Forest Growth after Fire and Clearing for Seismic Lines in the Upland Habitats of the Gwich'in Settlement Area

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ABSTRACT

Within the Gwich'in Settlement Area, extensive seismic exploration was conducted in the upland areas during the 1960's and 1970's, and as a result there are many linear disturbances cut into the landscape. The uplands also have a large range of naturally burned areas and these two disturbances overlap continuously. With the proposed increase in oil and gas exploration activities in the region, this project was initiated with four main objectives; 1) Examine records and databases to determine the history and methods of seismic exploration in the Gwich'in Settlement Area. 2) Identify whether uplands habitats will regenerate following clearing for seismic exploration. 3) Determine habitat regeneration and growth rates following anthropogenic disturbances across the major habitat types in the upland areas. 4) Asses whether fire alters or re-sets the regeneration conditions along the seismic lines in the uplands. Within the uplands, four major habitats were examined; white spruce (*Picea glauca*) forests, black spruce (*Picea mariana*) forests, shrub meadows and fens.

Results suggest that the white spruce forests are regenerating. Some environmental changes were observed, but seedlings establish after a mean delay of 16 years and the understory composition of the forest is similar in the disturbed and undisturbed areas.

Black spruce forests are regenerating slowly on all of the seismic lines. Moisture is the main environmental factor affecting both tree and shrub regeneration. There is a lot of variation in site productivity and preliminary analysis suggests that forest regeneration will occur within 70 to 230 years.

Shrub meadows are regenerating rapidly. Although environmental changes can still be detected, the vegetation composition and abundance is very similar in disturbed and undisturbed areas.

Fen habitats, in which the ground cover was disturbed upon clearing, are showing no signs of regeneration. The vegetation changes in these areas have lead to a wetland plant association. In areas where the ground was not disturbed the black spruce seedlings are slow to establish because of the dense lichen and moss cover. These habitats are the most sensitive to the impacts of clearing.

Fire is not burning most of the areas cleared for seismic exploration. Because clearing leads to an increase in soil moisture, from permafrost degradation, and also removes all of the vegetation, there is no fuel to be burned until a later successional stage is reached.

INTRODUCTION

Little is known about forest productivity and regeneration in response to disturbances at northern latitudes. Fire and seismic exploration are the two most significant habitat disturbances within the Gwich'in Settlement Area. The lack of information about forest recovery from these two disturbances has led to concerns about habitat degradation and its impacts on the woodland caribou in the upland black spruce (*Picea mariana*) forests. Our ability to manage the forests in lieu of this will remain compromised until we gain a more complete understanding of the vegetation growth, recovery and regeneration rates in this region.

Fire is an integral feature of the northern boreal forest (Viereck 1973, Johnson and Rowe 1975) and postfire forest regeneration is a key process in the vegetation dynamics in northern areas. Plant succession, after fire, proceeds slowly at high latitudes. Black spruce is well adapted to the fire cycle. These trees have semiserotinous cones that open and release seeds after a fire (Vincent 1965). Fire modifies the environment for seedling establishment by removing competing vegetation and exposing mineral soil to increase germination success (Black 1978, Sirois and Payette 1989). Most spruce recruitment occurs immediately after fire and decreases after 20 years (Black and Bliss 1980, Sirois and Payette 1989). However, a disruption in the regeneration dynamics of spruce could cause a habitat shift from forest to tundra-like vegetation, as has been seen in a number of northern areas (Rowe and Scotter 1973, Black and Bliss 1978).

The sequence of vegetation change has been documented within black spruce forests in a number of northern areas (Black and Bliss 1978, Maikawa and Kershaw 1976, Morneau and Payette 1988, Arseneault and Payette 1992, Lanhausser and Wein 1993). These studies show that vegetation changes are both extremely area and site dependent. There is an abundance of literature examining initial successional changes in the first ten years after fire, yet very little work has been done to understand medium term succession and the resulting vegetation shifts.

Of the medium term work, Black and Bliss (1978) identified that the postfire recovery sequence of black spruce forests has a persistent shrub-dominated phase. The majority of changes in the vascular vegetation typically occur within the first 15 years after fire, yet the successional shifts in the mosses and lichens occur over a 100-year period (Morneau and Payette 1988).

The impacts of linear disturbance on habitats in northern environments has been poorly studied, however, it is clear that permafrost terrain is easily degraded (Mackay 1970, Lambert 1972, Zoltai and Pettapeice 1973, Lawson 1986, Mackay 1995, Jorgensen 2001). When vegetation is cleared from an area, increased radiant energy reaches the ground surface, which results in an increase in active layer depth. This increased depth of thaw causes melting of the underlying ice, water pooling on the surface and is often followed by ground subsidence and hummock formation (Mackay 1970, Gill 1973b, Lawson 1986, Mackay 1995).

The degradation of permafrost can lead to large changes in ecosystems (Osterkamp 1983, Jorgensen 2001) because it directly influences soil temperature, moisture, rooting zones and micro-topography. Melting of ice rich permafrost underneath forests could cause full ecosystem shifts from terrestrial to aquatic or wetland systems (Osterkamp et al 2000).

Stabilization of the active layer after clearing can take anywhere from 10 to 30 years (Lawson 1986). Work conducted near the Inuvik area indicates that variance in time to stabilization was so high that broad generalizations could not be made for any habitats within the area (Mackay 1995).

Regeneration can be discussed at different levels and be separated into a number of different issues such as habitat composition, structure, function or integrity. The ways in which regeneration is discussed as successful or failing depends on the end point defined and is often manipulated in its presentation. Definitions of successful regeneration of a particular habitat may be defined as 'the colonization of an area by plants after a disturbance' or 'return of a habitat to initial conditions that were present before disturbance'. This term is frequently manipulated and care should be taken in its interpretation. Development proposals for this region often downplay vegetation impacts and refer to residual impacts upon vegetation as medium-term, which suggests recovery within 10 years (Devlan 2002).

As each habitat was examined, any of the following questions could be addressed by this study. 1) Will the areas along the seismic lines regain the same structure as the adjacent undisturbed areas? 2) Is the species composition the same? 3) Will the environment return to the same natural disturbance regime?

Within the Gwich'in settlement area, extensive seismic exploration was conducted in the upland areas during the 1960's and 1970's, hence there are many linear disturbances cut into the landscape. The region is currently experiencing a significant increase in oil and gas exploration, which will inevitably lead to higher densities of linear disturbances. The uplands also have a large range of naturally burned areas and these two disturbances overlap continuously throughout the area. With the proposed increase in oil and gas exploration activities in the region, there is a need to gather baseline information about forest regeneration and sustainability with respect to both of these disturbances.

This project was initiated with five main objectives;

1) Examine records and databases to determine the history and methods of seismic exploration in the Gwich'in Settlement Area. This would facilitate a comparative analysis of the impacts of different clearing methods upon the vegetation and habitat regeneration.

2) Identify whether upland forested habitats will regenerate following clearing for seismic exploration

3) Determine tree regeneration and growth rates following anthropogenic disturbances across the major habitat types in the upland areas.

4) Assess whether post-cutting fire alters or re-sets the regeneration conditions along the lines in the uplands.

5) Generate recommendations for methods of future exploration work in this region

All of this work has been performed in conjunction with a Department of Resources, Wildlife and Economic Development (DRWED) study examining habitat use and selection by woodland caribou. Although, the status of woodland caribou in the Northwest Territories is 'threatened' (COSEWIC 2002), until recently these caribou had not been the focus of any biological studies in the Northwest Territories. Threats to the caribou include habitat degradation by oil and gas exploration, as well as forest fire. The impacts of these disturbances on caribou populations are unknown, although in other regions of Canada the disturbances have been negative to the point of caribou extirpation. This project is contributing baseline habitat information for caribou management in this area.

METHODS

Study Area

All of the work was conducted in the upland areas within the Gwich'in Settlement Area (GSA). The upland areas are dominated by open black spruce forests interspersed with fens and shrub dominated meadows. The flatter areas included mostly shrub meadows, fens and open black spruce forests; interspersed among these on slopes were open stands of white spruce and mixed stands of spruce and paper birch. The uplands have a large range of naturally burned areas in which succession is occurring and forests are regenerating.

History of Line Clearing for Seismic Exploration in the GSA

The records of exploration within GSA are sparse. Both the Department of Indian and Northern Affairs (DIAND) Inuvik office and the National Energy Board Frontier Records were searched for information relating to this area. The NEB has records for this area prior to 1973 and the DIAND Inuvik office maintains records for this area that begin in 1973.

Study Design

A total of 155 sites were surveyed within the GSA during the summers from 2001 through to 2003. The majority of the seismic lines surveyed were south of Fort McPherson and Tsiigehtchic in an area that supports a large number of woodland caribou (Appendix 1).

Sixty-six of the sites were in areas that have not burned and were used to examine patterns in vegetation recovery after seismic exploration. Most of the seismic lines in the GSA were cleared between 1966 and 1970, except two of the lines that were cleared in 1989. Along each seismic line, sites were located both in and out of a burn.

Eighty-nine sites were located in areas that burned after they had been cleared. The burned sites included locations within burns from the 1960's through to the 1990's. This allowed us to examine forest recovery from fire and seismic exploration. Twenty-seven sites were surveyed from fires that burned between 1968 and 1970, 29 sites were burned between 1980 and 1989 and 33 sites surveyed burned between 1990 and 1999.

The majority of sites were randomly selected for meeting sampling criteria of clearing and burned conditions. However 28-paired sites were established at fire boundaries, where one site was located within the burn and the other located outside of the burn. Twelve of these were at the intersection of a 1980's burn and sixteen at a 1990's burn.

Sampling Methods

At each site, one 5-meter x 5-meter vegetation plot was set up along the seismic line and a second plot was set up in the undisturbed forest adjacent to the line (Figure 1). A buffer of 50 meters was maintained between undisturbed plots and the seismic line. Each plot on the seismic lines was selected by counting a random number of steps along the line from the point of access. A complete vegetation survey was conducted within each of these plots. In all plots, descriptive variables were recorded and vegetation composition surveys were performed at set locations as shown in Figure 2.

Plot Description

The following variables were recorded at each plot: slope, aspect, moisture regime, duff depth (depth of organic layer), presence of hummocks and percent cover of surface water. Evidence of trail use, either animal or human, was recorded at all of the seismic sites. If there was evidence of subsidence along the seismic line, the depth of subsidence was recorded along four points delineating the edges of the plot (Figure2).

A five meter transect was laid down the centre of each plot and active layer depth (depth to permafrost) was recorded at five points along the transect (Figure 2).

Four soil cores were collected from each plot and returned to the laboratory to determine soil moisture (Figure 2). Soil moisture was determined as a percentage by weight. Soil cores were weighed, dried at 110°C for 48 hours and the weighed a second time to determine percent soil moisture.

Observations of line condition were recorded. Ground cover was visually compared between disturbed and undisturbed plots to see if the ground surface had been disturbed on the seismic line. In areas with thick duff layers it was easy to tell whether or not the ground cover had been disturbed during the clearing process. Observations of charred or burned ground surface were recorded to determine extent of burn.

