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Sustainable Forestry in the Gwich'in Settlement Area: Biological Perspectives

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Sustainable Forestry in the Gwich'in Settlement Area: Biological Perspectives*

SFM Network Project: Sustainable Alternatives to Industrial Forestry in the Gwich'in Settlement Area

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EXECUTIVE SUMMARY

The Sustainable Alternatives to Industrial Forestry in the Gwich'in Settlement Region was initiated in 1997 in cooperation with the Gwich'in Renewable Resources Board to support the drafting of a sustainable forestry management plan relevant to Gwich'in communities. The project is unique in that it combines the effort of a team of biological and social scientists to obtain a more holistic view on the central concepts and categories relating to forestry. At the heart of this research team is an attempt to conduct forest regeneration and productivity studies on sites identified by Gwich'in elders as being of concern to the community. The social science team conducted longitudinal studies of forest use in archives in both Winnipeg and in Ottawa and conducted extensive interviews with community members. The present report summarizes the findings of the biological science team.

The Mackenzie Delta Region landscapes are easily divided into the white spruce and willow dominated Delta landscapes and the surrounding black spruce, white spruce and white birch upland landscapes. On April 22, 1992 the Comprehensive Land Claim Agreement was established by the Gwich'in Tribal Council, the Canadian Government and the Government of the Northwest Territories. This agreement then was enforced by the passing of the Gwich'in Land Claim Settlement Act on December 22, 1992. This land claim created a 56, 935km² area which includes the lower Mackenzie River, part of the Peel River and the Arctic Red River watershed and supports four main settlements (Aklavik, Fort McPherson, Inuvik, Tsiigehtchic).

Our biological research focused on the regeneration and the productivity of the upland and especially on the Delta forests. In terms of regeneration, we examined white spruce seed viability after fire through experimental and survey approaches. We learned that white spruce killed by fire early in the season do not produce viable seed but if fire killed the trees in July there will be after-ripening of seed and viable seed for stand establishment is available in August. Second, we studied the regeneration and stand development on a 1999 fire using survey approaches. Our findings from the seed study could be confirmed after finding the highest seedling establishment rates in the sites that burned late in the season. Third, we examined the age distribution of trees in fire-origin upland white spruce stands using survey approaches. We learned that unevenaged stands dominate the uplands and that the major tree establishment period occurs generally in the first forty years after a fire.

In terms of forest productivity, we examined the true age of white spruce trees in the Mackenzie Delta. We learned that white spruce trees are up to one hundred years older than indicated by ring count at stem base. Sediment buildup buries the young tree bole during flood periods until the soil surface is elevated above flood levels. Second, we measured the productivity and growth rates of Delta vs. upland white spruce. We learned that the fire-originated upland white spruce stands show a higher productivity than the old-growth Delta spruce. The upland white spruce sites, however, are limited to small areas with more favorable growing conditions such as south slopes of well-drained eskers. Third, we measured the importance of tree release after selective cutting. We learned that contrary to southern forests, the old-growth delta forests show little, if any, release after selective cutting. Fourth, we measured regeneration after selective cutting in the Mackenzie Delta. We learned that old-growth delta forests do not regenerate after selective cutting due to site characteristic changes during the lifespan of the stand.

ACKNOWLEDGEMENTS

We acknowledge first and foremost the support of the peoples of the communities in the lower Mackenzie Valley; we dedicate our results to their future. Also we wish to thank the many others who made each day a pleasant experience.

The overall research was coordinated by David Anderson and Ross Wein and was supported financially by a project partnership of the Gwich'in Renewable Resources Board, the University of Alberta Sustainable Forest Management Network and the Department of Resources, Wildlife and Economic Development of the Government of the Northwest Territories. Other supporters and cooperators include, in alphabetical order, the Aurora Research Institute of Aurora College, the Gwich'in Tribal Council, Polar Continental Shelf Project, University of Erlangen, Germany (Dept. of Geography) and the University of Alberta (Departments of Anthropology and Renewable Resources).

The research was conducted under Scientific Research Licenses (1998- # 13006N, 1999- # 13058N, 2000- # 13128R) in File # 12-402-611 as issued by Aurora Research Institute, Aurora College.

INTRODUCTION AND GENERAL OBJECTIVES

Since 1997, the Gwich'in Renewable Resources Board, in collaboration with the Departments of Anthropology and of Renewable Resources at the University of Alberta, have been involved in a baseline study of existing forestry practices. The social sciences component of the team started their research in 1997 and used oral history, archival, participant observation within a context of industrial forest use in the recent past and within the context of proposed future developments. The research was designed to widen our knowledge of the quantity of logs taken by sawmills and steamships at the turn of the century. Our group has chosen to widen the research question to contrast the unique and flexible way that Gwich'in people traditionally use a variety of resources in the forest to the intensive use of timber by transport and building firms earlier in this century. It is this contrast, which currently rests behind present management decisions as communities are studying proposals for commercial cutting to supply materials for construction or to provide firewood for the four expanding Gwich'in communities in the Mackenzie Delta.

The biological science team carried out three studies to get a better understanding of white spruce regeneration at its northern limit. As fire is the driving factor that shapes the northern boreal forest, regeneration of the upland spruce is closely related to the local fire regime, the intensity, rotation and time of the fire. To show the complexity of the regeneration dynamics, each stage from seed to the mature forest was examined. An experimental as well as a field survey tested seed quality of white spruce after fire. Regeneration plots were established after a wildfire to determine the differences in seedling establishment when the fire burned during different times of the growing season. The third study focuses on the age distribution of mature stands that represents the long-term establishment rates after a fire.
In the delta, three studies were carried out with a main focus of white spruce productivity. True tree ages were determined and growth rate chronologies were derived from tree ring widths of delta and upland spruce stands.

The results of this research are intended to flow into a Sustainable Forestry Management Plan for the GSA.

THE GWICH'IN SETTLEMENT AREA

The GSA is a sub-Arctic boreal territory located at the northern boundaries of the Northwest Territories and Yukon Territory. The area is one of a small but growing number of lands where, after a period of long deliberation, the Government of Canada recognized the rights of a First Nation to regulate its own land, water, and wildlife resources. Although presently far from the industrial forests of northern Alberta and British Columbia, the GSA has some of the most northerly boreal forests in the world. Thus the region is special both politically and ecologically. Forestry in the Gwich'in Settlement Area is of interest to scholars for a variety of reasons. Key among these is the fact that the Gwich'in residents of this area maintain close ties to the land through activities, which in the past were referred to by academia as subsistence patterns. People refer to "staying" on the land and the physical space is divided up into people's "country" where a degree of tenure is held not through any sort of distanced political boundary creation but through direct knowledge of it and a sense of maintaining it through generations.

The Mackenzie Region is comprised of the lowlands with many rivers producing the Mackenzie River and of the highlands which rise to the Richardson Mountains. The forests in the Mackenzie Delta are dominated by black and white spruce, balsam poplar, paper birch and larch. The banks of the rivers and back-channels are usually bordered by willows. The highlands and the mountains are mostly tundra with some stunted spruce and birch trees growing in the valleys and some larger spruce trees growing along some of the larger creeks.

Figure 1: Aerial view of the Mackenzie Delta showing the main channel, many smaller channels and oxbow lakes

On April 22, 1992 the Comprehensive Land Claim Agreement was signed by the Gwich'in Tribal Council, the Canadian Government and the Government of the North West Territories. This agreement was enforced by the passing of the Gwich'in Land Claim Settlement Act on December 22, 1992. This land claim created a 56,935km² area, which includes the lower Mackenzie River and part of the Peel River and the Arctic Red River watersheds. The Gwich'in Settlement Area should not be confused with the Gwich'in Settlement Region, which includes the GSA in the Northwest Territories and an area in the Yukon where Gwich'in have user rights to natural resources.

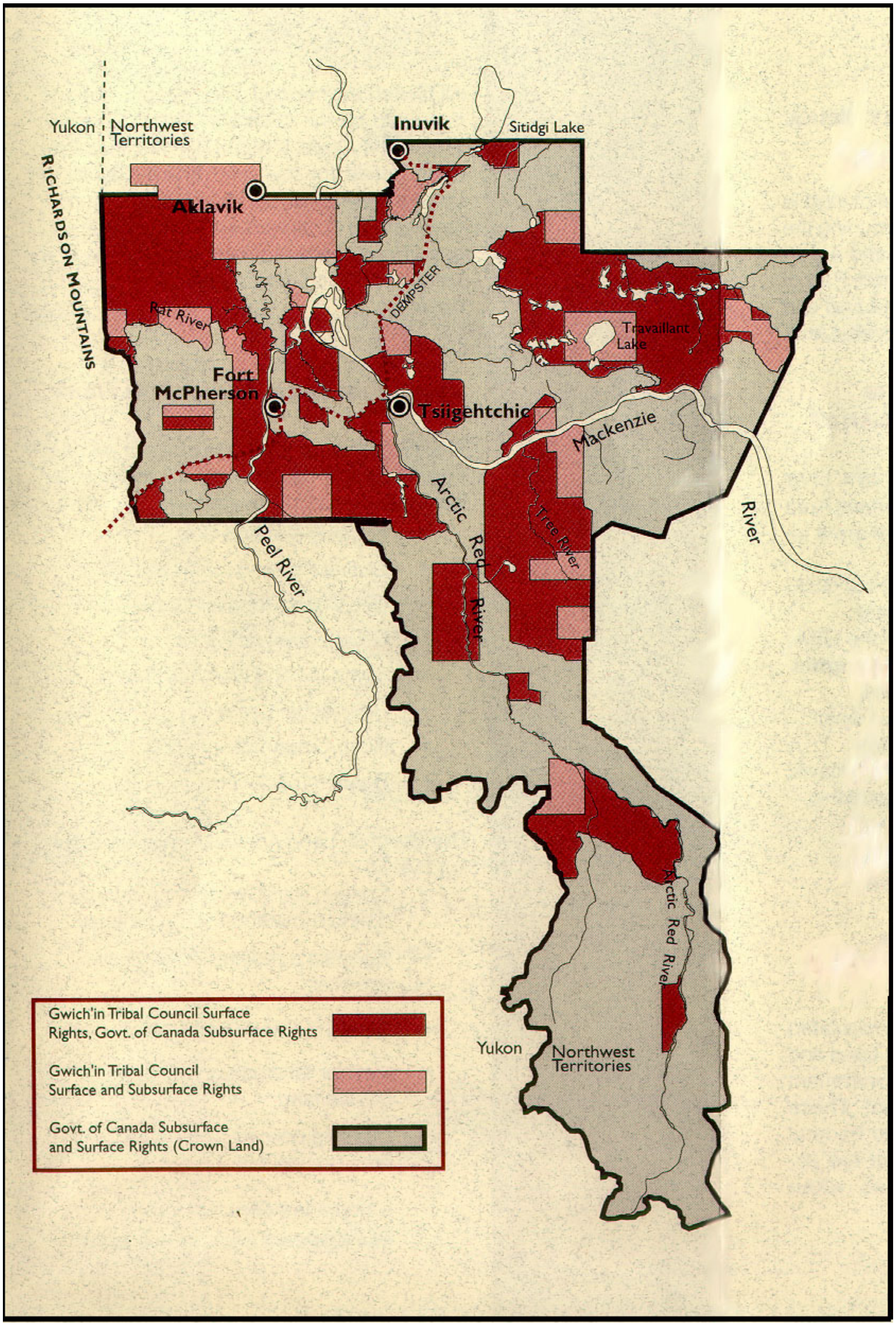

Figure 2. The Gwich'in Settlement Area is a 56,935km² area located on the Peel, Arctic Red and Mackenzie Rivers and supports four main settlements.

Beneficiaries of the land claim have the legal right to access all the land in the GSA for the purposes of subsistence activities, i.e., they may hunt, fish, trap and harvest forest products for personal use. If one of these beneficiaries wishes to conduct commercial activity then he/she must first ascertain if the land involved is Gwich'in Private Land or Crown Land. Gwich'in Private Land composes approximately 40% of the land in the GSA, which is made up of 53 parcels (33 are surface rights and 20 include subsurface rights). If the land in question is Gwich'in Private Land then the beneficiary must first contact the owner for approval. If the land in question is located on the 60% of the GSA, which has remained Crown Lands, then the beneficiary must contact the Gwich'in Land and Water Board for approval. Non-beneficiaries must comply with all Federal and Territorial laws governing access to Crown Lands. On Gwich'in Private Land they must contact an agent of the Gwich'in Tribal Council for details concerning access other than for casual use of waterfront lands, i.e., canoeing, sport fishing, hiking, etc. An agent of the Tribal Council includes the Gwich'in Land Administration and Community Renewable Resource Councils located in Aklavik, Fort McPherson, Inuvik and Tsiigehtchic. The Gwich'in Land Administration is the organization, which regulates research and forestry activities on Gwich'in Private Lands.

