4) unburned 30+ year old seismic lines (CLUB) (Table 1). A total of 73 vegetation plots (200 m^2 each) were completed (see Appendix 3 for plot locations). With the exception of three plots, these plots were paired (35 pairs + 3 unpaired plots). For every plot located within a linear disturbance, a second plot was completed in the adjacent forest, at least 50 metres away from the edge of the linear disturbance. Pairs of plots were located at randomly chosen sites along the linear disturbances, separated by 250 to 500 m. The unpaired plots included two additional, undisturbed, unburned plots adjacent to seismic lines, as well as one unburned seismic line + winter road plot. The initial intention of the research team was to carry out additional sampling of the latter disturbance type. However, reconnaissance of the K-58 winter road by helicopter following completion of this plot revealed almost no further, unburned areas along the length of the road. Thus, it was not possible to adequately sample this disturbance type.

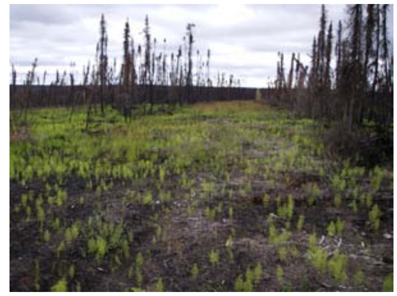
Within each plot, all plant species were identified. Lichens and mosses were also identified to species or genus. Abundance of individual species and total vegetation were estimated using an 8-point Braun-Blaunquet cover class scale[1] (Mueller-Dombois and Ellenberg, 1974). In each plot, slope, exposure, depth to permafrost, and depths of moss and organic soil were recorded. Depth to permafrost was recorded by pushing a 1.5 m length (9.5 mm diameter) of rebar down to refusal and measuring its submergence. Soil samples were also taken from the surface layers (A and B horizons) in each plot for later analysis of moisture content (by Norwest Labs in Surrey, BC).

[1] R=rare; +=few individuals; 1=numerous individuals but less than 5% cover; 2=5-10% cover; 3=11-25% cover; 4=26-50% cover; 5=51-75% cover; 6=75-100% cover. A value of 0.1 was substituted for R, and a value of 0.5 was substituted for + in mean cover class calculations.

Table 1. Description of types of sites sampled.

Site Grouping	**Characteristics of Site Grouping**	**Number of Plots**	**Photograph**
CLB	Burned seismic line	5	
ADJ CLB	Burned forest adjacent to burned seismic line	5	
CLRDB	Burned winter road constructed on existing seismic line	11	
ADJ CLRDB	Burned forest adjacent to burned winter road constructed on existing seismic line	11	

Table 1. Description of types of sites sampled, *continued...*

Site Grouping	Characteristics of Site Grouping	Number of Plots	Photograph
WRDB	Burned winter road	10	
ADJ WRDB	Burned forest adjacent to burned winter road	10	
CLUB	Unburned seismic line	8	
ADJ CLUB	Unburned forest adjacent to unburned seismic line (i.e. undisturbed forest)	11	
RDCLUB	Unburned road constructed on existing seismic line	1	--
ADJ RDCLUB	Unburned forest adjacent to unburned road constructed on existing seismic line	1	--

2.3 Analysis

Vegetation species composition was analyzed using the tabular methods developed by Braun-Blaunquet to determine patterns of association of species, and to identify the dominant site edaphic factors (Mueller-Dombois and Ellenberg, 1974).

Mean cover class values of the more common vegetation species (present in at least 10% of plots) were calculated for each site grouping listed in Table 1. Owing to the use of an ordinal cover class scale, and to the small sample sizes for each site grouping, the following non-parametric statistical analyses were employed to test for significant difference in cover class values. Kruskal-Wallis tests were used to test for a significant difference between mean cover class values among the site groupings. Post-hoc Mann-Whitney U tests were performed to identify significant differences between pairs of site groupings (i.e. sites within each linear disturbance vs. paired sites in the adjacent forest, and groups of burned and unburned plots) (SPSS, 2005). The site grouping RDCLUB described in Table 1 was not included in the analysis due to its limited sample size.

Mean moisture content, depth to permafrost, and depths of organic soil and moss were calculated for each site grouping. Data for all of these variables were non-normal. Kruskal-Wallis tests, followed by Mann-Whitney U tests, were again employed to detect significant differences among the eight site groupings and between paired site groupings for these variables (SPSS, 2005).

3.0 RESULTS

3.1 Vegetation Composition

Overall, species composition was highly uniform among all of the disturbance types and adjacent forest areas. Fourteen species were found in all types of sites, including the following shrubs: green alder (*Alnus crispa),* scrub birch *(Betula glandulosa),* trapper's tea *(Ledum decumbens),* Labrador tea *(Ledum groenlandicum),* willow *(Salix planifolia),* spirea *(Spiraea beauverdiana),* cloudberry *(Rubus chamaemorus),* and lingonberry *(Vaccinium vitis-idaea).* Several herbs were also among these fourteen common species, including: fireweed *(Epilobium angustifolium)* wood horsetail *(Equisetum sylvaticum),* and coltsfoot *(Petasites frigidus* ssp. *frigidus).* As well, one grass species, slimstem reedgrass (*Calamagrostis stricta),* one moss species, juniper haircap moss *(Polytrichum juniperinum),* and several lichens (*Cladina* sp.*)* were found in all types of sites (Table 2).

Additionally, seven species were found in more than 50% of plots, including many of the same shrubs and herbs: scrub birch (*B. glandulosa)*, trapper's tea (*L. decumbens)*, cloudberry (*R. chamaemorus)*, tea-leaved willow (*S. planifolia)*, lingonberry (*V. vitis-idaea),* wood horsetail *(E. sylvaticum),* fireweed *(E. angustifolium),* coltsfoot *(P. frigidus* ssp. *frigidus*), and slimstem reedgrass *(C. stricta*). Prickly rose *(Rosa acicularis)* and *Sphagnum* mosses were also present in over 50% of plots (Table 2).

Table 2. Percent frequency of occurrence of species in each type of site (burned and unburned linear disturbances and adjacent forest).

	Burned						Unburned		
	Undisturbed			Linear disturbance				Undisturbed	
	Adjacent to burned seismic line (ADJ CLB)	Adjacent to burned seismic line + winter road (ADJ CLRDB)	Adjacent to burned winter road (ADJ WRDB)	Burned winter road (WRDB)	Burned seismic line + winter road (CLRDB)	Burned seismic line (CLB)	Unburned seismic line (CLUB)	Adjacent to unburned seismic line (ADJ CLUB)	**ALL PLOTS**
Calamagrostis stricta	100	91	100	100	100	80	100	92	**96**
Salix planifolia	60	91	100	70	100	100	100	92	**90**
Betula glandulosa	80	100	90	70	91	80	100	92	**89**
Ledum decumbens	60	91	90	80	45	60	100	100	**79**
Rubus chamaemorus	60	100	80	100	36	40	50	100	**74**
Petasites frigidus ssp. *frigidus*	80	73	80	70	27	100	75	75	**68**
Vaccinium vitis-idaea	80	82	100	30	18	40	88	83	**66**
Ledum groenlandicum	80	82	100	60	18	100	63	25	**60**
Cladina sp.	20	45	20	50	9	40	75	67	**41**
Polytrichum juniperinum	80	45	30	30	18	60	38	17	**36**
Eriophorum vaginatum	60	100	40	70	9	20		50	**45**
Marchantia polymorpha	40	36	90	90	73	60	13		**49**
Ranunculus lapponicus		36	20	30	18			17	**18**
Spiraea beauverdiana	60	45	30	60	64	60	75	67	**58**
Vaccinium uliginosum	20	45	30	10	36		63	33	**32**
Equisetum sylvaticum	60	45	80	50	82	60	25	42	**56**
Epilobium angustifolium	60	36	20	90	91	100	25	17	**52**
Rosa acicularis	40	45	90	70	36		38	50	**51**
Alnus crispa	20	18	50	20	36	40	38	25	**32**
Sphagnum sp.		45	10	60	55	20	88	83	**51**
Salix glauca	20			30	9	40	13	33	**18**
Calamagrostis canadensis	20				73	40	25		**19**
Carex lugens					45		75		**15**
Equisetum arvense					36	40	25		**12**
Salix bebbiana	20				45		38		**12**
Stellaria sp.			10	10	27		13	8	**10**
Carex aquatilis					55		13		**10**
Epilobium palustre			10		45				**8**
Rumex sp.					9				**1**
Potentilla palustris					9				**1**
Carex rostrata					9				**1**
Caltha leptosepala					9				**1**
Senecio congestus					18				**3**
Eriophorum angustifolium					27				**4**
Picea mariana		9			18		88	100	**32**
Empetrum nigrum		9	10		9		75	50	**21**
Peltigera sp.							38	50	**14**

Table 2. Percent frequency of occurrence of species in each type of site (burned and unburned linear disturbances and adjacent forest)., *continued…*

	[----Burned----					]	[---Unburned---]		
	[---Undisturbed---		]	[---Linear disturbance---		]	[Undisturbed]		
	Adjacent to burned seismic line (ADJ CLB)	Adjacent to burned seismic line + winter road (ADJ CLRDB)	Adjacent to burned winter road (ADJ WRDB)	Burned winter road (WRDB)	Burned seismic line + winter road (CLRDB)	Burned seismic line (CLB)	Unburned seismic line (CLUB)	Adjacent to unburned seismic line (ADJ CLUB)	**ALL PLOTS**
Pleurozium schreberi							63	25	**12**
Cladonia sp.							13	50	**11**
Lycopodium clavatum							13		**1**
Andromeda polifolia							13		**1**
Lycopodium complanatum							13		**1**
Lycopodium annotinum							13		**1**
crustose lichens								8	**1**
Rubus idaeus							13		**1**
Arctostaphylos rubra							13		**1**
Pyrola chlorantha	60						13		**1**
Cladonia rugosa							13		**1**
Oxycoccus microcarpus							13	8	**3**
Rhytidium rugosum							13	17	**4**
Stereocaulon sp.							13		**3**
Rhytidiopsis robusta							38	17	**7**
Polytrichum commune					18	40	13	8	**8**
Polygonum alaskanum				10			13	8	**5**
Poa arctica			30			20			**5**
Equisetum fluviatile			10		18				**4**
Ribes lacustre	20		10						**3**
Viburnum edule			10						**1**
Poa glauca		9							**1**
Papaver lapponicum				10					**1**
Number of species present	23	23	27	24	38	22	44	32	**60**
Sample size	5	11	10	10	11	5	8	12	**72**

A total of 60 species were found overall. The greatest numbers of species were found in the unburned seismic line (CLUB, 44 sp.) and the burned seismic line + winter road (CLRDB, 38 sp.), followed by the unburned, undisturbed forest (ADJ CLUB, 32 sp.), the burned sites adjacent to the winter road (ADJ WRDB, 27 sp.), the burned sites adjacent to the other two linear disturbances (ADJ CLB and ADJ CLRDB, 23 sp.), and the burned seismic line (CLB, 22 sp.) (Table 2).