Vegetation Composition Surveys

Trees and Shrubs:

Cover classes were used to estimate plant abundance. Visual estimates were made over the 5 m x 5 m plots in order to estimate plant cover classes (measured as percent cover). The cover classes were Daubenmire groupings (Daubenmire, 1959) and were separated as follows: rare, present but less than 1% of total cover, 1-5%, 6-25%, 26-50%, 51-75%, 76-100%. For each of these categories the total cover of the category as a whole was recorded (i.e. total low shrub cover) and then divided and individual species cover was recorded (i.e. % cover *Ledum groenlandicum*, % cover *Rosa acicularis* etc.).

Cover classes of species were grouped in the following broad vegetation categories:

Tree Cover (trees >1.5 m)
Tall Shrubs (1.5 - 3 m)
Short Shrubs (0.1 - 1.5 m)

Heights and diameters of tree and large shrub species were measured, however, only heights were measured for the short shrub category.

Understory Vegetation Transects

A linear transect, five meters in length, was laid out across the centre of each plot (Figure 2). Along the transect a pin was dropped every 25 cm, and all plant species that came in contact with the pin, up to a height of 50 cm, were recorded. The number of times each species touched the pin was also recorded. This survey included all understory species, including mosses and lichens. Voucher specimens were collected for all unknown species

Shrub Samples

Cross-sectional disks were collected from three species of shrub at each site. Samples were collected from the tallest of *Betula glandulosa*, *Alnus crispa* and *Salix* spp within each plot. Branch heights were measured and disks were cut at ground level. The rings were counted on each disk to determine branch age.

Seedling Survey

Parallel to the active layer depth surveys, an area of one meter in width was searched for seedlings and saplings (Figure 2). This included all tree species up to a height of 1.5 m. For each individual found the following measurements were recorded: tree species, height, and diameter at base. The substrate that the seedling was rooted in was also recorded.

Two seedlings of each tree species were collected from each site for aging. Seedling ages were determined by counting growth rings at the base of the stem using a dissecting microscope.

Seedling height-diameter relationships were logarithmically transformed for normality and regression were conducted using the geometric mean regressions.

Stand Ages and Productivity

Tree Cores

Two tree cores were taken from trees in each of the undisturbed locations. The cores were taken from the tree with the largest diameter at breast height and a second random individual selected within the plot.

Cross-Sectional Disks

At 28 of the unburned- undisturbed sites, an additional plot with the dimensions 10-meters x 10-meters was surveyed. Within this plot all trees were measured; the height and diameter at breast height was recorded for each individual. Additional health and condition comments were recorded for each tree. Cores were taken from 2 trees within the plot.

One tree was felled for stem analysis within each plot. The tree selected was always the tallest and had the largest diameter at breast height. The stem was sectioned and cookies were taken at ground level, 0.3meters and then every 0.5meters for a minimum of 10 cookies per tree. The rings were counted on each cookie to determine section age using a dissecting microscope. This data was used to construct growth curves and compare these with site index tables.

Tree Density Survey

To estimate stand density (# of stems/ha) the ordered distance measure (Krebs 1999) was used in 2002. This involved picking 30 random locations and measuring the distance from the random point to the third closest tree. The height and diameter at breast height was recorded for each tree.

Stand density was estimated in 2003 from the number of trees within the additional 10–meter x 10-meter plot that was set up for cross sectional analysis.

Data Analysis

A variety of statistical techniques were used for data analysis. JMP IN was the statistical package used for all analyses. Data transformations were used to meet assumptions of normality when necessary. Statistical tests will be identified within the results section for each data set presented. Non-parametric tests were used when assumptions of normality could not be met.

SECTION I: AREAS CLEARED FOR SEISMIC EXPLORATION

RESULTS

History of Seismic Exploration

Very little information is available about the history of seismic exploration within the Gwich'in settlement region. The National Energy Board records are sparse and uninformative for the time that the work was completed in this region. The most extensive information available includes lists of equipment proposed to be included in a particular seismic program.

The majority of the seismic lines within the GSA were cleared between 1963 and 1970, and many are not accounted for in any of the databases we were able to access. Hence, it is very difficult to identify the ways in which the area was cleared or draw any comparative conclusions about the clearing methods.

The most detailed account of line clearing methods come from a 1969 report of seismic exploration near Fort McPherson. This report indicates that vegetation was removed and 'walked' on with bulldozers. The snow was packed with a bulldozer and clearing was done by 'high blading' so that the ground surface was not broken or exposed.

After 1973, the regulations involved in land use permits required mushroom shoes or other similar devices to be used along the base of the cutting blade in order to minimize surface disturbance while clearing. Timber disposal was to be done by either compacting the material with heavy machinery or windrowed.

Because of the limited information available, clearing methods could not be compared and the surveys were limited to field observations of ground cover condition. Ground cover comparisons were only possible when thick moss, sphagnum and lichen cover were involved. Comparisons permitted the observation of either 'disturbed ground cover' or 'undisturbed ground cover' by the relative condition of the cleared area versus the adjacent undisturbed forest. This was possible in almost all of the fen sites and a number of the forested areas.

Uplands Vegetation Types

Open black spruce forests dominate the forest stands throughout the study area. Black spruce stands included in the sampling area were mostly uneven aged stands with stand densities that ranged from 0.3 trees/m^2 to 0.86 trees/ m^2. The flatter areas included mostly shrub meadows, fens and open black spruce forests; interspersed among these on slopes were open stands of white spruce and mixed stands of spruce and paper birch. The study sites were categorized into four main habitat types that are; White spruce, Shrub Meadow, Black Spruce and Fen type habitats (Table 1). The characteristics of each of these stands are outlined below.

White spruce stands are found on well-drained slopes, underlain with mineral soils, deep active layers and they are typically located on creek, river and lake-edge slopes. The tree densities are low; all of the sampled stands fell between 0.2 to 0.3 trees/ $m^{2.}$ The understory species associated with the white spruce stands were *Arctostaphylos rubra*, *Arctostaphylos uva-ursi*, *Ledum groenlandicum* and *Salix* spp. Ground cover was composed largely of litter, exposed soil and a small amount of moss and lichen cover.

Shrub meadows were interspersed within open spruce stands in riparian areas and along drainages. These were dominated by a combination of *Betula glandulosa* and *Salix* species. On the flat plains sites, the soils were high in moisture, had poor drainage and shallow active layers with a thick moss layer as ground cover.

The majority of the study area was covered with open black spruce forest with a low shrub layer dominant in the understory. These forests ranged in density from 0.3 to 0.8 trees/ m^2 and the understory vegetation was composed primarily of *Vaccinium uliginosum*, *Betula glandulosa* and *Salix* species. These were mostly in poorly drained plains areas, underlain with poorly drained soils and shallow active layers. Ground cover is high with a number of different moss species particularly feather mosses and peat mosses.

Fen habitats were common along the plains. In these habitats, the black spruce trees covered less than five percent of the areas, there is dense dwarf shrub vegetation dominated by *Ledum decumbens* and the major ground cover species are *Cladina rangiferina* and *Cladina stellaris*. These areas typically have poorly drained organic soils, shallow active layers and a very thick duff layer.

Because the majority of the sampling area is covered with open black spruce forests and fen habitat types, most of the data was analyzed with respect to these two habitats. General regeneration trends are discussed with respect to the other major habitats, although, these analyses are limited by the small sample sizes involved. Overall regeneration trends will be presented for each habitat group.

Black Spruce Forests and Fen Habitats

Abiotic Changes Associated with Seismic Clearing

The majority of the seismic lines included in this study were cleared in 1966 although a few were cleared in 1970. Therefore the regeneration and vegetation changes described in this study along the seismic lines represent between 37 and 33 years of growth.

Black spruce forests and fens had very similar environmental changes from seismic clearing and these two groups have therefore been grouped for all abiotic variables. The changes in vegetation will be discussed separately.

Subsidence

In total 34% of the disturbed sites sampled in 2003 and 49% of the sites in 2002 show evidence of subsidence. However, when the site position is accounted for, 44% of the disturbed sites on the plain have subsided whereas only 20% of the disturbed sites on slopes have subsided. Sites with high soil moisture have subsidence occurring significantly more than areas with lower soil moisture (Pearson test, Chi-square = 8.117, $p<0.0044$, N=82). Sixty-four percent of wet sites sampled have subsided compared to 12% observed on the mesic sites. The mean soil moisture is significantly higher in areas with subsidence with an average moisture content of 65% versus a mean of 50% in the areas where there is no evidence of subsidence (Figure 3).

Active Layer Depth

The mean active layer depth is significantly deeper in disturbed areas than in undisturbed areas (Figure 4). The mean active layer depth in disturbed areas after 33 to 37 years is 58 $\pm$ 3cm and is 43 $\pm$ 3 cm in undisturbed locations. The mean difference in active layer depth between disturbed and undisturbed sites is 15cm and does not change significantly with soil moisture conditions.

Soil Moisture

The soil moisture classification scheme is consistent with the soil moisture measurements, which indicates that the classification was consistent across field technicians (ANOVA, F=19.4, $p< 0.0001$, N=82).

The distribution of soil moisture measurements is bimodal indicating two distinct types of moisture regimes (Figure 5). The division is clearly separated by sites located on slopes or in the plains, with the plains averaging 67 $\pm$ 2% soil moisture whereas the slopes are much lower with an average of 43 $\pm$ 2% soil moisture.

The analysis shows that soil moisture across the study area is determined by slope, yet is not significantly affected by disturbance. This does not support field observations of increased moisture along lines; wetland expansion along lines or pooling associated with subsidence from clearing effects on the active layer. All of this either suggests that our sample size is too small, the observations are inconsistent, or the sampling methodology was insufficient to detect this. Soil moisture was examined with respect to timing of disturbance and again no trends were found. Pooling and standing water were recorded at each site and the results do not show that there is significantly more pooling on the seismic lines.

Vegetation Changes from Clearing in Black Spruce Forests

The general vegetation on the disturbed and undisturbed sites was compared for the black spruce forests. The mean proportions of ground cover groups show significant changes in both abundance and composition between the disturbed sites and the adjacent areas.

The amount of exposed mineral soil increases significantly as a result of clearing from a mean of 1.5% to 7% and the amount of lichen cover decreases from a mean of 26% to 11% (Figure 6). There was variation detected in ground cover species across slope, moisture and disturbance, but could not be quantified into species shifts because the technicians identified ground cover groups rather than individual species.

The trees have not formed a canopy yet on any of the lines. The tall shrubs are significantly more dense upon the seismic lines covering an average between 5 and 25% of the area, whereas, tall shrubs only constitute 1-5% of the undisturbed black spruce forest (t-ratio = 1.5, $p<0.07$, N=65 pairs). In most of the sites the increase in tall shrub layer is in both Willow (*Salix* spp.) and Birch (*Betula glandulosa*).

The shorter shrubs are denser upon the seismic lines with a mean cover difference of one group. The short shrubs cover an average of 50-75% of the seismic lines 30-37 years after clearing whereas the undisturbed black spruce forests adjacent to these areas typically have between 25-50% ground coverage (t-ratio = 4.22, $p< 0.0001$, N=41 pairs).

There are species shifts in the short shrub layer associated with disturbance type (Table 2). In open black spruce forests areas bilberry (*Vaccinium vitis-idaea*) and Labrador tea (*Ledum groelandicum*) decrease in abundance in disturbed areas whereas *Betula glandulosa*, bog rosemary (*Andromeda polifolia*), shrubby cinquefoil (*Potentilla fruticosa*), *Salix* spp and paper birch *Betula papyrifera* all increase after disturbance. Overall the plant species composition of disturbed sites in the black spruce forests is not significantly different from the undisturbed forests.

