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The Silvics and Ecology of Boreal Spruces

1989 IUFRO Working Party S1.05-12 Symposium Proceedings

B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors

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THE SILVICS AND ECOLOGY OF BOREAL SPRUCES

Proceedings of the 11th IUFRO Northern Forest Silviculture and Management Working Party S1.05-12 Symposium

12 - 17 August 1989

Central Newfoundland, Canada

B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors

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ABSTRACT

The 11th Meeting and Symposium of the IUFRO Northern Forest Silviculture and Management Working Party (S1.05-12) met in Gander and Grand Falls, Central Newfoundland, Canada, on 12-17 August 1989. Over 70 delegates from 5 circumpolar countries met to discuss the Symposium theme, "The Silvics and Ecology of Boreal Spruces", through formal presentations and field trips. Seventeen scientific papers were presented during four paper sessions: Site Preparation for the Establishment of Boreal Spruces, the Ecology of Boreal Spruces, the Genetics of Boreal Spruces, and the Natural Regeneration of Boreal Spruces. Eleven posters were presented. A Summary Paper was given at the end by an invited scientist. In addition, five papers were presented by representatives of the local forestry sector to introduce delegates to the forest resources and industry in Newfoundland and Labrador. Visits to a range of sites in central Newfoundland provided a forum for discussion of local black spruce silvicuture and management problems and opportunities. Three Post-Symposium tours to Labrador, Western Newfoundland, and Nova Scotia were held.

B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. 1990. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271. p. 203.

RÉSUMÉ

La 11th rencontre-symposium annuelle du Groupe de travail sur la sylviculture et la gestion des forêts du Nord de l'UIIRF (S1.05-12) a eu lieru à Gander et à Grand Falls, au centre de Terre-Neuve (Canada) du 12 au 17 août 1989. Plus de 70 délégués de cinq pays circumpolaires y ont profité d'exposés didactiques et de voyages d'études reliés au thème de cette année, "La sylviculture et l'écologie des forêts boréales d'épinettes". Dix-sept exposés scientifiques y ont été présentés dans le cadre de quatre séances sur les thèmes suivants. Préparation du terrain en vue de l'établissement de for,ts boréales d'épinettes, écologie des forêts boréales d'épinettes, Génétique des épinettes, de la forêt boréale et Régénération naturelle des épinettes de la for,t boréale. Onze affiches ont également été présentées. A la fin de la rencontre, un chercheur invité a prononcé un exposé sommaire. En outre, des représentants de l'industrie forestière locale ont soumis cinq exposé afin de familiariser les délégués avec les ressources et l'industrie forestières de Terre-Neuve et du Labrador. Des visites dans diverses stations du centre de Terre-Neuve ont permis la tenue d'entretiens sur les problèmes à régler et les possibilités à exploiter en matière de sylviculture et d'aménagement des forêts locales d'épinettes noires. Après le symposium, on a organisé trois tournées dans le Labrador, l'ouest de Terre-Neuve et la Nouvelle-Écosse.

ACKNOWLEDGEMENTS

In order to ensure speedy publication, all authors were requested to submit computer disks as well as hard copies, and the typesetting/printing process was carried out electronically. This venture into a new production method for the Newfoundland and Labrador Region entailed much trial and error. The Editors therefore wish to thank the following staff for their patience and invaluable assistance in producing this report: Bruce Pike for handling all the hard- and software aspects, Joan Rockwood for carrying out the final corrections once all files were in Word Perfect, and Hildegarde Dunphy for overseeing the production of the Report. The Editors also wish to thank all authors for heeding the deadlines required to produce the Proceedings.

PREFACE

The hosting of the 1989 IUFRO Northern Forest Silviculture and Management Working Party (S1.05-12) offered the forestry sector in Newfoundland and Labrador the unique opportunity of hearing scientific papers presented and participating in silvicultural field tours and discussions with an international group of foresters on our own land base. To say that our guests have left us with some food for thought would be an understatement, and we thank all who participated for their thoughtful input and comments regarding forestry in our Province.

Assembling a slate of international speakers proved to be a challenging task. Initially, the Organizing Committee was charged at the 1987 Symposium in Finland with organizing a Symposium on black spruce for the Working Party, much along the lines of the 1982 Symposium held in Hinton, Alberta, Canada, on "Lodgepole Pine: Regeneration and Management". However, it became apparent to the Organizing Committee once some way into the task that black spruce, unlike lodgepole pine, would be of a much narrower interest to an international group of foresters, and thus the topic was expanded to include all boreal spruces. Any apparent emphasis on black spruce in the Proceedings is as a result of this expansion of the theme in mid-stream.

Unlike previous Symposia, the Organizing Committee asked for offered papers, to complement invited papers. We were overwhelmed with the number and quality of abstracts submitted, and regret that we could only accept a limited number of papers, based upon relevance to the Symposium theme and past interests of the Working Party as judged by the Organizing Committee. It is apparent from the response that a major Symposium on the "Silvics and Ecology of Black Spruce" may well be warranted, and would likely generate a large number of offered papers of great interest to the scientific community and operational foresters alike.

A Poster Session was also held, and all posters offered were accepted. The Organizing Committee opted to publish the abstracts and pertinent Figures and Tables, in the belief that the amount of work that goes into producing posters that are shown at a Symposium for a few brief hours justifies reproduction in a more permanent medium.

Finally, I wish to thank the Organizing Committee for their input and hard work. The Symposium was the product of a coordinated effort that bodes well for future integrated work between the forestry agencies in the province. I also wish to thank the many other people from all the agencies who are too many to mention who carried out so many necessary tasks: from preparing meals to serving coffee to ensuring that cold beverages were where they needed to be at the correct time - all essential details when one is on a field tour!

Financial support from Forestry Canada, the Department of Forestry & Agriculture, Abititbi Price Inc. and Corner Brook Pulp & Paper Ltd. is also gratefully acknowledged.

Brian D. Titus
Chairman
Organizing Committee

Organizing Committee

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Wayne Brown	(Corner Brook Pulp and Paper Ltd.)
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Lorne West	(Forestry Canada)

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Labrador:	Eric Earle (Department of Forestry and Agriculture, Happy Valley, Labrador)
Newfoundland:	Doyle Wells (Forestry Canada, St. John's, Newfoundland)

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INTRODUCTION

by

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The eleventh international gathering of IUFRO Working Party S1.05-12, Northern Forest Silviculture and Management, occurred on the Island of Newfoundland, which is the youngest province in Canada.

As elsewhere in the world, Newfoundland's Northern Forest provides many opportunities. Historically, these forests provided domestic building materials for local fishing vessels that plied the waters of the North Atlantic, lumber for homes, and fuel with which to heat them. The large white pine were also cut for export to Britain. Large tracts of Northern Forest wilderness can be found in Newfoundland, and especially in Labrador. The abundant lakes and rivers are home to Atlantic salmon, arctic char, trout, and northern pike - natural links between North America and Eurasia - and provide some of the best fishing anywhere in the Northern Forests of the world. Hunting still plays an important role in the rural economy, and the forests provide habitat for moose, woodland caribou, hares and ptarmigan. Many species of berries familiar to people who live in the Northern Forests around the globe can also be found in Newfoundland and Labrador, notably bake-apples (*Rubus chamaemorus* L.), partridge berries (*Vacciniuum vitis-idaea* L.), blueberries (*V. angustifolium* Ait.) and cranberries (*Vaccinium* spp).

Today, the Northern Forest of Newfoundland is managed for people by: providing jobs in small to medium-sized sawmills and three major pulpmills; providing recreation, including sport fishing, hunting, berry picking, hiking, camping and boating; and providing spectacular views of the North Atlantic that no one can forget, with the rocks and sea framed by balsam fir and spruce trees struggling and clinging to the ground, or hiding behind any obstacle that blocks the relentless wind.

The forests of Newfoundland are exciting. We had an opportunity to see impressive successes and equally impressive challenges. As chairman of IUFRO Working Party S1.05-12, I wish to acknowledge the efforts of our Newfoundland hosts. Particular thanks is owed to Dr. Brian Titus of the Newfoundland and Labrador Region of Forestry Canada who chaired and organized the workshop. It is fully recognized that Brian had fantastic support and I wish to acknowledge and thank his colleagues on the Organizing Committee: Bill Alexander, Ed Blackmore, Wayne Brown, Bill Furey, Mike Lavigne, Allan Masters, Bill Meades, Peter Newton, Neil Stocker, and Lorne West. I also wish to acknowledge the support of the following organizations: Forestry Canada, the Department of Forestry and Agriculture, Abititbi-Price and Corner Brook Pulp and Paper - without them the workshop could not have been the success that it was.

Packee, E.C. 1990. Introduction. 1990. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, p. 1.*

SCIENTIFIC PAPERS

TRIALS TO APPRAISE THE BIOLOGICAL EFFECTIVENESS OF MECHANICAL SITE PREPARATION EQUIPMENT IN BRITISH COLUMBIA: FRDA PROJECT 1.10

by

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ABSTRACT

This trial was designed to evaluate and demonstrate the effectiveness of mechanical site preparation for backlog rehabilitation. The trial, established in 1986, encompasses six research installations established on a range of ecosystems. Within each installation, treatment types are represented by a series of "mini-stands" randomly allocated within blocks. The mini-stand design is useful for determining the effect of the various treatments on microclimate, revegetation, soil fertility, and rodent damage. Growth response in the mini-stands can also be followed to stand closure or even to harvest if plot markings are maintained. Since seedlings were planted in 1987 and 1988, performance differences among treatments are not yet definitive. However, early seedling response to site preparation is evident, particularly on harsh sites.

INTRODUCTION

During the past decade British Columbia has seen significant growth in its reforestation program (Figures 1 and 2, after B.C. Ministry of Forests 1988). The program gained particular momentum in 1985 with the signing of a five-year $300 million, Canada-British Columbia Forest Resource Development Agreement (FRDA) that emphasized bringing older, unsatisfactorily restocked forest land back into full production.

Early in the FRDA program it was recognized that mechanical site preparation would play a major role in the reforestation of backlog sites. While considerable experience had been gained prior to the start of FRDA, the projected increase in program size, the opportunities provided by newly introduced site preparation equipment such as power disc trenchers, and the variety of planting stock available, indicated strongly that a systematic evaluation of the biological response of stock to various types of planting spots was needed if the best use was to be made of FRDA funds.

This paper provides an overview of FRDA Project 1.10, a trial designed to evaluate and demonstrate mechanical site preparation equipment for backlog rehabilitation. The project consists of large research installations established on six different sites over a range of ecosystems. A number of prerequisites and products were essential in making the installations meaningful.

As far as possible, the sites chosen had good machine access. Accessible sites enhance field tours and facilitate long term monitoring. Within the site, plots were given wide spacing to allow machine access and operation without excessively tight turns.

Sites were stratified prior to treatment so that treatment plots could be located on uniform and representative parts of the site. Aberrant areas were avoided.

Subsequent to site stratification, an array of treatments were applied to each site. This strategy is more economical than locating a few treatments over many sites. The various treatments will be monitored until stand closure or beyond.

METHODOLOGY

Experimental Design

The field trials on all sites were a complete randomized block design, with up to ten treatment plots (30 m x 25 m) replicated five times (Figure 3).

Bedford, L. and McMinn, R.G. 1990. Trials to Appraise the Biological Effectiveness of Mechanical Site Preparation Equipment in British Columbia: FRDA Project 1.10. In: *B.D. Titus, M.B. Lavigne, P.F. Newton, and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-217, pp. 3-12.*

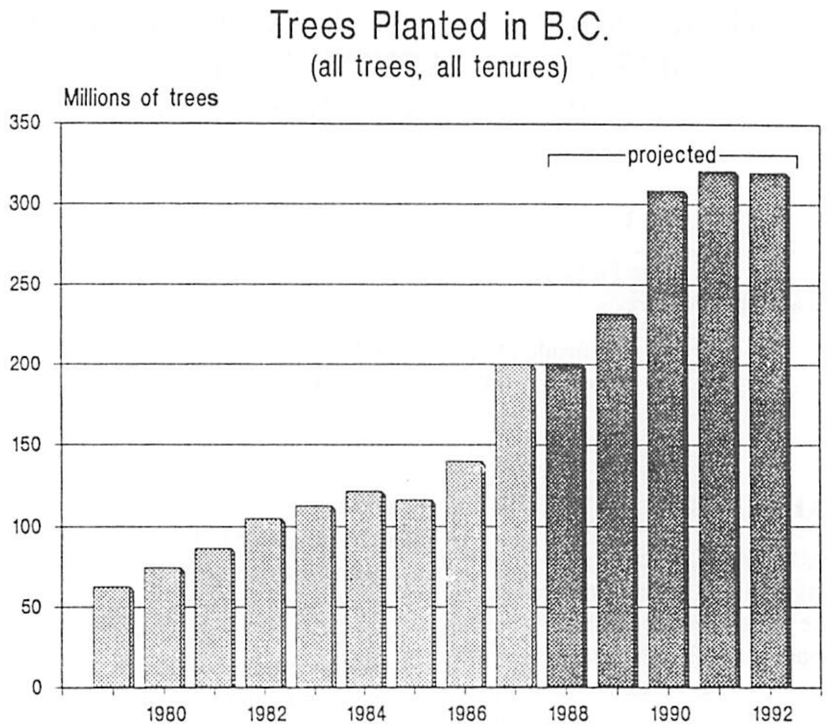

Figure 1. Trees planted in B.C.