Slight differences in species composition were observed between burned and unburned treatments. A number of species were found exclusively in unburned plots, including several shrubs: bog cranberry (*Oxycoccus microcarpus),* kinnikinnik *(Arctostaphylos rubra),* red raspberry *(Rubus idaeus),* and bog rosemary *(Andromeda polifolia).* Several mosses (*Pleurozium schreberi, Rhytidium rugosum, Rhytidiopsis robusta*) club mosses (*Lycopodium clavatum, L. complanatum, L. annotinum),* and lichens *(Peltigera* sp., *Cladonia* sp., *Cladonia rugosa,* crustose lichens, *Stereocaulon* sp.*)* were also found only in unburned sites. However, the frequency of occurrence of these species was low (a number were found only once) (Figure 2, Table 2).

Two additional species were found more frequently in unburned sites than burned sites: black spruce *(Picea mariana)* and crowberry (*Empetrum nigrum).* In contrast, green-tongue liverwort *(Marchantia polymorpha)* was found frequently in burned sites, but was not found in unburned, undisturbed sites (ADJ CLUB), and was rare in unburned, disturbed sites (CLUB). Additionally, minimal presence of surviving black spruce was noted in burned sites, and no black spruce seedlings were found in these plots (Figure 2, Table 2).

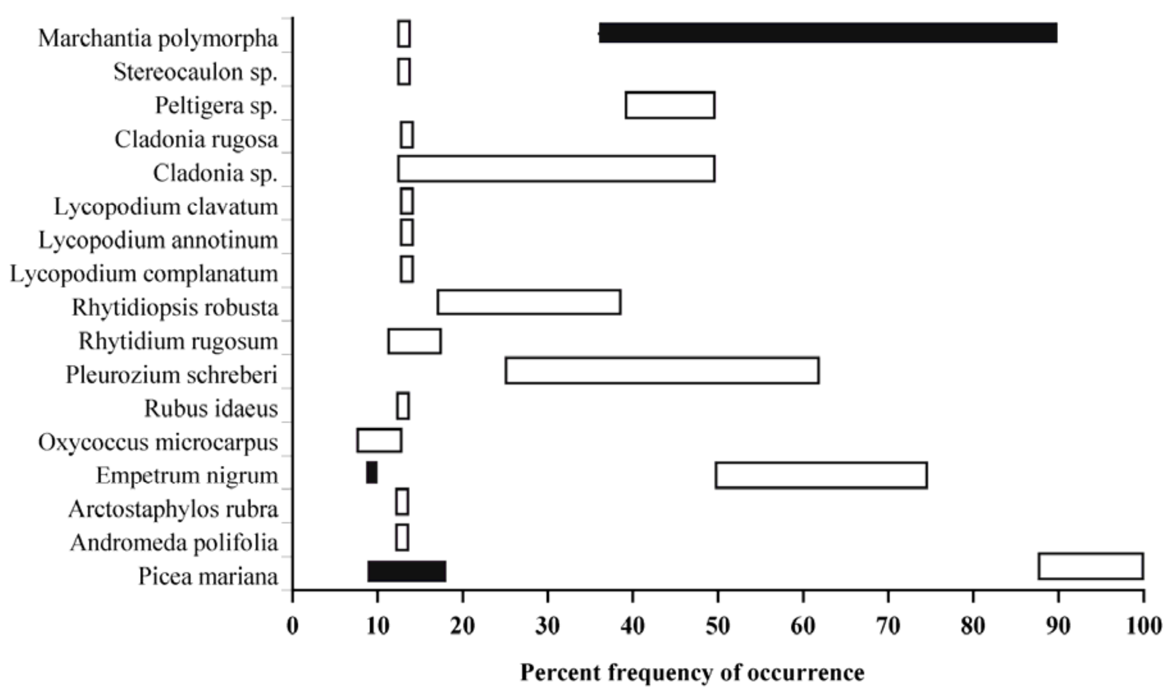


Figure 2. Range in percent frequency values of species found exclusively or more frequently in unburned than burned sites. Light bars indicate unburned sites (CLUB, ADJ CLUB) and dark bars indicate burned sites (CLB, ADJ CLB, WRDB, ADJ WRDB, CLRDB, ADJ CLRDB).

Disturbance types that included a seismic line (CLB, CLRDB, CLUB) showed slight differences in species composition in comparison with the adjacent forest and burned winter road sites. A number of species were found exclusively in seismic lines, including the burned and unburned seismic lines (CLB, CLUB), as well as the burned seismic line + winter road (CLRDB). These included the following shrubs: red bearberry (*A. rubra),* red raspberry *(R. idaeus),* bog rosemary *(A. polifolia),* and Bebb's willow *(Salix bebbiana)*. Several herbs were also found exclusively in these sites, including common horsetail *(Equisetum arvense),* marsh fleabane *(Senecio congestus),* marsh marigold *(Caltha leptosepala),* marsh cinquefoil *(Potentilla palustris),* and dock *(Rumex* sp.)*,* as well as several sedge species: beaked sedge *(Carex rostrata),* water sedge *(C. aquatilis),* spruce muskeg sedge *(C. lugens)* and narrow-leaved cottongrass *(Eriophorum angustifolium)*, and several club mosses *(L. annotinum, L. complanatum, L. clavatum).* However, the frequency of occurrence of most of these species was low (many occurred only once), with the exception of aquatic sedge (*C. aquatilis)* and spruce muskeg sedge (*C. lugens)*. Aquatic sedge (*C. aquatilis)* occurred in 55% of burned seismic line + winter road (CLRDB) sites, and spruce muskeg sedge (*C. lugens)* occurred in 45% of burned seismic line + winter road plots (CLRDB) and 75% of unburned seismic line (CLUB) plots (Figure 3, Table 2).

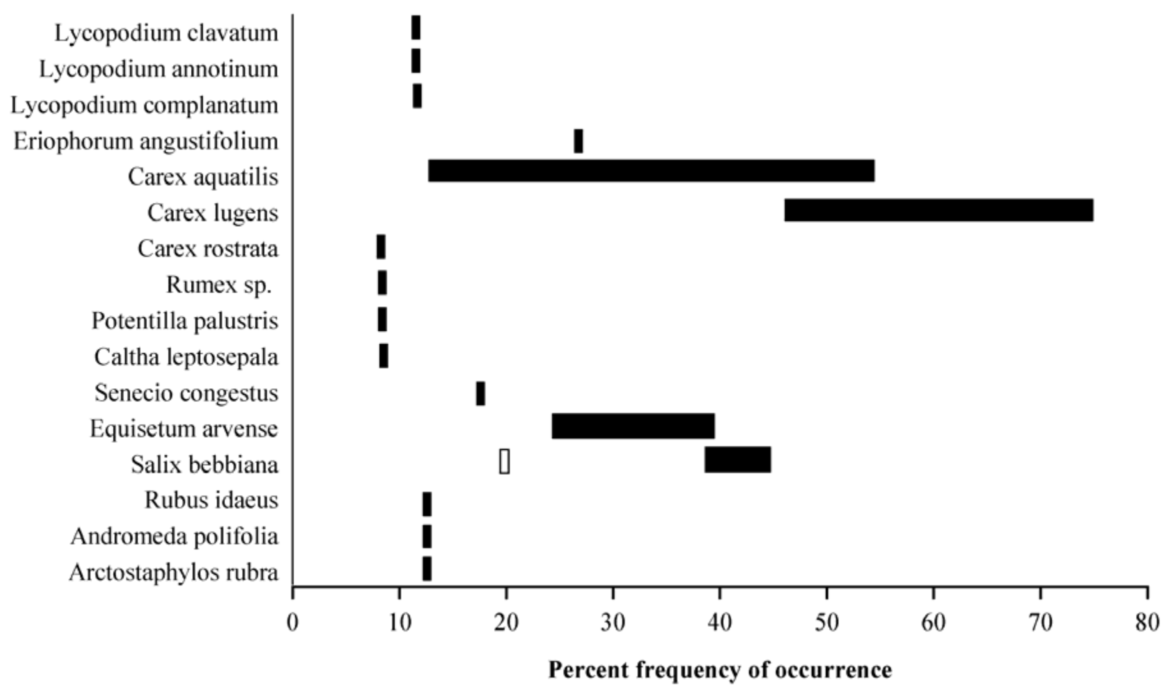


Figure 3. Range in percent frequency values of species found exclusively or more frequently in disturbance types that included a seismic line in comparison to other sites. Dark bars show disturbance types that include a seismic line (CLRDB, CLB, CLUB). Light bars show all other sites (ADJ CLRDB, ADJ CLB, ADJ CLUB, WRDB, ADJ WRDB).

Vegetation composition was similar in the burned winter road (WRDB) and the adjacent forest (ADJ WRDB). Virtually all species present in the burned winter road (WRDB) were also found in the adjacent, burned forest (ADJ WRDB), with the exception of Lapland poppy (*Papaver lapponicum),* wild rhubarb *(Polygonum alaskanum)* and grey-leaved willow *(Salix glauca),* which were found only in the winter road (WRDB), and swamp willowherb (*Epilobium palustre)*, crowberry (*Empetrum nigrum)*, arctic bluegrass (*Poa arctica)*, swamp horsetail (*Equisetum fluviatile)*, black gooseberry (*Ribes lacustre)* and highbush cranberry (*Viburnum edule)*, which were found only in the adjacent forest. However, these species all occurred with extremely low frequency (Table 2).

3.2 Vegetation Abundance

Total vegetation cover was highest in the unburned, undisturbed sites (ADJ CLUB, 5.9 mean cover class) and the burned seismic line + winter road sites (CLRDB, 5.1 mean cover class), followed by the unburned seismic lines (CLUB, 3.8 mean cover class), burned seismic lines (CLB, 3.4 mean cover class), and the burned sites adjacent to the latter two disturbances (ADJ CLUB, 2.3 mean cover class; ADJ CLB; 2.6 mean cover class). Mean cover values were similar for the burned winter road (WRDB, 2.2 mean cover class) and adjacent plots (ADJ WRDB, 1.9 mean cover class) (Table 3).

Overall, the most abundant species in the study area (≥1.0 mean cover class) included slimstem reedgrass (*Calamagrostis stricta)*, scrub birch (*Betula glandulosa)*, trapper's tea (*Ledum decumbens)*, tea-leaved willow (*Salix planifolia)*, swamp horsetail (*Equisetum sylvaticum),* and *Sphagnum* mosses. These were followed by several other shrub species, including cloudberry (*Rubus chamaemorus)*, lingonberry (*Vaccinium vitis-idaea)*, coltsfoot (*Pedasites frigidus* ssp. *frigidus),* and lichens of the genus *Cladina* (≥0.7 mean cover class). Numerous species present in the study area were rare or represented by few individuals, resulting in low mean cover values (≤0.5 mean cover class).