Plant community diversity increased as a result of disturbance. An average of 7 shrub species were found in the disturbed sites, whereas there was an average of 5 species of shrub in the adjacent undisturbed sites.

Vegetation Changes from Clearing in Fen Habitats

The ground cover plant groups in the fen habitats do not show a mean significant change in composition. This is a result of the different clearing methods used; six of the sites surveyed showed ground disturbance and the others had the ground layer left intact. When the ground surface was not disturbed the groundcover vegetation is dominated by a thick lichen and moss bed both in the disturbed and undisturbed areas. However, when the ground surface was disturbed there was pooling water, bare ground and an abundance of aquatic vegetation such as sedges (*Carex* species) and Leather-leaf (*Chamaedaphne calyculata*) along the seismic lines.

In the fen habitats there is a significant decrease in the cover of *Ledum decumbens* after clearing (Table 2). There is consistently a higher number of shrub species in disturbed areas compared to the adjacent undisturbed controls ($t = 3.9$, $p < 0.002$, $N = 14$pairs).

The most significant change in vegetation as a result of clearing is not in overall shrub cover, yet is reflected in species composition shifts. In disturbed fen sites, the shrub vegetation shows an increase in cover; however, when the ground cover is disturbed the shrub composition shifts from a *Ledum decumbens* dominated undisturbed forest to a shrub layer dominated by *Chamaedaphne calyculata*, which is a wetland species.

Black Spruce Growth and Regeneration

Tree and Site Productivity

Twenty-eight black spruce trees were cut down for stem analysis from within the open black spruce forests to examine trends in tree growth. Site index curves have not been generated for black spruce trees in this region, therefore, the curves created by Quenet (1989) in the Yukon were used to examine trends in tree growth. According to these tables, the site index of the trees within the sample plots ranged from 2 to 9 with an average of 5. Fifty percent of the trees had site indexes between 4 and 6, this indicates that when a tree reaches a breast height age of 50 years, the tree height will be between 4 and 6 meters (Figure 7). The range of years to breast height among the trees that were analyzed was between 9 and 106 with a mean of 33 years ±4.

Site index and stand density are significantly related to terrain and moisture (Figure 8 A and B). Black spruce forests growing on slopes have site index values, which range between 5 and 9, which is higher than the range of 2 to 5 within the plains forests. Wet plains sites have lower site productivity and stand densities.

Black Spruce Seedlings

Seedling Establishment

The substrates on which black spruce seedlings established were compared with substrate availability. The seedling establishment shows positive association with both litter and moss and negative association with both lichen and exposed mineral soil. Forty-nine percent of the seedlings measured were growing in moss and 42% were in litter whereas less than 2% were in bare soil and 5% were in lichen. Selection ratios were calculated by comparing the amount of each substrate group available at each sample site against the location the seedling has established (Table 4). Positive association was identified with black spruce seedlings in both moss and litter and avoidance of both lichen and bare soil.

Short shrub cover has a significant effect on black spruce seedling number. Sites with low shrub densities greater than 25% cover had significantly more seedlings than areas with low shrub density less than 25% ($t= 2.35$, $p<0.02$, $N=165$).

The density of black spruce seedlings is most significantly influenced by disturbance ($F= 5.1$, $p< 0.0047$, $N= 180$). Seedling density is consistently higher in areas cleared for seismic exploration than in the adjacent undisturbed forests.

Within disturbed areas seedling density is significantly influenced by site position. The mean density of seedlings on sloped plots is 1.92 seedlings/m^2 and there is a mean of only 0.92 seedlings/m^2 on flat sites ($t=2.5$, $p <0.018$, $N= 45$). In the undisturbed forest stands adjacent to these clearings, there are no significant differences in seedling density with site position that suggests seedling establishment is increased on soils with lower moisture.

Open black spruce forests have higher densities of seedlings establishing along seismic lines than fen habitats (Figure 9). Mean seedling densities in open black spruce forests are 1.4 seedlings/ m^2 $\pm$ 0.3 which is higher than the mean of 0.75 seedlings/ m^2 $\pm$ 0.3 observed in the fen habitats.

Growth

The height and diameter at base was measured for 1809 black spruce seedlings over 2002 and 2003. Different height- diameter relationships were identified for seedlings in each disturbance type (Figure 10). The slopes for the relationships are significantly different. Seedlings growing on disturbed sites are taller relative to diameter at base than those growing in undisturbed locations.

Black spruce seedling height-diameter relationship is not related to productivity of adjacent forest stands. Although there are differences in site productivity between stands, parallel trends were absent in seedlings adjacent to these sites.

Growth rings were counted and ages tabulated for a total of 347 seedlings black spruce seedlings over 2002 and 2003. When regressed against both seedling height and diameter, diameter was a stronger predictor of age. Because of differences in ratios between height, diameter, and age, separate age prediction equations were generated for each disturbance group (Figure 11, Table 3). Log transformations were required for all regressions to meet assumptions of normality.

When the diameter at base age relationships are compared between disturbance groups, the seedlings growing in undisturbed forest are consistently older at any given diameter at base, which suggests that they grow more slowly (Figure 11).

Time to Establish

From these aging equations (Table 3), it was possible to examine trends in time required for seedling establishment along seismic lines. The mean time required for seedlings to start growing along the lines is 17 ± 0.8 years (N= 720). This was calculated with 720 seedlings over 55 sites (Figure 12). Seedlings exceeding the diameter dimensions of the seedlings used to generate the age predictions were excluded from the analysis.

It was difficult to determine the lines on which the ground cover was left intact upon clearing. Six of the fen sites surveyed had the ground cover intact, which was identified by the ground cover vegetation including the moss and lichen layers. Of these the mean seedling establishment time was 19 years, although this result was not significantly different from the other seismic lines in black spruce forests. This suggests that leaving ground intact when clearing lines may delay seedling establishment rather than ameliorate the regeneration conditions, particularly in habitats with high lichen cover.

Tamarack Seedlings

Tamarack (*Larix laricina*) seedlings were observed on 22% of the sites along the seismic lines. All of these were in sites associated with black spruce forests.

The relationship between Tamarack seedling height and diameter at base is shown (Figure 13). The data was collected over both 2002 and 2003. Diameter at base is the strongest predictor of age, again using a geometric mean regression, when both variables are Log transformed (Table 2).

Tamarack seedlings also showed a delay in establishment after both fire and clearing disturbances. In areas that have been cleared for seismic exploration it takes an average of 14.1 years for Tamarack seedlings to start growing.

White Spruce Forests

Abiotic Changes Associated with Clearing

No significant changes in abiotic conditions were found when comparing cleared areas in white spruce forests with the adjacent undisturbed areas. This is most likely a result of the small sample sizes involved. The mean active layer depth along the disturbed areas was 50 ± 9cm, which is deeper than the mean for the adjacent controls of 45 ±9cm. Subsidence was observed on only one of the nine sites sampled. No significant differences were found in soil moisture content between disturbed and undisturbed areas, the mean soil moisture across these sites was 42 ± 8%.

Vegetation Changes Associated with Clearing

There were no significant differences in the composition of the vegetation on the seismic line when compared to the undisturbed forest.

Seedling Growth and Establishment

The relationship between white spruce seedling height and diameter at base is shown (Figure 12). When both variables are Log transformed diameter at base is a strong predictor of age (Table 2).

White spruce forests have high densities of seedlings establishing on the seismic lines (Figure 11). Mean seedling densities along the cleared areas adjacent to white spruce stands were 1.3 seedlings/ m^2 ± 0.3, N=9.

The average amount of time required for white spruce seedlings to establish was 16.6 ± 0.86 years. Of all the sites surveyed, the shortest amount of time observed was 10.5 ± 0.2 years.

Shrub Meadows

Only four sites were examined within the shrub dominated meadows. Of these 2 had subsidence along the cleared areas. The soil moisture was high and variable with a mean of 57 ±10%. The active layer depths along the cleared areas had a mean depth of 47 ± 4cm, which is not significantly deeper than the 39 ± 4cm observed in the adjacent areas.

In all sites the shrubs on the disturbed areas had the same mean height on both the seismic lines and the adjacent forests. All of the same shrub species are present in both the disturbed and undisturbed areas. Although it was not statistically significant, the observed short shrub cover was higher in all disturbed sites when compared with the adjacent meadows.

DISCUSSION

This study was limited to comparisons between the states of the seismic lines versus the adjacent habitats 33 to 37 years after clearing. It is observational as opposed to experimental and cannot identify cause only correlations. The comparisons that are made examine only composition and structure of each habitat along the seismic lines against that within the adjacent undisturbed forest.

The significant variation between different habitats requires that each habitat be analyzed and discussed separately. The major factor affecting regeneration and establishment across all habitats was moisture. Sites with slopes typically have lower soil moisture, less subsidence, deeper active layers and increased seedling establishment. In contrast wetter sites have higher amounts of subsidence and lower seedling densities. This is determined primarily by the soils underlying each habitat group. The fens are underlain by poorly and imperfectly drained organic soils whereas the black spruce forest are supported by a range of soil drainage types and composition whereas white spruce forests are only located on slopes with well drained mineral soils.

Black Spruce Forests

All of the black spruce forests surveyed are showing signs of regeneration along the seismic lines. The regeneration and growth is seen in all vegetation groups and is proceeding slowly. After an area has been cleared the mean time of 17 years for seedling establishment likely reflects the amount of time required for the abiotic changes to stabilize.

Soil moisture and terrain type have the most significant effects on regeneration. Because the plains are underlain with poorly drained soils, any terrain characteristic such as slope, which increases drainage, accelerates regeneration and overall habitat re-growth.

Overall the seedling densities are sufficient to generate stand replacement if high survival rate assumptions can be made for the seedlings. All of the main shrub and herbaceous vegetation species are re-establishing in the disturbed areas; however, the colonization by the mosses and lichens is unknown. The abundance of lichens has decreased significantly which agrees with the results (Black and Bliss 1979) that suggest succession among these groups takes hundreds of years.

The data collected in this study suggests that the black spruce forests will regenerate in the uplands. Soil moisture is the environmental factor that has been identified as the key determinant of both tree establishment and growth in disturbed areas. Soil moisture is determined by terrain, soil type and permafrost degradation

There was a consistent delay in seedling establishment along all of the cleared areas in the black spruce forests. The 17-year delay is most likely a result of the terrain changes due to permafrost degradation.

We anticipated that regeneration and seedling establishment would be highest in the stands that were between 75 and 200 years old. Work on the reproductive capacity of black spruce trees suggests that their maximum reproductive potential is reached when the stands are within this age range (Zasada 1971, Black and Bliss 1980). However, no differences were detected in seedling establishment as a function of the age or productivity of adjacent undisturbed trees.

The productivity curves used to look at tree growth suggest that an average tree growing in plains sites will take approximately 83 years to reach a height of 5 meters. If we add the 17-year delay in seedling establishment on seismic lines with the additional mean error of 11 in age estimates (calculated by Desrochers and Gagnon 1997), we can expect a forest on an average plains site to reach 5 meters in height 111years after clearing. The range of growth rates observed across the uplands suggest that it could take anywhere from 72 years in the most productive well-drained sloped sites to 232 years in the wet plains forests for the black spruce forest to reach a height of 5meters.