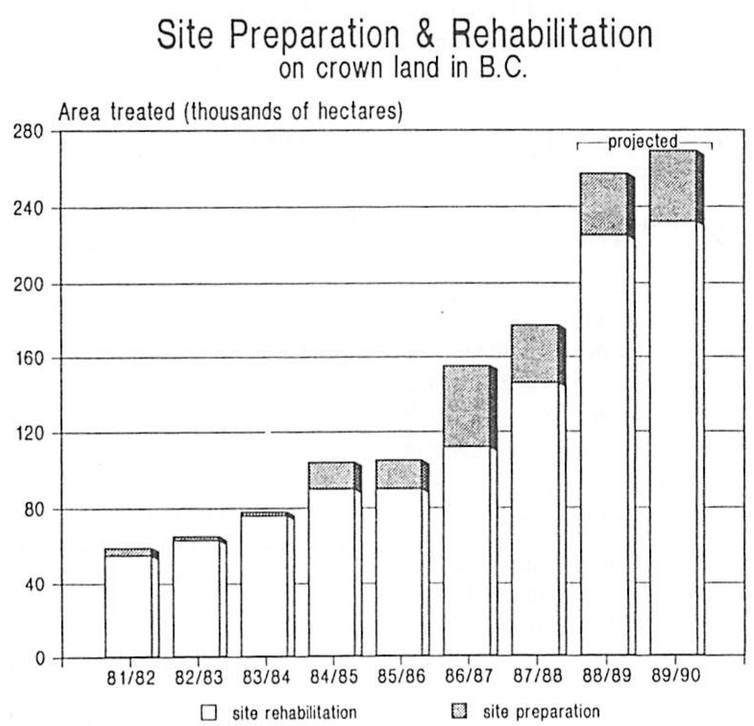

Figure 2. Site preparation and rehabilitation on crown land in B.C.

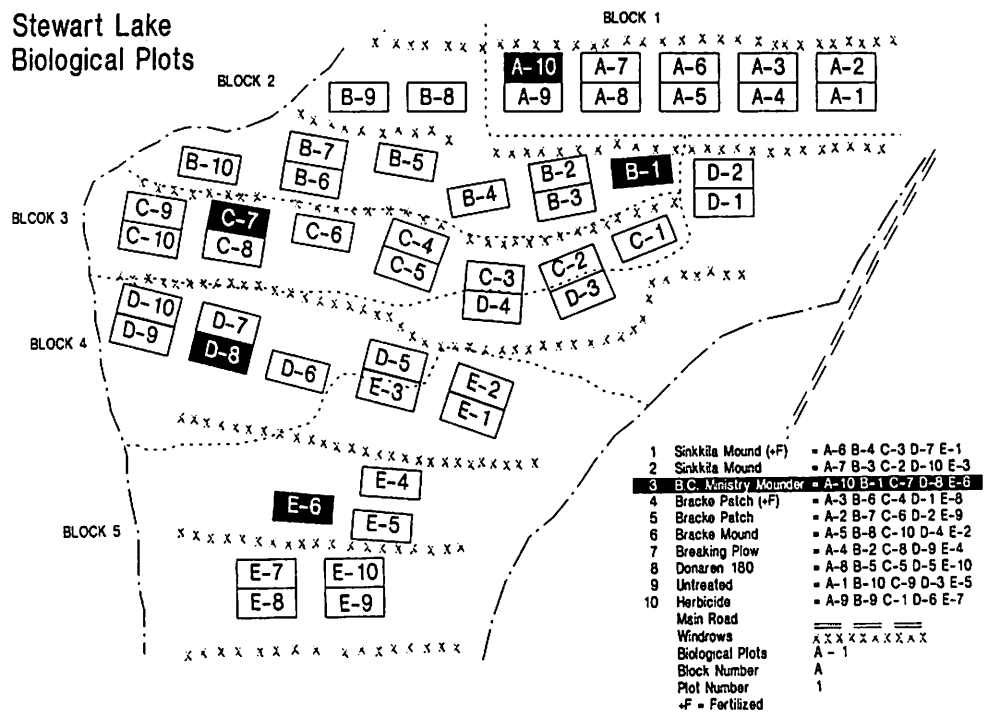

Figure 3. Stewart Lake biological plots.

A wide range of site treatments were used on each installation, however, not all treatments were used on all installations. Although the treatments applied were generally considered appropriate to the site, treatments presumed to be inappropriate were included on most sites to demonstrate their inappropriateness or to demonstrate the validity of preconceptions. The range of treatment types and the associated planting microsites are listed below:

bedding plough: top of coarsely mixed bed;

Bräcke cultivator: *shoulder*, with or without the addition of fertilizer;

Bräcke mounder: top of the *inverted humus mound* or *mineral mounds* simulated by placing a mound of mineral soil dug by hand from the patch in the appropriate position on the shoulder;

breaking plough: single inverted humus mineral soil covered furrow slice resting on mineral soil;

burned windrow: blackened FH layer, boot screefed;

Delta disc trencher: *hinge, berm,* or *furrow*;

Donaren disc trencher: *hinge* and *berm*;

herbicide: applied as a site treatment or as a follow-up treatment;

Madge rotoclear: intensively *mixed LFH and mineral soil* giving an organic matter enriched mineral soil surface;

Ministry spot mounder: *mounds of inverted humus with mineral soil capping;*

Sinkkilä (HMF) mounder: *mounds of inverted humus with mineral soil cappings* and *scalped patches;*

subsoiler: *ripped subsoil* with *minimal surface disturbance;*

untreated: *boot screefed* patch planted with standard or alternative stock;

V-blade: strips of *exposed mineral soil* (or partially screefed);

Wadell cone trencher: *hinge;*

WIT plough: single or double width *inverted furrow slice* on undisturbed LFH;

The performance of standard planting stock on the untreated plots allowed evaluation of gains "bought" by treatment. No preparation was a treatment option.

In some installations, an alternative stock such as a different species (e.g., white spruce (*Picea glauca*) in a lodgepole pine (*Pinus contorta* var. *latifolia*) installation) or a larger stock, were planted in untreated plots to determine if such alternatives were economical.

Plots consisted of 48 core trees giving a potential of 240 trees per treatment. When treatment differences are appreciable, measurement of only one quarter to one half that number can show statistically significant differences. However, the larger number allows for mortality and other aberrant conditions such as tip weevil occurrence.

Preparation of an area sufficient to plant 80 trees at operational spacing (≈3 x 3 m) gave approximately 750 m^2 of treated area, enough to limit edge effects. Thirty-two trees were planted around the 48 core trees to provide a buffer, forming a mini-stand. Operational planting was conducted in the areas between plots reinforcing the semblance of plots being in complete stands.

Plot size appeared to be adequate for the treatments used. Larger plots would be needed to monitor major site changes such as drainage effects following ditching, or broadcast burning. Such treatments were not attempted in the six installations established.

Growth responses in the "mini-stand" may be followed to stand closure or even to harvest if plot markings are adequately maintained. Line plots have the disadvantage that a successful line, bordered by an unsuccessful line, may be followed only for the period before normal stand closure. The unsuccessful line does not provide the same competition in a comparable time frame that trees in a successful line offer each other.

Seedling Assessments

Seedling performance was used as the primary measure of the biological effectiveness of site preparation treatments.

Each tree was marked with a numbered, colour-coded plastic tag secured to a spring steel wire. Tall wires (65 cm) were used in plots with tall vegetation to facilitate location of seedlings for measurements. The spring-steel wires, which were resistant to snow press, have saved considerable time (and cost) in locating seedlings compared to the fine wire markers used initially. The fine wires were flattened by snow-pressed vegetation, making them extremely difficult and time-consuming to find. Numbering trees allowed individual occurrences, such as tip weevil damage, to be followed. The spring-steel markers should last 10 years, by which time markings could be transferred directly onto the remaining trees.

Survival, degree of winter damage, growing season frost damage, drought effects, and animal damage were recorded. Stem diameter at ground line, total height and current leader increment were measured. Results could then be expressed as seedling volume, commonly a more demonstrative measure of performance than height alone.

Seedlings have been excavated at periodic intervals to measure root growth.

Competing Vegetation

Vegetation height, density, and species composition were assessed at the time of maximum development (late July to early August). Ingrowth of competing vegetation will be monitored for the first three years following site treatment. First year differences among treatments were apparent.

Soil Monitoring

The soil of each installation was characterized during mapping to establish the location of plots. Depth of LFH layers, soil texture and other properties relevant to interactions between treatment and site were recorded. C:N ratio, soil mineralization, and soil bulk density were determined to find the effect of site treatments on these soil properties. Bulk density and soil mineralization measurements will be continued.

Environmental Monitoring

Climatic recording stations to monitor macro- and microclimate were installed in four of the six installations. Wind speed, solar irradiance, air temperature, humidity, and precipitation were recorded on an hourly basis with data loggers (McLeod and Osberg 1988). Thermisters and soil moisture blocks placed at various depths monitored conditions in a variety of planting spots.

SITE DESCRIPTIONS

Kluskus

Kluskus Moist Cold Sub-Boreal Spruce variant (SBSmc3) (DeLong, Hope, and McLeod 1985; Hedin 1987; Wehr 1989). The lodgepole pine stand characteristic of the relatively dry climate of this area was cut in 1977. Vegetation regrowth was modest prior to treatment in 1986, which is characteristic of the site. The soil is well drained. Lodgepole pine was planted in spring 1987.

Bednesti

Dry Warm Sub-Boreal Spruce variant (SBSdw3). The lodgepole pine stand characteristic of the relatively dry climate of this area was cut in 1963-64 with the two chain leave strips cut in 1971. The NSR stems were winter sheared and windrowed in winter 1987. The various site preparation treatments were made in summer 1987 on the well drained soils that are characteristic of most of the site. Lodgepole pine was planted in spring 1988.

Mackenzie

Finlay-Peace Wet Cool Sub-Boreal Spruce variant (SBSwk2). The site was cut in winter 1977, then chain dragged essentially clearing it of slash. The site was a severe frost pocket, being level and surrounded on three sides by higher ground. Soils are relatively fine textured, with poorly drained patches. Vegetation regrowth prior to treatment was generally dense, with patches of aspen about 3 m tall. Treatments were made in 1986 with white spruce planted in spring 1987.

Between August 8 and September 15, 1987, just prior to seedling assessment at the end of the first growing season, 23 of the 39 nights had freezing (0°C) or lower temperatures 1.3 m above ground. The minimum temperature on September 13 was -8°C (P.M. Osberg, B.C. Ministry of Forests, 1011-4th Ave., Prince George, B.C., V2L 3H9, Canada, pers. comm.). Temperatures at ground level would probably have been lower. (Severe spring frost damage had also been observed, however, precise weather data were not available because environmental monitoring stations were not installed until August, 1987).

Stewart Lake

Peace Moist Warm Boreal White and Black Spruce variant (BWBSmw1). The area had been selectively logged at various times during the previous 30 years and was burned by wildfire in the mid-1960s and in 1971. The resulting aspen stand was winter sheared and windrowed in April 1986. The site is gently rolling and the soils fine textured. Treatments were made in 1986 and the area planted with white spruce in spring 1987.

Iron Creek

Graham Wet Cool Boreal White and Black Spruce variant (BWBSwk2). The area was selectively logged in 1966 and clearcut in 1977. The aspen regeneration and residual conifers were sheared and windrowed in winter 1985. The site is essentially flat but bordered on two sides by long, gentle slopes. Soils are fine textured with some poorly drained areas. Treatments were made in 1986 and the area planted with white spruce in 1987.

Inga Lake

Peace Moist Warm Boreal White and Black Spruce variant (BWBSmw1). Aspen and willow, originating from wildfire in the mid 1950s, were sheared and windrowed in winter 1986/87. Soils are fine textured and generally well drained but with some wet areas. Site treatments were made in 1987 and the area planted with white spruce in spring and summer 1988.

SYNOPTIC RESULTS

Since seedlings were planted in 1987 and 1988, performance differences among treatments are not, in most cases, definitive. Some preliminary results, however, are evident.

Seedling Assessment

Bioassay

Although it is premature to present seedling performance data for all of the FRDA Project 1.10 installations, second-year data for the Bednesti site (Figure 4) is given in order to highlight several gross trends.

The Bednesti site is not harsh, however, seedling performance is limited by low nutrient and moisture availability. Root growth is also limited by a compacted layer approximately 10 cm below the surface. Treatments which ameliorated the sites "limiting factors" improved early seedling performance.

Seedlings planted in burned windrows out-performed all mechanical treatments in both height increment and seedling volume. The excellent growth on this treatment can be attributed in part to increased nutrient availability and to reduced moisture loss. Moisture loss was minimized by a deep ash mulch and also by excellent vegetation control.

The Madge, breaking plough, bedding plough and TTS-Delta (hinge) produced microsites that resulted in slightly improved seedling growth. Improved seedling growth was likely due to less compaction in the rooting zone and a slightly improved nutrient regime associated with the more rapid mineralization of the humus. Soil temperature and moisture also varied by treatment and would also have slightly affected seedling growth (the effect of soil moisture and temperature will be fully discussed in a subsequent report).

Mineral mounds did little to enhance seedling growth on this site. Re-compaction of the mineral mounds was rapid and seedlings planted on the mounds were more prone to drought stress. The poor seedling performance on this site is in sharp contrast to the performance of seedlings planted on inverted humus mounds in other installations where soils were cold and drainage was poor.