In addition to the abovementioned species, dominant vegetation (≥0.8 mean cover class) in the unburned, undisturbed areas (ADJ CLUB) included black spruce (*Picea mariana)*, spirea (*Spiraea beauverdiana),* and a well-developed ground cover of lichens (*Cladina* sp., *Cladonia* sp.) and mosses (*Pleurozium schreberi*, *Sphagnum* sp.). In unburned, disturbed areas (CLUB), many of the same species were abundant (≥0.8 mean cover class), including the following shrubs: trapper's tea (*L. decumbens)*, cloudberry (*R. chamaemorus)*, lingonberry (*V. vitis-idaea)*, scrub birch (*B. glandulosa)*, spirea (*S. beauverdiana)*, tea-leaved willow (*S. planifolia)*, bog blueberry (*Vaccinium uliginosum),* Labrador tea *(Ledum groenlandicum)*, and crowberry (*Empetrum nigrum).* Coltsfoot (*P. frigidus* ssp. *frigidus)*, slimstem reedgrass (*C. stricta)*, sphagnum mosses (*Sphagnum* spp.) and lichens (*Cladina* spp.) were also abundant (≥0.8 mean cover class).

Within the burned winter road (WRDB), slimstem reedgrass (*C. stricta)*, cloudberry (*R. chamaemorus)*, wood horsetail (*E. sylvaticum)*, green-leaved liverwort (*M. polymorpha)* and sphagnum mosses (*Sphagnum* spp.) were present with the greatest cover (≥0.8 mean cover class).

Table 3. Mean cover class for species in each site grouping (burned and unburned linear disturbances and adjacent forest).

	Burned seismic line (CLB)	Adjacent to burned seismic line (ADJ CLB)	Burned seismic line + winter road (CLRDB)	Adjacent to burned seismic line + winter road (ADJ CLRDB)	Burned winter road (WRDB)	Adjacent to burned winter road (ADJ WRDB)	Unburned seismic line (CLUB)	Adjacent to unburned seismic line (ADJ CLUB)	**Total (all plots)**
Ledum decumbens	0.4	0.8	0.2	1.0	0.6	1.0	2.4	2.6	**1.2**
Rubus chamaemorus	0.3	0.8	0.2	1.0	1.0	0.8	0.8	1.3	**0.8**
Petasites frigidus ssp. frigidus	1.0	0.6	0.4	0.6	0.6	0.7	0.9	0.8	**0.7**
Vaccinium vitis-idaea	0.2	0.7	0.1	0.6	0.1	0.5	1.8	1.8	**0.7**
Ledum groenlandicum	0.5	0.8	0.1	0.7	0.4	0.8	1.0	0.3	**0.5**
Cladina sp.	0.1	0.2		0.4	0.4	0.1	1.9	1.8	**0.7**
Eriophorum vaginatum	0.4	0.8	0.1	1.2	0.6	0.6		0.5	**0.5**
Marchantia polymorpha	0.5	0.8	0.7	0.5	0.9	0.9	0.1		**0.5**
Equisetum sylvaticum	1.2	1.0	1.2	0.6	1.1	1.4	0.3	0.8	**1.0**
Epilobium angustifolium	0.6	0.6	0.7	0.2	0.6	0.2	0.3	0.1	**0.4**
Rumex sp.			0.1						**0.0**
Carex rostrata			0.2						**0.0**
Caltha leptosepala			0.1						**0.0**
Senecio congestus			0.1						**0.0**
Eriophorum angustifolium			0.3						**0.0**
Calamagrostis canadensis	0.3	0.2	1.7				0.4		**0.3**
Carex lugens			0.7				0.6		**0.2**
Equisetum arvense	0.8		0.5				0.4		**0.2**
Salix bebbiana			0.3				0.3		**0.0**
Polytrichum commune	0.4		0.3				0.3	0.3	**0.2**
Stellaria sp.			0.3		0.1	0.1	0.1		**0.1**
Carex aquatilis			1.4				0.1		**0.2**
Epilobium palustre			0.5						**0.1**
Sphagnum sp.	0.2		0.9	0.5	0.8	0.1	2.6	2.0	**1.0**
Picea mariana							1.9	2.1	**0.6**
Empetrum nigrum							1.5	0.6	**0.3**
Peltigera sp.							0.4	0.7	**0.2**
Pleurozium schreberi							1.5	0.8	**0.3**
Cladonia sp.							0.3	0.9	**0.2**
Lycopodium clavatum							0.3		**0.0**
Andromeda polifolia							0.3		**0.0**
Lycopodium complanatum							0.1		**0.0**
Lycopodium annotinum							0.1		**0.0**
crustose lichens								0.2	**0.0**
Rubus idaeus							0.1		**0.0**
Arctostaphylos rubra							0.1		**0.0**
Pyrola chlorantha							0.1		**0.0**
Cladonia rugosa							0.3		**0.0**
Oxycoccus microcarpus							0.1		**0.0**
Rhytidium rugosum							0.1	0.2	**0.0**

Table 3. Mean cover class for species in each site grouping (burned and unburned linear disturbance and adjacent forest), *continued...*

	Burned seismic line (CLB)	Adjacent to burned seismic line (ADJ CLB)	Burned seismic line + winter road (CLRDB)	Adjacent to burned seismic line + winter road (ADJ CLRDB)	Burned winter road (WRDB)	Adjacent to burned winter road (ADJ WRDB)	Unburned seismic line (CLUB)	Adjacent to unburned seismic line (ADJ CLUB)	**Total (all plots)**
Stereocaulon sp.							0.3		**0.0**
Rhytidiopsis robusta							0.6	0.3	**0.1**
Calamagrostis stricta	1.4	1.3	2.5	1.4	1.2	1.3	1.3	0.8	**1.4**
Salix planifolia	1.4	0.4	2.2	0.7	0.5	0.7	1.9	1.3	**1.2**
Betula glandulosa	1.0	0.6	1.3	1.0	0.4	0.7	2.6	2.3	**1.3**
Spiraea beauverdiana	0.6	0.4	0.6	0.3	0.2	0.2	0.8	1.0	**0.5**
Vaccinium uliginosum		0.1	0.1	0.2	0.1	0.2	0.9	0.4	**0.2**
Rosa acicularis		0.2	0.2	0.4	0.4	0.8	0.4	0.4	**0.4**
Alnus crispa	0.6	0.1	0.1		0.1	0.3	0.4	0.4	**0.2**
Polytrichum juniperinum	0.6	0.8	0.3	0.5	0.3	0.3	0.5	0.5	**0.4**
Salix glauca	0.2	0.1	0.1				0.1	0.3	**0.1**
Ranunculus lapponicus			0.1	0.2	0.2	0.2		0.1	**0.1**
Polygonum alaskanum					0.1				**0.0**
Poa arctica	0.2								**0.0**
Equisetum fluviatile			0.5			0.1			**0.1**
Total Veg. Cover	3.4	2.6	5.1	2.3	2.2	1.9	3.8	5.9	**3.5**
Sample size (# of plots)	5	5	11	11	10	10	8	12	**72**

The most abundant species (≥1.2 mean cover class) in the burned seismic line + winter road (CLRDB) included slimstem reedgrass (*C. stricta)* and bluejoint (*C. Canadensis),* the shrubs tea-leaved willow *(S. planifolia)* and scrub birch *(B. glandulosa),* water sedge *(C. aquatilis)*, and wood horsetail (*E. sylvaticum)*. In the burned seismic lines (CLB), slimstem reedgrass (*C. stricta)*, tea-leaved willow (*S. planifolia),* wood horsetail (*E. sylvaticum)*, common horsetail (*E. arvense)*, scrub birch (*B. glandulosa)*, and coltsfoot (*P. frigidus* ssp. *frigidus)* were most abundant (≥0.8 mean cover class). In burned, undisturbed areas (ADJ CLB, ADJ WRDB, ADJ CLRDB), the most abundant species included many of those listed above (trapper's tea, Labrador tea, cloudberry, scrub birch, prickly rose, slimstem reedgrass, green-leaved liverwort and wood horsetail), as well as sheathed cottongrass (*E. vaginatum*) and juniper haircap moss (*P. juniperinum*) (≥0.8 mean cover class). As the above paragraphs reveal, a number of species were relatively abundant in all of the disturbance types. However, cover of some of these species differed between the linear disturbances and the adjacent forest, and between burned and unburned sites.

Mean cover class of ten species differed significantly between plots in the burned, seismic line + winter road (CLRDB) and the adjacent, burned forest (ADJ CLRDB). Species with significantly higher cover in the burned seismic line + winter road (CLRDB) included two grasses, bluejoint (*C. canadensis)* and slimstem reedgrass (*C. stricta*), tea-leaved willow (*S. planifolia*), fireweed

Table 4. Difference in mean cover class values of species in different types of disturbed and undisturbed sites.

Direction of difference	Species	Significance
Higher in burned seismic line + winter road than in adjacent burned forest (CLRDB vs. ADJ CLRDB)	*Calamagrostis canadensis*	Mann Whitney U=16.500, p<0.005
	Sphagnum sp.	Mann Whitney U=22.000, p<0.035
	Epilobium angustifolium	Mann Whitney U=22.500, p<0.010
	Calamagrostis stricta	Mann Whitney U=15.000, p<0.002
	Salix planifolia	Mann Whitney U=2.500, p<0.000
	Total Vegetation Cover	Mann Whitney U=7.000, p<0.000
Lower in burned seismic line + winter road than adjacent burned forest (CLRDB vs. ADJ CLRDB)	*Ledum decumbens*	Mann Whitney U=8.000, p<0.000
	Rubus chamaemorus	Mann Whitney U=8.000, p<0.000
	Vaccinium vitis-idaea	Mann Whitney U=18.000, p<0.004
	Ledum groenlandicum	Mann Whitney U=15.000, p<0.002
	Eriophorum vaginatum	Mann Whitney U=5.000, p<0.000
Higher in burned winter road than in adjacent burned forest (WRDB vs. ADJ WRDB)	*Epilobium angustifolium*	Mann Whitney U=17.500, p<0.011
Lower in burned winter road than in adjacent burned forest forest (WRDB vs. ADJ WRDB)	*Vaccinium vitis-idaea*	Mann Whitney U=6.000, p<0.000
	Ledum groenlandicum	Mann Whitney U=17.000, p<0.011
	Betula glandulosa	Mann Whitney U=22.500, p<0.035
Higher in burned seismic lines than in adjacent forest (CLB vs. ADJ CLB)	*Salix planifolia*	Mann Whitney U=1.500, p<0.016
Higher in unburned seismic lines than in adjacent unburned forest (CLUB vs. ADJ CLUB)	*Carex lugens*	Mann Whitney U=12.000, p<0.004
Higher in unburned seismic lines than in burned seismic lines (CLUB vs. CLB & CLRDB)	*Ledum decumbens*	Mann Whitney U=1.000, p<0.003
	Vaccinium vitis-idaea	Mann Whitney U=3.500, p<0.011
	Carex lugens	Mann Whitney U=5.000, p<0.03
	Sphagnum sp.	Mann Whitney U=3.500, p<0.011
	Picea mariana	Mann Whitney U=2.500, p<0.006
	Empetrum nigrum	Mann Whitney U=5.000, p<0.03
	Betula glandulosa	Mann Whitney U=3.000, p<0.011
Higher in undisturbed, unburned than in undisturbed, burned sites (ADJ CLUB vs. ADJ CLB, ADJ CLRDB & ADJ WRDB)	*Ledum decumbens*	Mann Whitney U=2.500, p<0.001
	Vaccinium vitis-idaea	Mann Whitney U=10.500, p<0.037
	Sphagnum sp.	Mann Whitney U=5.000, p<0.006
	Picea mariana	Mann Whitney U=0.000, p<0.000
	Salix planifolia	Mann Whitney U=9.000, p<0.027
	Betula glandulosa	Mann Whitney U=5.500, p<0.006
	Cladina sp.	Mann Whitney U=26.000, p<0.025
	Total Vegetation Cover	Mann Whitney U=0.000, p<0.000
Higher in undisturbed, burned than in undisturbed, unburned sites (ADJ CLB, ADJ CLRDB & ADJ WRDB vs. ADJ CLUB)	*Marchantia polymorpha*	Mann Whitney U=6.000, p<0.000