Fen

The fen habitat shows the least regeneration of all of the habitat types surveyed. The seismic lines that appear to have been cleared to the soil layer have shifted to aquatic vegetation and the lines where the ground surface remains intact show very little shrub and tree regeneration.

Thick lichen cover is thought to prevent seedling establishment (Morneau and Payette 1988) and the observed black spruce seedlings did show a distinct negative association with lichen. Therefore, forest and shrub re-establishment on the intact lines might be delayed for a long period of time, much greater than the 37 years observed in this survey.

It is unclear whether any remedial work could be done to promote forest regeneration in these areas. Clearing small patches of ground down to bare soil might facilitate both tree and shrub establishment and not alter abiotic conditions sufficiently to affect either moisture regime or active layer depths. Functionally, these areas seem to be important areas for late winter woodland caribou habitat (pers. communication John Nagy 2004) with the abundance of ground lichen for forage. If the ground lichen layer is not disturbed these areas may continue to be critical caribou habitat.

Clearly these fen habitats should never be subject to ground clearing for exploration purposes. The areas within fen habitats that have been subject to this kind of treatment are not showing any regeneration towards a similar plant community association. The vegetation changes at this point seem to indicate a permanent shift from a fen to a wetland plant association. However, overall the plant community composition is showing positive yet delayed regeneration trends in areas where the ground cover has not been disturbed.

White Spruce Forests

The white spruce forests are located primarily on slopes, and in riparian areas within the uplands. All of the sites surveyed showed changes in the abiotic variables as a result of clearing, although the differences identified between the disturbed and adjacent undisturbed areas are less than those in the wetter sites of other habitat types.

Although there is a delay of approximately 16 years before the white spruce seedlings begin to establish, the seedling densities are greater than stand densities which suggests that this forest type will regenerate from these disturbances. All of the same understory plant species are re-establishing. Timelines of regeneration are difficult to estimate from the small sample sizes involved in these surveys. Canopy tree ages were extremely variable and site indexes could not be determined. The range in canopy ages was 48 to 100 years for trees anywhere between 4 and 8.5 meters. Given the establishment delay of 16 years and the range in canopy ages, white spruce forests will take a minimum of 65 years but possibly as long as 116 years to establish a canopy.

Overall white spruce habitat regeneration is expected in the upland areas. Species composition and abundance suggests that a white spruce forest will re-establish on the seismic lines, however, the timeline of regeneration is unclear.

Shrub Meadows

The meadows show the fastest regeneration of all habitats. The shrub layer has re-established with the same species, although, the disturbed areas have shrub cover that remains shorter in height and higher in density. The active layer depth and percent soil moisture remain higher on disturbed sites although the observed differences are less than the forested sites.

Species composition and abundance in the shrub meadows shows that the disturbed and undisturbed areas are very similar. A number of environmental effects remain from clearing; however, this habitat is showing positive regeneration trends.

Further Questions

There are a number of questions that should be addressed to increase understanding of habitat regeneration in this area:

1) An increase in tree growth and productivity data would increase the accuracy of the estimates of time of habitat recovery and regeneration. Expanding the estimates to examine white spruce growth would help to generate timelines of recovery in these habitats

2) The effect of soil compaction has not been addressed in any of this work and is likely to have a significant effect.

3) Developing a series of permanent plots and a monitoring program would be a useful way to examine continued forest recovery from seismic disturbances.

SECTION II: VEGETATION REGENERATION ON SEISMIC LINES IN AREAS THAT HAVE BURNED

RESULTS

Sites were sampled along seismic lines and in adjacent forested sites that have burned in the last 3 decades. This allowed us to compare succession in black spruce forests with succession along the sites cleared for seismic exploration. Eight-nine sites were chosen from areas that burned between 1968 and 1999 after the seismic lines had been cleared. The burned sites included locations within burns from the 1960's through to the 1990's. This allowed us to examine forest recovery from fire and seismic exploration. Twenty-seven sites were surveyed from fires that burned between 1968 and 1970, 29 sites were burned between 1980 and 1989 and 33 sites surveyed burned between 1990 and 1999.

Within the first few years after fire, the shrub vegetation re-establishes rapidly. It appears that many shrub species will reproduce vegetatively from unburned subterranean roots. Sites that burned in the 90's have low shrubs covering between 26 and 50% of the ground. The shrub species that showed immediate regeneration were primarily *Salix* spp. and, *Betula glandulosa*. *Epilobium angustifolium*, *Rosa acicularis* and grasses were prominent in the understory. Tree seedlings were found in all recently burned areas.

Succession during the next 20 to 30 years involves an increase in shrub densities. Sites that burned in the 70's and 80's have a tall shrub canopy that covers between 5 and 25% of the area. Shorter shrubs also became increasingly dense, covering between 51 and 75% of the area sampled. The herbaceous plant community diversifies and ground cover of mosses and lichens increases.

A canopy of *Betula papyrifera*, between 2 and 4 meters in height has established on the majority of sloped or well-drained burned sites after 30 years of regeneration.

Abiotic Changes after Fire

Active Layer Depth

Active layer is significantly affected by fire, clearing and the interaction of the two variables (Figure 4), although fire and seismic clearing independently account for the majority of the variation in active layer depth. Burned areas that have not been cleared have an average active layer depth of 59.5 ± 2.5cm whereas cleared areas remain deeper with a mean of 65 ± 3cm.

The mean difference in active layer depth between cleared and uncleared sites changes with fire (Figure 6). The mean difference in active layer depth between the cleared and undisturbed areas is diminished from an average of 15cm in unburned areas to 6cm after burning.

Subsidence

Subsidence was observed significantly more along lines that had not burned subsequent to clearing. Subsidence was observed on only 22% of the burned seismic lines whereas 42% of the unburned sites had subsidence.

Soil Moisture

No consistent or significant differences were found between the soil moisture along the burned seismic lines and the adjacent burned forests.

Vegetation Changes after Fire

Most of the vegetation seems to be establishing at the same rate on the burned and adjacent cleared-burned areas. The only significant difference identified is that there is significantly more tall shrub cover on the seismic lines. The tall shrub averages between 5 and 25% cover, which is larger than the mean of less than 5% in adjacent undisturbed areas, and this is consistent across moisture regimes ($t=2.04$, $p< 0.0224$, $N=74$ paired sites). The increased shrub cover on the disturbed areas does not change with respect to time between clearing and fire disturbances and is most likely because of the pre-fire increase in shrub density which re-sprouts from unburned subterranean rhizomes The increased tall shrub layer was composed primarily of Betula *glandulosa* and *Salix* species.

Ground cover groups are not significantly different between cleared and adjacent undisturbed areas after fire (Figure 15).

Black Spruce Seedlings

Seedling Establishment

Within the burned areas, cleared plots have seedling densities equal to the adjacent undisturbed plots. The mean seedling densities found within burned forests are 0.85 ± 0.1seedlings/m^2 and 0.8 ± 0.1seedlings/m^2 along the seismic lines within the burns.

Seedling Growth

Different height- diameter relationships were identified for seedlings of different disturbance types (Figure 10). The slopes for the relationships are significantly different; seedlings growing on disturbed sites have a higher height-diameter at base ratio than those growing in adjacent burned locations.

Growth rings were counted and ages tabulated for a total of 347 black spruce seedlings over 2002 and 2003. Because of differences in ratios between height, diameter, and age, separate age prediction equations were generated for each disturbance group (Figure 11;

Table 3). Log transformations were required for all regressions to meet assumptions of normality.

Establishment Time

From the aging equations, it was possible to examine trends in time required for seedling establishment in burned sites. The mean time required for black spruce seedlings to start growing after a burn is 4.6 ± 1.5years. This was calculated with 325 seedlings over 37 sites, however all burned sites have seedlings establishing as early as one year after fire (Figure 12). After fire, the mean delay in tamarack seedling establishment is 12.2 ± 4 years.

Fifty-three percent of the seedlings found on the burned-disturbed sites were established along the lines before the area burned, which indicates that the lines were either not burned or only partially burned. All of the lines which had greater than 50% of the seedlings establish after fire, had a separation time of more than 20 years between clearing and burning events.

Shrub Establishment Times

The range of shrub establishment times within the burned uncleared areas was between one and five years after fire for both *Salix* spp. and *Betula glandulosa*. Alder (*Alnus crispa*) was much more variable with a range of establishment times between one and 10 years after fire, however, it was found in only 15% of sites after fire.

In the areas that were cleared for seismic exploration prior to burning, the shrub establishment times were different. The aging results for the fires that occurred after 1980 show that only 10% of the lines burned completely. A line was considered to have burned completely if all of the shrubs are younger than the burn. In 30% of the sites surveyed all of the shrub ages predate the fire and 60% of the sites suggest partial or incomplete burning because of a mixture of shrub ages that are both older and younger than the fires.

The data recorded for seismic lines that were in areas that burned before 1980 are unclear. The shrub samples collected on the seismic lines do not show that any of the plants established prior to the burn, which suggests that the seismic lines burned However, the reason for the lack of shrubs predating the fires is possibly a function of the lifespan of shrub branches. The oldest shrub samples collected in the unburned-undisturbed sites across the study areas found no shrub branches older than 32 for *Salix*, 31 for *Alnus cripsa* and 35 for *Betula glandulosa.* These ages are less than the time since fire in many of the sampling areas. Fires that occurred between 1968 and 1970 were therefore excluded from this analysis because these areas require shrub branches survival to exceed between 37 and 33 years.

DISCUSSION

Did an Area Cleared for a Seismic Line Burn?

The shrub cookies and seedling ages collected from the burned areas clearly show which seismic lines did and did not burn. Of the disturbed sites which were located within burns between 1980 and 1999, the aging of the shrubs and seedlings show that many of these plants had established on the lines prior to the occurrence of fire.

Lines were considered to have burned when no plants predate the fire. This was observed on 10% of the seismic lines surveyed and agreed with field observations of burning. Seismic lines were identified as not burned when all of the plant samples collected on the lines predate the fire. This was identified in 30% of the sites. Sixty percent of the sites had partial evidence of burning. The results from these partially burned areas included a mixture of field observations and aging data.

Do Fires Re-set Regeneration Conditions?

All of the lines which had greater than 50% of the seedlings establish after fire, had a separation time of more than 20 years between clearing and burning events. This likely reflects the time required for abiotic factors to stabilize. The initial clearing event results in environmental conditions with increased moisture and pooling water because of the disturbance to permafrost. The removal of the vegetation combined with the increase in surface water does not provide a fire with fuel or the conditions required to burn a cleared area

If twenty years is required for a cleared area to burn, this is about the same amount of time required for seedlings to establish unburned-disturbed areas. This suggests that the overall effect of fire does not increase or ameliorate establishment conditions for trees during the initial 20-year time period after clearing.

We expected that fire would re-set regeneration conditions along the seismic lines. Fire does decrease the difference in a number of variables between the seismic lines and adjacent burned areas. The mean difference in active layer depth changes from 15cm to 6cm between burned and unburned areas, the vegetation cover and ground cover composition are also more similar in burned and burned-disturbed areas than in areas cleared for seismic and their adjacent forests. However, this analysis suggests that the environmental changes that occur in response to two different types of disturbance are more similar to one another than either is to the undisturbed forest.