It is important to note the effect of planting position on seedling growth. For example, seedling growth on the hinge position of the TTS Delta treatment was significantly greater than seedling growth in the trench. In this case, the bottom of the trench proved to be a particularly inhospitable environment with low nutrient

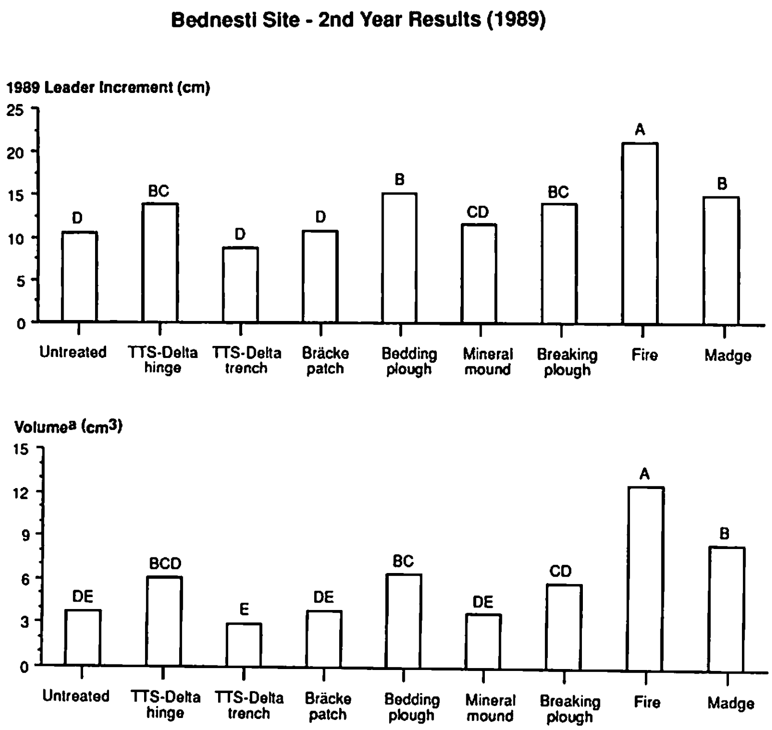

Figure 4. Bednesti site - second year results. The bedding plough, breaking plough and mineral mound were planted approximately 4 cm deeper than the other treatments. Deep planting was adopted to reduce summer drought stress. Values with the same letter are not significantly different at the 95% confidence level.

$$^{a}\text{Volume} = \frac{(\pi r^2 \times \text{height})}{3}$$

availability and bulk density readings as high as 1.5 g/cm^3. High trench density was attributed to the removal of the uncompacted surface layer which in turn exposed the denser material deeper in the soil profile.

While seedling performance varied significantly between treatment types, survival did not. Second year survival for this site averaged 99.3% with no significant differences between treatments.

Frost

The occurrence and intensity of frost damage varied significantly among installations and treatment types. The incidence of first year frost is noted for three contrasting installations (Table 1).

Both the Mackenzie and Iron Creek sites were severely affected by frost during the growing season. This was particularly evident in the plots treated with herbicide. At Mackenzie, 77% of seedlings in the herbicide plots were affected by the end of the first growing season, compared to 50% in the untreated plots. At Iron Creek, 35% of seedlings in the herbicide plots were affected by frost compared to 16% in the untreated plots. Protection by plant cover was entirely absent from the herbicide treated plots during the first growing season. In an area adjacent to the Mackenzie trial, seedlings under a residual canopy of aspen were largely unaffected by frost. These results suggest that in severe frost pockets, a nurse crop may be necessary for re-establishment of conifers, despite the possibility of conifer seedling growth being inhibited subsequently.

At Iron Creek, the exposed mineral soil and raised position of seedlings on mounds were sufficient to reduce frost damage during the growing season. At Mackenzie, the amount of mineral soil and the height of mounds were insufficient to protect seedlings from frost because the depth of cold air on this site, resulting from cold air drainage, was greater than the height of seedlings, even on mounds.

In the ploughing treatments at both Iron Creek and Mackenzie, the breaking plough and the V-plough, respectively, reduced frost damage. Evidently re-radiation from the exposed mineral soil reduced the incidence of frost damage.

Lodgepole pine seedlings, planted as an alternative stock at Iron Creek, were unaffected by frost.

Table 1. Frost damage.

Treatment	% Frost Damage Iron Creek (Spruce PSB 313)	 Mackenzie (Spruce PSB 3-13)	 Vanderhoof (Pine PSB 211)
Sinkkilä Mound	5 b	49 b	–
Ministry Mound	9 c	52 b	0 a
Bräcke Mound	11 cd	54 b	–
Bräcke Patch	24 e	–	1 a
Plough	1 a (Breaking Plough)	23 a (V Blade)	1 a (V Blade)
Control	16 d	50 b	3 a
Alternate Stock	0 a (Pine PSB 211)	–	28 b (S PSB 3-13)
Herbicide	35 f	77 d	–
Donaren 180 (Berm)	–	53 b	2 a
Donaren 180 (Furrow)	–	63 c	1 a

Values in a column with the same letter are not significant at 95% confidence level.

Pine was planted on all treatments at the Kluskus installation. The resistance of pine to frost minimized damage throughout this trial. In contrast, 28% of the white spruce seedlings planted in untreated plots were damaged by frost.

Root Growth

First year root growth varied significantly among treatments for all installations except Bednesti. The number of new root tips 70 days after planting (Von der Gonna 1986) are indicated (Table 2 and Figure 5) for Stewart Lake and Mackenzie.

On cold, imperfectly drained sites, the benefits of exposed mineral soil and mounding are clearly reflected in increased root growth. The number of new roots on seedlings growing in untreated areas (LFH layer intact) was only half that of seedlings growing in the mounds. Also maximum soil temperatures in the mounds made by the Ministry Mounder were higher than beneath the duff layer of untreated plots or in the small scalped patches.

The improved drainage associated with the mounded microsite influenced root growth at both sites. Drainage was particularly important at Stewart Lake where exceptionally heavy summer rains combined with imperfectly drained, fine textured soils, led to considerable surface ponding. On this site root growth was actually retarded by the saturated Bräcke patches, resulting in less root growth in the patch than in the untreated plots.

Competing Vegetation

The effect of mechanical site preparation on competing vegetation varied by treatment and site. On brush prone sites, such as Inga Lake, vegetation control varied considerably among treatments. However, on installations such as Bednesti, where competing vegetation was not aggressive, the difference in vegetation control among treatment types diminished.

Ingrowth during the second growing season after planting at the Iron Creek plot was considerable, especially in untreated plots (Table 3). Ingrowth was least on mineral-soil capped inverted humus mounds, that remained comparatively free from significant levels of competing vegetation (A. MacKinnon, B.C. Ministry of Forests, 31 Bastion Square, Victoria, B.C., Canada, V8W 3E7, pers. comm., 1988).

Soil Monitoring

Concern that mixing vegetation and LFH layers into the mineral soil with the Madge Rotoclear could cause nitrogen deficiency seems to be have been unfounded (Figure 6, after Butt 1988). No change in C:N ratio was found at the Inga Lake site and mineralizable nitrogen levels were increased, at least in the short term.

CONCLUSION

The "mini-stand" experimental design for mechanical site preparation trials allows for statistically valid comparisons that can be extended to stand closure and beyond.

Table 2. Mean number of new unsuberized, white root tips growing from the root plug, 70 days after planting (Von der Gonna 1986).

Root Category	Stewart Lake		Mackenzie	
	Mean	Treatment	Mean	Treatment
Side, < 1 cm	64.58 a	Ministry mounder	108.40 a	Ministry mounder
	47.16 b	Bräcke mounder	87.10 b	Bräcke mounder
	41.26 b	Bräcke plough	73.94 bc	patch
	28.98 c	control	57.46 c	control
	15.96 d	patch		
Side, > 1 cm	23.46 a	Ministry mounder	31.00 a	Ministry mounder
	16.34 b	Bräcke mounder	21.30 b	Bräcke mounder
	12.96 b	Bräcke plough	18.02 bc	patch
	8.16 c	control	5.28 c	control
	4.98 c	patch		
End, < 1 cm	20.94 a	Ministry mounder	48.34 a	Ministry mounder
	17.80 ab	Bräcke mounder	31.14 b	Bräcke mounder
	17.18 b	Bräcke plough	20.46 c	patch
	13.20 c	control	18.72 c	control
	7.08 d	patch		
End, > 1 cm	20.66 a	Ministry mounder	37.78 a	Ministry mounder
	15.94 b	Bräcke mounder	27.24 b	Bräcke mounder
	13.48 b	Bräcke plough	21.26 b	patch
	9.58 c	control	20.88 b	control
	3.48 d	patch		

Values in a column with the same letter are not significantly different at 95% confidence level.

Table 3. Ingrowth of competing vegetation during the first two years following treatment of a site with fine soil texture and high potential for competing vegetation (Iron Creek Site, after A. MacKinnon, B.C. Min. For., pers. comm., 1988).

Treatment	Competitive Index[a]	
	First Year	Second Year
Untreated	45 b	1608 b
Bräcke Patch	36 b	272 a
Ministry Mounder	9 a	102 a
Herbicide	3 a	187 a

[a] $\text{Competitive Index} = \dfrac{\text{mean \% cover x mean vegetation height}}{\text{distance from seedling to nearest vegetation}}$

Values in a column with the same letter are not significantly different at 95% confidence level.

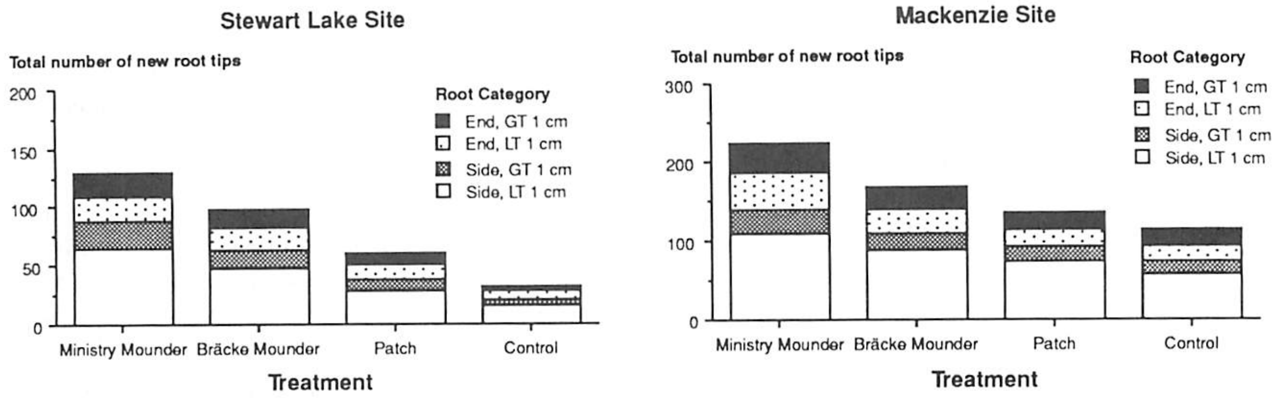

Figure 5. Total root egress 70 days after planting (after Von der Gonna 1986).

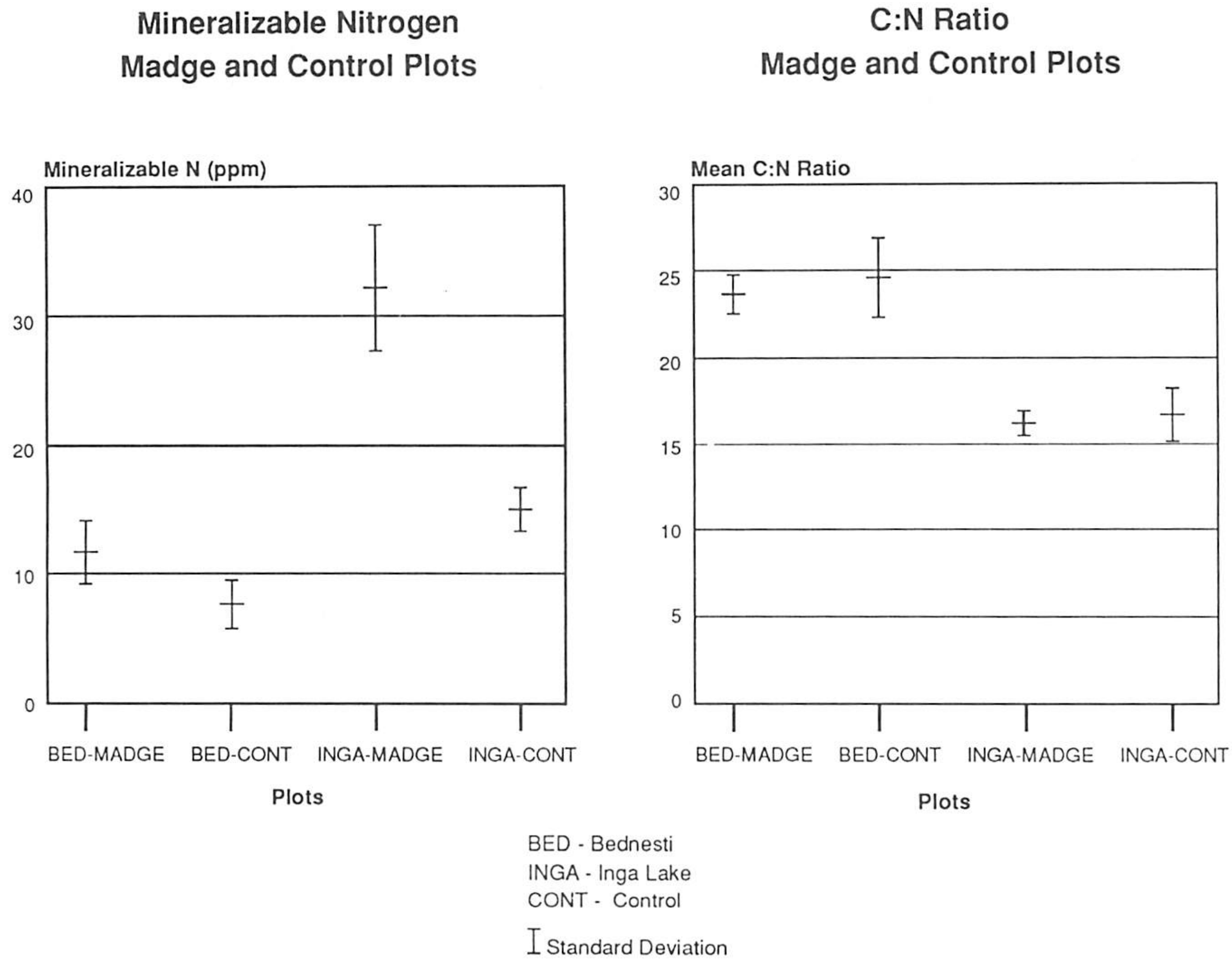

Figure 6. Mineralizable nitrogen and C:N ratio, Madge and control plots (after Butt 1988).