(*E. angustifolium*), and *Sphagnum* mosses. Total vegetation cover was also significantly higher in the burned seismic line + winter road (CLRDB) than in the adjacent, burned forest (ADJ CLRDB) (Table 4).

Species with significantly lower cover in the burned seismic line + winter road (CLRDB) than in the adjacent, burned forest (ADJ CLRDB) included the shrubs trapper's tea (*L. decumbens)*, cloudberry (*R. chamaemorus)*, lingonberry (*V. vitis-idaea)*, and Labrador tea (*L. groenlandicum)*, as well as sheathed cottongrass (*E. vaginatum*) (Table 4).

With a few exceptions, the abundance of vegetation species was similar between the burned winter road (WRDB) and the adjacent, burned forest (ADJ WRDB). Fireweed (*E. angustifolium)* was significantly higher in cover in the burned winter road (WRDB). As well, the shrubs lingonberry (*V. vitis-idaea)*, Labrador tea (*L. groenlandicum)* and scrub birch (*B. glandulosa*) were significantly lower in cover in the adjacent, burned forest (ADJ WRDB) (Table 4).

Mean cover class of tea-leaved willow (*S. planifolia)*, was significantly higher in the burned seismic lines (CLB) than the adjacent, burned forest (ADJ CLB). Mean cover class of spruce muskeg sedge (*C. lugens)* was significantly higher in unburned seismic lines (CLUB) than the adjacent, unburned forest (ADJ CLUB), and was also significantly higher in unburned seismic lines (CLUB) than in burned seismic lines (CLB) (Table 4).

Cover of a number of species was significantly higher in unburned plots, including both disturbed and undisturbed sites. These included black spruce (*Picea mariana)*, several shrubs (crowberry, scrub birch, trapper's tea, and lingonberry), and *Sphagnum* mosses (Table 4).

Lichens (*Cladina sp.)* had significantly higher cover in unburned, undisturbed sites than in burned, disturbed sites, as did total vegetation cover. One liverwort species, *M. polymorpha,* had significantly higher cover in undisturbed, burned sites than in undisturbed, unburned sites (Table 4).

3.3 Soil Moisture

Soil moisture was variable among the plots and within site groupings, with values ranging from 13.3% to 86.7%. Mean soil moisture ranged from 41.5% in sites adjacent to the burned winter road to 67.4% in sites adjacent to unburned seismic lines. No significant difference was found in mean soil moisture between linear disturbances and adjacent sites, or between burned and unburned sites (Figure 4).

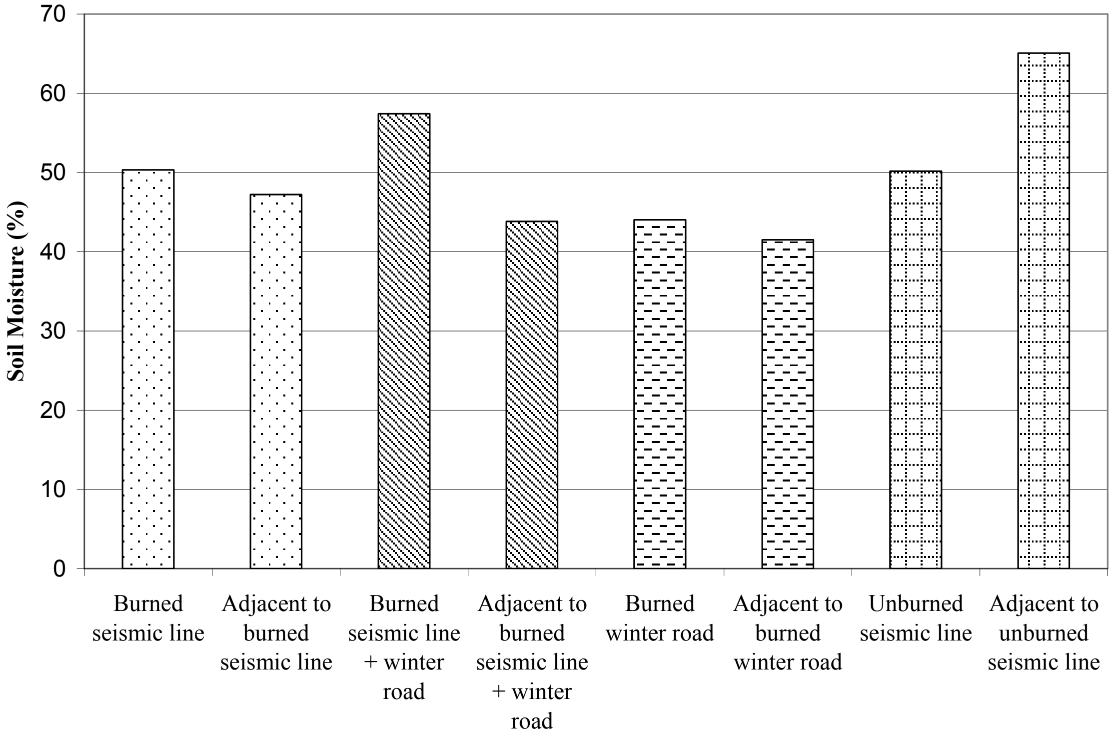


Figure 4. Mean percent soil moisture in burned and unburned linear disturbances and adjacent forest sites.

3.4 Depth to Permafrost

Depth to permafrost ranged from 0.25 m in an unburned, undisturbed plot, to 1.04 m in a burned seismic line plot. Mean depth to permafrost ranged from 0.35 m in sites adjacent to burned seismic lines to 0.57 m in the burned seismic lines. Although the mean depth to permafrost was lower in all three burned linear disturbances than in adjacent sites, these differences were not found to be significant (Figure 5).

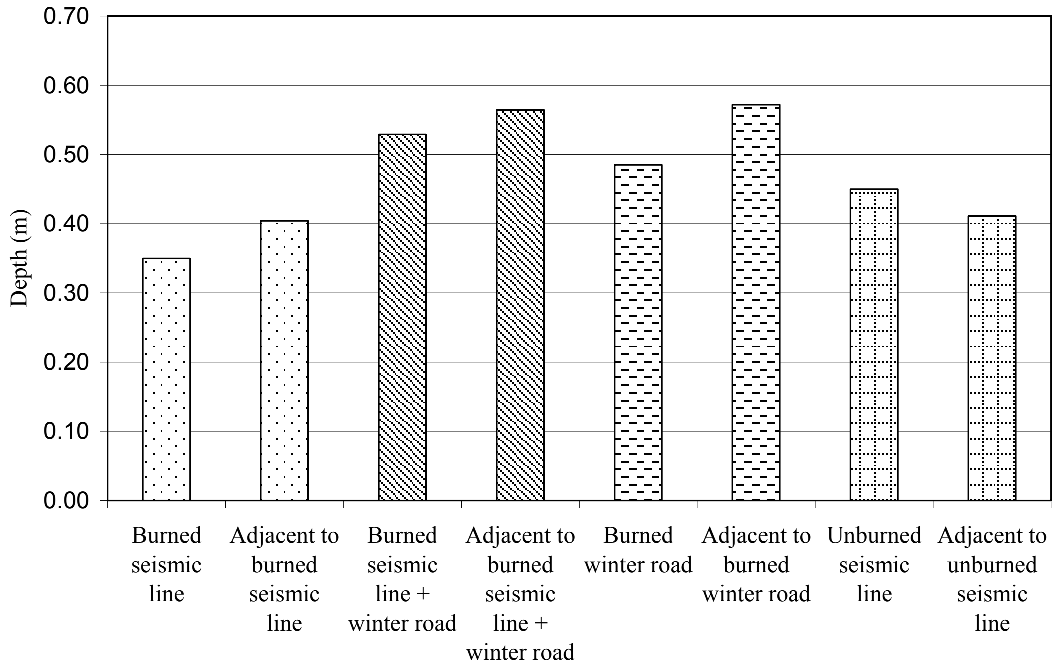


Figure 5. Mean depth to permafrost in burned and unburned linear disturbances and adjacent forest sites.

3.5 Depth of Organic Soil

Depth of organic soil ranged from 0.0 cm in a seismic line + winter road plot, to 35 cm in an unburned seismic line plot. Mean depth of organic soil ranged from 4.8 cm in the burned seismic line + winter road sites, to 21.1 cm in the winter road sites. Soil depth in the burned seismic line + winter road was significantly lower than the adjacent, burned forest (Mann Whitney U=3.000, p<0.000). Although soil depth was also lower in the burned seismic lines than in the adjacent, burned forest, this difference was not found to be significant. Soil depth in the burned winter road was significantly higher than in the adjacent, burned forest (Mann Whitney U=16.000, p<0.017). No significant differences were found between other linear disturbances and their adjacent plots, or between burned and unburned site groups (Figure 6).