Summary

When fire and linear disturbances overlap we can examine whether the cleared areas in black spruce forests return to the same natural disturbance regime. Fire removes the canopy of the forest surrounding the seismic line, hence making them less visible however the cleared areas are not consistently burning. Over 30 percent of the lines that are in burned areas have not actually burned and 60 percent have only partially burned. Only 10 percent of the surveyed area had completely burned.

In the initial stages after clearing, the disturbance to the environment results in increased active layer depth from melting permafrost, which can release water and sometimes cause subsidence or pooling surface water. Very little vegetation will re-establish in these wet conditions. Since the majority of the vegetation has been removed along the lines and the area is now extremely wet, these seismic clearings will not burn until they dry out and vegetation re-establishes.

The time required for abiotic conditions to stabilize after clearing is between 15 and 20 years. This is the same amount of time required for seedlings to start establishing in the unburned sites. The probability of a cleared area burning increases with time since clearing, particularly after 20 years.

In the majority of the sites included in this study, fire does not seem to be resetting or altering regeneration conditions on the seismic lines because few of the sites are burning. The range in time between disturbance types of fire and burning in this study was between 2 and 32 years. The proportion of sites that burned increased with time between clearing and fire. Of the sites surveyed in this study, few areas have both burned and regenerated in a way that allows them to return to the natural disturbance regime. Increased time between clearing and burning will change this. Once later successional plant communities establish upon the seismic lines, this will increase the amount of fuel for fire and increase the chances of a cleared area burning.

If clearing methods were used that ensured the ground cover vegetation was left intact, this would diminish the disturbance to the active layer and hence reduce the amount of surface water and subsidence. This would diminish the chances of shifting the plant community from a muskeg to an aquatic plant association, and increase the chances of the area burning and being reset in parallel with the adjacent burned forest.

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Table 1: Summary of characteristics of 4 main habitat groups across the study area. These habitat descriptions were compiled with data collected in 2003.

Habitat Type	**White Spruce Forest**	**Shrub Meadows**	**Black Spruce Forest**	**Fen**
Dominant Tree Species	White Spruce	NA	Black Spruce	Black Spruce
Stand Density (trees/ m^2)	0.24 +/- 0.02	NA	0.33 +/- 0.03	Less than 5% Cover
Dominant Shrubs	*Ledum Groenlandicum, Betula glandulosa, Salix spp*	*Betula glandulosa, Salix* spp	*Betula glandulosa, Salix* spp.	*Ledum decumbens, Andromeda polifolia*
Understory Species	*Arctostaphylos rubra, A. uva-ursi*	*Carex* spp, Grasses	*Vaccinium* uliginosum	*Rubus chamaemorus*
Ground Cover Groups	Litter, Moss, Soil	Moss, Litter, Lichen	Feather Moss, *Sphagnum* spp., Lichen spp	*Cladina rangiferina*, *Cladina stellaris*, moss, *Sphagnum* spp.
Mean Percent Soil Moisture	46% +/- 8	60% +/- 9	56% +/- 7	72% +/- 5
N	9	4	24	15

Table 2: Direction of change in shrub abundance after disturbance. Each species was calculated separately over 186 sites.

Species	Direction of Change in Cover	Significance
Alnus crispa	None	NS
Andromeda polifolia	Increase with Disturbance	Prob > t, 0.06
Arctostaphylos rubra	None	NS
Arctostaphylos uva-ursi	None	NS
Betula glandulosa	Increase with Disturbance	Prob > t, 0.0017
Betula papyrifera	Increase with Disturbance	Prob > Chi, 0.038
Chamaedaphne calyculata	None	NS
Empetrum nigrum	Decrease with Fire	Prob > Chi, 0.05
Larix laricina	None	NS
Ledum decumbens	Decrease with Disturbance	Prob > t, 0.05
Ledum groenlandicum	Decrease with Fire	Prob > Chi, 0.0076
Linnaea borealis	None	NS
Myrica gale	None	NS
Oxycoccus microcarpus	None	NS
Potentilla fruticosa	Increase with Disturbance	Prob > t, 0.008
Ribes triste	None	NS
Rododendron lapponicum	None	NS
Rosa acicularis	Increase with Fire	Prob > Chi, 0.04
Rubus arcticus	None	NS
Rubus Chamaemorus	Decrease with Fire	Prob > Chi, 0.04
Salix spp	Increase with Disturbance and Fire	Prob > Chi, 0.034
Shepherdia canadensis	None	NS
Vaccinium uliginosum	Decrease with Fire	Prob > Chi, 0.02
Vaccinium vitis-idaea	Decrease with Disturbance	Prob > t, 0.03

Table 3: Summary of equations generated to predict seedling age.

Species	Disturbance Type	Predictive Equation for Age	r^2	N
Black Spruce	Unburned, Undisturbed	Log (Age) = 0.865 + 0.721*Log (Diameter at Base)	0.83	50
Black Spruce	Unburned, Disturbed	Log (Age) = 0.956 + 0.494*Log (Diameter at Base)	0.7	109
Black Spruce	Burned, Undisturbed	Log (Age) = 0.868+0.518 *Log (Diameter at Base)	0.59	83
Black Spruce	Burned, Disturbed	Log (Age) = 0.964 + 0.418*Log (Diameter at Base)	0.41	99
White Spruce	All	Log (Age) = 0.916 + 0.623 Log (Diameter at Base)	0.8	26
Tamarack	All	Log (Age) = 0.822 + 0.533 Log (Diameter at Base)	0.54	44

Table 4: Selection ratios calculated by comparing the amount of each substrate groups available at each sample site against the cover on which the seedling has established. Selection ratios greater than one indicate positive association, or selection and ratios less than one indicate negative association or avoidance. The selection ratios were calculated with seedlings from 63 sites in 2003 and 53 sites in 2002.

Substrate	Selection Ratio
Lichen	0.51
Litter	1.94
Moss	1.49
Soil	0.21

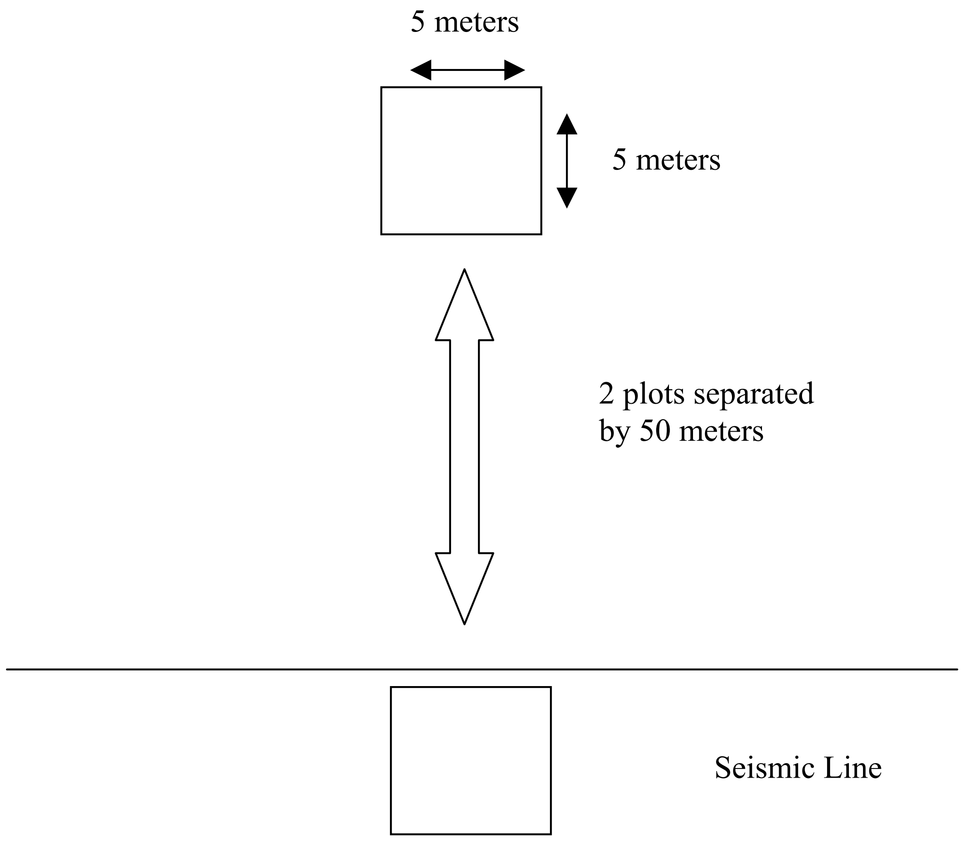


Figure 1: Diagram of plot sampling locations at each site. At each sampling site there are two plots. One plot with the dimensions 5 meters by 5 meters is located on the seismic line and a second plot with the dimensions of 5 meters by 5 meters is located in the adjacent undisturbed forest. A distance of 50 meters separates these two plots.