The legal landscape created by the formation of the GSA was considered to be necessary by the Gwich'in Tribal Council in order to better manage Gwich'in land for the benefit of the Gwich'in people. Prior to its formation both Gwich'in and non-Gwich'in had the same rights of access and had to comply with the same Federal and Territorial laws. This situation put Gwich'in people into a position where they were committing criminal acts when they tried to maintain their traditional practices on what they considered to be their land. While this legal landscape is different from the traditional model, it does aid in regulating non-Gwich'in impacts and aims at preserving an identity, which relies on Gwich'in people maintaining ties to the land.

FOREST REGENERATION PROJECTS

1. POST-FIRE WHITE SPRUCE SEED VIABILITY NEAR THE ARCTIC TREELINE

INTRODUCTION

Fire is an important driving force in the circumpolar boreal forest and even near the arctic treeline fires occur, although at a lower frequency than farther south. Near the North American arctic treeline there is some evidence that *Populus* species may invade the tundra after late-season, severe fires (Landhaeusser and Wein 1993). The two dominant conifer *Picea* tree species have different strategies for establishment after fire. Black spruce (*Picea mariana*) retains serotinous cones in the crown for many years and after crown fires the seed stored in many-aged cones open and seed is released quickly. White spruce (*Picea glauca*) does not show this ability to store seeds in the tree canopy; instead, the species produces and disseminates seed each year. At the arctic treeline seed storage is thought to be a critical factor determining post-fire recovery since harsh climatic conditions reduce the number of productive seed years (Nienstaedt and Zasada 1990).

The length of fire season in the boreal forest decreases in duration with distance northwards (Simard, 1975), with the main fire season occurring during the months of June to August in the northern Northwest Territories (Murphy *et al.* 1980). In the Inuvik area, fires can occur as early as May and as late as September; the highest fire weather index values have been recorded during June and July (Kadonaga 1997). It is generally accepted that white spruce only slowly re-occupies burned areas through seed transport from the unburned forest edges or survivors over longer distances (Black and Bliss, 1980).

The objective of this study was to test the potential of white spruce trees killed by surface fires to release viable seeds after fires that kill trees at differing times during the growing season. In essence we wished to determine how late in the growing season seed bearing trees could be killed and still produce viable seed. It was hypothesized that seeds from trees killed late in the season could have the ability to mature on the dying tree and thus provide a seed source for stand replacement rather than a slow, long distance seed transport from the unburned forest edge.

METHODS AND MATERIALS

Study area

The study area was located on an upland area bordering the eastern edge of the Mackenzie Delta, Northwest Territories and just to the south of the arctic treeline. The rolling terrain is mainly dominated by white spruce on well-drained till and black spruce in moist depressions (Mackay, 1963). The Mackenzie Delta area is characterized by sub-arctic climate with annual mean temperatures of -9° C and a total annual precipitation of 260 mm with the peak precipitation occurring in late summer (Climatic records supplied by Environment Canada, 2000). In 1999, the year of the study, dry spring weather provided a high fire hazard; the total 1999 May precipitation of 5.8 mm (1.5 mm rain, 4.3 mm snow) fell below the mean May precipitation of 17.8 mm (1957-1999). The weather conditions in 1998 and 1999 also supported unusually high cone production in the study area with some of the slender spruce trees bending from the crown weight.

Field studies

An experimental approach was used to determine seed maturation in relation to date of burning on white spruce trees located near the town of Inuvik at about 68°20’10.9’’N, 133°39’22.7’’W. Fifteen cone bearing white spruce trees were selected randomly for treatments that simulated killing by low intensity fires at different times during growing season. Since earlier pilot studies suggested that August was the critical month for seed maturation, cone-bearing branches were selected randomly and on 4, 11, 18 and 25 August one branch on each tree had a 2 cm ring of bark removed close to the bole. On the same dates, samples of five cones were collected from untreated branches on each tree to establish the level of seed germination and an additional three cones were collected to determine the degree of embryo and endosperm development. On August 29, five cones were collected from each treated branch and one untreated branch. For the germination study, the cones were air dried until they opened and then the seeds were stored in a frozen condition until tested for viability. For the seed maturation study, the three cones from each date were frozen immediately after collection and held in that condition until the seeds were extracted manually and examined for state of maturity.

A field survey study was conducted on a 172 000 ha fire that started on June 16, 1999 and burned throughout the summer at 67°34'27" N, 132°47'47" W. The location of the fire fronts was well documented by fire suppression personnel during the season so it was known when stands of white spruce were killed. At the end of August when cone opening started, four burn dates were selected and twenty fire-killed trees were selected randomly for each date. Ten cones were collected from at least five branches on each tree.

Germination studies

Cones from both experimental and survey germination studies were air dried until they opened; then seeds were extracted manually (Plate 1). A random sample of approximately 200 seeds from each tree from the survey and from each branch for the experimental study was placed into a petri dish lined with moist filter paper to which a mild fungicide (Thiram) was applied. Seeds were moist stratified at 3°C for a period of 21 days. Germination tests were carried out under 18/6 hr light/dark cycles and diurnal temperature fluctuations of 25/10°C (Nienstaedt & Zasada, 1990). Over a period of three weeks, seeds were counted as germinated when the radicle emerged from the seed coat.

Seed maturation

To determine the date of seed maturation, the frozen cones were cut in half and the exposed seeds along the cone axis were compared to the four development stages suggested by Hamilton (1993). When embryos and endosperm filled the seed cavity to more than 75%, the seed was considered as mature. The cones originated from the same 15 trees that were selected for the experimental study and were collected from each tree on 11, 18, and 25 August.

RESULTS

Seed maturation

There was rapid filling of the seed cavity by the embryo and endosperm during the month of August. By August 11, 80% of the seed showed a cavity filling of only 25-50%. Seventy nine percent of the seeds tested from August 25 had the seed cavity filled by more than 75% and were considered mature (Table 1). Thus, seed maturation took place between August 18 and August 25. Field observations noted the first cone opening and seed release around August 29. However, a high number of seed could not be used for testing because of severe damage by spruce seed moth (*Cydia strobiella*).

Experimental study

No significant difference was detected among germination rates from seed of branches girdled at different dates. The germination rate of seeds from girdled branches was significantly higher than the untreated in early August. Germination percentages on treated and untreated branches approximate as maturation date approaches. Germination rate (mean ± SE) of 57 ± 4.5% of the branches girdled at August 25 was slightly higher than untreated branches collected on August 29, showing a rate of 55 ± 6.0% (Fig. 1). A comparison of the branches girdled on August 04 and the trees burned on August 06 shows no significant difference (Fig. 2).

Field survey

Lowest germination within the 1999 fire (21 ± 4 % mean + SE) was found in white spruce seed collected in areas burned in June. A significantly higher germination rate was found in early August (41 ± 4 %) and late August (36 ± 6 %) (Mann-Whitney-Test, $P < 0.01$).

DISCUSSION

The date of stem-killing fire has a pronounced effect on the maturation and viability of white spruce seeds; the later the fire in the growing season, the greater the number of viable seeds. In 1999, which was an exceptional year for numbers of cones, seed maturation occurred late in the growing season between 18 August and 25 August 1999. Fires that kill trees earlier in July or August show after-ripen on a dying branch. Fires that kill the cambium only interrupts the carbohydrate transport out of the branches, the green foliage near the cones is still able to photosynthesize and supply the seeds with storage products. The results of the study are supportive of an earlier survey, where white spruce recolonized large burned areas in northern Alberta, where no post-fire residual trees could have functioned as a seed source (Schoplick, in press).

Modeling approaches have been used to examine the changes in vegetation in northern forests under a changing climate. In general an altered forest composition is predicted, where early succession species will dominate because of a higher disturbance frequency. Changes in biomass production as well as in age class distributions are expected. In general, a changing vegetation is closely related to a changing disturbance regime caused by a changing climate (Overpeck *et al*. 1990). Modeling approaches have been used as well to examine the fire season characteristics under climate change scenarios. Early models (Street, 1989; Overpeck *et al*. 1990) suggested a shift of the severe fire months later into the season due to an increase in spring precipitation and a decrease in late summer precipitation. Fire severity/intensity is expected to increase as well as the area burned (Flannigan and Van Wagner, 1990). Generally, with rising temperatures, the fire season is expected to start earlier in spring and extend later into the autumn (Wotton and Flannigan, 1993) An increase of severe, deep burning fall fires will result in large areas with exposed mineral soil that provides a favorable seedbed for white spruce. More recent modeling efforts suggest that Fire Weather Index (FWI) and fire frequency might decrease in some areas of western and northwestern Canada despite increasing temperatures. This trend is based on an increase in precipitation frequency (Flannigan *et al*. 1998). Although models that are based on General Circulation Models (GCM) provide the best available means to estimate the impact of climate change on future fire activity, the interactions leading to a single fire are too complex to be included in large scale models. Not only the amount of precipitation and temperature but also ignition agents, the variability of extreme events, fuel conditions and other variables are likely to change under a changing climate regime (Flannigan and Wotton, 2001).

There is little field evidence that tests the above climate change hypotheses. Climate change may result in a change of vegetation cover of the forest tundra ecotone as suggested by

Landhäusser and Wein (1993); they found evidence near Inuvik for an increasing density of deciduous species such as *Populus* and *Betula*. An increased fire activity caused by rising temperatures may be more important than the slower, direct effects of climate change. Under current conditions, black spruce is the dominant species on the upland landscapes near the northern treeline of northwestern Canada. White spruce is restricted to areas of well-drained southwest slopes and glacial gravel depositions. Under climate change predictions, it is expected that the active layer will increase in depth and white spruce may increase in areal extent at the expense of black spruce. With a shift in the fire season into the autumn period, increased seed availability could allow white spruce to compete successfully with the presently dominant black spruce. Near the arctic tree line in the late 1970s black spruce germination was rather low (28-35%) and germination decreased with the age of the seed that remained in the cones (Black and Bliss 1980). Despite the advantage of crown seed storage in black spruce, the white spruce habitat may expand with changing climate and a changing fire regime.

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FIGURES AND TABLE

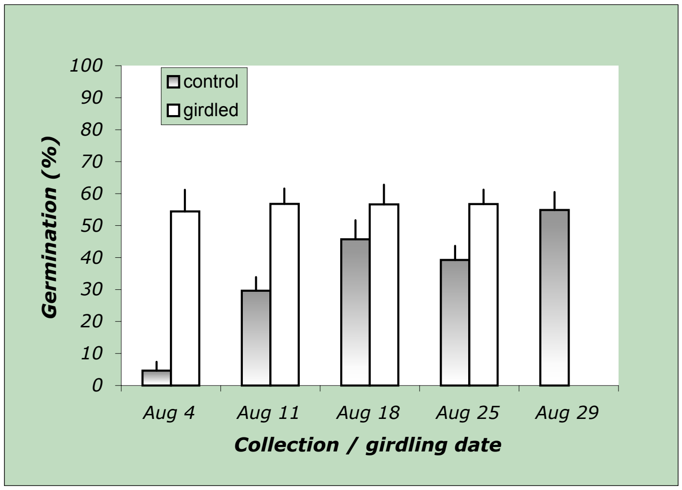

Fig. 1. Experimental study: Germination percentage (mean ± SE) of seed from 15 *Picea glauca* trees near the town of Inuvik, NWT. White bars represent the germination percentage for seeds from 5 cones collected from one untreated branch from each tree at each date. Cones from the same trees were collected on Aug. 29, 1999 from one branch of each tree that was girdled on the given dates. About 28,000 seeds were tested, the number of seeds per sampled branch ranged from about 60 to 400.

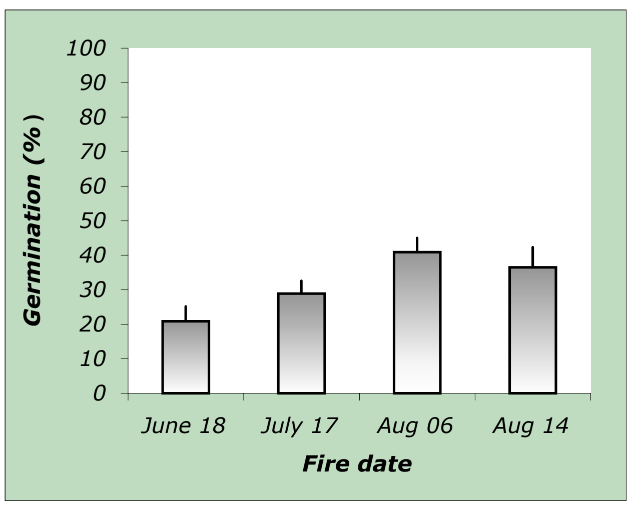

Fig 2. Survey study: Germination percentage (mean ± SE) of *Picea glauca* seeds, collected in the 1999 fire southeast of Inuvik, NWT. Seeds were extracted from cones collected on August 27, 1999 from different branches of 20 white spruce trees for each site that burned on different dates within this fire. About 15,000 seeds were tested, the number of seeds per sampled tree ranged from about 40 to 350.

Table 1. Progression of seed filling by date at Inuvik, NT in summer 1999. On August 25, the seed cavity of 78.9 % of all seed was filled more than 75% and was therefore considered mature. Seed was extracted from three cones per collection date.