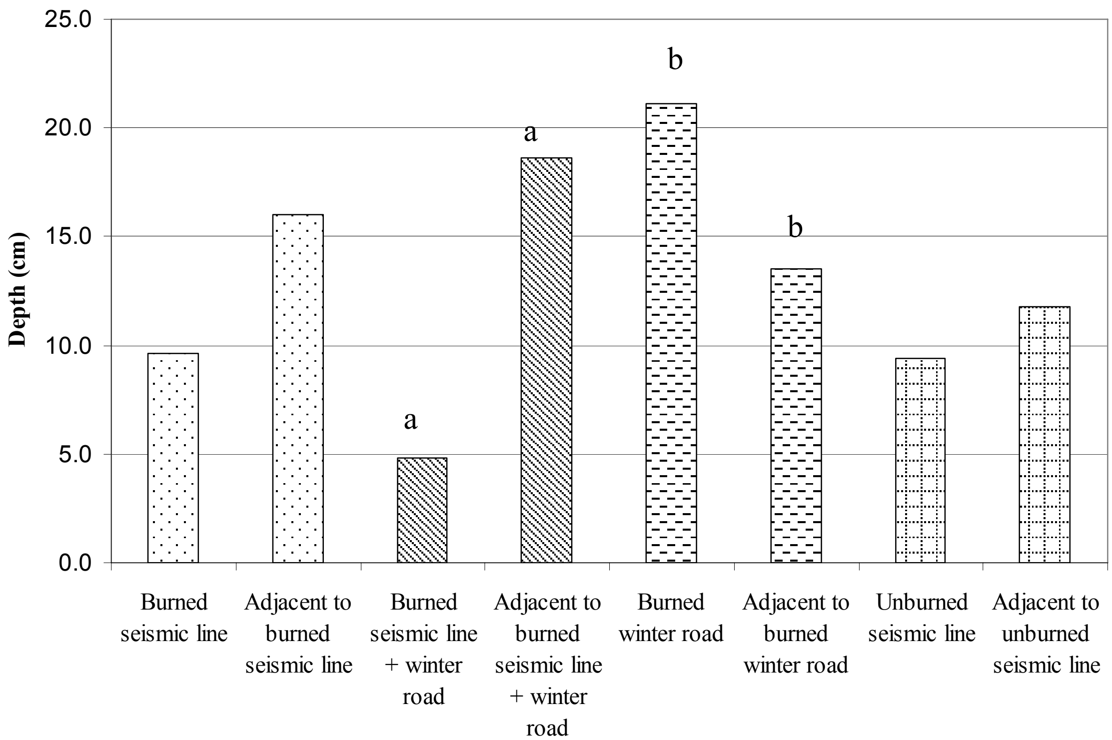


Figure 6. Mean soil depth in burned and unburned linear disturbances and adjacent forest. Values labelled with "a" are significantly different from each other (Mann Whitney U=3.000, p<0.000), as are values labelled "b" (Mann Whitney U=16.000, p<0.017).

3.6 Moss Depth

Moss depth ranged from 0 to 10 cm in the various plots. No significant differences were found between moss depth in burned and unburned linear disturbances and their adjacent sites. However, mean moss depth was significantly higher in one group of unburned, undisturbed plots (adjacent to seismic lines) than in burned, undisturbed plots (adjacent to seismic lines) (Figure 7). Although moss depth was also higher in burned seismic lines and burned seismic line + winter road sites than in adjacent forest, these differences were not found to be significant.

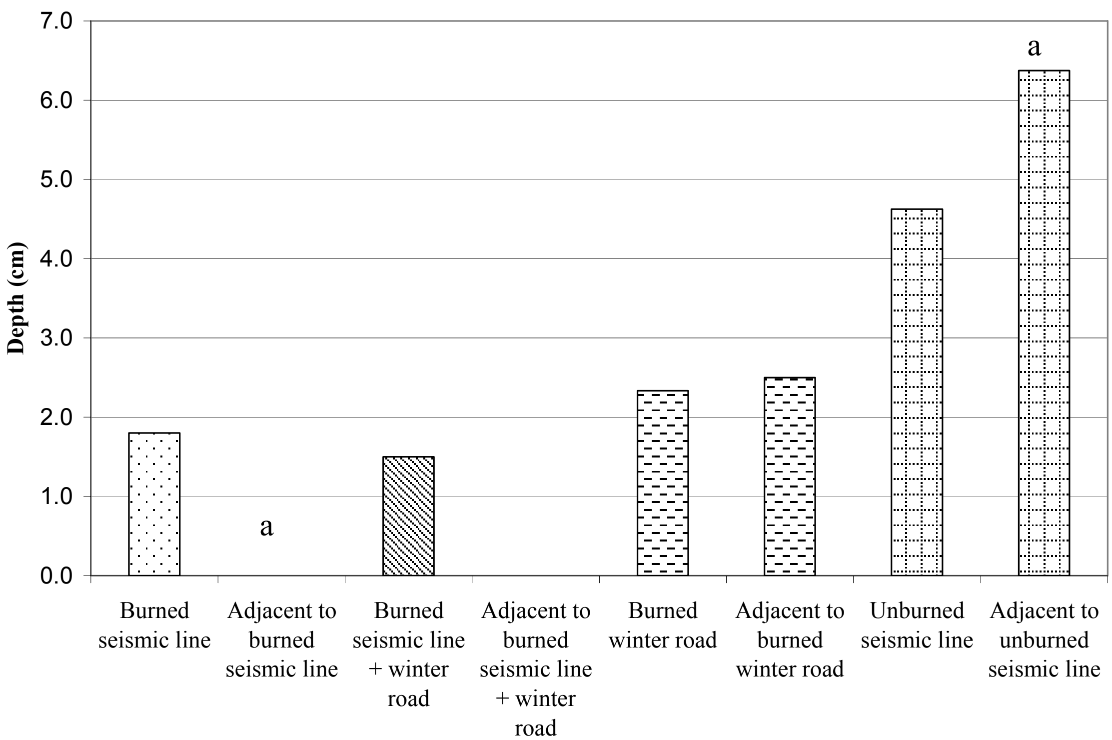


Figure 7. Mean moss depth in burned and unburned linear disturbances and adjacent forest sites. Values labeled “a” are significantly different (Mann Whitney U=0.000, p<0.002).

4.0 DISCUSSION

In the first year following the burn, re-vegetation is occurring rapidly on linear disturbances, as is typical of post-fire regeneration in this ecosystem. Fire in permafrost terrain does not usually penetrate the soil, although it is hot enough to destroy trees. As a result, regeneration occurs rapidly via vegetative propagation from preserved below-ground sources and surviving seeds (Black and Bliss, 1978; Nowak, Kershaw and Kershaw, 2002). The dominant vascular plant species in the unburned, undisturbed forest are re-generating across all disturbance types. Typical colonizing plants, including willows (*Salix* spp.), scrub birch (*Betula glandulosa)*, grasses (*Calamagrostis* sp.), horsetails (*Equisetum* sp.), the liverwort *Marchantia polymorpha,* and the moss *Polytrichum juniperinum*, are relatively abundant in burned areas.

Succession in sub-arctic black spruce forests is characterized not by these vascular plant species, but by the progressive development of lichen and moss species assemblages (Black and Bliss, 1978; Morneau and Payette, 1988). In this study, a number of lichen species (*Cladonia* sp., *Peltigera* sp., and crustose lichens) were found exclusively in unburned areas, and others (*Cladina* sp.) were found in greater abundance and depth in unburned, undisturbed areas. The relatively limited presence and abundance of lichens in burned and disturbed sites is not surprising, given documented patterns of post-fire vegetation succession in black spruce forests. For example, Black and Bliss (1978) have reported that recovery of *Cladonia* and *Peltigera* lichens does not begin until 15-20 years after fire, and that abundance of *Cladina* lichens does not reach a peak until decades later. Thus, regeneration of the lichen layer in burned and disturbed sites in the study area is to be expected, but at a later stage than this first post-fire growing season.

Another notable difference between burned and unburned sites is the absence of black spruce seedlings in burned areas. This is not surprising, however, given the documented delay times for post-fire seedling recruitment of between 4 and 14 years (Black and Bliss, 1978; Seccombe-Hett and Walker-Larson, 2004). Given that this study was completed in the first post-fire growing season, it remains to be seen how regeneration of spruce seedlings will compare between burned linear disturbances and the adjacent forest. Seccombe-Hett and Walker-Larson (2004) found rates of black spruce seedling establishment in burned areas to be similar in seismic lines and the adjacent forest, suggesting that post-fire regeneration on linear disturbances in this study area is also to be expected. They also posed the question of whether fire re-sets regeneration conditions for black spruce on linear disturbances, and concluded that fire does not improve or diminish conditions for seedling recruitment, in comparison to unburned areas, because seismic lines do not consistently burn. Of note, they also concluded that post-fire seedling establishment improves for seismic lines greater than 20 years old, possibly due to higher fuel loads (resulting in more complete burning) and stabilization of abiotic factors in these older clearings.

It remains to be seen how fire will affect spruce regeneration in this study site. However, the response of this dominant tree species is a significant component of vegetation regeneration in linear disturbances, since black spruce is considered to be the distinguishing feature between boreal forest and boreal shrub-heath communities that otherwise demonstrate considerably homogeneity in species composition (Arsenault and Payette, 1992). Thus, assessment of regeneration in linear disturbances subject to wildfires is incomplete without examination of long term black spruce regeneration, something that was not possible in this study in the first growing season after the fire.

With respect to understory vegetation, previous studies of post-fire regeneration in linear disturbances have emphasized pre- and post-fire similarities in floristic composition, while highlighting differences in abundance (Nowak, Kershaw and Kershaw, 2002; Seccombe-Hett and Walker-Larson, 2004). The relative homogeneity of vegetation across burned and unburned linear disturbances and adjacent forests in this study area re-enforces these previous findings regarding floristic composition.

In this study, the greatest differences in species composition and abundance were observed between the burned 30+ year old seismic line + winter road (CLRDB) and the adjacent burned forest (ADJ CLRDB). A number of vascular plant species were found only in the burned 30+ year old seismic line + winter road (CLRDB), although rarely. More importantly, this combined disturbance type (fire + seismic line + winter road) exhibited higher total plant cover, higher cover of a number of vascular plant species, in particular grasses and willows, and higher cover of sphagnum moss, in comparison to the adjacent forest. This is consistent with findings of Nowak, Kershaw and Kershaw (2002), who noted that the most disturbed sites re-vegetated most rapidly following fire, with the highest species diversity and plant cover. They attributed this response to the lower fuel loads in disturbed areas that resulted in greater patchiness of the fire, allowing for immediate propagation from preserved seeds and plants.

Previous studies of linear disturbances (not compounded by fire) have also noted changes in species abundance, but not in species composition, between the disturbance and adjacent forest. Willows and grasses, in particular, are more abundant on seismic lines (Seccombe-Hett and Walker-Larson, 2004). Similarly, in this study, the willow, *Salix planifolia,* was significantly more abundant in both the burned seismic line (CLB) and the burned seismic line + winter road (CLRDB) than in the adjacent forest (ADJ CLB and ADJ CLRDB). The grasses, slimstem reedgrass (*Calamagrostis stricta)* and bluejoint (*C. canadensis),* were also significantly more abundant on the burned seismic line + winter road (CLRDB) than in the adjacent forest (ADJ CLRDB).