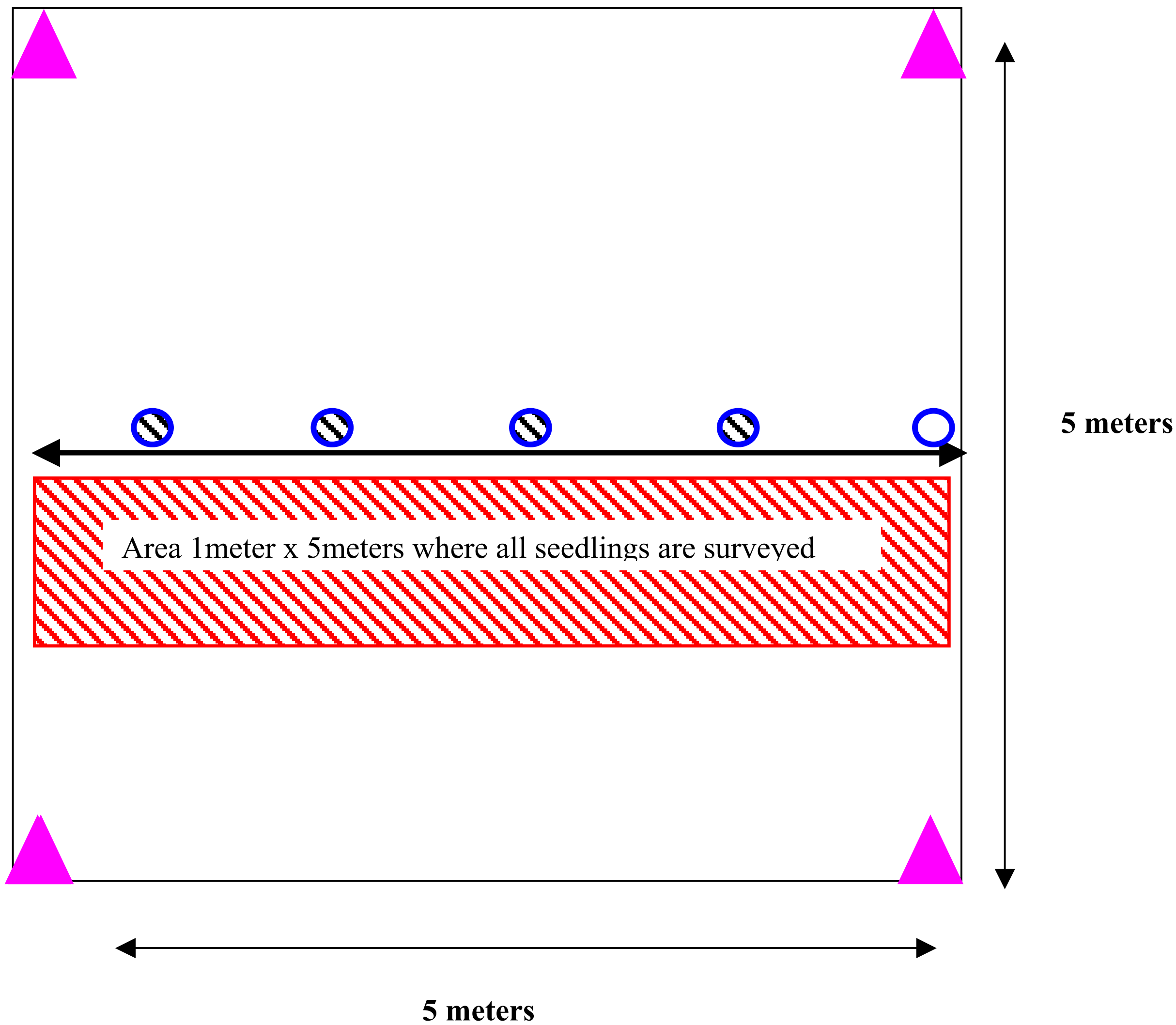


Figure 2: Diagram of within plot sampling design. The four purple triangles indicate the points at which subsidence measurements were made. The 5 blue circles indicate the points at which active layer depths were taken. The blue circles with crossed lines indicate the point at which soil cores were taken. The red box shows an area of 1 meter by 5meters that was searched for seedlings. The understory vegetation surveys were conducted along the central transect which is identified by the black arrow.

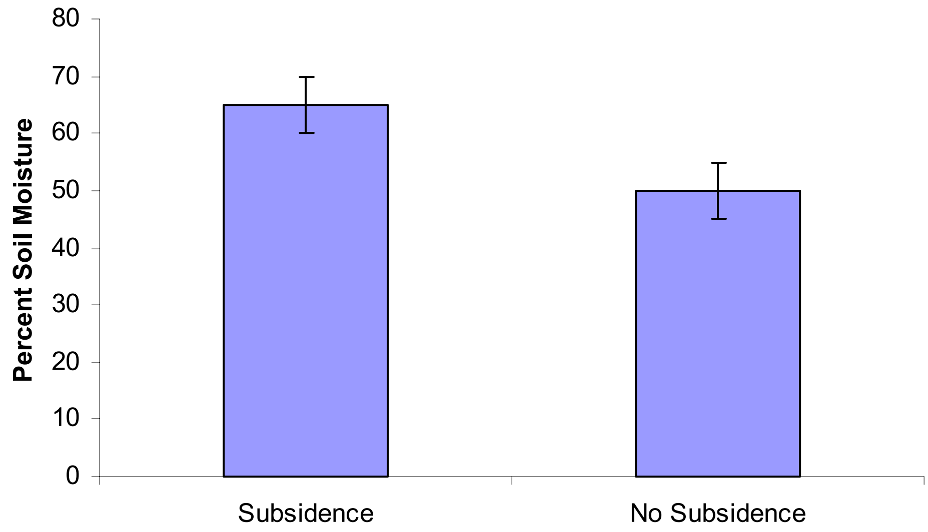


Figure 3: Comparison of the mean soil moisture content in sites that have evidence of subsidence against sites that have no evidence of subsidence t= 2.73, p< 0.09, N=41.

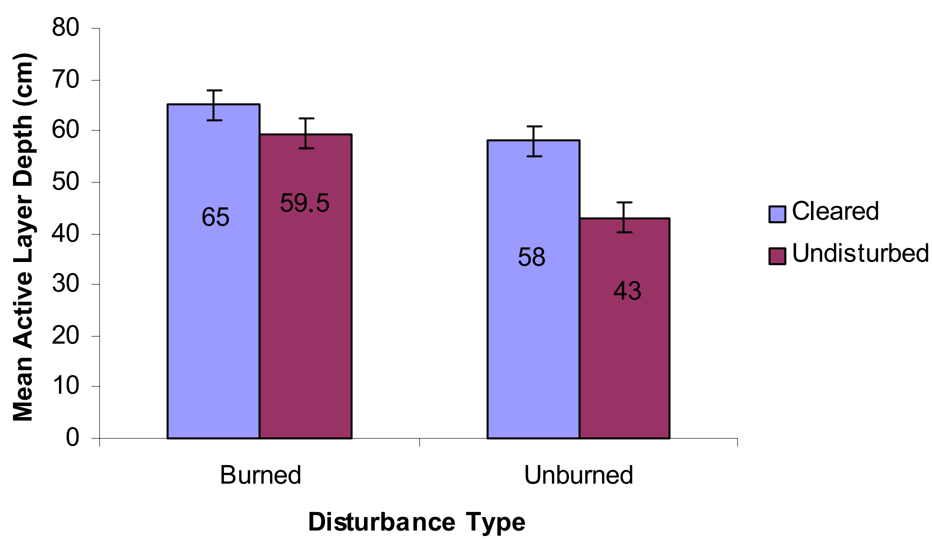


Figure 4: Mean active layer depth across disturbance type. N=920, F= 24.61, p< 0.0001.

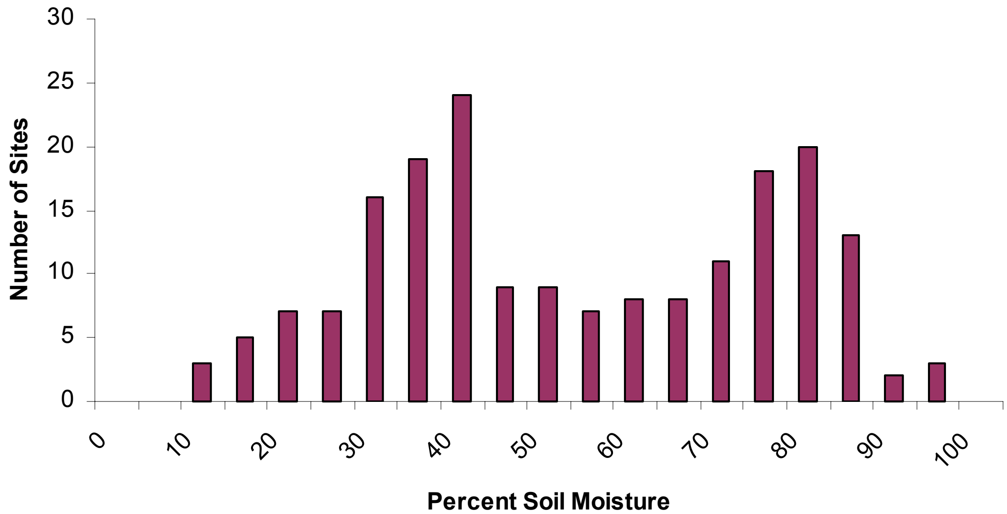


Figure 5: Histogram showing distribution of soil moisture across sample sites. N=186.

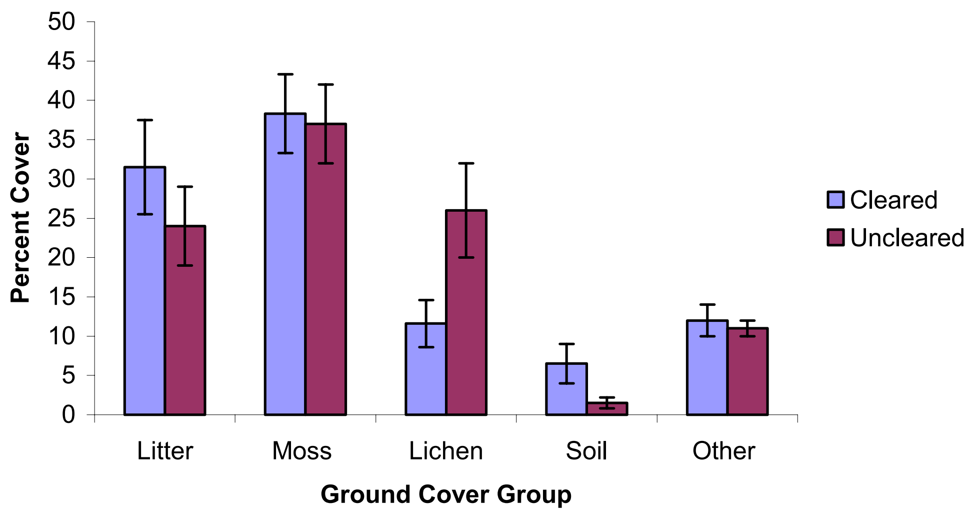


Figure 6: Percent cover of ground cover groups. Means are calculated over 41-paired sites. Comparisons were made using a Wilcoxon test. The proportion of mineral soil is significantly different at p<0.02 and lichen is significantly different at p<0.004 using a Wilcoxon test.

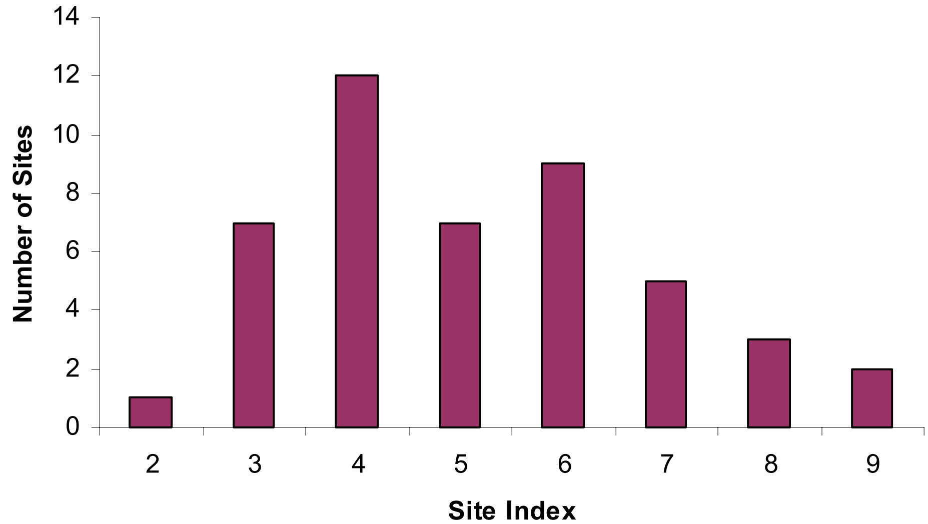
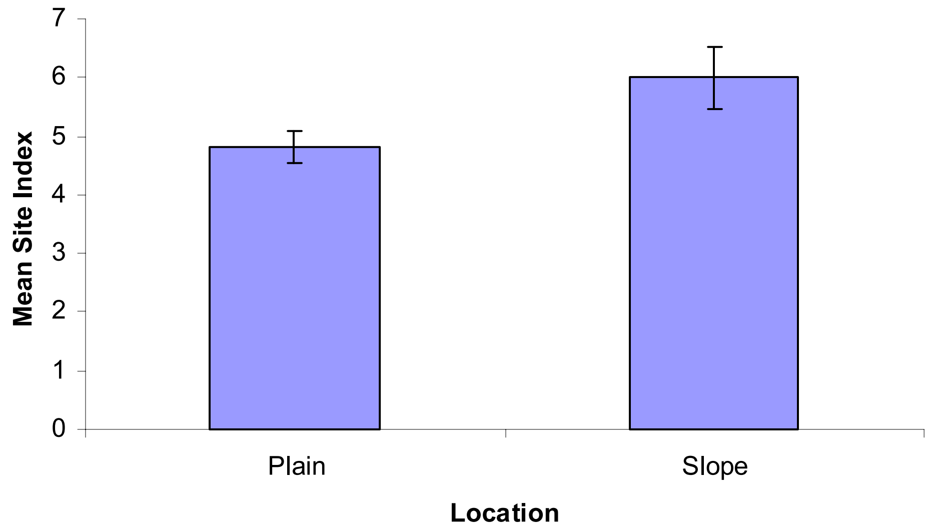


Figure 7: Histogram showing range of site indices for open black spruce forests. The sample size includes trees that were collected in 46 plots.