The trial discussed in this paper reinforces the conviction that site treatments must be site specific. A microsite that is suitable in one ecosystem may not be suitable in another ecosystem. In addition, there is a continuing need to establish and monitor trials for extended periods. Early seedling growth may not reflect long term seedling performance.

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EFFECT OF MECHANICAL SCARIFICATION AND PLANTING METHOD ON ARTIFICIAL REGENERATION OF FLOOD-PLAIN WHITE SPRUCE IN INTERIOR ALASKA

by

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ABSTRACT

The boreal forests of interior Alaska contain productive stands of white spruce (*Picea glauca* (Moench) Voss) on both upland and flood-plain landforms. Reforestation options for two different flood-plain sites were compared on an island in the Tanana River near Fairbanks, Alaska (latitude 64°51' N, longitude 148°31' W). Survival of containerized seedlings after outplanting on both sites was generally above 95%, regardless of harvest cutting method or mechanical site preparation, and declined little between the third and fifth growing season. Establishment and survival after direct seeding on seed spots was more variable and differed by flood-plain site, harvest cutting method, type of site preparation, and somewhat with the use of plastic seed shelters for seedling protection. Terminal leader growth of planted seedlings increased 60% between the third and fifth growing season in clearcut units on the better site, but terminal leader growth on planted seedlings in shelterwood units increased only about 10%. In clearcut units prepared by blading, basal diameter of seedlings five seasons after outplanting was almost 50% more than on similar surfaces in shelterwood units. Planted seedlings on unscarified surfaces and in small scalped patches had similar basal diameters, regardless of harvest cutting method or flood-plain site. Results suggest that similar interior Alaska flood-plain forests of white spruce can be successfully regenerated by using the clearcut or shelterwood harvest cutting method, nursery-reared seedlings and, in specific cases, mechanical site preparation.

Youngblood, A.P. 1990. Effect of Mechanical Scarification and Planting Method on Artificial Regeneration of Flood-Plain White Spruce in Interior Alaska. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 13-24.*

INTRODUCTION

The boreal forests of interior Alaska, located between the Brooks Range to the north and the Kenai-Chugach Mountains to the south, include about 5.45 million ha of forest with mean annual increment at least 1.4 m^3 ha^{-1} (W. van Hees, Forest Inventory and Analysis for Alaska, Anchorage, Alaska, 1989, pers. comm.). White spruce (*Picea glauca* (Moench) Voss) is currently the principal species in timber stand management and is found in relatively pure stands on warm slopes, well-drained benches and flood plains. More often, these same sites support white spruce mixed with paper birch (*Betula papyrifera* Marsh.), quaking aspen (*Populus tremuloides* Michx.), and balsam poplar (*Populus balsamifera* L.). On colder, wetter sites, white spruce is often interspersed with black spruce (*Picea mariana* (Mill.) B.S.P.) and scattered tamarack (*Larix laricina* (Du Roi) K. Koch) (Viereck *et al.* 1986).

Flood plains along major rivers in interior Alaska support a high proportion of the productive forests of white spruce and balsam poplar (Viereck *et al.* 1986). Historically, these forests were exploited for white spruce cordwood during the gold rush and settlement period of the early 1900s, when large steam-powered sternwheelers delivered supplies and equipment to mining operations throughout interior Alaska. More recently, white spruce has been harvested for house logs, timbers, and rough-cut lumber. Use of white spruce from flood plains is projected to increase with establishment of the Tanana Valley State Forest. Little is known, however, of the timber management options within these flood-plain stands, especially the options for securing adequate forest regeneration after harvesting in mature stands.

Regeneration and stand management of white spruce within the flood-plain ecosystem present unique challenges. Stands are often small and scattered amongst hardwood stands composed of balsam poplar, paper birch, alders (*Alnus* spp.), and willows (*Salix* spp.). This patchy distribution is often the result of both primary and secondary successional processes after river migration and past timber cutting activity. With age, white spruce stands accumulate organic matter in a thick humus layer that often inhibits the establishment of natural regeneration. Seasonal access to commercial stands often limits the time available for logging operations and mechanical site preparation and the transportation of harvested logs, with most logging activities being scheduled for winter months before river ice breakup. Cyclic seed production and the rapid regrowth of competing vegetation prevent reliance on natural regeneration. Finally, discontinuous ownership patterns limit stand management to only a fraction of the total area of the flood plain.

An extensive cooperative study was begun in 1981 to learn more of the ecology and management of interior Alaska white spruce flood-plain forests, including site classification, soil and vegetation relations (Zasada 1984, Dyrness *et al.* 1988), stand structure and hypothesized development (Juday and Zasada 1984), winter logging techniques (Zasada *et al.* 1987), and consequences of prescribed fire (Zasada and Norum 1986, Wurtz 1988). One of the objectives of this work was to determine the effects of different management alternatives on white spruce artificial regeneration. Reforestation options selected for testing included planting, spot seeding with and without protection, blade and patch mechanical scarification, and both clearcutting and shelterwood harvest cutting methods. Preliminary results after five growing seasons are reported.

METHODS

Study Area

The study was conducted on Willow Island, a 200-ha island in the Tanana River flood plain about 32 km southwest of Fairbanks, Alaska (Figure 1). The island is about 123 meters above sea level in elevation and has a topographic relief of about 2 m. Numerous silt-filled channels and natural levees dissect the island, creating a series of terraces indicative of past river crosscutting. Climate of the study area is strongly continental, with extreme winter temperatures of -50°C, mean daily temperatures in January below -20°C, and an average of 214 days continuous snow cover (Slaughter and Viereck 1986). Temperatures during the nearly 100-day growing season remain relatively constant with extended day length at this latitude. The mean daily temperature in July is 17°C. Annual precipitation is low (285 mm at Fairbanks). August is generally the wettest month, with about 60 mm rainfall. Soils are

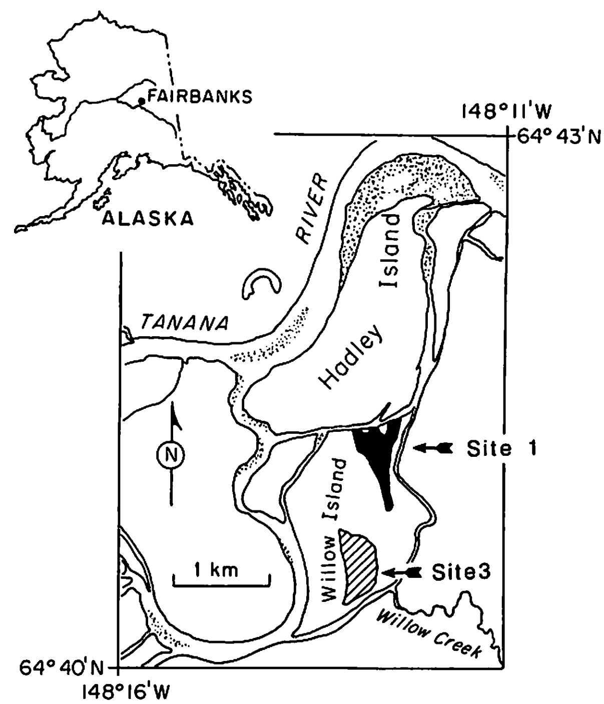

Figure 1. Location of harvest units on Willow Island in the Tanana River near Fairbanks, Alaska.

characteristically young and are derived from water-laid deposits of sand and silt alternating with buried forest floor layers. The dominant soil mapping unit is classified as belonging to the Salchaket series of Typic Cryofluvents. Phases of this series are recognized based on depth to permafrost (Dyrness *et al.* 1988).

The northern portion of Willow Island supports a heterogeneous grouping of stands, loosely defined as belonging to the Open *Picea glauca/Alnus/Vaccinium vitis-idaea/Hylocomium splendens* vegetation type (Dyrness *et al.* 1988). During harvest treatment, two age classes (100 and 300 years) of white spruce were present (Juday and Zasada 1984). Total canopy cover of white spruce was about 35%, and basal area was about 13 m^2 ha^{-1}. Paper birch was also present with about 15% canopy cover. Both green alder (*Alnus crispa* (Ait.) Pursh) and thinleaf alder (*A. tenuifolia* (Nutt.)) were present. Organic horizons on the forest floor were more than 0.1 m thick, and intermittent frost layers at depths of 0.4 to 0.6 m often persisted late into the growing season.

The southern portion of Willow Island supported mature forest stands belonging to the Open *Picea glauca/Alnus tenuifolia/Hylocomium splendens* vegetation type (Dyrness *et al.* 1988). These stands differed from the northern stands in that balsam poplar rather than paper birch was found as a minor associate with the mature white spruce, and the undergrowth lacked lowbush cranberry (*Vaccinium vitis-idaea* L.). Basal area of white spruce was about 22 m^2 ha^{-1}, and maximum ages were only about 100 years at breast height. Soils belong to the deep phase of the Salchaket, based on a lack of permafrost. Surface organic layers were less than 0.1 m deep.

Thirteen harvest units totaling 47.7 ha were whole-tree logged in January and February 1983. A single 11.3 ha unit was clearcut in the northern stands and is hereafter referred to as Site 1. Eight smaller units on Site 2 were not considered in this paper. Four additional 2.4 ha units were established on the southern portion of Willow Island and are hereafter referred to as Site 3. Two of these units were clearcuts, and two were cut with a uniform shelterwood seed cut, leaving about 100 residual stems per ha at a 9 m spacing. Snow conditions and winter logging techniques are described by Zasada *et al.* (1987).

Study Design

The experiment on Site 1 used a randomized complete block design incorporating a split-split-plot structure, replicated four times. Three mechanical site preparation methods (blade, patch scarification, and control) and three artificial regeneration methods (planting, direct seeding with protection, and direct seeding without protection) were applied. Time was an additional factor.

Each 0.54 ha block was divided into three adjacent 30 by 60 m whole plots. On two of the whole plots, mineral soil was exposed by mechanical scarification with either a straight-edged blade mounted on a rubber-tire skidder or a Bräcke patch scarifer. The skidder blade left rectangular strips 4 to 8 m long, and the patch scarifier created small 0.5 by 0.75 m scalps. The third whole plot served as a control. Within each mechanical site preparation plot, three methods of artificial regeneration were randomly assigned to subplots. Containerized white spruce seedlings (1-0 stock) were planted in June 1983 at roughly 2.5 by 2.5 m spacing. At the same time, about 8 to 10 uncoated seeds from the same collection were sown directly on to seed spots. Seeds on half the seed spots were protected by small plastic shelters (Putman and Zasada 1986), and the remaining seed spots were left unprotected. From each regeneration subplot, 50 seedlings or seed spots were systematically selected and tagged for assessing survival and growth.

The experimental design for Site 3 was completely randomized, with three sizes of experimental units used. Harvest cutting method (regeneration cut) was applied as a whole plot treatment, with clearcut and shelterwood methods each replicated twice. Three methods of mechanical site preparation (blade, patch scarification, and control) were applied to subplots, and three methods of regeneration (planting, direct seeding with protection, and direct seeding without protection) were applied to sub-subplots similarly to Site 1. Time was considered an additional factor.

Assessment

After the third growing season, seedlings at each seed spot were counted. Current, terminal leader length (annual height growth) was measured to the nearest centimeter for each planted seedling and the single tallest protected and unprotected seedling at each seed spot. Leader length was remeasured after the fifth growing season. In addition, stem diameter above the root collar on all planted seedlings was measured to the nearest millimeter.

Survival was based on the presence of at least one seedling at each of the 50 seed spot or planting sites, and the data were modified with an arcsine transformation prior to analysis. Means for annual height growth and basal diameter were based on the number of trees present. Means for treatment combinations were compared using analysis of variance. Significant treatment combinations were examined using orthogonal contrasts.

RESULTS

A previous vegetation classification study (Dyrness *et al.* 1988) indicated that Site 1 and Site 3 differ in environmental factors influencing tree growth, and thus results are presented separately for each site.

Site 1

A total of 1,764 of the 1,800 planting sites or seed spots (98%) were measured for the third-year assessment, and a few more were found during the fifth-year survey. Table 1 presents the results of an analysis of variance. Mean survival across all treatments and time periods on site 1 was 57% and differed little between the third and fifth year (p = 0.13). There was little evidence, if any, of an interaction between time and the main factors of site preparation or regeneration method.

There was a strong interaction ($p < 0.01$) between site preparation and regeneration method. Means for this treatment combination, averaged across both time periods, are presented in Figure 2. Survival ranged from a low of nearly 4% for direct seeding on unprepared surfaces to almost 99% for containerized

Table 1. Results of analysis of variance in a split-split-plot design for measures of survival and annual height growth for white spruce seedlings on Site 1, Willow Island.