Date	*n*	Percentage seed cavity fill			
		< 25 %	25-50 %	50-75 %	> 75 %
Aug-11	1244	7.3	81.0	11.7	0.0
Aug-18	1177	0.0	11.6	79.3	9.2
Aug-25	1267	0.0	2.4	18.7	78.9

Plate 1. Seed cones were dried and seeds were extracted.

2. REGENERATION AND STAND DEVELOPMENT ON THE ALL-SEASON FIRE "EV 006" OF 1999

INTRODUCTION

Time of burning during the season probably affects the revegetation patterns, but these patterns have not been well studied in the northern boreal forest. From June to August of 1999, a fire burned over 172,000 ha of mostly treed land southeast of Inuvik. This provided a unique opportunity to study these patterns because fire suppression personnel mapped the boundaries of the fire at regular intervals during the summer.

Therefore, it is known when stands of white spruce burned. Unlike many older fires where this critical information is unknown, the prerequisites for a long term monitoring project are available. Monitoring the burned area from year one after the fire also enables us to give a detailed description of the starting conditions, such as the number and distribution of surviving trees, number of cones left on surviving trees etc. The knowledge of the germination rates of the burned trees in the sample area will also help to make predictions for further establishment as well as to develop a regeneration model.

From our experimental studies on seed maturity over the season, it was hypothesized that the establishment of spruce seedlings would be highest on sites that burned late in the growing season. It was further hypothesized that seedling establishment would be related to the ground vegetation that establishes within the first two years after the fire. While ash or exposed mineral soil surfaces were expected to be too dry for germination, a moss cover that modifies surface moisture would support germination. Species like the liverwort *Marchantia polymorpha,* which is a pioneer species in the moister parts of a freshly burned area was expected to provide a poor seedbed due to its dense surface coverage of thick leaves.

METHODS

Study sites:

White spruce areas that burned in June, July and August were identified from the air (Figure 1). Most white spruce stands had some trees that survived the fire or at least still had green needles one year after the fire.

In August 1999, seeds were collected from burned white spruce in areas that burned in June, July and August. As germination tests were carried out under optimum conditions in the greenhouse, this provides an estimation of the maximum establishment of spruce seedlings in the burned area.

On each selected site, a square plot of 30 x 30 m was established with permanent stakes and GPS readings (Figure 2). Each tree was mapped using the two sides of the plot as x and y-axis of a coordinate system. Tree attributes included alive/dead, standing/fallen, percentage of green/brown/dead branches and needles, exposed roots, scorched stem and cone number. Site characteristics included slope and aspect. All spruce seedlings, if present, were mapped and the associated vegetation recorded. In order to detect variations in the ground vegetation, permanent sample plots were established and monitored for percent cover. Data were entered into an ArcView managed database.

RESULTS

Germination tests showed that the germination rates were highest for seed from trees that burned late in the growing season when the embryo was almost fully developed at the time the fire burned these trees.

Site 1: June Burn - Located near where the fire started at 08W 0594159; 7497092 (UTM). A stand of white spruce with single black spruce and birch individuals was located on the southwest slope (248°) of 10° of a small hill lies within a large area of mainly black spruce. The white spruce stand did not burn completely. Most of the ground vegetation and duff layer were removed by the fire but some of the spruce trees did not support a crown fire and still had green needles. The vegetation one year after the fire mainly consisted of species that reproduce through suckering such as *Betula papyrifera, Salix, Alnus, Vaccinium vitis-ideae, Ledum groenlandicum* and *Vaccinium uliginosum* as well as invading species like *Epilobium angustifolium* and *Ceratodon purpureus*. *Calamagrostis canadensis* is a minor component at present. About 20% of the total area is currently covered with regrowth, the rest is exposed mineral soil or a layer of partly burned duff.

Site 2: July burn - Located near the Rengleng River at (08 W; 0587150; 7501409). The white spruce stand contains a few black spruce and birch trees. Some small unburned patches remained within the plot, but only a small percentage of trees survived the fire. The stand is located on a southeastern (168°) slope of 1° and is surrounded by black spruce swamps except for white spruce that growth along the creek. The ground fire severity was low as evidenced by the higher remaining ground cover and only few exposed spruce roots. Cones were found on about half of the dead and live trees.

Site 3: August burn – Located at (67°42.933'N, 133°35.064'W). The burned white spruce stand is located on a 18° southwestern slope that shows evidence of an intense ground fire since mineral soil is exposed in most of the area and some tree roots are exposed. However, some trees survived the fire. A high number of seedlings that germinated during the summer of 2000 was found. Old fire scars on dead trees indicated a 1930 fire.

Photo 1: Site3, burned in June 1999 3 in the EV 006 fire.

In the areas that burned in June and July no seedling were found in the plots. Some trees were still alive but most of them had more than 50 % dead branches and some foliage started to turn yellow. Some of the trees still had green needles but had fallen over. Some white spruce trees that were damaged but not killed by the fire had few scorched cones in the crown. The establishment of new spruce seedlings is not limited to the dead trees and will be present for the time period until all trees are dead. On the site that burned in August and had well-developed seeds, , a relatively high number of seedlings (744 seedlings/ha) was found. This corresponds to earlier findings from our experimental seed development study where germination percentages were highest for the trees that burned in July or later. Most seedlings were found in depressed microsites that appear to be moister and are covered by moss or liverwort.

On a long-term basis, sites that burned at different times of the year are expected to develop different age structures. While the surviving trees of a spring fire may produce seeds for a long period of time, the potential of viable seed from burned trees is limited to the present cones.

ACKNOWLEDGEMENTS

Ernie Francis provided valuable assistance in the field. The Gwich'in Renewable Resource Board supported the project financially and administratively. Helicopter transportation was provided by the Polar Continental Shelf project. The G.N.W.T. Department of Resources, Wildlife and Economic Development supported the project logistically.

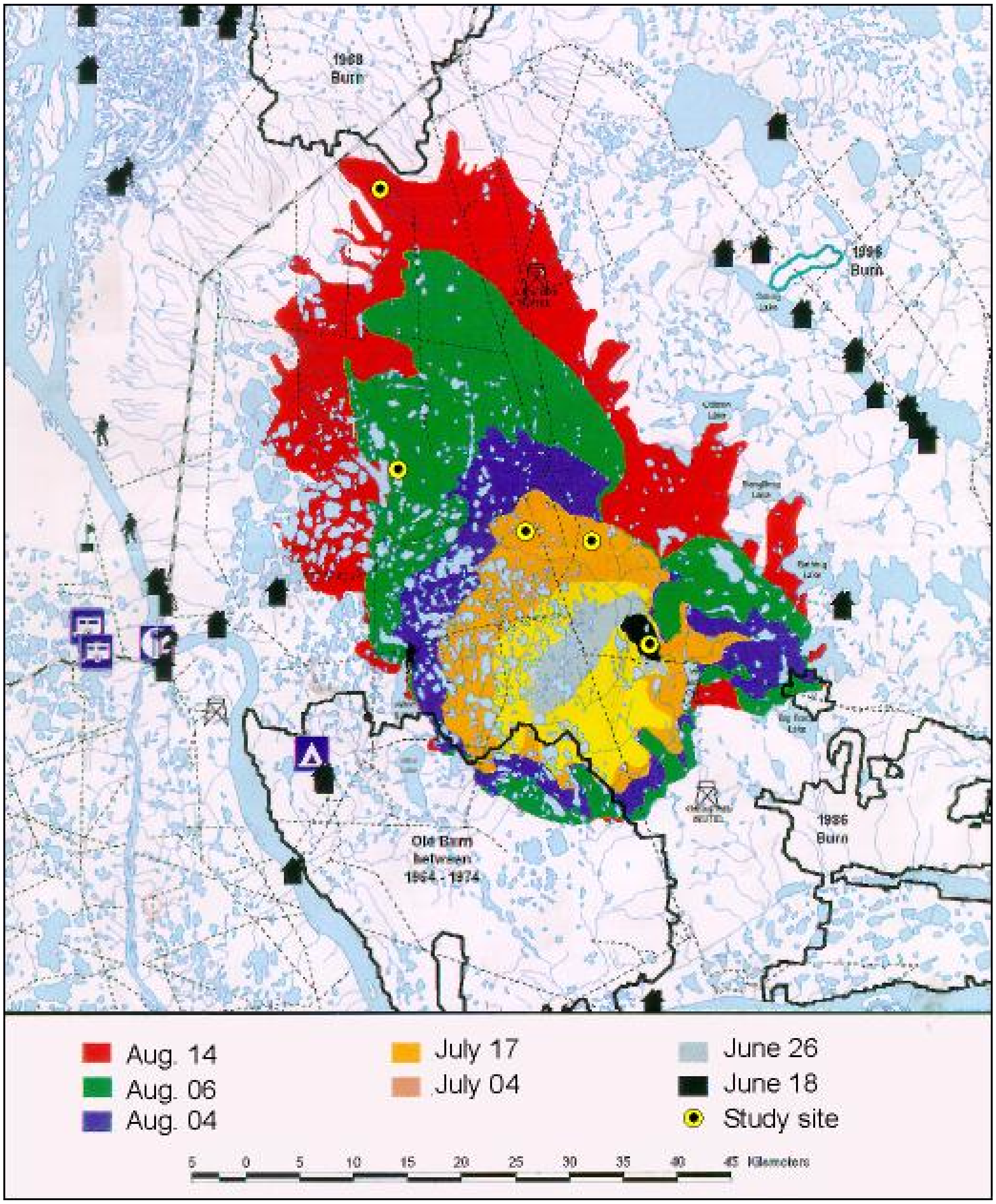

Figure 1. Areal extent of the fire over the summer months of 1999.

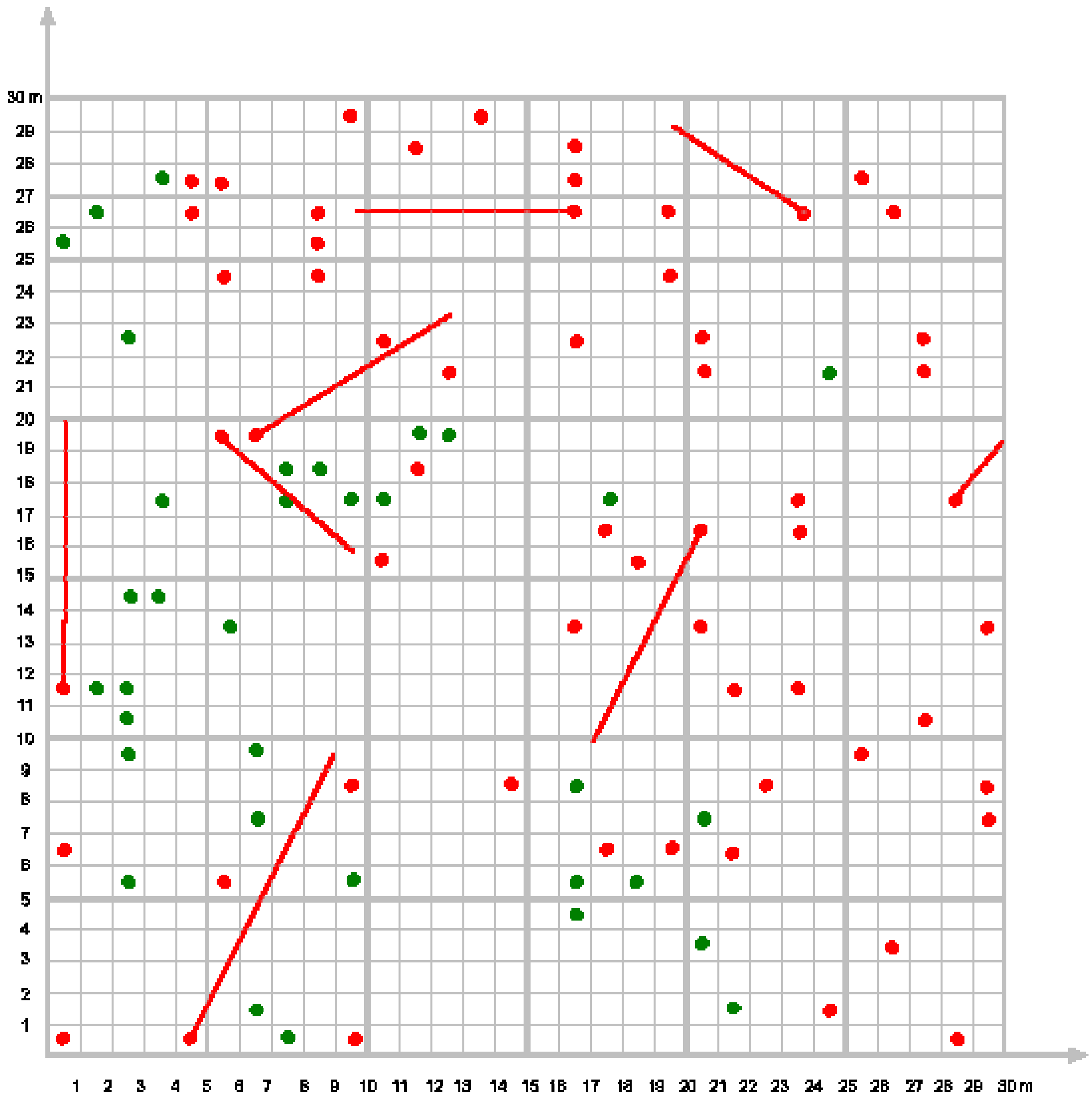

Figure 2: Site 1, Plot 1 shows the standing and fallen dead (red) and living trees (green). Spruce seedlings and regrowth of other species will be added in subsequent years. No seedlings were present one year after the fire.