A



B

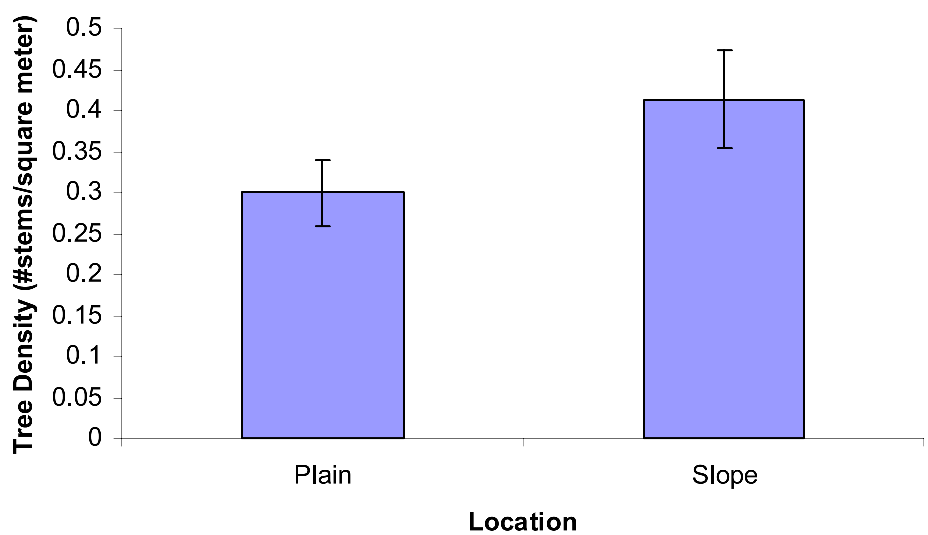


Figure 8A: Mean site index compared across terrain type. The means are significantly different and include trees collected from 43 sites, $Z = 1.977$, $p < 0.0481$.

Figure 8B: Mean stand densities compared with site position. Densities were collected over 28 sites and are significant at $t=2.055$, $p<0.1$.

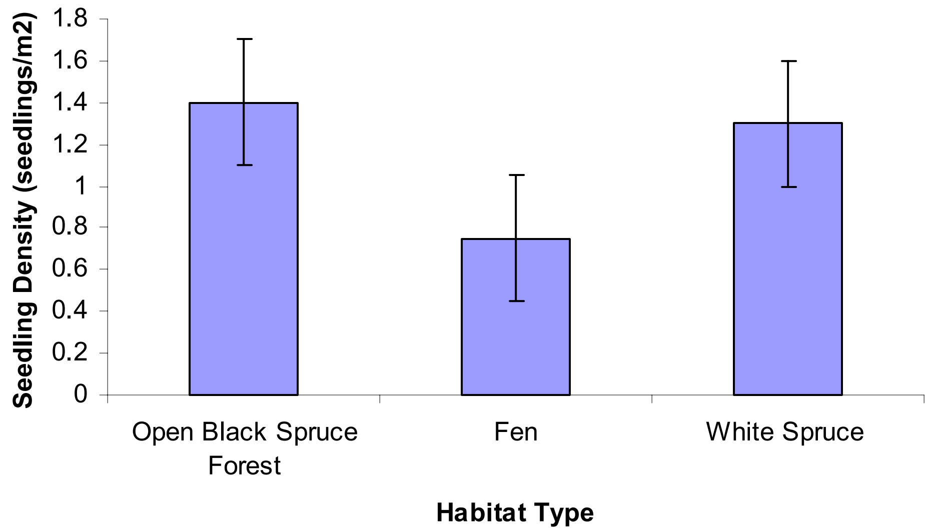


Figure 9: Mean seedling densities in different habitat types along the seismic lines. $N_{Black\ Spuce}$= 24, $N_{White\ Spuce}$= 9, N_{Fen}= 15.

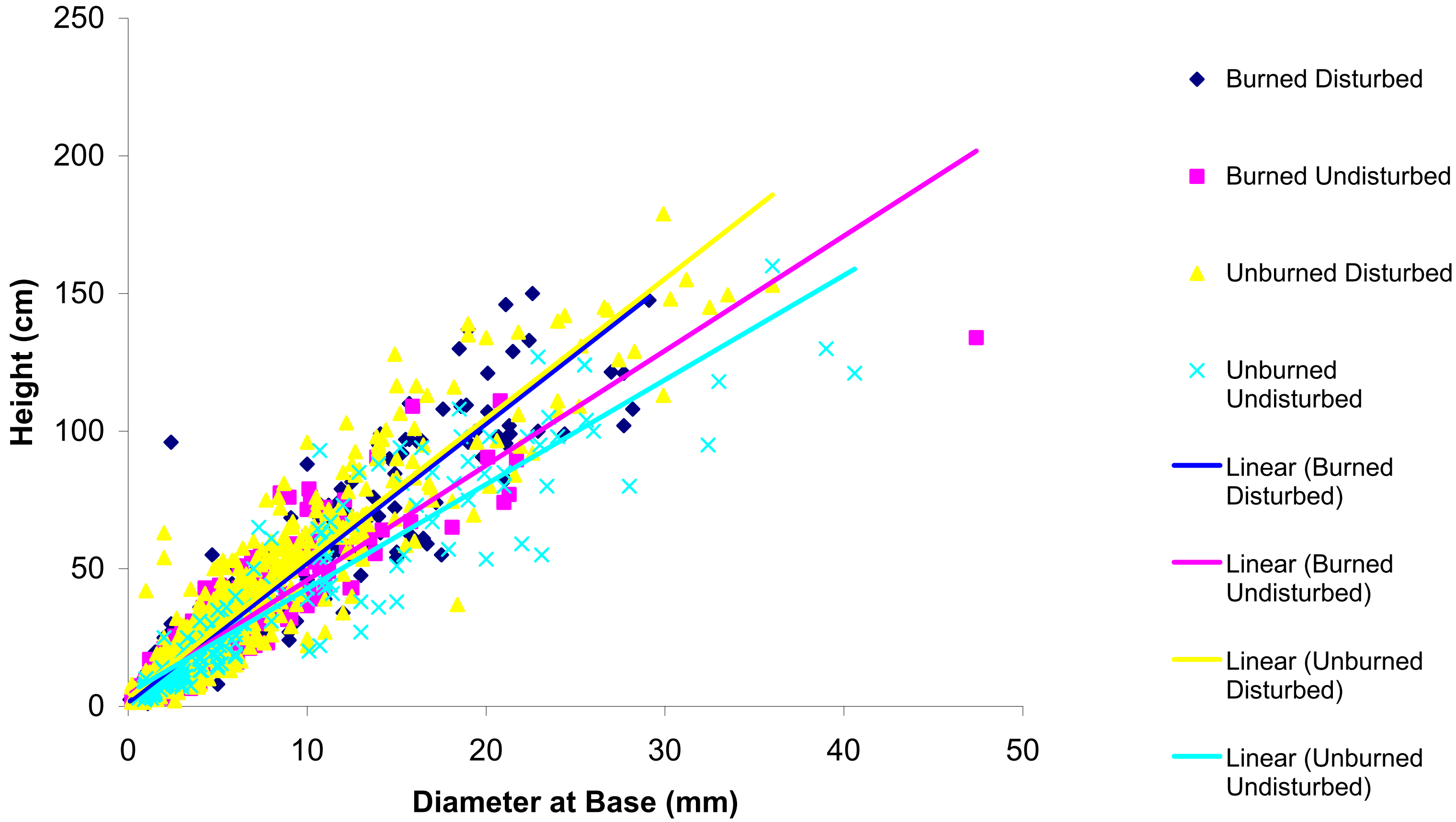


Figure 10: Comparison of the slopes of height and diameter at base between seedlings from disturbed and undisturbed areas. Slopes are significantly different ($F=25.65$, $p<0.001$, $N=1809$).

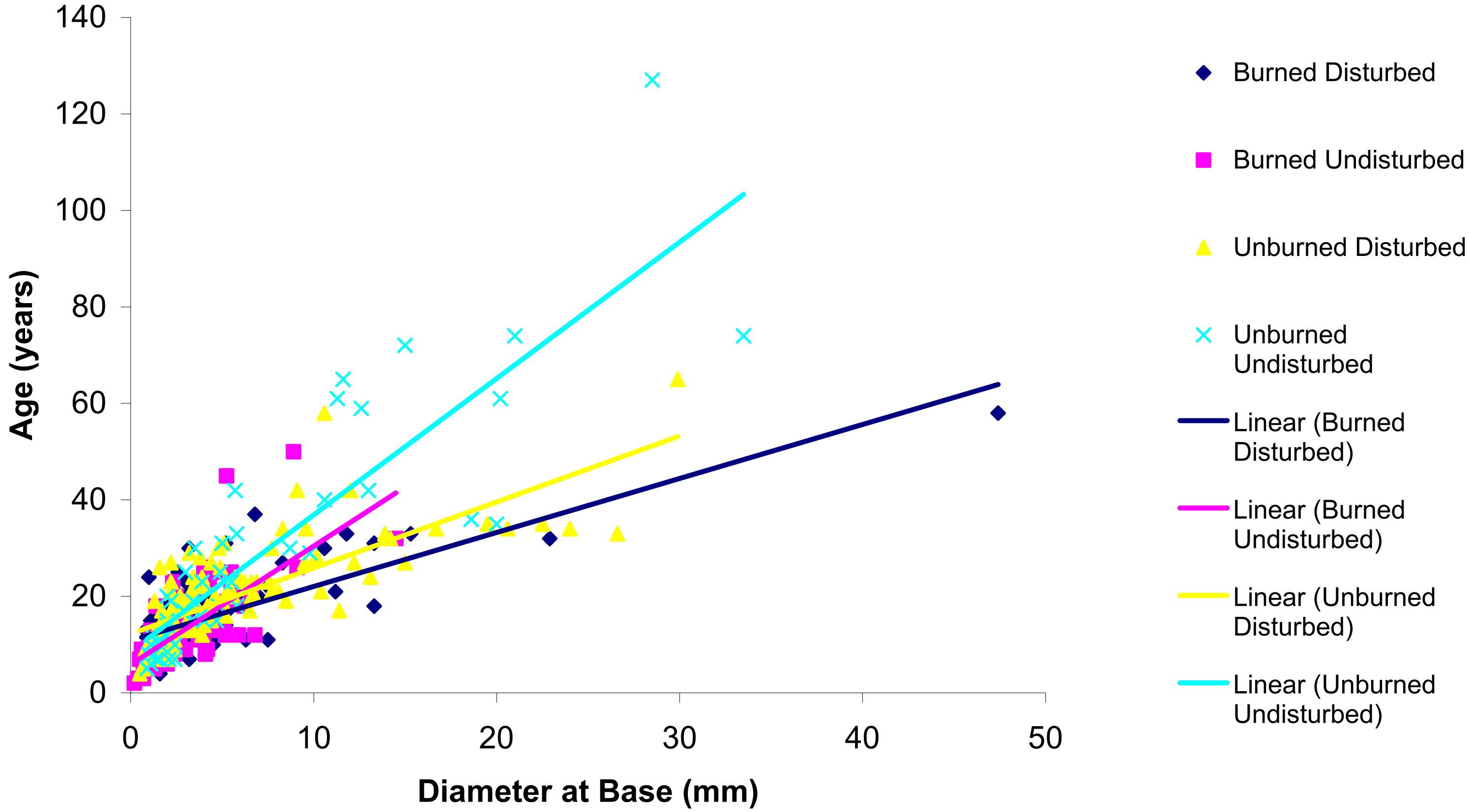


Figure 11: Comparison of slopes using diameter to predict seedling age. Slopes are significantly different ($F=152$, $p<0.001$, $N=347$).