Source of variation	df	MS	F	p
Survival				
Block	3	0.168	1.77	0.2530
Site Preparation Contrasts (S)				
Blade vs Patch	1	0.033	7.43	0.5786
Scarify vs Control	1	1.510	15.85	0.0073
Error *a*	6	0.095		
Regeneration Method Contrasts (R)				
Plant vs Seed	1	11.264	211.85	0.0001
Protected vs Unprotected Seed	1	0.217	8.95	0.0078
S x R Contrasts				
Blade-Patch vs Plant-Seed	1	0.225	4.22	0.0547
Blade-Patch vs Protected-Unprotected	1	0.378	7.11	0.0157
Scarify-Control vs Plant-Seed	1	0.274	5.16	0.0356
Scarify-Control vs Protected-Unprotected	1	0.259	4.87	0.0406
Error *b*	18	0.053		
Time (T)	1	0.024	2.38	0.1345
S x T	2	0.013	1.29	0.2916
R x T	2	0.015	1.51	0.2397
S x R x T	4	0.004	0.44	0.7812
Error *c*	27	0.010		
Annual Height Growth				
Block	3	5.265	3.59	0.0857
Site Preparation Contrasts (S)				
Blade vs Patch	1	1.043	0.71	0.4314
Scarify vs Control	1	16.546	11.27	0.0153
Error *a*	6	1.468		
Regeneration Contrasts (R)				
Plant vs Seed	1	169.743	139.82	0.0001
Protect vs Unprotected Seed	1	0.106	0.09	0.7706
S x R	4	1.661	1.37	0.2841
Error *b*	8	1.214		
Time (T)	1	38.162	48.59	0.0001
S x T	2	0.199	0.25	0.7776
R x T Contrasts				
Plant-Seed vs Time	1	27.260	34.71	0.0001
Protected-Unprotected vs Time	1	0.157	0.20	0.6586
S x R x T	4	0.273	0.35	0.8434
Error *c*	27	0.785		

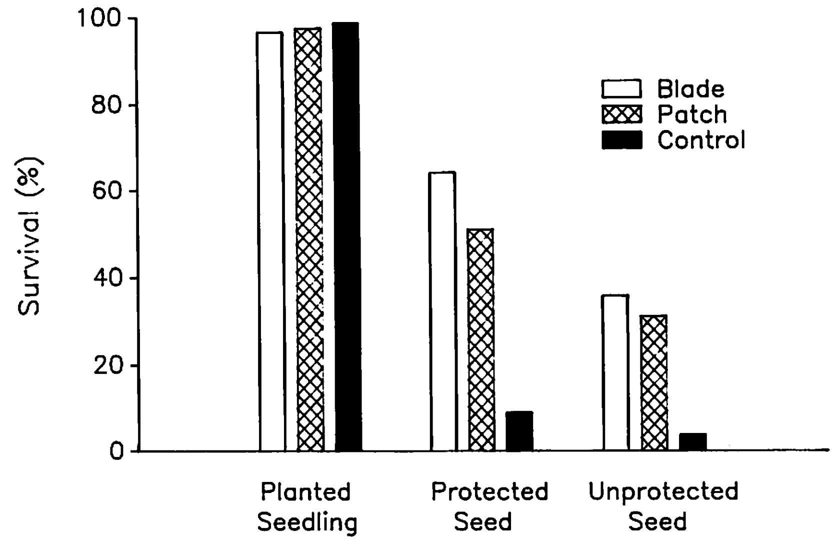

Figure 2. Survival of white spruce regeneration (mean of third and fifth growing seasons) on Site 1, Willow Island, by mechanical site preparation and regeneration method treatments (standard error of means = 0.663).

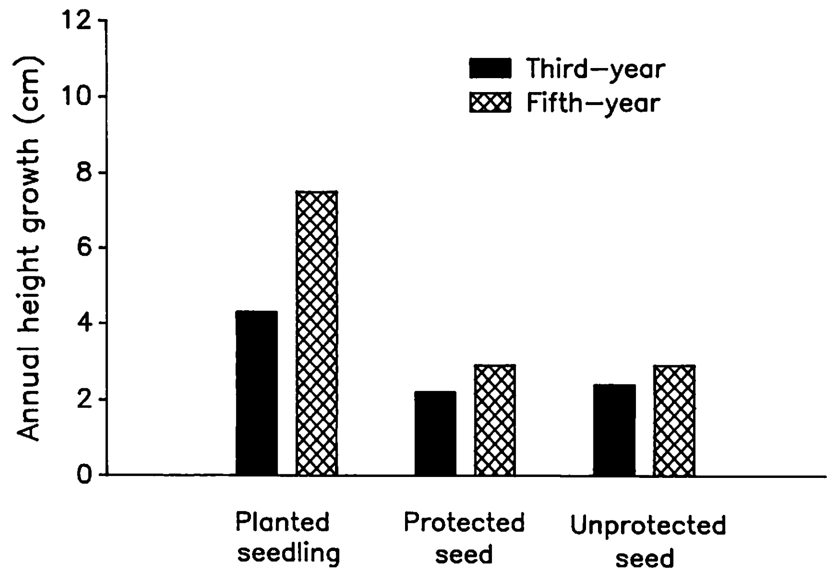

Figure 3. Annual height growth of white spruce regeneration on Site 1, Willow Island, by regeneration method and time (standard error of means = 0.256).

seedlings on similar ground. Survival of containerized seedlings was greater than 96% with or without site preparation. Site preparation increased establishment and survival on seed spots, although to a lesser degree than when seed spots were unprotected. On unscarified surfaces, survival was less than 10%.

The regeneration method was responsible for differences in survival, with survival of planted seedlings (98%) superior to seedlings germinating on the site (30%) ($p < 0.01$). The effect of site preparation was positive, with survival on bladed or patch scarified plots averaging 66%, and unscarified plots averaging only 37% ($p < 0.01$). Differences between blade and patch scarification methods were negligible ($p = 0.58$).

Unlike survival, there was a difference in annual growth (terminal leader extension) attributed to the repeated measure factor of time ($p < 0.01$) and an interaction of time with regeneration method ($p < 0.01$). Examination of this interaction indicated a mean growth of 4.3 cm for planted seedlings during the third season, 7.5 cm for planted seedlings during the fifth season, and a mean growth of 2.6 cm for seedlings on seed spots in both the third and fifth seasons (Figure 3).

Although annual growth was greater in scarified areas as compared with unscarified areas ($p = 0.02$), and planted seedlings grew more than seeded seedlings ($p < 0.01$), there was little evidence of an interaction between site preparation and regeneration method ($p = 0.28$).

Basal diameter of planted seedlings was examined as an additional measure of growth response to silvicultural treatment. There was little difference, if any, in means among the three mechanical site preparation treatments ($p = 0.37$ with 2 degrees of freedom, MSE = 0.2693 with 6 degrees of freedom). The overall mean basal diameter was 5.2 mm after five growing seasons.

Site 3

Unlike Site 1, treatments imposed on Site 3 included both clearcut and shelterwood harvest cutting methods. A total of 1,732 of the 1,800 planting sites or seed spots (96%) were measured for the third-year assessment, and 1,792 were found during the fifth-year survey. Table 2 presents the results of an analysis of variance. Mean survival across all treatments and time periods on Site 3 was 66.4%. There was little difference, if any, between survival after three growing seasons and after five seasons ($p = 0.12$). Although overall survival with the shelterwood harvest cutting method (69%) was only marginally better than survival after the clearcut method (64%) across both periods ($p = 0.11$), the interaction of harvest cutting method and time was more evident ($p = 0.04$). Examination of this interaction revealed fewer stocked locations in shelterwood units after the fifth season (64%) compared to the third season (74%). There was little evidence of interactions between time and mechanical site preparation or regeneration method.

Although differences in survival existed between the three regeneration methods, the interaction between harvest cutting method and regeneration method and the interaction between site preparation and regeneration method may be more important in understanding the pattern of white spruce seedling survival. Means for harvest cutting method and regeneration method treatment combinations (Figure 4) ranged from 98% survival for planting in either clearcut or shelterwood units to 21% survival for unprotected seedlings in clearcuts. This interaction is due to a strong difference in survival between planted and seeded seedlings ($p < 0.01$). Means for site preparation and regeneration method treatment combinations (Figure 5) ranged from a high of 99% for planted seedlings on patches to a low of 2% for unprotected seeds on control surfaces. This interaction is due in part to differences in survival between scarified surfaces that were planted and those that were seeded ($p < 0.01$) and the differences between scarification method and seeding protection ($p < 0.01$). Blade scarification and protection with funnels gave the best survival (71%) on seed spots. Mechanical site preparation failed to influence survival of planted seedling; survival was over 97% with or without scarification.

Mean annual height growth of seedlings on Site 3 cannot be as clearly interpreted as survival. Although growth differed between harvest cutting methods ($p < 0.01$, Table 2), site preparation methods ($p = 0.04$), regeneration methods ($p < 0.01$), and time ($p < 0.01$), interactions exist between these factors. The three-way interaction of harvest cutting method, regeneration method, and time, depicted in Figure 6, is due to a difference in annual height growth between third-year and fifth-year planted or seeded seedlings in clearcut units compared to shelterwood units ($p < 0.01$). The annual growth rate increased 60% between the third and fifth year on planted seedlings in clearcuts, and the rate increased only 10% for planted seedlings in shelterwood units. Annual height growth rate increased about 35% for seeded seedlings in clearcut units and 26% for seeded seedlings in shelterwood units. The two-way interaction involving only regeneration method with time again is due to differences in annual growth between planted or seeded seedlings and time ($p < 0.01$). Planted seedlings grew about 8 cm the third year and over 10 cm the fifth year. Seedlings on seed spots, however, grew less than 3 cm the third year and 3.5 cm the fifth year.

Differences in annual growth existed between site preparation and regeneration method treatment combinations and are attributable to more rapid growth of planted seedlings compared to seedlings sown on seed spots. Removal of much of the surface organic layer through blading apparently created the better microsites, and planted seedlings on blade scarified

Table 2. Results of analysis of variance in a split-split-split-plot design for measures of survial and annual height growth for white spruce seedlings on Site 3, Willow Island.

Source of variation	df	MS	F	p
Survival				
Harvest Cutting Method (H)	1	0.053	7.74	0.1086
Error *a*	2	0.007		
Site Preparation Contrasts (S)				
Blade vs Patch	1	0.065	0.80	0.4203
Scarify vs Control	1	2.438	29.89	0.0054
H x S	2	0.016	0.20	0.8262
Error *b*	4	0.082		
Regeneration Method Contrasts (R)				
Plant vs Seed	1	8.063	332.83	0.0001
Protect vs Unprotected Seed	1	0.513	21.16	0.0006
H x R Contrasts				
CC-SW vs Plant-Seed	1	0.476	19.65	0.0008
CC-SW vs Protected-Unprotected	1	0.019	0.80	0.3873
S x R Contrasts				
Blade-Patch vs Plant-Seed	1	0.394	16.28	0.0017
Blade-Patch vs Protected-Unprotected	1	0.610	25.18	0.0003
Scarify-Control vs Plant-Seed	1	0.005	0.22	0.6487
Scarify-Control vs Protected-Unprotected	1	0.000	0.00	0.9572
H x S x R	4	0.008	0.33	0.8506
Error *c*	12	0.024		
Time (T)	1	0.035	2.68	0.1188
H x T	1	0.062	4.73	0.0433
S x T	2	0.000	0.00	0.9956
R x T	2	0.007	0.56	0.5786
H x S x T	2	0.009	0.66	0.5293
H x R x T	2	0.002	0.18	0.8376
S x R x T	4	0.006	0.47	0.7585
H x S x R x T	4	0.006	0.45	0.7746
Error *d*	18	0.013		
Annual Height Growth				
Harvest Cutting Method (H)	1	43.894	1304.11	0.0008
Error *a*	2	0.067		
Site Preparation Contrasts (S)				
Blade vs Patch	1	11.830	3.29	0.1438
Scarify vs Control	1	43.711	12.17	0.0252
H x S	2	5.618	1.56	0.3149
Error *b*	4	3.593		
Regeneration Method Contrasts (R)				
Plant vs Seed	1	587.185	349.98	0.0001

.../cont'd

Table 2 (Concluded). **Results of analysis of variance in a split-split-split-plot design for measures of survial and annual height growth for white spruce seedlings on Site 3, Willow Island.**

Source of variation	df	MS	F	p
Protected vs Unprotected Seed	1	6.020	3.59	0.0825
H x R Contrasts				
CC-SW vs Plant-Seed	1	30.787	18.35	0.0011
CC-SW vs Protected-Unprotected	1	5.014	2.99	0.1095
S x R Contrasts				
Blade-Patch vs Plant-Seed	1	6.195	3.69	0.0787
Blade-Patch vs Protected-Unprotected	1	2.053	1.22	0.2903
Scarify-Control vs Plant-Seed	1	12.064	7.19	0.0200
Scarify-Control vs Protected-Unprotected	1	4.042	2.41	0.1466
H x S x R	4	4.919	2.93	0.0664
Error *c*	12	1.678		
Time (T)	1	41.125	39.89	0.0001
H x T	1	12.870	12.48	0.0024
S x T	2	0.486	0.47	0.6314
R x T Contrasts				
Plant-Seed vs Time	1	16.575	16.80	0.0008
Protected-Unprotected vs Time	1	0.018	0.02	0.8938
H x S x T	2	2.677	2.60	0.1021
H x R x T Contrasts				
CC-SW-Plant-Seed vs Time	1	15.770	15.30	0.0010
CC-SW-Protected-Unprotected vs Time	1	0.311	0.30	0.5895
S x R x T	4	1.591	1.54	0.2321
H x S x R x T	4	0.405	0.39	0.8109
Error *d*	18	1.031		

Table 3. Results of analysis of variance in a split-plot design for basal diameter of planted white spruce seedlings five years after planting on Site 3, Willow Island.