Additionally, two sedge species were abundant in the burned seismic line + winter road (CLRDB) and in the unburned seismic lines (CLUB): water sedge (*Carex aquatilis)* and spruce muskeg sedge (*C. lugens).* Water sedge, in particular, has been associated with disturbed stands that exhibit closeness to mineral substrate (Magnusson and Stewart, 1987). In this study, occurrences of these species were also associated with sites exhibiting the lowest organic soil depths of all site groupings.

Two shrubs dominant in the black spruce woodland, Labrador tea (*Ledum groenlandicum)* and lingonberry (*Vaccinium vitis-idaea)*, were significantly reduced in cover in the burned seismic line + road (CLRDB). These same shrubs were also less abundant on the burned winter road (WRDB) than in the adjacent forest (ADJ WRDB). Similar decreases in abundance of Labrador tea and lingonberry have been noted in previous studies of linear disturbance (Magnusson and Stewart, 1987; Seccombe-Hett and Walker-Larson 2004).

Differences between burned seismic lines (CLB) and the adjacent forest, and between unburned seismic lines (CLUB) and the adjacent forest, were less pronounced than differences between the combined disturbance of the burned seismic line + winter road (CLRDB) and the adjacent forest. With respect to species composition, some species were present in burned and unburned seismic lines but not in adjacent plots, but these were rare occurrences. Additionally, the only species that differed significantly in cover was tea-leaved willow (*Salix planifolia)*, which was more abundant in the burned seismic line than the adjacent forest.

Differences between the burned winter road (WRDB) and adjacent forest were also less pronounced than the differences between the combined disturbance of the burned seismic line + winter road (CLRDB) and the adjacent forest. With the exception of the shrubs mentioned above, species composition and abundance were similar in the burned road and adjacent forest. A previous study of post-fire vegetation regeneration in cleared rights of way did find differences in species abundance between the disturbance and adjacent forest (Nowak, Kershaw and Kershaw, 1987). However, these cleared right of ways were 10 and 22 years old, and sampling was carried out two and three years after fire, leaving more time for pre- and post-fire environmental changes to occur that may have affected vegetation.

Sampling of several additional variables, including soil moisture, permafrost depth, and depth of organic soil, was intended to help identify the environmental factors responsible for variations in vegetation regeneration among linear disturbance types. These variables showed surprisingly few significant results, considering that changes in soil and permafrost conditions are cited as important factors in the persistence of linear disturbances. Limited samples sizes in each disturbance type may be a factor in this result.

Organic soil depth was significantly lower for the combined disturbance type of the burned winter road + seismic line (CLRDB) than the adjacent forest. Organic soil depth was also notably lower in the burned seismic line than in the adjacent forest, but this difference was not significant. As well, organic soil depth was slightly lower in the unburned seismic line than the adjacent forest, but this difference was not significant either. Thus, it appears that the combined disturbance of fire + winter road + seismic line had the greatest effect on organic soil depth, followed by the combination of fire + seismic line, and then the seismic line alone. Interestingly, organic soil depth was significantly higher in the burned winter road than in adjacent forest. One possible explanation for the greater depth of soil here is that the road may not have burned as severely as the adjacent forest due to the lighter fuel load. Also, mitigation strategies in place during road construction may have effectively preserved the organic soil layer.

Soil moisture was not found to vary between disturbance types, a result that re-enforces previous findings of Seccombe-Hett and Walker-Larson (2004), who also detected no significant difference between burned and unburned seismic lines and adjacent forest sites. They did, however, detect that depth to permafrost was significantly greater in burned clearings (2-32 year old clearings) than in adjacent burned areas, and in burned forests than unburned forests (5-36 year old fires). Mean permafrost depths were slightly lower in all three linear disturbances than in the adjacent forest in this study; however, this difference was not found to be significant. No differences were detected in mean permafrost depth between burned and unburned forests. Again, sample sizes in each disturbance type may have been too limited to adequately detect significant active layer trends. It is also possible that changes in active layer depth may occur over time in burned areas.

Depths of moss were slightly higher in burned linear disturbances when compared to adjacent forests, although no significant differences were found. This slight difference again suggests that these disturbed sites may not have burned as severely as the adjacent forest.

5.0 CONCLUSIONS

Post-fire, linear disturbances appear to be proceeding along a trajectory that will result in re-vegetation of the characteristic species assemblage of the adjacent forests, with typical vascular plant species in the unburned, undisturbed forest re-generating across all disturbance types. Completion of this study in the first post-fire growing season prevented assessment of black spruce regeneration, which occurs slowly and after a delay of several years. In sub-arctic, black spruce dominated forests, this species is an important structural attribute of the ecosystem, since its absence has been shown to significantly alter the ecosystem (Arsenault and Payette, 1992; Arsenault and Payette, 1997). Thus, a thorough assessment of re-vegetation of linear disturbances requires longer term monitoring of black spruce regeneration.

Completion of this study in the first post-fire growing season also prevented assessment of lichen re-establishment, another important element of vegetation succession in black spruce forests, which occurs after an initial delay of one to two decades for certain species (Black and Bliss, 1978). Again, a thorough assessment of re-vegetation of linear disturbances requires longer term monitoring of lichen re-establishment.

The results of this study suggest that, where fire is a factor, combined linear disturbances (winter road constructed on existing seismic line) have the greatest impact on vegetation regeneration relative to adjacent reference sites. The winter road + seismic line showed rare occurrences of a number of species not found in the adjacent forest, as well as differences in abundance of a number of species in comparison to the adjacent forest. Determining whether or not this alteration is detrimental or beneficial to overall ecosystem function requires investigation of the impact of this altered landscape on wildlife and other ecosystem elements -- an investigation that is beyond the scope of this study.

Returning to the question of whether fire resets the disturbance regime, it appears that fire causes linear disturbances to regenerate with vegetation composition and abundance characteristic of pre-fire conditions. Seismic lines (including the seismic line + winter road) regenerated with vegetation species composition and abundance that is documented as typical of such disturbances in the absence of fire (i.e. higher willow and grass cover, and rare presence of a number of species not found in the adjacent forest). This rapid regeneration is likely the result of vegetative propagation of species present before the fire from below-ground sources, and re-growth of individuals that were not completely burned. In this case, fire does not appear to immediately re-set conditions to those of the surrounding black spruce forest. Rather, the seismic line and the winter road + seismic line appear to be re-vegetating with composition and abundance that is similar to their pre-fire conditions.

In contrast, the burned, one-year-old winter road appears to be regenerating with vegetation species composition and abundance that is more similar to the burned adjacent, undisturbed forest. Because the winter road was cut in the same year immediately preceding the fire, there was limited opportunity for changes in vegetation or abiotic conditions to occur before the burn. Mitigation strategies in place to minimize soil disturbance may also have contributed to preservation of organic soil and below ground vegetative structures, thus facilitating the observed post-fire re-generation. Based on the immediate response of this very recent linear disturbance, fire could be said to reset the disturbance regime in this new winter road. Unfortunately, no unburned one-year-old winter road was available to compare pre- and post-fire conditions in this disturbance type.

In conclusion, it is important to note the overall uniformity in vegetation composition throughout disturbance types and undisturbed forests. This study illustrates the relative differences in vegetation response to fire in three different linear disturbances, with the combined disturbance of the winter road constructed on a 30+ year old seismic line demonstrating the greatest observed differences, in comparison to the adjacent forest. Ultimately, longer term monitoring of post-fire regeneration is needed to determine vegetation response over time in all types and ages of linear disturbances, with particular attention to regeneration of black spruce and characteristic lichen species.

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APPENDIX 1. VEGETATION TABULAR DATA

	ADJ CLB 16	ADJ CLB 17	ADJ CLB 32	ADJ CLB 33	ADJ CLB 6	ADJ CLRDB 18	ADJ CLRDB 19	ADJ CLRDB 20	ADJ CLRDB 21	ADJ CLRDB 22	ADJ CLRDB 23	ADJ CLRDB 24	ADJ CLRDB 25	ADJ CLRDB 3	ADJ CLRDB 4	ADJ CLRDB 5	ADJ WRDB 1	ADJ WRDB 1	ADJ WRDB 11	ADJ WRDB 12	ADJ WRDB 13	ADJ WRDB 14	ADJ WRDB 15	ADJ WRDB 7	ADJ WRDB 8	ADJ WRDB 9	WRDB 1	WRDB 1	WRDB 11	WRDB 12	WRDB 13	WRDB 14	WRDB 15	WRDB 7	WRDB 8	WRDB 9
Ledum decumbens	1	1	2			1		1	1	1	2	1	1	1	1	1	0.5	1	0.5	1	0.5	1		1	2	2	0.5	1			1	0.5	0.5	1	1	0.5
Rubus chamaemorus	2		1	1		1	1	1	1	1	1	1	0.1	1	1	2	0.5	1	1	1			1	1	1	1	1	1	1	0.5	2	1	0.5	0.5	1	1
Petasites frigidus ssp. frigidu	1	1		0.5	0.5	1	1	1	1	1		0.5		1		0.5	0.5	1	2	0.5	1		0.5	0.5	1		0.5	0.5	1	1			0.5	1	1	
Vaccinium vitis-idaea	1	1	1	0.5		1	0.5		0.5	0.5	0.5		1	1	1	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.5					0.1			0.1		0.5
Ledum groenlandicum	1	1	1	1		1	1	1	1	1	1	1	0.5		0.5		0.5	1	1	0.5	1	0.5	1	0.5	1	1	0.5					0.5	0.5	0.5	0.5	1
Cladina sp.	1						0.5		1		1	1	1											0.5		0.5		1	0.1					0.5	2	0.5
Eriophorum vaginatum	0.1		3	1		0.1	1	0.5	2	1	2	2	2	1	0.5	1	0.5							2	1	2	0.5	2	0.1			0.1	0.1		1	2
Marchantia polymorpha		2		2		2								1	1	1		1	1	1	1	1	1	1	1	P	1	1	1	1	1	1	1	0.5		1
Equisetum sylvaticum	1	2			2	1		1						1	2	2	1	1		2	2	2	2		2	2			2	3	3	2	1			
Epilobium angustifolium		0.5		0.5	2	0.5				0.1				1	0.5							0.5			1		0.5		0.5	0.5	1	0.5	0.5	1	0.5	0.5
Rumex sp.																																				
Potentilla palustris																																				
Carex rostrata																																				
Caltha leptosepala																																				
Senecio congestus																																				
Eriophorum angustifolium																																				
Calamagrostis canadensis					1																															
Carex lugens																																				
Equisetum arvense																																				
Salix bebbiana					0.1																															
Polytrichum commune																																				
Stellaria sp.																	0.5																	0.5		
Carex aquatilis																																				
Epilobium palustre																										0.1										
Sphagnum spp.									1	1	1		1		1		0.5										2	1	1		1			2	1	
Picea mariana												0.5																								
Empetrum nigrum													0.1													0.1										
Peltigera sp.																																				
Pleurozium schreberi																																				
Cladonia sp.																																				
Lycopodium clavatum																																				
Andromeda polifolia																																				
Lycopodium complanatum																																				
Lycopodium annotinum																																				
crustose lichens																																				
Rubus idaeus																																				
Arctostaphylos rubra																																				
Pyrola chlorantha																																				
Agrostis stolonifera																																				
Populus balsamifera																																				
Hieraceum graciela																																				
Salix raticulata																																				
Hordeum gibratum																																				
Cladonia rugosa																																				
Oxycoccus microcarpus																																				
Rhytidium rugosum																																				
Stereocaulon sp.																																				
Rhytidiopsis robusta																																				
Calamagrostis stricta	1	1	0.5	2	2	1	1	1	2	2	2	2		1	1	2	1	1	1	0.5	1	2	1	2	2	1	1	1	1	0.5	1	1	1	2	2	1
Salix planifolia	0.5	0.5		1		0.5	0.5		0.5	1	0.5	1	1	1	1	0.5	1	1	0.5	0.1	1	0.5	1	1	0.5	0.5	0.5	1	0.5	1	0.5			1	0.5	
Betula glandulosa	1	0.5	1	0.5		1	0.1	0.5	P	2	1	1	2	1	1	0.1	0.5	1		0.5	1	1	0.5	1	1	0.5		0.5	0.5		0.5		0.5	0.5	0.5	0.5
Spiraea beauverdiana	0.5	0.5			1		1	0.5						0.5	0.5	0.5						1	0.1	1			0.1		0.5		0.5	0.1	0.5			0.5
Vaccinium uliginosum				0.5					0.5		0.1	0.5	1		0.1		0.5								0.5	0.5		0.5								
Rosa acicularis	0.5	0.5				1					0.5	1		0.5		1	0.5	1	1	1	1	1	1	0.1	1			0.5	0.5	0.5	1	0.5	0.5	0.5		
Alnus crispa	0.5													0.1	0.1		0.5			0.5		1			0.5	0.1				0.1				0.5		
Polytrichum juniperinum	1	1	1	1					1	1			1		1	1			1				1	1				1			1				1	
Salix glauca		0.5																									0.1	0.1	0.1							
Ranunculus lapponicus									1	1			0.5			0.1								1		0.5		1	0.5					0.1		
Polygonum alaskanum																															1					
Poa arctica																		0.1			0.1		0.1													
Equisetum fluviatile																			1																	
Ribes lacustre		0.1																				0.1														
Viburnum edule																	0.1																			
Poa glauca																0.1																				
Papaver lapponicus																																				0.1
Total Veg. Cover (%)	2	2	4	2	3	2	2	2	2	3	3	2	3	2	2	2	2	2	2	2		3	2	3		3	2	2	2	3	3	3	2		3	2