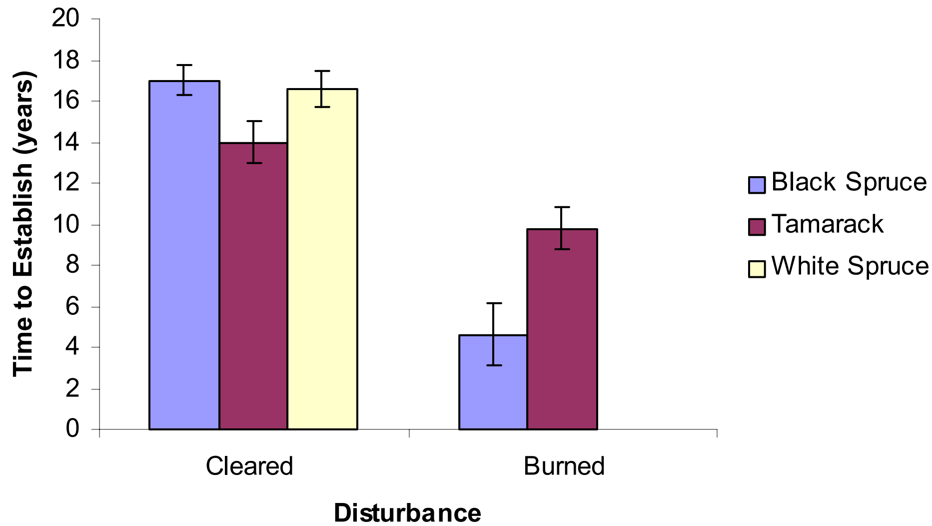


Figure 12: Mean amount of time required for seedlings to establish after clearing and fire.

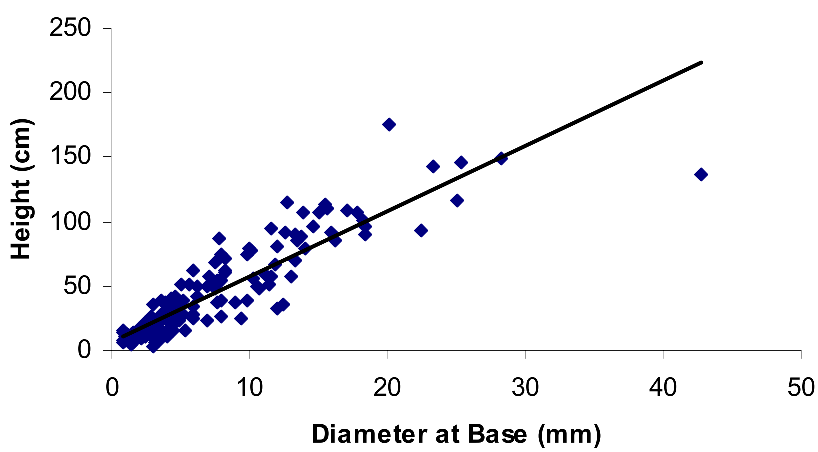


Figure 13: Relationship between seedling height and diameter at base for Tamarack seedlings r^2=0.8, $p<0.001$, N=155.

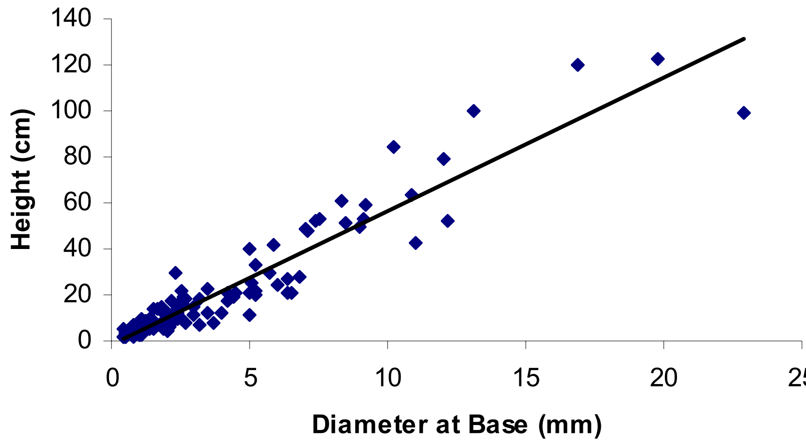


Figure 14: Relationship between seedling height and diameter at base for White Spruce seedlings $r^2=0.95$, $P<0.001$, $N=165$.

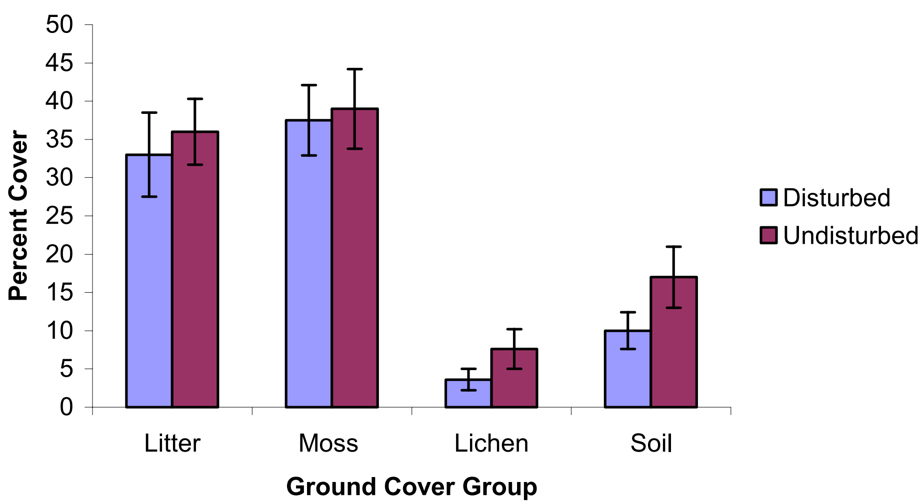
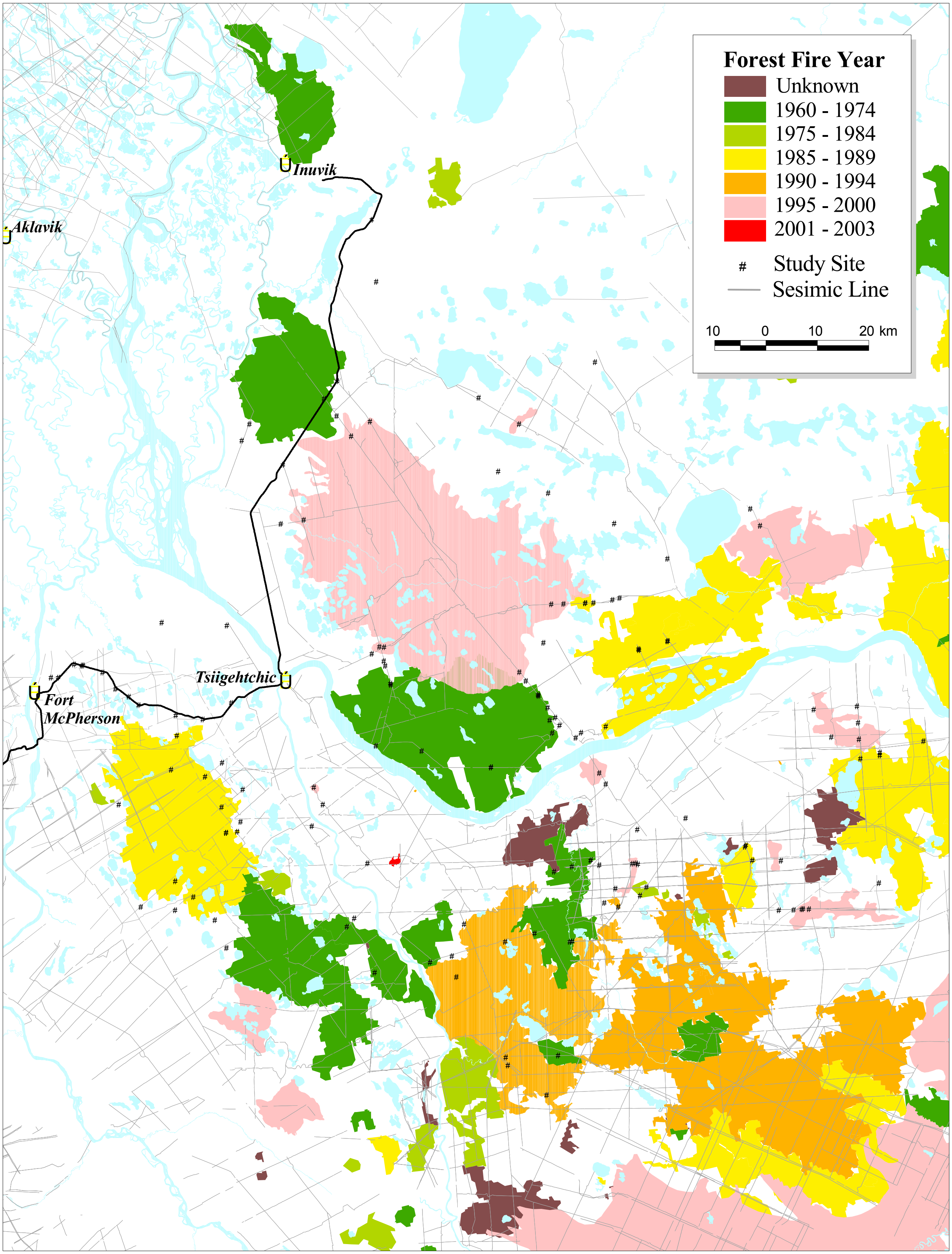


Figure 15: Comparison of mean percent cover of ground cover groups within the burned areas. No significant differences were identified between ground cover groups.



Appendix 1: Map of survey site locations within the Gwich'in Settlement Area.