Source of variation	df	MS	F	p
Basal Diameter				
Harvest Method (H)	1	13.362	45.00	0.0215
Error *a*	2	0.594		
Site Preparation Contrasts (S)				
Blade vs Patch	1	6.141	45.85	0.0025
Scarify vs Control	1	2.831	21.14	0.0100
H x S Contrasts				
CC-SW vs Blade-Patch	1	0.840	6.28	0.0664
CC-SW vs Scarify-Control	1	1.150	8.59	0.0428
Error *b*	4	0.134		

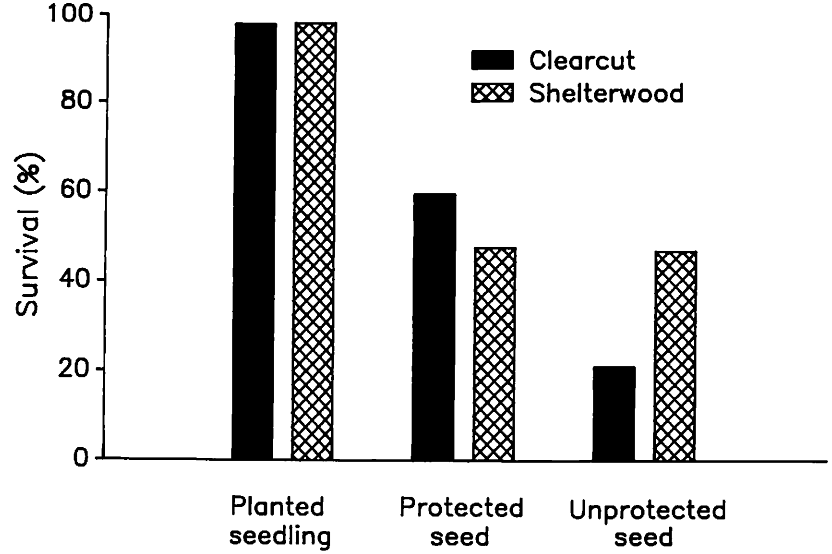

Figure 4. Survival of white spruce regeneration (mean of third and fifth growing seasons) on Site 3, Willow Island, by harvest cutting and regeneration method treatments (standard error of means = 0.202).

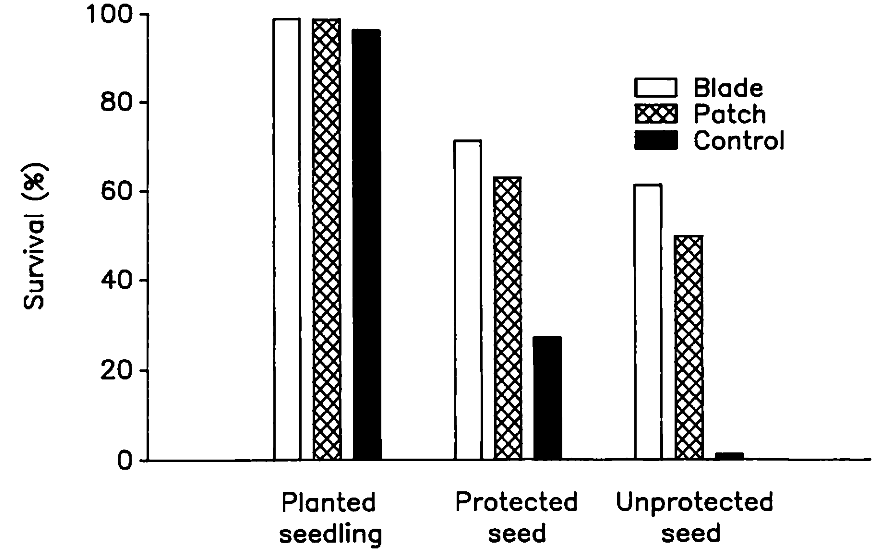

Figure 5. Survival of white spruce regeneration (mean of third and fifth growing seasons) on Site 3, Willow island, by site preparation and regeneration method treatments (standard error of means = 0.302).

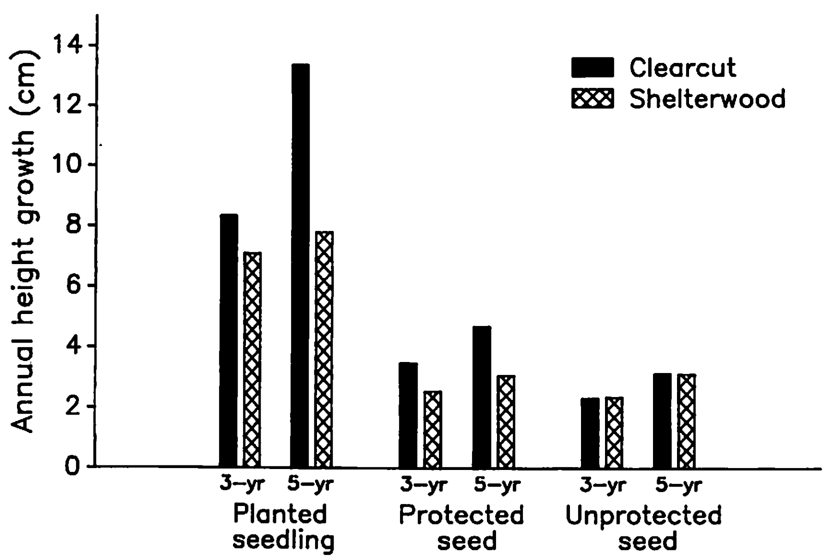

Figure 6. Annual height growth of white spruce regeneration on Site 3, Willow Island, by harvest and regeneration method and time (standard error of means = 0.414).

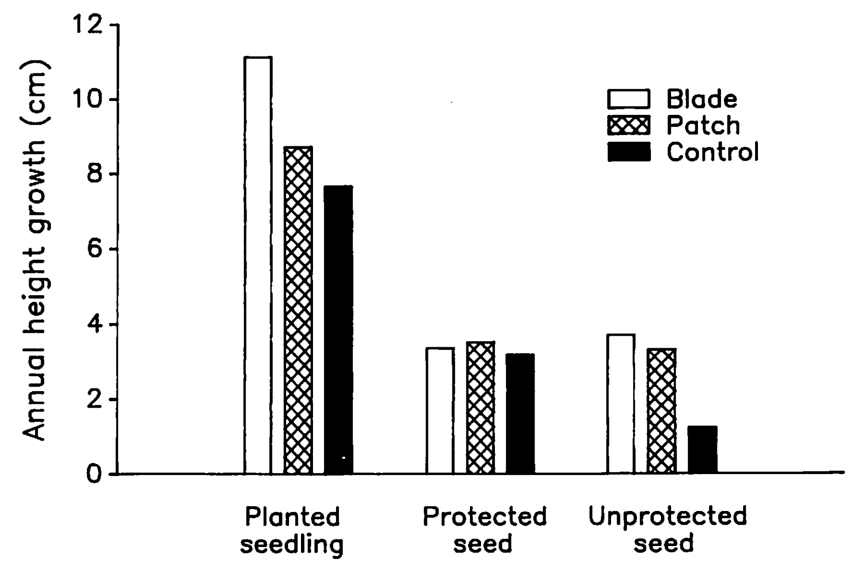

Figure 7. Annual height growth of white spruce regeneration (mean of third and fifth growing seasons) on Site 3, Willow Island, by site preparation and regeneration method (standard error of means = 0.457).

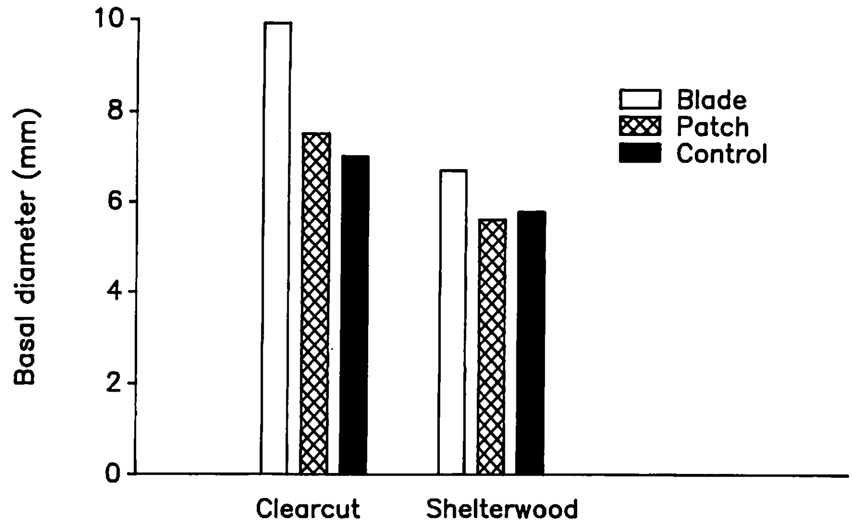

Figure 8. Basal diameter of planted seedlings (after five growing seasons) on Site 3, Willow Island, by harvest method and site preparation treatments (standard error of means = 0.259).

plots averaged more than 11 cm height growth across the third and fifth years (Figure 7). In contrast, growth on patch scarified plots was almost 9 cm, and planted seedlings on unscarified surfaces grew only about 8 cm. Growth on seed spots was much less. Protected seed spots and scarified, unprotected seed spots supported seedlings with mean annual growth for both periods of about 3.5 cm, or about three times greater than that for unprotected seedlings on unscarified microsites. The superior growth of planted seedlings was enhanced with scarification ($p = 0.02$). There was only marginal evidence of a difference in growth between blade and patch scarification for planted compared to seeded seedlings ($p = 0.08$). Growth of planted seedlings on blade-scarified plots was considerably more than that for patch-scarified plots, but the two scarification methods resulted in nearly equivalent growth on seed spots. Interpretations of annual growth of seedlings on unscarified microsites in both protected and unprotected situations should be made with caution as these treatment combinations resulted in poor survival.

Seedling diameter growth may be a more sensitive measure of seedling physiology because of the relation to competing vegetation. Basal diameter of planted seedlings averaged 7.1 mm across all four harvest units. Table 3 presents the results of an analysis of variance. Basal diameter was greater in clearcut units ($p = 0.02$) and in scarified plots ($p = 0.01$). A significant interaction existed between these factors, however, and is portrayed in Figure 8. This interaction is largely due to greater diameter growth on scarified plots in clearcut units than in shelterwood units ($p = 0.04$). Planted seedlings on bladed plots in clearcut units were almost 50% larger in diameter than planted seedlings in bladed plots in shelterwood harvest units. Blading in shelterwood units produced larger seedlings than did patch scarification and was about equal to unscarified plots in clearcut units. Patch scarification applied after either clearcut or shelterwood harvest method failed to produce seedlings with larger diameters than those on unscarified surfaces.

DISCUSSION

Survival of nursery-reared, containerized seedlings was excellent, regardless of harvest cutting method, site preparation treatment, or flood-plain site. In almost all cases, seedlings were found alive and growing five years after outplanting. These results differ slightly from previous high-latitude flood-plain regeneration studies in the Yukon Territory, Canada, in which survival after five years on unscarified surfaces averaged only about 75%, and scarified surfaces averaged about 90% (Gardner 1983).

Results for reforestation by spot seeding on these two interior Alaska flood-plain ecosystems was more variable and was apparently influenced by site characteristics, site preparation methods, silvicultural harvest methods, and microsite protection. Although the general trends of survival for both Sites 1 and 3 by site preparation and regeneration method were similar (Figs. 2 and 5), slightly higher survival was noted on scarified plots on Site 3, presumably because of overall warmer soil temperatures and improved drainage. Microsite protection of seed, either by plastic cones on scarified surfaces or plastic funnels on unscarified surfaces, proved beneficial on Site 1 and on clearcut units on Site 3, but no benefit was noted for shelterwood units (Figure 4). One possible explanation for this inconsistency in survival for different harvest methods was the degree to which the shelterwood overstory ameliorated the surface environment and controlled growth of competing vegetation. This degree of protection was possibly sufficient to negate additional benefit of seed spot shelters. In contrast, clearcutting may have created an environment favoring rapid establishment of competing vegetation, and thus protective cones on scarified sites provided a more uniform environment with reduced competition. These results are similar to those obtained by Dominy and Wood (1986) in northern Ontario and substantiate in part the preliminary findings of Putman and Zasada (1986).

Height growth of containerized seedlings is difficult to compare directly with seedlings on seed spots as planted seedlings start with a developed, fully functional root system and are thus able to begin height growth immediately after planting. This study, however, compared height growth of planted and sown seedlings three and five growing seasons after outplanting. Differences among regeneration methods presumably diminish with time. The growth rate of planted seedlings in clearcut units was accelerating after five growing seasons, however, in comparison to sown seedlings (Figs. 3 and 6). Planted seedlings benefited from site preparation only on Site 3. One possible explanation for the lack of benefit on Site 1 is the persistence of surface organic matter functioning as ground insulation, even after scarification (Wurtz 1988). This suggests the need to consider either more thorough scarification or broadcast burning to reduce the thickness of surface organic layers. Little or no difference in annual height growth was noted for seedlings on seed spots with scarified or unscarified surfaces. Annual growth of unprotected seedlings is similar to that reported for white spruce along the Meister and Liard Rivers in Yukon Territory, Canada (Gardner 1983).

Although diameter growth on planted seedlings was not affected by site preparation on Site 1, seedlings in clearcuts on Site 3 clearly benefited from site preparation by blading. This relation reinforces the concept of tree growth and yield differing in response to environmental conditions, and suggests the need to use ecosystem classification schemes in flood-plain timber management.

CONCLUSIONS

This study provides preliminary results indicating the potential for similar interior Alaska flood-plain forest stands to be successfully regenerated. In general, survival of containerized seedlings was excellent. Germination and establishment from spot seeding was variable, and was improved in clearcut harvest units by using seed shelters for protection. The influence of mechanical site preparation on planted seedlings was variable. A combination of mechanical site preparation and planting of containerized seedlings after clearcut harvesting resulted in high seedling survival, height growth, and basal diameter growth.