3. AGE DISTRIBUTION OF TREES IN FIRE-ORIGIN UPLAND WHITE SPRUCE STANDS

INTRODUCTION

Generally white spruce stands show uneven age distributions because seed invades from trees in refugia (Nienstaedt, H. & J.C. Zasada 1990). After disturbances like fire, it can be hypothesized that recruitment takes place in waves and therefore forms even aged stands. After the seedrain of the cones that remained on the burned trees produces a first generation of seedlings with a relative low population, a second "recruitment wave" will follow after this first generation reaches the stage of seed production.

Different patterns of age structure are likely to be found depending on each sites fire history. The season of fire is expected to be the determining factor. According to an earlier study, fires that burn late in the growing season result in a higher seed viability of burned white spruce than fires that occur in spring. Spring fires may result in a very small generation of seedlings that will establish immediately after the fire from either surviving trees or the low number of viable seeds from the burned trees. A late summer fire is likely to kill the majority of trees; however, these trees still produce viable seeds. These stands will add an age distribution to that which established immediately after the fire. The establishment will take place during the first two years after the fire since white spruce release most of their seed in the year of seed production. Once the first generation reaches the age of cone production, which is after approximately 80-100 years, the second generation will establish.

METHODS

Age distribution:

Nine study sites were selected to determine age distribution of white spruce stands in the upland area east of the Mackenzie Delta.
Nine white spruce sites were selected along the Dempster Highway between Inuvik and Fort McPherson. On each site, a 5m wide transect was randomly located. Measurements were taken from the first 60 trees within that transect, or if the population of the site was too small, from 30 trees. Tree cores were taken at a height of approximately 20 cm. Trees with a diameter smaller than 5 cm were sampled destructively, discs were taken from 0 cm and 20 cm to estimate the missing rings for the cores through linear regression. Seedlings smaller than 30 cm were collected and the age determined in the laboratory.

Fire history

In each site evidence of an old fire was recorded if present (fire scars, charred stumps) and the year of the last fire was determined by counting the tree rings from the present ring to the scar following methods described by Arno and Sneck (1977) and McBride (1983).

RESULTS

The age distributions of the nine sites, however, could not confirm the hypothesis. No recruitment waves could be found. Further research should include a detailed stand development reconstruction for each site to explain the current age structure. Generally, tree establishment is dependent on the occurrence of fire and seems to reach its peak within forty years after a fire.

ACKNOWLEDGEMENTS

Donald Andre, Ernie Francis and Johnny Edwards assisted in the field. The Gwich'in Renewable Resource Board and the G.N.W.T. Dept. of Resources, Wildlife and Economic Development supported the project administratively, logistically and financially.

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APPENDIX 1: Age distribution and dates of last fire

Site 1: The last fire occurred in 1911. A few large trees that show unusual large ring widths for the approx. 50 years following the fire survived a fire at a young age (approx. 20 years). In the past 40 years, the growth rates have decreased considerably which indicates that it took 50 years for the permafrost table to rise and the moss to grow and provide poor growing conditions.

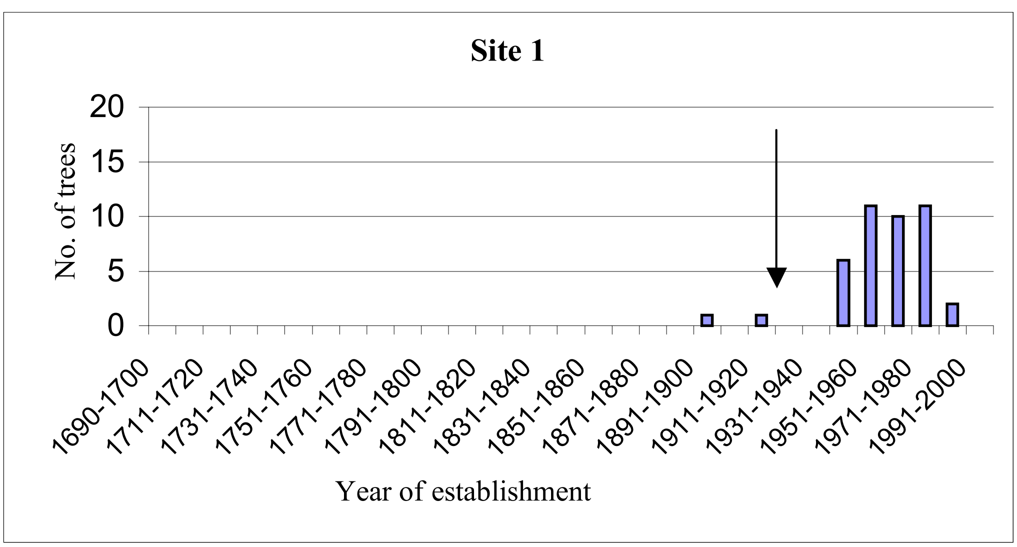

Figure 1: Age distribution of site 1. The arrow indicates the year of the last fire.

Site 2: Only one fire scar was found in this site. However, charred stumps and roots are present. According to the scar, the last fire occurred in 1891.

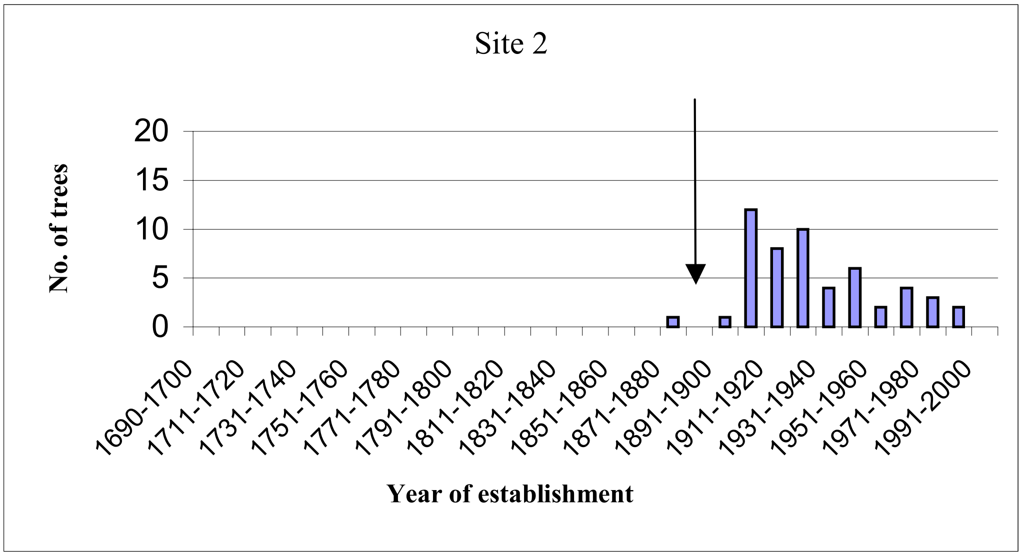

Figure 2: Age distribution of site 2. The arrow indicates the year of the last fire

Site 3: No fire scars could be found in spite of evidence of fire (old charred stumps and stems) It can be assumed, that the fire was either too intense so that no trees in this area survived or that the fire was not intense enough to scar the surviving trees.

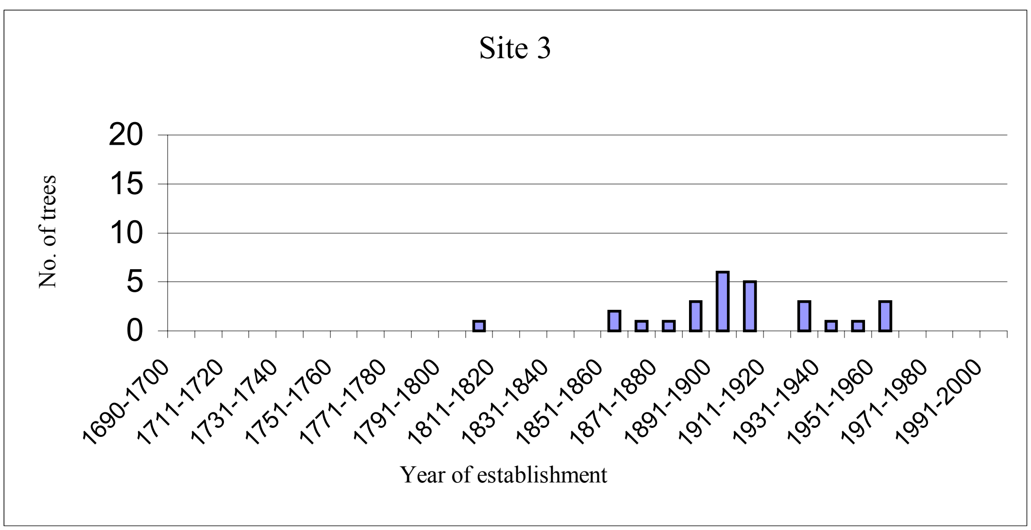

Figure 3: Age distribution of site 2. No fire scars were present to date the last fire

Site 4: Two discs give evidence that the last fire occurred approx. 200 years ago. The fire date was either 1800 or 1801. For an exact date, more fire scars from this site should be counted, because more scars were present but were not sampled to keep destructive sampling low.

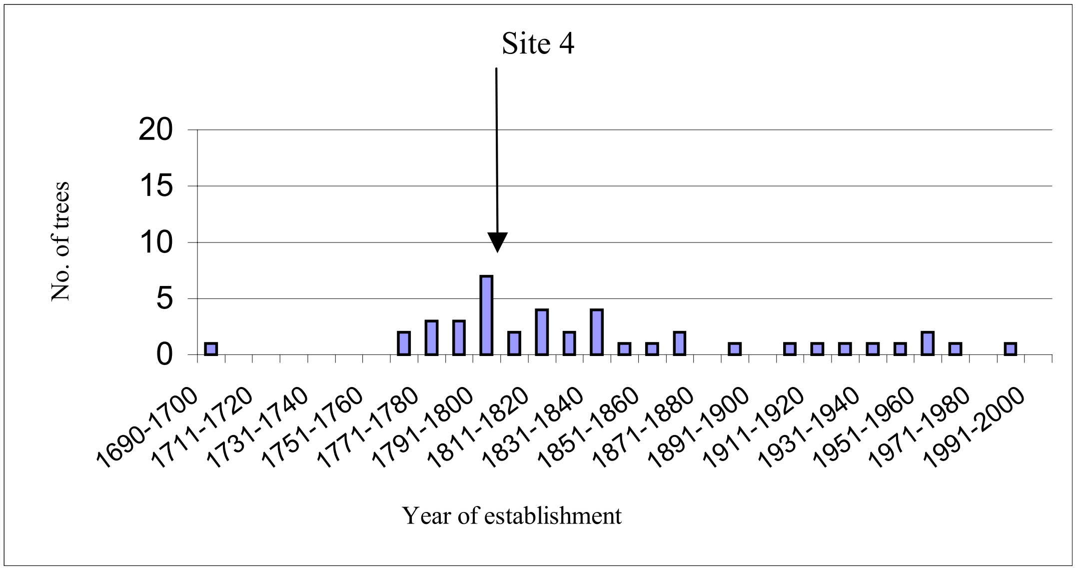

Figure 4: Age distribution of site 4. The arrow indicates the year of the last fire.

Site 5: Since site 5 is located just outside of the 1968 fire outside Inuvik, one scar could be dated from this fire. An older scar gave evidence for an earlier fire that occurred in 1914. Even though a relative high number of old trees are present, no fire scars were visible at the tree trunks. .

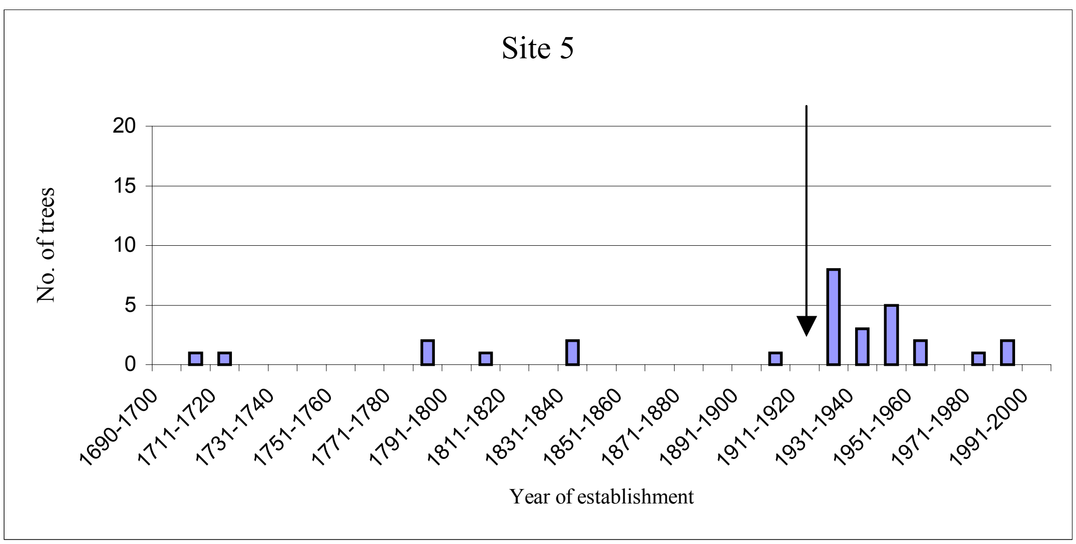

Figure 5: Age distribution of site 5. The arrow indicates the year of the last fire.