	CLRDB 18	CLRDB 19	CLRDB 20	CLRDB 21	CLRDB 22	CLRDB 23	CLRDB 24	CLRDB 25	CLRDB 3	CLRDB 4	CLRDB 5	CLB 16	CLB 17	CLB 32	CLB 33	CLB 6	CLUB 26	CLUB 27	CLUB 28	CLUB 29	CLUB 30	CLUB 31	CLUB 34	CLUB 35	UB SB NR 29	ADJ CLUB 26	ADJ CLUB 27	ADJ CLUB 28	ADJ CLUB 29	ADJ CLUB 30 N	ADJ CLUB 30 S	ADJ CLUB 31 N	ADJ CLUB 31 S	ADJ CLUB 34	ADJ CLUB 35	ADJ RDCLUB 2	RDCLUB 2
Ledum decumbens	0.1	0.5		0.5				0.5			0.5	0.5	0.5	1			3	3	2	1	1	3	3	3	3	2	3	3	3	2	2	3	2	3	3	2	
Rubus chamaemorus		0.1				1				0.5	0.5			1		0.5	1				2		1	2	0.5	2	0.5	2	2	2	1	1	1	1	2	1	
Petasites frigidus ssp. frigidu	1	2									1	1	2	0.5	1	0.5		1	1		1	1	1	2		1	0.5	2		1	1		1	1	1	1	
Vaccinium vitis-idaea	0.5										0.5		0.5		0.5		1	3	1		2	3	2	2	2	2	2	2	1	2		3	2	3	2		0.5
Ledum groenlandicum	0.5						0.5					0.5	1	0.5	0.5	0.1	3	1	1		1	2				1	2									0.5	
Cladina sp.							0.5					0.1	0.5				2	3			1	3	3	3		3	0.1	3		3	3	4		3	2		
Eriophorum vaginatum	1													2												0.5						0.5	3	1	1	0.5	
Marchantia polymorpha	1	1	1		1			1	1	1	1			0.5	1	1				0.5																	
Equisetum sylvaticum	0.5	2	0.5	2	2		1		1	1	3	2	2			2		1	1						1		1		4				1			2	2
Epilobium angustifolium	0.5	2	0.1	1	0.1		1	0.5	0.5	1	1	1	0.1	0.5	0.5	1		1		1							0.5		0.5								2
Rumex sp.						1																															
Potentilla palustris							0.5																														
Carex rostrata							2																														
Caltha leptosepala					1																																
Senecio congestus							1	0.5																													
Eriophorum angustifolium		0.5	2				0.5																														
Calamagrostis canadensis		P	2	3	3	3	3	2			1	0.5				1			2	1																	1
Carex lugens			1		0.5	3	1	2									2	0.1	0.5	0.5		0.5	1														
Equisetum arvense	1		1	2				1				2	2				0.5			3																	5
Salix bebbiana	1		0.5	1				0.5			0.5							0.1	1	1																	
Polytrichum commune	2	1										1	1							2							4										
Stellaria sp.					1		1	1												0.5												0.1					
Carex aquatilis		2	3	2			3	3		2													1														
Epilobium palustre			0.5	1	2		1	1																													
Sphagnum spp.	2	1	1	2		2					2			1			2		6	1	4	2	4	2	2	3		1	1	4	4	3	1		3	2	1
Picea mariana			0.1	0.1													2	3	2		1	3	2	2	2	2	2	3	0.5	2	3	3	2	2	2	2	0.5
Empetrum nigrum							0.1										3	2			2	1	2	2		2	1			0.1				2	2	0.1	
Peltigera sp.																		0.5				1		2		0.1		4		2			1		P	1	0.5
Pleurozium schreberi																		2			4	2	2	2				4			2	3					2
Cladonia sp.																		2									2		2				2	1	1	3	0.1
Lycopodium clavatum																	2																				
Andromeda polifolia																	2																				
Lycopodium complanatum																		1																			
Lycopodium annotinum																		1																			
crustose lichens																											2										
Rubus idaeus																				1																	
Arctostaphylos rubra																					1																
Pyrola chlorantha																					0.5																
Agrostis stolonifera																																					0.5
Populus balsamifera																																					1
Hieraceum graciela																																					0.5
Salix raticulata																																					0.1
Hordeum gibratum																																					0.5
Cladonia rugosa																							2														
Oxycoccus microcarpus																							1							0.1							
Rhytidium rugosum																		1								1		1									
Stereocaulon sp.																		2																			0.5
Rhytidiopsis robusta																					2	1	2						1		2						
Calamagrostis stricta	3	2	2	2	3	3	2	2	2	3	3	2		2	2	1	0.5	1	2	2	0.5	1	1	2	0.5	1	1	1	0.5	1	1	1		1	1	P	1
Salix planifolia	2	2	3	3	3	2	2	2	1	2	2	2	1	1	1	2	1	2	4	2	2	0.5	2	2	2	1	0.1	2	2	2	2	2	1	1	1		1
Betula glandulosa	1	P	2	2		2	2	2	0.5	0.5	1	2		1	1	1	3	1	3	3	3	2	3	3	3	2	3	3	4	3	2	2	1	2	2		1
Spiraea beauverdiana	1	2	1	1					0.5	0.5	1	1	1			1	0.5	1		1	1	2		1	1	1	2	2	2	1					0.5	2	0.5
Vaccinium uliginosum		P	0.1				0.1		0.5								3	1	0.5		2		1			2	1			0.5				1			
Rosa acicularis	0.5					1				0.5	0.5									1		1		1			1			0.5	1	1		0.5	1		0.1
Alnus crispa		0.5							0.1	0.1	0.5		1			2	1		1	1					3				1							1	0.5
Polytrichum juniperinum									1		2	1	1	1			2	1	1								4		2								1
Salix glauca										1		0.5	0.5								0.5								1		0.5		1				0.5	2
Ranunculus lapponicus				0.1				0.5																		0.5			1								
Polygonum alaskanum																			0.1								0.5										0.5
Poa arctica																																					
Equisetum fluviatile												1																									
Ribes lacustre					4		2																														
Viburnum edule																																					
Poa glauca																																					
Papaver lapponicus																																					
Total Veg. Cover (%)	5	5	6	6	6	5	6	5	2	5	5	4	4	3	2	4		6		6	6	6	6		6	6	6	6	6	6	6	6	6	6	6	5	5

Cover Values

R=rare=0.1

+=few=0.5

1=many individuals but less than 5% cover

2=5-10% cover

3=11-25% cover

4=26-50% cover

5=51-75% cover

6=76-100% cover

Plot Labels

CLRDB = Cut (Seismic) Line + Winter Road, Burned

CLB = Cut (Seismic) Line, Burned

CLUB = Cut (Seismic) Line, Un-burned (or old burn)

WRDB = Burned winter road

UB SB NR 29 = Un-burned spruce bog near plot 29

RDCLUB = Un-burned winter road

ADJ = 50 m away from above treatments in adjacent forest

APPENDIX 2. SOIL MOISTURE DATA

Prepared by:

Norwest Labs, #104, 19575-55 A Ave., Surrey, BC. V3S 8P8, Phone: (604) 514-3322, Fax: (604) 514-3323

	Report Id	890914	890914	890914	890914	890914	890914	890914	890914	890914
	Lot Id	485747	485747	485747	485747	485747	485747	485747	485747	485747
	Lot Reference Number	1	2	3	4	5	6	7	8	9
	Sample Id	1977502	1977510	1977511	1977512	1977513	1977514	1977515	1977516	1977517
	Site Id	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006
	Sample Description	CLUB 028	ADJ CLUB 028	Club 027	ADJ CLUB 027	ADJ RDCLB2	CLUB 030	ADJ RCLBO3	ADJ OO1	ADJ CLB 033
	Completed Date	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text
%	0.1	67.5	78.7	85.9	86.7	50.9	35.7	33.8	19.4	57.5