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INTERACTIONS BETWEEN VEGETATION COMPETITION, NUTRIENT AVAILABILITY, SOIL SURFACE MODIFICATION AND THE EARLY GROWTH OF PLANTED SPRUCE

by

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ABSTRACT

Data from three experimental plantations in the boreal, sub-boreal spruce, and Great Lakes-St. Lawrence forest regions were used to quantify the effects of site modification treatments on the early growth of three species of planted spruce (*Picea glauca, Picea mariana, Picea glauca X engelmannii*). Soil temperature was strongly controlled by characteristics of the soil surface, and scarification increased soil temperature by 3 to 7 C° on the three sites. Soil moisture availability was reduced by either uncontrolled development of competing vegetation or scarification. Nutrient availability was increased by fertilization and by brush control. These changes in environment caused changes in the ratio of foliar non-structural carbohydrates to nitrogen. Treatments that increased carbon assimilation relative to nitrogen uptake, such as scarification, widened this ratio, while treatments that increased nitrogen availability more than carbon, such as fertilization, reduced this ratio. Changes in the availability of one environmental factor, such as light, affected the efficiency of use of other factors such as nitrogen. Growth responded most to the control of competing vegetation on all three study sites. Use of scarification before planting also reduced the rate of development of competing vegetation and, through improvements in soil temperature, increased growth beyond the response expected from differences in non-crop competition alone. Fertilization was most effective at increasing tree growth when vegetation was controlled or the soil surface scarified. The spruce species studied showed 300 to 1500% increases in biomass across the range of treatments tested, indicating the opportunity for improvements in the success rate of spruce reforestation programs.

Brand, D.G. and Penner, M. 1990. Interactions Between Vegetation Competition, Nutrient Availability, Soil Surface Modification and the Early Growth of Planted Spruce. In: *B.D. Titus, M.B. Lavigne, P.F. Newton, and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271 pp. 25-33.*

INTRODUCTION

Spruce forests comprise over 30% of Canada's standing timber volume and over 40% of the total coniferous volume (Anon. 1988a). Current reforestation programs use spruce for 60% of the area planted. White spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) B.S.P.) are the primary reforestation species, and represented 31% and 26%, respectively, of trees planted annually between 1981 and 1986 (Kuhnke 1989). Despite their widespread use in reforestation, spruces have generally performed poorly in plantations and are looked upon as a silvicultural problem (Vyse 1981, Anon. 1988b, Weetman 1989).

Many of the problems with spruce plantation performance can be attributed to the natural ecology of the species and the successional patterns of the sites on which they are planted. Spruces generally grow on moist to wet sites and, in the case of white spruce, are usually mixed with hardwoods. Moist sites supporting spruces are less susceptible to wildfire, and the various species have generally adapted to regenerating without major disturbance. White spruce and its hybrids with Engelmann spruce (*Picea engelmannii* Parry) form reasonably pure stands in the northern interior of British Columbia, regenerating under the open forest canopy on these sites. In the mixedwood regions of the boreal forest, white spruce is almost always mixed with aspen (*Populus tremuloides* Michx.) or birch (*Betula* spp.) Again, it regenerates and grows slowly in the understorey, reaching a scattered dominant position in stands due to its greater ability to tolerate shade and its longer life span.

Black spruce is better adapted to regenerate after fire owing to semi-serotinous cones and seed retention, but still grows conservatively and can be readily outgrown by competing vegetation following timber harvest (Heinselman 1957, Brumelis and Carleton 1988). Black spruce regenerates also via layering, a phenomenon whereby the lower branches root and produce new stems; this frequently leads to mixed aged stands.

Given that the spruces are more conservative and, aside from fire-origin black spruce, do not occur naturally in even-aged monocultures, it is not surprising that they are more problematic to grow as even-aged plantation crops. As the natural conditions for regeneration and growth of these species differ in many ways from the currently practiced reforestation regime of site preparation, planting, and brush control, it is necessary to examine the ecological requirements of these species and tailor reforestation activities to those requirements. This requires understanding of their response to different levels of environmental factors such as light, moisture, nutrients, and air or soil temperature. In this paper, we will use results from a series of experimental plantations to describe the response of spruces to silvicultural modification of environmental factors.

METHODS

The Experiment

The data used in this paper are derived from an experimental program designed to study the environmental control of plantation development. Three research plantations were located in different Canadian forest regions: the Great Lakes-St. Lawrence (GLSL) and Boreal (B) (Rowe 1972), and the Sub-boreal Spruce (SBS) biogeoclimatic zone (Krajina 1970). Details of the locations of the plantations, experimental design, and treatments used are contained in Brand (1989).

This paper will use a portion of the data set to demonstrate the response of three spruce species to changes in soil temperature, brush competition intensity, and nutrient availability. All experiments are of factorial treatment combination with four replications. In this paper, results from a 2 x 2 x 2 factorial of the above factors are used. The soil surface was modified at two levels, with level 0 representing an undisturbed post-harvest condition with the forest floor intact, and level 1 representing blade scarification to remove logging debris and forest floor material. The vegetation competition factor was also set at two levels, with level 0 being unconstrained growth of competing vegetation, and level 1 the annual control of competing vegetation with the herbicide glyphosate (n-phosphonomethyl glycine). The nutrient availability factor was set at level 0 (no nutrient amendment) and level 1 (annual application of "17-6-10 plus Minors" Osmocote™ slow release fertilizer, formulation 9.1% NH_4^+, 7.9% NO_3^-, 6.0% P_2O_5, 10.0% K_2O, 1.5% Ca, 1.0% Mg, 4.0% S, 0.02% B, 0.05% Cu, 0.40% Fe, 0.10% Mn, 0.001% Mo, 0.05% Zn, with an 8-9 mo. release term, applied at a rate of 30 g per tree in the first growing season and 40 g per tree in the second growing season). The factorial combination used gives eight plots ranging from 0,0,0 to 1,1,1 for the three factors. Spruce species used were white spruce in the Great Lakes-St. Lawrence plantation (GLSL), black spruce in the Boreal plantation (B), and a hybrid white X Engelmann spruce in the Sub-boreal Spruce plantation (SBS).

In each of the 32 experimental plots per site, three spruce seedlings were harvested annually over the first two growing seasons. Measurements taken at the end of each growing season included total biomass, leaf area (Brand 1987), foliar nutrient concentrations, and foliar non-structural carbohydrate concentration, using the technique described in Marshall and Waring (1985). In addition, one (B, SBS) or two (GLSL) replicates of each experiment were instrumented for continuous monitoring of soil moisture tension and soil temperature. A series of PAR sensors (LI-190SB, Licor, Lincoln, Neb.) were used to determine the amount of light reaching the seedlings in the various treatment plots, as described in Brand and Janas (1988).

From the growth and environmental data two derived indices of resource use efficiency were calculated:

Light Use Efficiency (LUE) = growth per unit light intercepted

$$LUE=(1/J) \cdot (dW/dt) \quad [1]$$

where J=total light intercepted during the growing season, and W is total plant biomass calculated from harvests at the end of the first and second growing season as mean values (see Brand 1989 for details).

The nitrogen use efficiency is calculated similarly:

Nitrogen Use Efficiency (NUE) = rate of biomass accumulation per unit of foliar nitrogen

$$NUE=(1/N) \cdot (dW/dt) \quad [2]$$

where N is the weight of nitrogen in the foliage of the seedling.

RESULTS AND DISCUSSION

Silvicultural Treatments and Environmental Changes

The primary goal of a silvicultural treatment is to modify environmental conditions on a site and stimulate growth of the desired species. Most silvicultural treatments modify more than one factor in

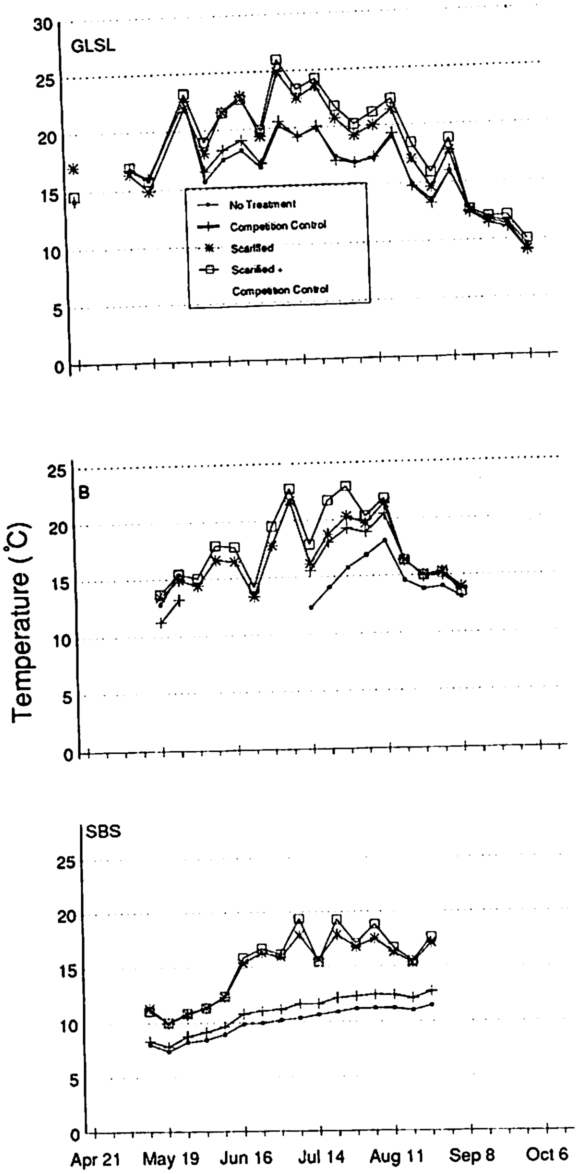

Figure 1. Soil temperature trends at 2 cm mineral soil depth on study sites in three regions of Canada.

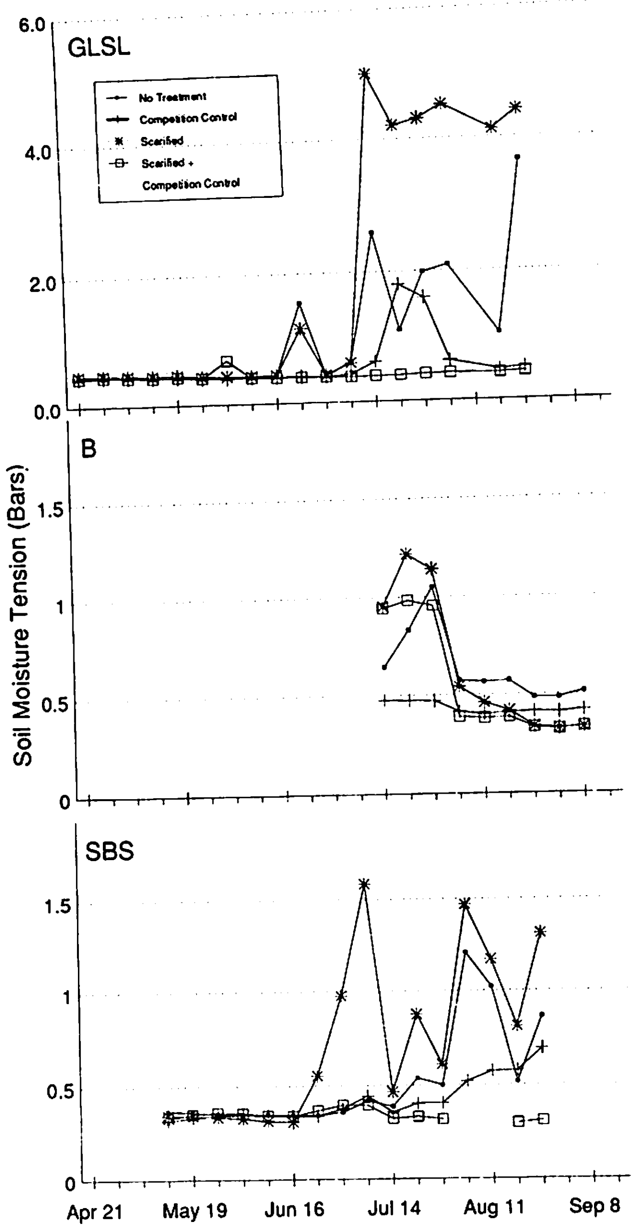

Figure 2. Soil moisture tension trends at 10 cm mineral soil depth on study sites in three regions of Canada.

the environment. Moreover, treatment effects may interact. For example, soil temperature is a function of the radiation received at the soil surface, the conductivity of the surface organic horizons to heat, and the heat capacity of the soil. The radiation received depends on latitude, climate, aspect, and presence of shade from ground or canopy vegetation. The thermal conductivity of the soil depends on the soil aeration, moisture content, and compaction (Rosenberg *et al.* 1983). Soil heat capacity is largely related to moisture content, as water has a high specific heat capacity. Brush control can increase the amount of radiation reaching the soil surface. Figure 1 indicates the magnitude of increase in soil temperature due to scarification with and without brush control. Scarification increases soil temperature the most where forest floor layers removed are deepest. On the SBS site, for example, forest floor layers removed were up to 30 cm deep, and scarification proved more important than brush control in raising soil temperature. Figure 2 indicates that both scarification and brush control also affect soil moisture availability. Scarification, by exposing the soil surface to direct radiation, increases evaporation of moisture. Brush control, on the other hand, decreases transpiration and reduces the depletion of moisture in the soil. Scarification would therefore be

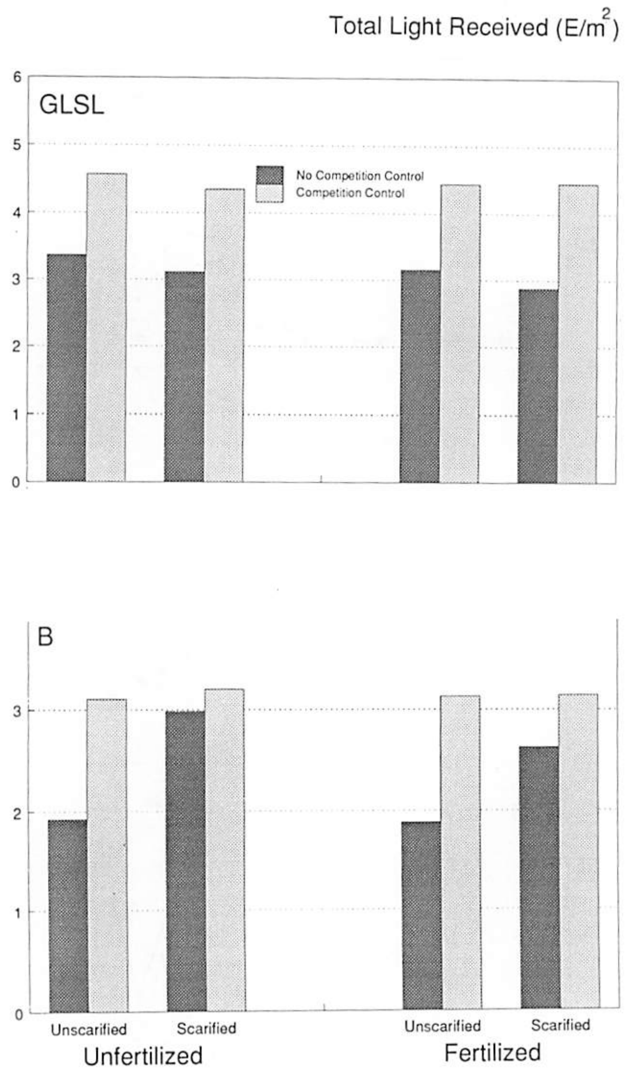

Figure 3. Bar charts representing the impact of treatments on total light received at planted tree level.