Site 6: No fire scars were found. The proximity of Site 7 however suggests that the last fire occurred around 1900.

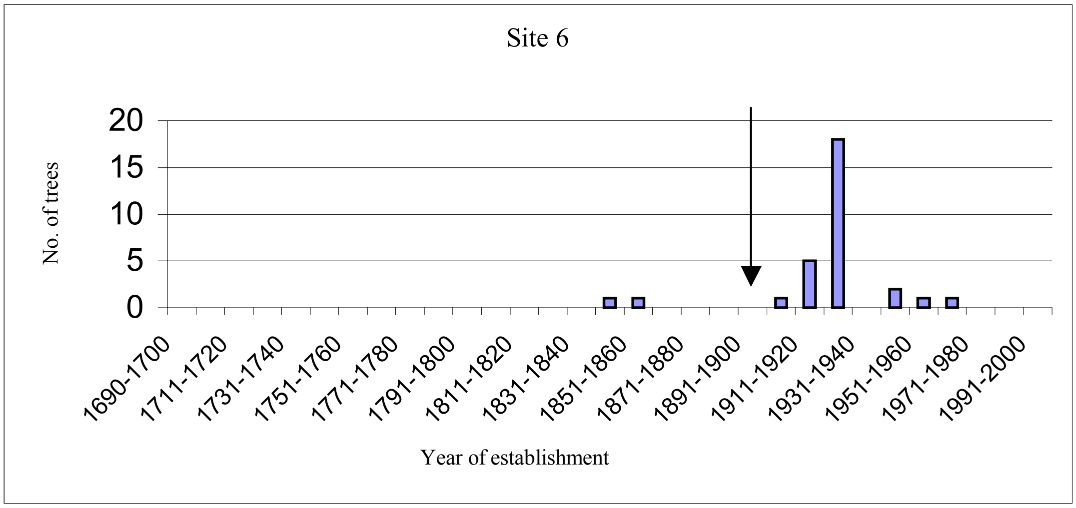

Figure 6: Age distribution of site 6. The arrow indicates the year of the last fire.

Site 7: The counting of two scarred discs resulted in two different fire years: 1905 and 1897. It is suggested though that the difference of eight years may result from an erratic count rather than two fires. One of the samples came from a tree that was approx. 500 years old. Ring widths are extremely narrow and made counting difficult. The age distribution suggests that a fire burned before 1850.

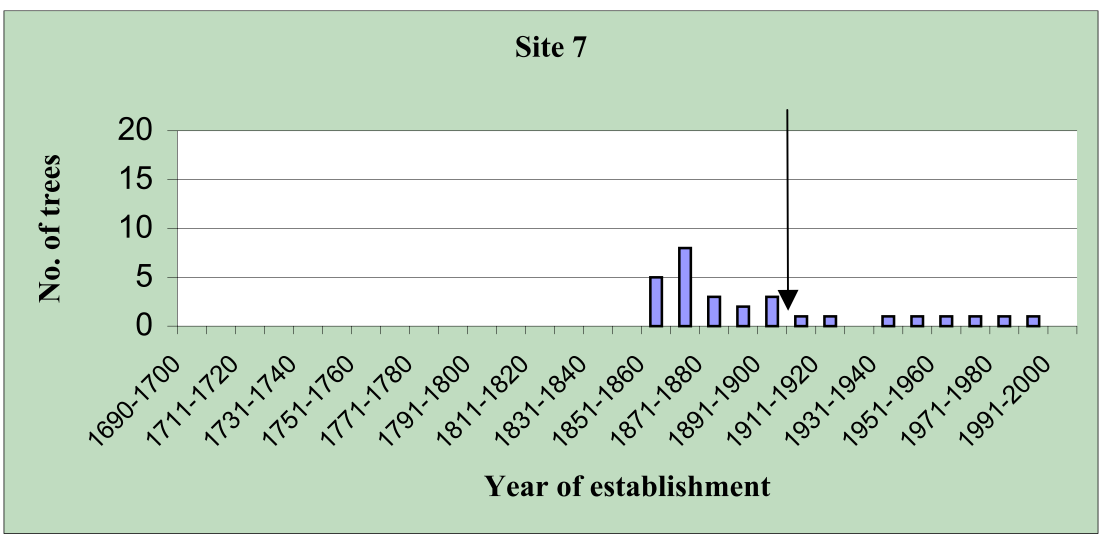

Figure 7: Age distribution of site 7. The arrow indicates the year of the last fire.

Site 8: The last fire occurred in 1921. However, multiple scars were found on one sample, which suggests that two previous fires burned in 1901 and 1884.

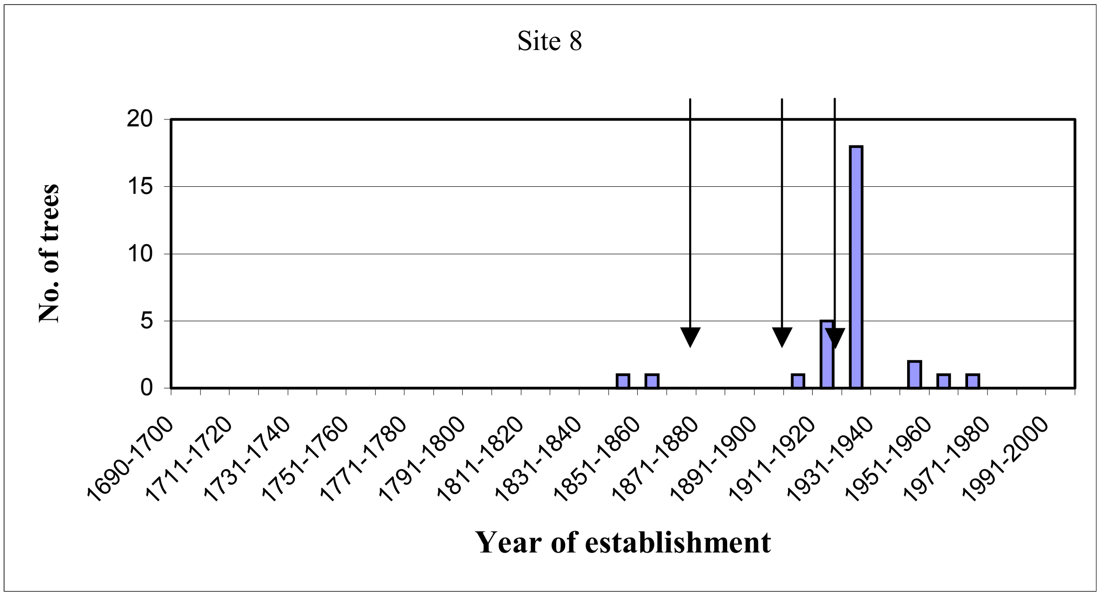

Figure 8: Age distribution of site 8. The arrows indicate the years of fire.

Site 9: Only one scar was found. It could be dated to the year of 1949. The age distribution suggests that the last major fire occurred before 1850.

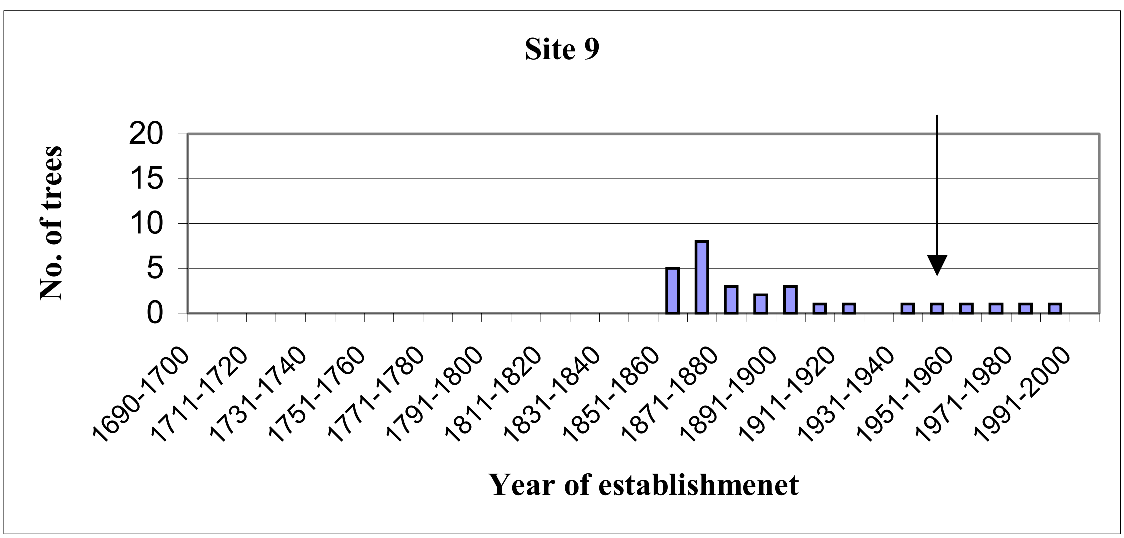

Figure 9: Age distribution of Site 9. The arrow indicates a possible fire in 1949.

APPENDIX 2 – Site Characteristics

Site 1 (N 68^{0}18.267', W 133^{0}19.079'):

The dominate height class is the sapling stage <1.30 m. Individual black spruce trees are found within the stand. The surface is hummocky with patches of standing water. The shrub layer is dominated by *Salix* species and *Betula glandulosa*. The site is located on a gentle south-facing slope. The tree density is 9230 stems/ha including white spruce from all size classes, predominantly small seedlings. Crown closure is below 20%. Sixty trees were sampled in a 13 x 5 m plot on June 14, 2000.

Site 2 (68^{0}11.283'N, 133^{0}26.886'W):

The white spruce stand is located on a south facing slope (ca. 8^o) with rock outcrops of limestone of the Campbell hills range containing patches of loose gravel. The stand is mature white spruce, with a few Black Spruce trees. Slope and aspect provide good drainage and the shallow soils are dry. The ground coverage consists of *Vaccinium vitis-ideae*, *Arctostaphylos uva-ursi*, *Arctostaphylos rubra*, *Empetrum nigrum* and some *Alnus crispa*. Crown closure ranges to an almost closed canopy. Sixty trees were sampled in a 71.5 x 5 m transect on June 15. Tree density is 1680 stems/ ha.

Site 3 (67^{o}23.14.840'N, 134^{o}14.840'W)

The stand is located on a southwest facing slope (20 ^{o}) of a hill that was formed by glacial deposits. Due to the small site and Black Spruce individuals within the stand, only 30 trees were sampled on a 31 x 10 m transect on June 16. The density of white spruce is 968 stems/ha. The ground cover consists of *Junipus communis*, *Lupinus arcticus*, *Vaccinium vitis-idaea*, *Arctostaphylos uva-ursi*, *Arctostaphylos rubra* and *Rosa acicularis*. Even though there were some old charred stumps, no fire scars were found.

Site 4 (68^o 06.858' N, 133^o 27.844W)

The stand is located on a western slope (18^o) of an esker between Campbell Lake and Caribou creek. Ground vegetation consists of *Empetrum nigrum*, *Vaccinium vitis-idaea*, *Arctostaphylos rubra* and *Rosa acicularis*. The stand appears to be old, with many dead trees lying on the forest floor and many of the standing trees rotten in the center. 60 trees were sampled in a 30 x 10 m transect on June 19.

Site 5 (68°20.179'N, 133°39.400'W)

The stand is located close to the town of Inuvik on a gentle southwest facing slope. The hummocky terrain is wet and covered by *Salix*, *Betula glandulosum*, *Arctostaphylos rubra*, *Empetrum nigrum* and *Vaccinium vitis-idaea*. The stand appears to be young with only a few tall individuals. 60 trees were sampled on a 28 x 5 m transect on July 5.

Site 6 (68°12'19.4" N, 133°24'18.2"W)

The site is located on a 24° south slope along a gravel road to an old quarry site across from Campbell Lake. Shallow soils and rock outcrops are characteristic for this stand. The ground cover consists of *Ledum groenlandicum*, *Vaccinium vitis-idaea*, *Sheperdia canadensis*, *Salix*, *Cladina* spp., *Arctostaphylos rubra* and *Juniperus*. White spruce dominates the stand, but black spruce and paper birch are present. 60 trees were sampled on a 24 x 10 m transect. The tree density is 2500 stems / ha. Annual growth rings show poor growth for the last 40 years.