	Report Id	890914	890914	890914	890914	890914	890914	890914	890914	890914
	Lot Id	485747	485747	485747	485747	485747	485747	485747	485747	485747
	Lot Reference Number	10	11	12	13	14	15	16	17	18
	Sample Id	1977518	1977519	1977520	1977521	1977522	1977523	1977524	1977525	1977526
	Site Id	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006	8/9/2006
	Sample Description	ADJ CLUB 031	ADJ CLUB 034 wet	ADJ CLUB 034 dry	CWB 034	RD CLB 004	ADJ RCLB04	ADJR CLB05	RDCLUB 002	CLB 006
	Completed Date	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text
%	0.1	56.5	57	60.9	60.2	57.6	37.8	33	85.9	58.3

Unit											
	Report Id		890914	890914	890914	890914	890914	890914	890914	890914	890914
	Lot Id		485747	485747	485747	485747	485747	485747	485747	485747	485747
	Lot Reference Number		19	20	21	22	23	24	25	26	27
	Sample Id		1977527	1977528	1977529	1977530	1977531	1977532	1977533	1977534	1977535
	Site Id		8/9/2006	8/9/2006	8/9/2006	8/9/2006					
	Sample Description		CLB 033	CLUB 034	ADJ CLRDB 021	ADJ CLB 006	CLUB 029	ADJ CLUB 029	ADJ CLUB 30	CLB 032	ADJ CLUB 026
	Completed Date		8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix		Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit		Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text
%		0.1	35.5	65.9	55	24.8	52.2	54.8	62.5	39	65.4

	Report Id		890914	890914	890914	890914	890914	890914	890914	890914	890914
	Lot Id		485747	485747	485747	485747	485747	485747	485747	485747	485747
	Lot Reference Number		28	29	30	31	32	33	34	35	36
	Sample Id		1977536	1977537	1977538	1977539	1977540	1977541	1977542	1977543	1977544
	Site Id										
	Sample Description		ADJ CLB O32	RCLB 005	CLUB 037	CLUB 026	RD CLB 003	WIN RD 001	WIN RDR 013	ADJ CLRR 024	WIN RB 015
	Completed Date		8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix		Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit		Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text
%		0.1	41.6	32.5	42	17.7	84.8	31.7	58.8	45.6	41.2

	Report Id	890914	890914	890914	890914	890914	890914	890914	890914	890914
	Lot Id	485747	485747	485747	485747	485747	485747	485747	485747	485747
	Lot Reference Number	37	38	39	40	41	42	43	44	45
	Sample Id	1977545	1977546	1977547	1977548	1977549	1977550	1977551	1977552	1977553
	Site Id					8/9/2006	8/9/2006			
	Sample Description	ADJ WRB 015	CLB 017	ADJ CLRR 020	CLRDR 019	CLB 016	CLRDB 018	ADJ CLRDB 018	WIN RB 014	ADJ CLB 016
	Completed Date	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text
%	0.1	13.3	65.8	16	75.9	53.1	38.6	70.5	55.1	43.1

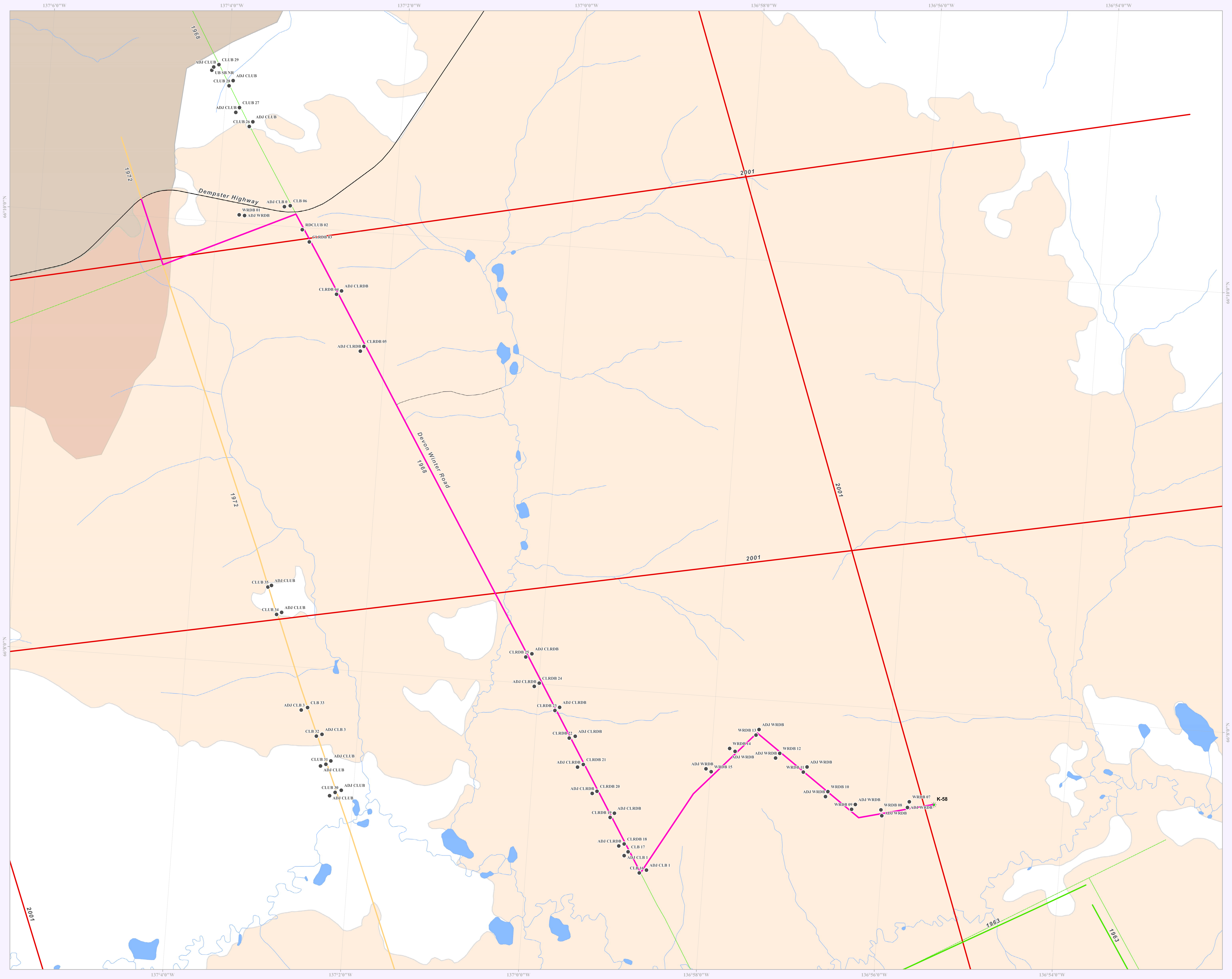
	Report Id	890914	890914	890914	890914	890914	890914	890914	890914	890914
	Lot Id	485747	485747	485747	485747	485747	485747	485747	485747	485747
	Lot Reference Number	46	47	48	49	50	51	52	53	54
	Sample Id	1977554	1977555	1977556	1977557	1977558	1977559	1977560	1977561	1977562
	Site Id									
	Sample Description	WIN RDB 010	ADJ CLRB 023	ADJ WRB 014	CLRB 020	ADJ CLRDB 022	ADJ CLRDR 019	ADJ CLB 017	ADJ WRB 013	CLRB 023
	Completed Date	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text
%	0.1	43.4	54.6	38.8	39.6	51	40.9	69.1	35.6	70

	Report Id	890914	890914	890914	890914	890914	890914	890914	890914	890914
	Lot Id	485747	485747	485747	485747	485747	485747	485747	485747	485747
	Lot Reference Number	55	56	57	58	59	60	61	62	63
	Sample Id	1977563	1977564	1977565	1977566	1977567	1977568	1977569	1977570	1977571
	Site Id							8/9/2006	8/9/2006	
	Sample Description	WRDB 007	WINRDB 011	ADJ WRB 011	CLRDB 021	WIN RDB 008	CLRD 024	WIN RDB 012	CLROB 022	WINRDB 009
	Completed Date	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text	Result Text
%	0.1	44.4	22.5	39.7	54	48.4	67.2	49	54	45.8

	Report Id	890914	890914	890914	890914	890914
	Lot Id	485747	485747	485747	485747	485747
	Lot Reference Number	64	65	66	67	68
	Sample Id	1977572	1977573	1977574	1977575	1977576
	Site Id					
	Sample Description	ADJWRB 007	ADJWNRDB 009	ADJWRB 012	ADJWRB 008	ADKWRB 010
	Completed Date	8/21/2006	8/21/2006	8/21/2006	8/21/2006	8/21/2006
	Matrix	Soil	Soil	Soil	Soil	Soil
Unit	Detection Limit	Result Text	Result Text	Result Text	Result Text	Result Text
%	0.1	58.9	58.9	22.4	61.3	66.8

APPENDIX 3. MAP OF PLOT LOCATIONS AND SEISMIC LINES

MPERG 2006 Regeneration on Linear Development Subject to Wildfires in a Zone of Continuous Permafrost



Map Features

- Vegetation Plots
- Existing Oil and Gas Wells
- Cut Line
- Ford
- Limited-used road
- Trail
- Devon Winter Road

Seismic Lines

- 1961; 1963; 1964
- 1967
- 1970; 1971; 1972; 1973; 1974
- 1976; 1978
- 1982; 1983
- 2000; 2001

Yukon Fire History

- 1991
- 2005
- Fire Overlap

Fire boundaries not exact

0 0.2 0.4 0.8 Kilometers

1:10,000

For Illustrarative use only. Not to be used for legal or navigational purposes

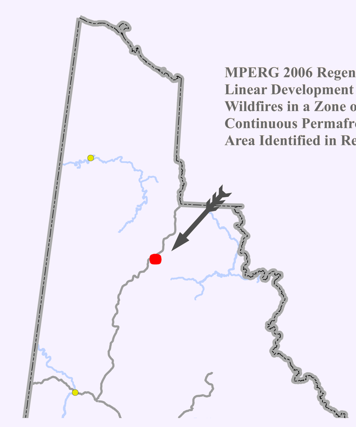
Data Sources

- Yukon Oil and Gas Management Branch - Wells, Photos, Seismic
- Yukon Wild Fire Management - Yukon Fire History
- Environmental Dynamics Inc. -Vegetation Plots
- Centre for Topographic Information - 50 K base data

Yukon Albers Equal Projection

False Easting: 500000.000000
False Northing: 500000.000000
Central Meridian: -132.500000
Standard Parallel 1: 61.666667
Standard Parallel 2: 68.000000
Latitude Of Origin: 59.000000

North American Datum 1983 (NAD83)



MPERG 2006 Regeneration on Linear Development Subject to Wildfires in a Zone of Continuous Permafrost Map Area Identified in Red

Yukon Energy, Mines and Resources

Oil and Gas Management Branch
www.emr.gov.yk.ca/oilandgas

3170-30-06233 Photo Index for EDI (unburned plots)
January, 2007