Site 7 (68°12.666' N, 133°23.922'W)

The site is located close to Site 6 on a gentle western slope. The ground cover is denser than in the adjacent stand and the organic matter is thicker. Generally, the site is located in a moister regime with some *Equisetum* spp. Other species are *Potentilla fruticosa*, *Vaccinium uliginosum*, *Ledum groenlandicum*, *Alnus*, *Salix* and *Carex* spp. Thirty trees were sampled.

Site 8 (68°18.682' N, 133°19.198' W)

Located on a 5° south-facing slope. White spruce grows with mixed in black spruce in a very high density of 5607 stems/ha. Thirty trees were sampled. Ground vegetation consists of *Empetrum nigrum*, *Vaccinium vitis-idea*, *Arctostaphylos rubra*, *Ledum groenlandicum*, and *Sheperdia canadensis*.

Site 9 (67 ° 23.430' N, 134 ° 12.793' W)

Located on a steep hill formed of glacial deposits between Arctic Red and Fort McPherson. Species such as *Dryas*, *Arctostaphylos uva-ursi* and *Juniperus* indicate a dry environment, due to the south-facing 20° slope and the well drained parent material. Thirty trees were sampled.

PROJECTS – FOREST PRODUCTIVITY

1. TRUE AGE OF WHITE SPRUCE TREES IN THE MACKENZIE DELTA

INTRODUCTION

Soils in the Mackenzie Delta are characterised by fluvial deposits along the channels of the Mackenzie River. Alluvial deposits produce fine textured soils. In contrast to upland sites, these fluvial soils can support a productive forest cover of white spruce (*Picea glauca* (Moench) Voss) and balsam poplar (*Populus balsamifera* L.). This is largely due to generally warmer soil temperatures, and deeper active layers during the growing season. Forests of the delta are mostly dominated by riverine disturbances, such as flooding, erosion, and fluvial deposits. In addition, these sites have longer fire return intervals than upland sites, which allows trees to become very old. In the southern part of the delta, forests can produce impressive trees >40 cm diameter at breast height (1.3m). In some instances coring or cutting these trees (30 cm above ground) revealed that the trees were only about 100 to 200 years old (Mackenzie Delta Forest Inventory

1997). Therefore the productivity and growth of these trees should be comparable with sites in the more southern regions of the boreal forest.

Since white spruce in the Mackenzie Delta establish under the flooding regime of the Mackenzie River, stems of seedlings and saplings get partially buried by silt deposits after each flooding event. Gill (1975) found that silt deposits are larger close to the stems of existing trees due to the obstruction of flow and the formation of eddies. The increased deposits will not only lead to a burial of the stem but also to lower soil temperatures and soil oxygen concentrations surrounding the tree. Decreased soil temperature and oxygen level lead to less root growth and reduced root activity resulting in decreased water and nutrient uptake (Grossnickle 1987). To counteract the negative effects of silt deposits, white spruce is able to produce adventitious roots further up the buried stem, creating multi-layered root systems (Jeffrey 1959). The ability to grow roots, helps to avoid the less optimal condition in the deeper portions of the soil by replacing the dying or only partially functioning elements of the roots system in the deeper soil layers (Strong and La Roi 1983, Gill 1975). Therefore the buried stem of these trees can easily be mistaken as a tap root; however, tap rooted white spruce has only been reported for sandy soils in northern Ontario (Jeffrey 1959; Wagg 1967).

In the case of a stem buried by fluvial deposits, the evidence of the true age of a tree is also buried with the stem under ground; therefore, age measurements taken above-ground or at ground level are younger than expected (DesRochers and Gagnon 1997). It is thought that even-aged stands on fluvial deposits are generally the result of a catastrophic event such as floods (Jeffrey 1961). Many of the white spruce stands in the Mackenzie Delta appear to be even-aged due to similar heights and diameters; however, stem diameter is not a good indicator of tree age (Smith *et al*. 1997).

The objective of this study was to determine the true age of buried white spruce trees excavated near the arctic tree by Inuvik and to determine radial growth rates over the last two centuries.

METHODS

In the summer of 1999, 5 white spruce trees were selected along a cutbank on the east channel about 2 km north of the town site of Inuvik. Trees were excavated using a portable high-pressure fire pump (Figure 1a). Stem discs were also taken at breast height (BH) and at ground level. The stumps and discs were transported to Edmonton for further examination. Three of the excavated tree stems were buried to a depth of 1.0 m, while the other two were buried to about 0.5m (Figure 1b). The stumps were cut into 2.5cm thick discs and sanded up to 400 grit (Figure 2 and 3). Rings were counted under a stereo dissecting scope. Using a sharp razor blade and chalk for increased contrast of the vascular cells, the tight tree rings were highlighted and counted (Figure 3). If possible, the root collar was determined by the transition from the pith to a central vascular cylinder (Esau 1960). The radial sections were then cross-dated using the skeleton plot method (Schweingruber 1989). Relative ring width, compression wood, false rings and other specific characteristics were used in the cross-dating.

Ring width measurements were also taken on discs cut at ground level to describe the radial growth rates during that period of growth.

RESULTS

The 5 selected trees had an average age at breast height (BH) of 213 years. The ages ranged from 176 to 245 years (Table 1). The age at current ground level was between 209 and 317 years, which resulted in an average difference of 44 years between BH age and ground level age. All of the tree stumps had a rotten or missing central part of the stem therefore the transition from pith to central vascular cylinder could not be determined. As a result the precise total age of the tree could not be determined. The portions, which could be cross-dated, added an average of 36 years to the age of the tree at ground level (Table 1).

There were, however, remaining lower portions of the stems, which could not be cross-dated (Table 1). Conservative estimates of the age of the remaining portions were made and added to the total age of the tree. The age was estimated by assuming an average height growth of 3 cm. The average height growth was derived from the age difference between the breast height age (1.3m) and the ground level age. Therefore the estimated total age of these three trees was determined to be between 261 and 400 years (Table 1).

On average there were 47 years buried with the stem in the fluvial deposits. However, the number of years ranged from a minimum of 26 years to a maximum of 83 years. It is very likely that these numbers are still an underestimation of the true age, since all trees were missing stem sections below the excavated stem (see blunt end of stem in Figure 2).

Measuring the ring width at ground level of all five trees revealed that ring width has been increasing by ten fold from 10µm to 100µm (notice logarithmic scale of y-axis) (vertical arrow) (Figure 4). Only tree number 5 showed an earlier increase in ring width (horizontal arrow). This increase is largely due to the presence of reaction wood. Reaction wood is the preferential allocation of wood towards parts of the stem or branches to compensate for stresses such as leaning or bending. In the case of conifers, compression wood is formed on the underside. This results in the production of larger rings in that region to support the leaning trunk. Due to difficulties (rot) on the opposite side of the stem, the tree ring widths in the compression wood had to be used for the measurements, artificially increasing the ring width.

DISCUSSION

A significant amount of growth of the white spruce trees in the Mackenzie Delta is concealed due to past and present flooding events depositing substrate around the stems of the trees. This study determined that an average of 47 years of growth was hidden under ground. The length of the buried stem did not appear to be a good indicator of the number of years, which need to be added to the tree age. For instance, tree number 5 had about 50cm of its stem buried, this length represented about 83 years of growth. This stands in contrast to tree number 3, where 76 cm of the stem was buried. This represented 32 years of growth. Generally these results have to be carefully interpreted. This study looked only at a limited number of stems and can be seen as an exploratory study producing more questions than answers. The determination of the true age of these trees and the amount of stem buried in the fluvial deposits are likely an underestimation. Even the careful excavation of the trees from the cutbanks of the river did not allow for a full recovery of the stems. Therefore it is not known, how much of the bottom end of the stems is actually missing. To avoid these problems it would be probably better to extract trees further away from the edge of the river, since the bottom parts of the stems might be preserved in the higher permafrost table (Gill 1975).

The establishment of white spruce in this selected stand north of Inuvik, as determined by the five trees, did not to occur at the same time, resulting in an uneven-aged stand structure. This suggests that white spruce establishment in the delta probably occurs in waves, which coincide with major flooding events rather than catastrophic events such as fires (Jeffrey 1961). However this line of inquiry needs further testing. These fluvial deposits create favourable seedbeds and when coincide with good seed crops in nearby mature stands they will result in periods of spruce establishment (Jeffrey 1961; Wagg 1964). Once the seedlings have established, major flooding events, which deposits large amounts of silt will be detrimental to the growth and survival of these newly established seedlings. The establishing seedlings must have sufficient height growth to be able to out-grow subsequent silt deposits from the succeeding flooding events.

Tree discs at ground level of all five trees showed a substantial increase in ring width of about 10 fold from 10µm to 100µm since the turn of the last century. It can, however, only be speculated whether the response is due to climatic or flooding factors or both. However, data like these could give the opportunity to correlate radial growth with existing climatic and flooding data over the last fifty or so years which might be available for the region. Additionally, the small size of rings during earlier growth raises another important issue. During various periods, the five trees in this study showed remarkable narrow growth rings therefore accurate age determination in the field seems impossible. The chronological data clearly show that in the case of these five collected trees, up to 200 years are represented in rings, which are between 10 and 50µm wide. This could lead to gross mistakes in determining ages at either breast height or ground level.

As indicated earlier, this study presents the opportunity to use the buried stems as an indicator for past and present climate or flooding regimes. If it was possible to find deeply buried stems of earlier white spruce stands preserved in the permafrost, ring width data could be cross-dated with current tree data and extended into the past over longer time periods. These growth data could then be correlated to past and present climate and/or flooding regimes.

The pattern of adventitious root development is an interesting area in the autecology of flood plain white spruce (Jeffrey 1959; Wagg 1964) which has not been addressed in detail. The pattern of rooting is most likely the response to soil temperature and soil oxygen minima. As the thickness of the fluvial deposit layer increases new adventitious roots are produced to keep the tree alive. By cross-dating the initiation of the roots in each layer with the main stem, fluvial deposit patterns could be determined and projected into the future. Research in this area could lead to a better understanding of white spruce autecology in response to flooding and soil temperature regimes. This information is pertinent for the prediction of establishment and growth of white spruce in flood plains and will assist in the future regeneration and maintenance of northern riparian forest stands.

ACKNOWLEDGEMENTS

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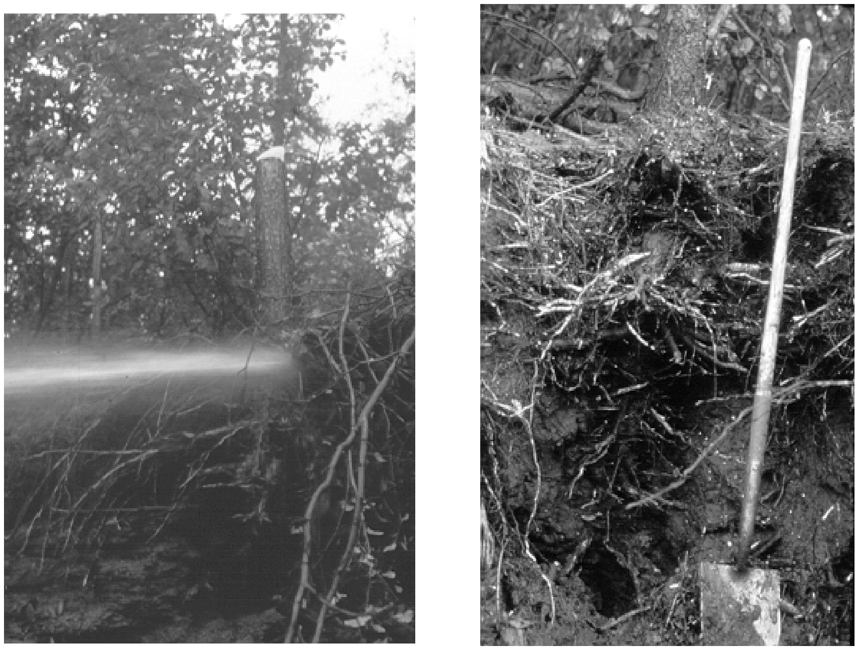

Figure 1a and b: a) Water excavation of trees and b) the stump after excavation showing several layers of major adventitious roots.

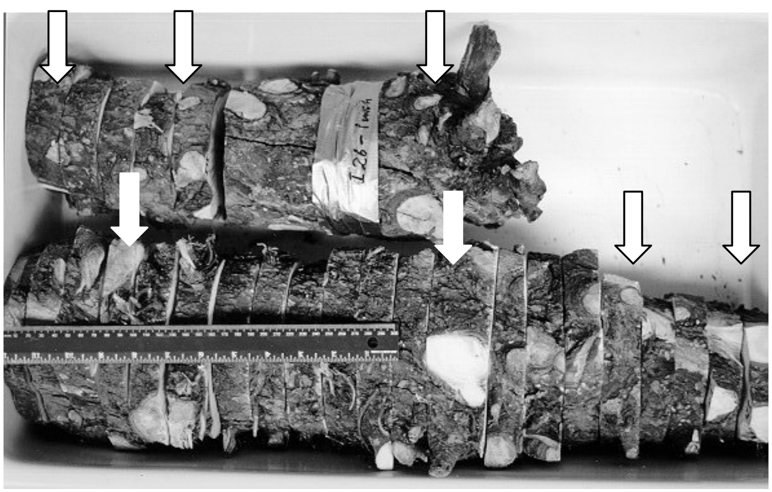

Figure 2: Tree #3 total length 79cm. Arrows indicate the establishment (layers) of major adventitious roots.

Figure 3: Discs of tree #3 from base and last measurable disc of buried stem at 64 cm.

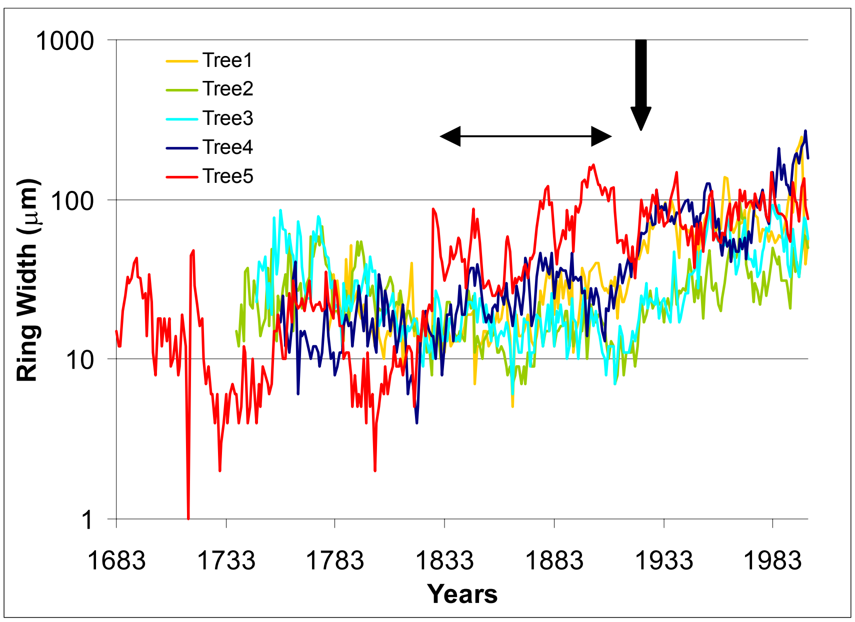

Figure 4: Tree ring width at ground level of five trees collected near Inuvik in 1999.

Table 1: Dendrochronological analyses of 5 White Spruce trees collected near Inuvik in 1999.

Tree	Age at BH (1.3m) (years)	Age at base (years)	Cross-dated Age (years)	Remaining stump length (cm)	Conservative estimate of total age (years)
1	176	209	236	65	261
2	224	262	300	6	303
3	224	254	278	15	286
4	198	242	258	20	268
5	245	317	391	6	400
AVG	213	257	293		304

2. PRODUCTIVITY OF WHITE SPRUCE IN THE MACKENZIE DELTA REGION

INTRODUCTION

The Mackenzie Delta region forms the most northerly closed forests in North America. While dense white spruce stands are present in the delta (Photo 1), the adjacent uplands are characterized by open black and white spruce stands. Fluvial action creates changes in the delta through flooding, sediment deposition and erosion. The numerous channels and lakes change size and shape as well as vegetation cover annually and over decades. Frequent flooding causes sediment deposition on the low land surfaces while the older levees change shape by cut bank erosion and channel shift.

On the uplands, fire is the driving force that changes vegetation cover. One of the limiting growth factors on the uplands are low soil temperatures, caused by the accumulation of organic matter that decomposes slowly due to the cold and moist conditions. Fire consumes these thick layers and the ash layer not only creates a good seedbed for conifers but also functions as a fertilizer.

OBJECTIVES

The objective of this study was to determine white spruce growth rates as a function of disturbance type and frequency. White spruce was chosen as the sample tree species as it is one of the tree line forming species that is present in both delta and uplands and provides the main timber source for the local residents.

METHODS

A total of 56 tree discs and 105 cores were taken from 20 delta and 9 upland sites (see map). Only co-dominant trees were sampled. Samples were taken from a height of 30 cm, sanded with progressively finer grades of sandpaper and two radii from each tree disc were scanned with high resolution (2000 dpi) to obtain an image of the ring series. The rings were then counted, measured and samples cross dated using the program DENDROSCAN. Tree ring index chronologies were produced using the program ARSTAN (Cool 1985).

To obtain comparable ring series, indices were computed by dividing each ring width measurement by the mean ring width value. Series were then normalized to a mean and standard deviation of 1. Chronologies were produced for the delta and the uplands. For the delta, all 99 series were included into one chronology because all sampled mature white spruce stands were located on the higher levees that are formed by the same silty substrate throughout the delta. Undergrowth and stand density did not show strong variability.
For the upland, chronologies were computed for each of the nine sites that vary greatly in stand age, time of fire and site characteristics such as slope and density.

RESULTS

Descriptive ring width statistics for the Delta:

At all sites, the mean ring width averaged approximately 0.04 cm(Table 1). Sites 48, 60 and 61 show wider rings, exceeding over 0.05 cm, with single rings up to one millimeter.

The oldest sampled trees were found in the delta at Jackfish Creek (Site 3). The site had one tree of 529 years and several around 300 years. The average tree age of the sampled trees was 286 years.

Table 1: Descriptive statistics of trees sampled at Mackenzie Delta sites

Site	No. of trees	No. of radii	Time span	Tree age (mean)	Mean Ring width (cm)	Mean sensitivity	First-order autocorrelation	Mean interseries correlation
1	3	6	1697-2000	274	0.036	0.23	0.87	0.362
2	8	14	1788-2000	182	0.052	0.21	0.79	0.153
3	9	17	1472-2000	361	0.032	0.22	0.77	0.124
4	3	6	1546-2000	379	0.03	0.24	0.84	0.39
5	2	4	1734-2000	262	0.046	0.22	0.82	0.381
6	2	4	1642-2000	328	0.037	0.23	0.79	0.214
7	2	3	1740-2000	232	0.037	0.27	0.82	0.054
8	2	2	1714-2000	247	0.049	0.23	0.73	0
9	2	4	1741-2000	258	0.042	0.23	0.8	0.497
10	2	4	1618-2000	375	0.029	0.24	0.84	0.465
11	2	4	1677-2000	288	0.04	0.22	0.8	0.449
12	2	4	1738-2000	249	0.027	0.25	0.83	0.583
13	1	2	1743-2000	258	0.043	0.2	0.81	0
19	2	4	1560-2000	397	0.043	0.22	0.88	0.39
35	2	4	1738-2000	258	0.045	0.24	0.9	0.729
38	2	4	1616-2000	379	0.032	0.2	0.85	0.532
40	1	2	1736-2000	264	0.036	0.23	0.81	0
48	2	4	1762-2000	203	0.063	0.19	0.77	0.288
60	2	3	1660-2000	262	0.052	0.2	0.89	0.525
61	2	4	1706-2000	271	0.065	0.22	0.85	0.233
total	53	99	1472-2000	286.35	0.0418	0.2245	0.823	

Mean sensitivity is a measure of the relative differences in width between adjacent rings (Fritts 1976). If the tree growth is strongly limited by environmental factors, the difference between the ring widths within a tree is greater thus the sensitivity will be high. In the case of the sampled trees in the Mackenzie Delta, the sensitivity values that range around 0.2 are low.

The measure of first-order autocorrelations is an estimate of the relationship between the ring widths of two adjacent years. Autocorrelation coefficient can be calculated for a number of lags (one year was used) to represent the linkage of each value with the value immediately preceeding. A high autocorrelation coefficient like the ones above represent the nonrandomness of ring width distribution within the series. The ring width of each year is highly correlated to the ring width, and thus the weather and growth conditions of the preceding year.
Mackenzie Delta Chronology:

The chronology clearly shows an increase of ring widths in the period between 1820 and 1920 (Figure 1). The series were standardized but not detrended before combining in the chronology. The assumption of a normal decreasing growth trend of a tree could not been confirmed. The increasing ring widths in the past 180 years is a clear trend that is present throughout the delta. However, width decreased after 1920, but still remains greater than in the past 300 years.

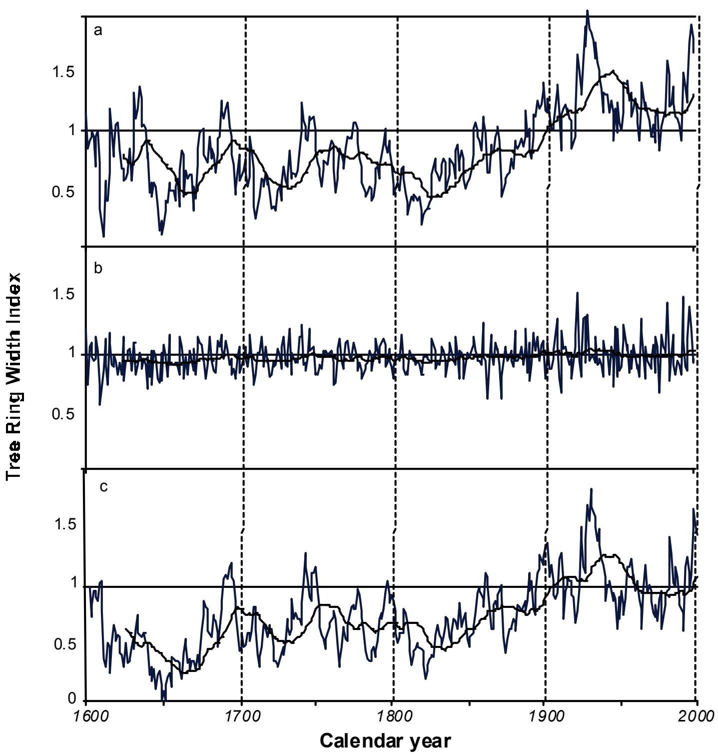

Figure 10: **Mackenzie Delta Chronology developed by fitting a line through the mean of 99 tree ring series from 54 trees, dividing each value by the curve value and normalizing to a mean and SD of 1 using the program ARSTAN. The solid line is the 25 year running mean. The standard chronology (a) does not apply auto-regressive modeling. The residual chronology (b) represents the autoregressive modeling of the series. The Arstan chronology (c) is the residual chronology with pooled autoregression added.**

Descriptive ring width statistics for the Mackenzie Uplands

In the upland sites the mean annual ring with varies between 0.23 and 0.72 mm(Table 2). While mean ring widths in the Delta sites show a very uniform pattern of ring widths, the upland ring width varies considerably within each site (e.g. site 3, with minimum values of 0.03mm and a maximum ring width of 3.18mm).

Table 2: Descriptive statistics of the trees sampled at Mackenzie Upland sites

Site	Mean Ring width (mm)	Standard Deviation	Standard Error	Minimum Ring width (mm)	Maximum Ring width (mm)	No. of trees	Mean Sensitivity	First Order Autocorrelation	Tree age (mean)	Mean interseries intercorrelation
991	0.37	0.18	0.02	0.06	1.22	4	0.23	0.76	133	0.411
992	0.59	0.31	0.03	0.04	2.5	8	0.25	0.75	81	0.473
993	0.67	0.33	0.03	0.1	3.77	9	0.22	0.75	121	0.29
1	0.33	0.17	0.02	0.03	1.99	9	0.27	0.52	50	0.144
2	0.71	0.31	0.03	0.02	2.91	19	0.234	0.69	80	0.26
3	0.72	0.3	0.03	0.03	3.18	14	0.224	0.69	94	0.214
4	0.23	0.16	0.01	0.02	1.74	9	0.307	0.76	163	0.067
5	0.36	0.18	0.02	0.03	1.72	19	0.291	0.62	59	0.215
6	0.64	0.31	0.04	0.03	2.31	37	0.247	0.72	75	0.368
Mean	0.51	0.25	0.03	0.04	2.37		0.25	0.70	95	0.27

Mackenzie Upland chronologies:

The nine curves that represent the upland stands show different patterns; however, the trend is comparable with the upland chronology which shows a strong growth in the period from the beginning of this century until the mid-1960s. This trend is expressed by the solid mean curve.

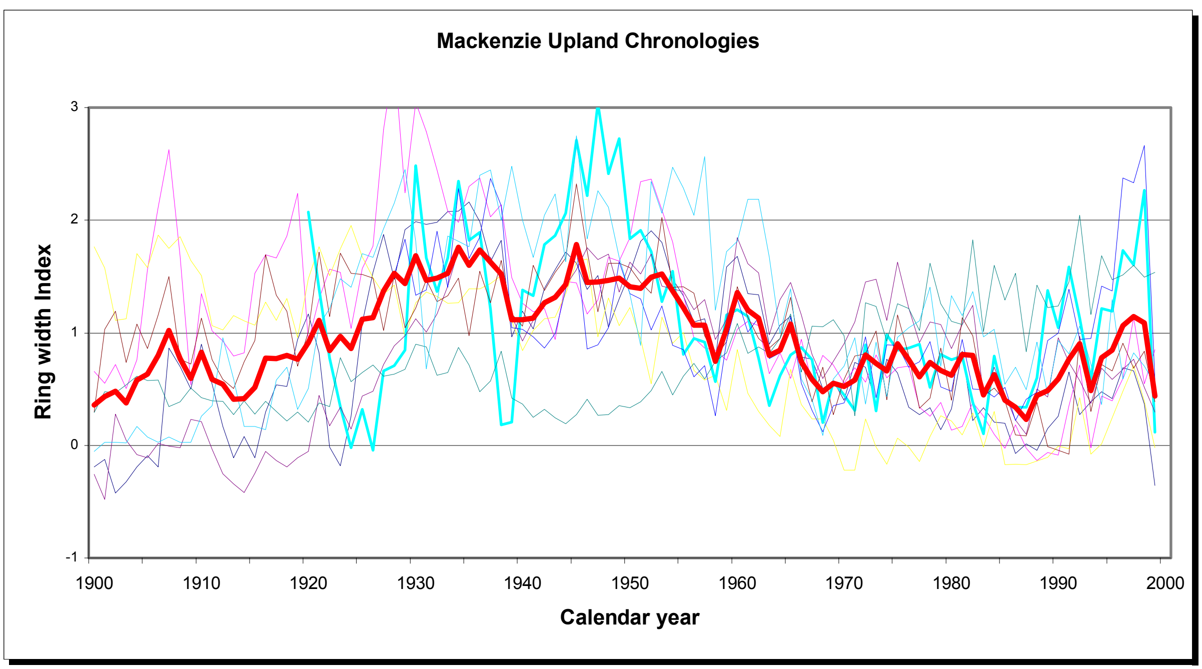

Figure 2: An individual chronology was built for each upland site because of variations in stand age, site characteristics and different disturbance events that occurred in each stand. Chronologies were built using the program ARSTAN by fitting a line through the mean of each curve and dividing each value by its curve value. The solid line represents the mean curve of all sites.

Delta vs. Upland tree growth:

Two main differences can be observed in a comparison of white spruce growth in the delta and in the uplands. Trees in the delta become older and generally grow slower than those in the uplands (Figure 3). While upland spruce stands are impacted by infrequent fire, the delta trees develop under flooding. As the stands grow older, the land surface builds up with the annual deposition of sediment until flooding is infrequent. Once this stage is reached, sites are more or less undisturbed. These stands mature until either the sites are eroded by shifting channels or become overmature and die. Growth rates in the uplands are generally higher depending on the site and microsite (Figure 4). As upland white spruce stands are unevenaged, different generations of trees establish under different growth conditions and vary in growth and productivity.

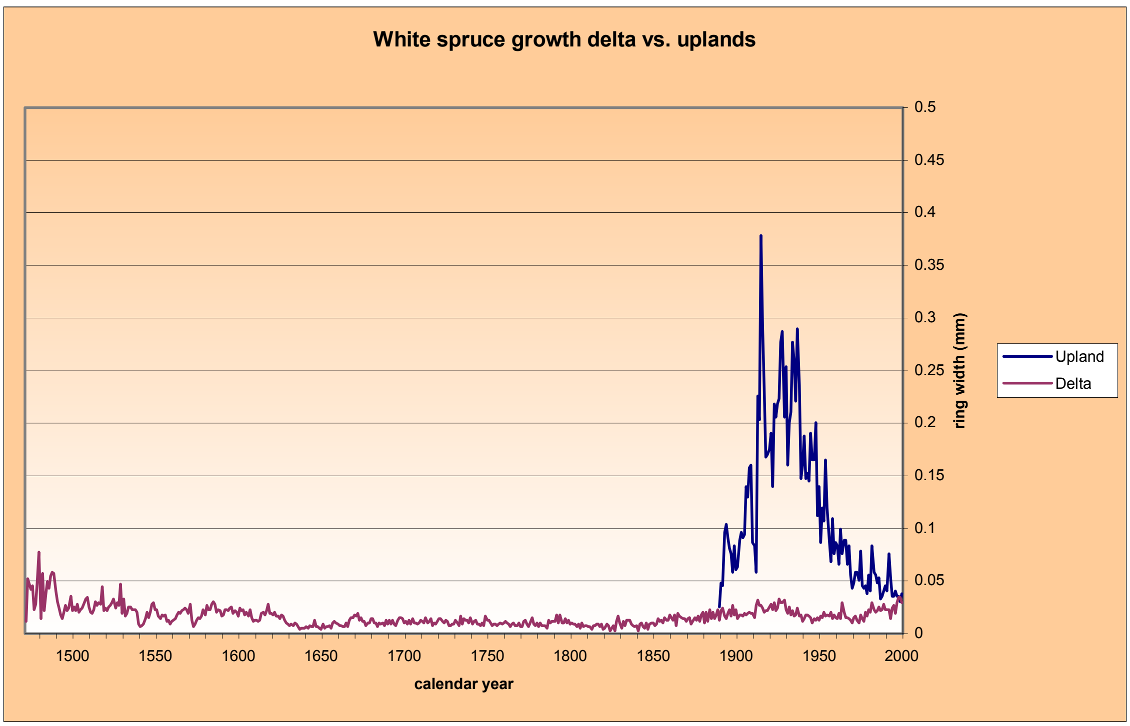

Figure 3: Different growth conditions of Delta and upland white spruce: Delta spruce shows a constant growth over a time span of 500 years (bottom) Upland spruce (top) are younger and show growth that is improved by fire, probably the removal of organic layer and the post-fire warmer soils.

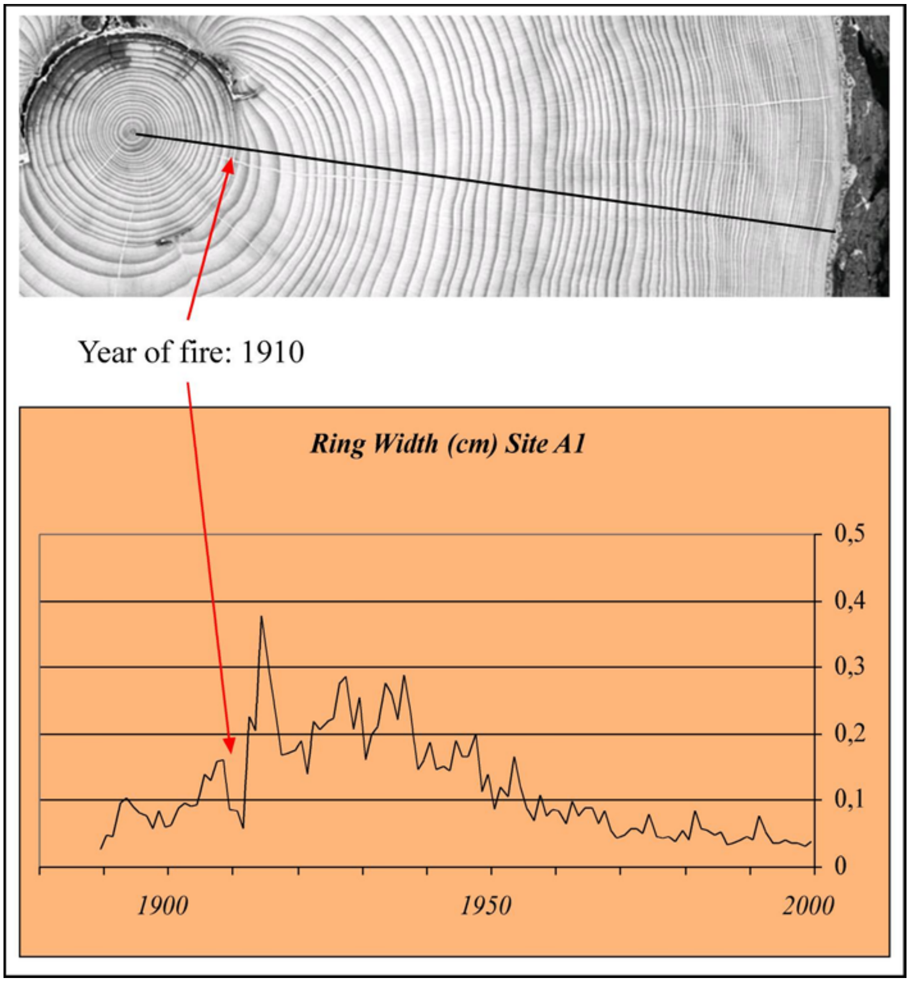

Figure 4: Typical growth of an upland white spruce tree: The tree survived a fire at approx. 20 years. After the fire, it shows a release due to less competition and better soil conditions. 50 years after the fire, the growth decreased as surrounding vegetation increased and soil temperatures decreased.

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APPENDIX: Site descriptions

White spruce is found in the Delta and on the uplands but the growth condition vary greatly in those regions. In the uplands, shallow active layers, poor drainage and thick organic duff layers provide poor growth conditions and restrict the occurrence of white spruce to favorable sites with better drainage, deeper active layer and less soil surface organic matter. These sites are found mainly on south and west facing slopes where the sun can heat up the soil and drainage is better than in the large boggy areas where water is held by the permafrost. In the Delta, white spruce areas are rather within the whole region.

1.1 Rocky outcrop sites (Uplands)

These white spruce sites are characterized by a shallow soil that covers rock outcrops such as in the Campbell Lake area. Here, the parent material consists mainly of limestone which provides a nutrient rich environment. White spruce usually grows in low densities on a soil that is too dry to support a thick organic matter built up. The ground vegetation is sparse and includes species like *Juniperus* and *Arctostaphylos uva-ursi* which indicate a dry environment.

1.2 Glacial deposits (Uplands)

South of the town of Inuvik as well as in the area between Tsiigehtchic and Fort MacPherson, small hills rise over the vast flats and swamps that are mainly covered with stunted black spruce. The hills are covered with white spruce trees that are much taller than the surrounding black spruce trees. The sites provide good growing conditions because of well draining parent material and steep slopes.

1.3 Lowland white spruce (Uplands)

When driving along the Dempster highway, the vegetation appears to be uniform with small trees and large areas of shrubland. Even though these trees are small, some of these poor growing trees are white spruce. Usually, black spruce is mixed within these flat, poorly drained stands. The ground vegetation consists of *Ledum groenlandicum, Vaccinium uliginosum*, *Salix spp*., *Alnus, Betula glandulosa* and often thick layers of *Sphagnum* mosses.

1.4 Delta white spruce sites

Most of the forested areas within the Mackenzie Delta are covered by white spruce. Only areas that have not been flooded for a long period, often on larger areas with a growing distance between two lakes or channels, are covered by black spruce. White spruce trees in the Delta are often much taller than trees in the upland areas which is the reason for more intensive cutting, especially when large logs are needed e.g. for pilings. Due to periodical flooding and sedimentation, the forest floor is not covered by thick organic layers but often covered with mineral soil. Due to these special soil conditions as well as a relatively warm mesoclimate, it was suggested that these delta sites are the most productive sites at this latitude.

Photo 1: White spruce covers most of the Mackenzie Delta land surface.

3. TREE RELEASE AFTER SELECTIVE CUTTING

INTRODUCTION

After partial cutting in the Mackenzie Delta, gap dynamics should play a role in the growth of the remaining trees. As competing trees are removed, the neighbor trees receive more sunlight as well as a more favorable nutrient regime. While there are various studies that describe the phenomenon in the southern forests, the impact of partial cutting on spruce in the northern alluvial environment is not well studied.

The objective of the study was to test the hypothesis that neighboring tree growth rates would increase after a tree is removed.

METHODS

Study sites

Twenty study sites were chosen in logged areas. Five sites could be identified as logged in the 1960s and 1970s, along the East channel between Inuvik and Jackfish Creek and along the Kalinek channel. Five sites of unknown date of cutting were chosen along the channels between Inuvik and Aklavik where evidence of cutting was suspected, such as near old abandoned campsites and old trails. Seven more sites are located along the Peel River, Peel channel and Mackenzie River, where people have cut trees for lumber and pilings.

Sample collection

For each of the 20 sites, one stump was chosen randomly and a tree disc from the nearest neighbor was sampled. A control tree that was located outside of the influence of cutting but within the same stand was also sampled.

Using the computer program DENDROSCAN, the rings of at least four cross sections were measured from each tree. The chronologies of each pair of trees were compared to find signals of increased growth after removing a neighbour tree.

RESULTS

The samples from the delta showed no significant release of growth. While some trees suggested a release of growth to a minor extent, it could not be related to cutting events. It is suggested, that the trees were too old (some older than 400-500 years) to show the expected signals. The samples will be used for an ongoing study and will support the growth and productivity study.

ACKNOWLEDGEMENTS

Willy Simon, a local logger from Inuvik, Ara Murray and Rob Wishert assisted in locating sites. Ernie Francis and Johnny Edwards provided assistance in the field. The project was financially and administratively supported by the GRRB. Logistical support was provided by DRWED. Helicopter transportation was provided by the Polar Continental Shelf Project and DRWED.