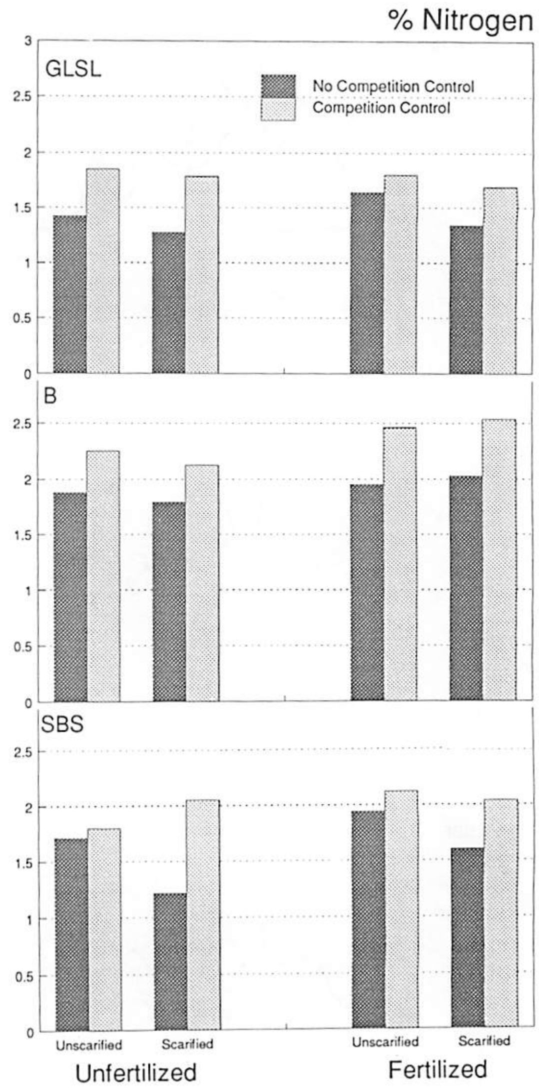

Figure 4. Bar charts representing the impact of treatments on foliar nitrogen concentration of three spruce species in three regions of Canada.

expected to decrease soil heat capacity and brush control would lead to an increase in soil heat capacity.

Overall, scarification improved the soil temperature regime, but reduced the moisture available during the growing season. Conversely, brush control had less impact on soil temperature, but significantly improved moisture availability. The combination of brush control and scarification on these boreal sites appeared to give the optimum microenvironment: warm soil and high levels of moisture.

Brush control and scarification can also interact in the control of light interception by competing vegetation. Scarification, by physically removing brush species and a large part of the stored seed pool, initially diminished the development of brush. However, the effect was transient, as the scarified site provided an excellent seedbed for light-seeded weed species. Scarification can also stimulate the development of vegetation that reproduces by suckering, such as trembling aspen. Figure 3 indicates the relative effect of scarification and brush control on photosynthetically active radiation at the seedling level on the GLSL and B sites. On the GLSL site light was increased by brush control, but slightly diminished by scarification due to stimulation of aspen suckering. On the B site, however, where competing vegetation consisted more of shrubby and herbaceous material, both scarification and brush control increased light levels.

Foliar nutrient concentrations are commonly used as an indicator of soil nitrogen availability. Figure 4

Table 1. The analysis of variance of the effect of a factorial treatment arrangement of soil temperature (T), fertilization (F), and brush control (B) on various measures of seedling condition after two growing seasons for spruce in three forest regions of Canada. In all cases of significant main effects, the response to treatment was positive.

Forest	Treatment	% N	Biomass	Foliar N	NUE	LUE
GLSL	Block	-	-	-	-	-
	T	-	-	*[a]	-	-
	F	-	**[b]	**	**	**
	B	**	**	*	-	-
	TxF	-	-	-	-	-
	TxB	-	-	-	-	-
	FxB	*	-	-	-	-
	TxFxB	-	-	-	-	-
B	Block	-	-	-	-	-
	T	-	*	*	**	-
	F	*	**	**	-	-
	B	**	**	**	**	**
	TxF	-	-	-	-	-
	TxB	-	**	*	-	-
	FxB	-	*	*	-	-
	TxFxB	-	-	-	-	-
SBS	Block	-	-	-	-	N/A
	T	-	**	*	**	N/A
	F	*	-	-	-	N/A
	B	**	-	*	-	N/A
	TxF	-	-	-	-	N/A
	TxB	*	-	-	*	N/A
	FxB	-	-	-	-	N/A
	TxFxB	-	-	-	-	N/A

[a] indicates significant at 5% (treatment > control)

[b] indicates significant at 1% (treatment > control)

indicates that brush control was important for increasing nitrogen availability to the planted trees. The increased N could have resulted from both a reduced uptake by competitors and increased nutrient diffusion rates in the moister soil in plots with competition control. Nitrogen fertilizer increased foliar N concentrations of planted spruce on two of the three sites (B and SBS), but was only effective on the GLSL site if brush was controlled (Table 1). On the SBS site, scarification reduced nitrogen availability unless brush was controlled. These two interactions indicate the importance of brush control to nutrient relations of planted trees.

Response of Spruce to Changes in Environment

Changes in one or more environmental condition can cause changes in plant biochemistry, physiology, and growth. Biochemical and physiological responses to changes in the environment often indicate the type of stress affecting the growth rate. The effects of environmental changes on the relative balance between assimilation of carbon and uptake of nitrogen by planted spruce, and the efficiency of light and nitrogen use, will be discussed in this section.

At a biochemical level, the concentration of non-structural carbohydrate (NSC) fractions such as starch and sugars has often been used as a measure of excess carbon uptake. A plant with high concentrations of NSC would most often be found in an environment where carbon is easily taken up relative to nitrogen. A plant growing in an environment with high nitrogen availability would be expected to have a high nitrogen concentration, and lesser concentrations of sugars and starch.

The ratio of foliar NSC to foliar nitrogen concentrations of spruce from the SBS site after the first and second growing season are given in Figure 5. In the first season scarification increased the NSC concentration significantly ($p = 0.01$) relative to nitrogen, and fertilization tended to increase the nitrogen concentration relative to NSC ($p = 0.07$).

In the second season, the scarification treatment caused less increase in NSC, but similar trends in response to treatments were evident. This rebalancing of internal biochemical processes may indicate that plants have an ability to buffer imbalances in environmental conditions over time through changes in morphology or biomass allocation.

The ratio of foliar NSC to N concentrations appears to be an useful measure of the change in environmental conditions between treatments. Sites without brush control or scarification had complete canopies of herbaceous vegetation and very low levels of light beneath the canopy. Under such circumstances growth of planted seedlings was presumably limited by carbon assimilation. Control of competing vegetation in these plots increases the NSC to N ratio, perhaps as a result of increased light available for photosynthesis. Scarification treatments also increased the ratio of NSC to N, again due to increases in light, but possibly also due to the positive effects on photosynthesis of soil temperature changes (i.e. changes in hormone production or water relations) and the negative effects on nitrogen availability of organic matter displacement. Fertilization decreased the ratio of NSC to N by increasing nitrogen availability.

A second measure of a plant's responses to changes in environment are indices of resource use efficiency. In this experiment data were collected that allowed calculation of light use efficiency (LUE) and nitrogen use efficiency (NUE) indices to estimate the amount of biomass produced per unit of light intercepted and per unit of foliar nitrogen, respectively.

Nitrogen use efficiency increases when resources such as light, moisture, or temperature become more available. NUE would also be expected to increase if nitrogen was critically limiting to the planted trees and the additional nitrogen added by fertilization was more physiologically active than that present without fertilization. Nitrogen use efficiency was measured for the three experimental plantations and the results are shown in Figure 6. Scarification treatments increased NUE on the B and SBS sites (Table 1). This increase can be attributed to the greater amount of available light and warmer soil temperatures; in turn, this results in an increased photosynthetic efficiency per unit of nitrogen. Brush control on the B site raised both foliar N concentration and NUE ($p = 0.01$), indicating both increased availability of nitrogen and increased light and moisture to improve NUE. On the GLSL site, fertilization alone increased NUE of white spruce, showing a potential critical limitation for nitrogen on that site.

Light use efficiency was studied on the B and GLSL sites only (Figure 7). Fertilization dramatically increased LUE on the GLSL site, but had little effect on the B site (Table 1). Conversely, brush control significantly increased LUE on the B site, but had little effect on the GLSL site. On both sites, scarification had a small positive effect on LUE. Part of the explanation for differences between sites or species may lie in the high degree of tolerance of the GLSL white spruce to growing under a canopy of aspen suckers. This is the natural habitat of the species, and it may have developed physiological mechanisms for maintaining LUE under lower light conditions. Black spruce, however, is more responsive to brush control, possibly having higher light and moisture requirements.

Growth and Productivity of Spruce in Response to Environmental Change

The total biomass of planted trees on the three sites is the net result of various physiological changes caused by modification in environmental conditions. Large increases in total biomass are evident across the eight treatments in Figure 8. However, the magnitude of response varied among species and sites, with brush control and fertilization being important on the GLSL and B sites, and scarification significant on the B and SBS sites (Table 1).

Clearly, there are differences among sites in the importance of specific environmental constraints to the growth of the spruce species tested. On the GLSL site, with aspen coppice as the major form of competition, white spruce did not seem as strongly limited by carbon assimilation as the species on the other two sites. Light intensity under the aspen canopy was 30-40% of full light at the GLSL site through much of the summer, versus 20-30% on the B and SBS sites (Brand 1989). The GLSL site also showed significant ($p = 0.01$) increases in growth resulting from fertilization, but growth response was greatest on plots with either scarification or brush control.

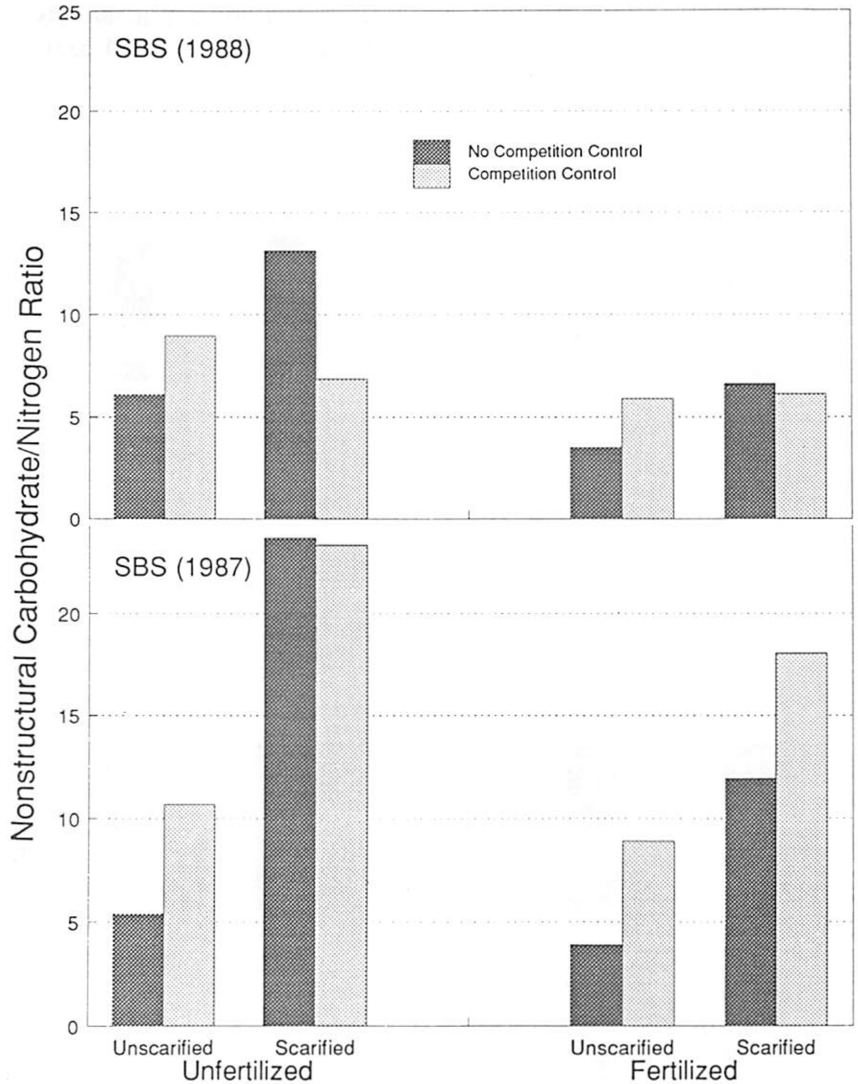

Figure 5. Ratio of foliar non-structural carbohydrate concentration to foliar nitrogen concentration after one and two growing seasons of hybrid spruce in experimental plots in the Sub-boreal Spruce study site.

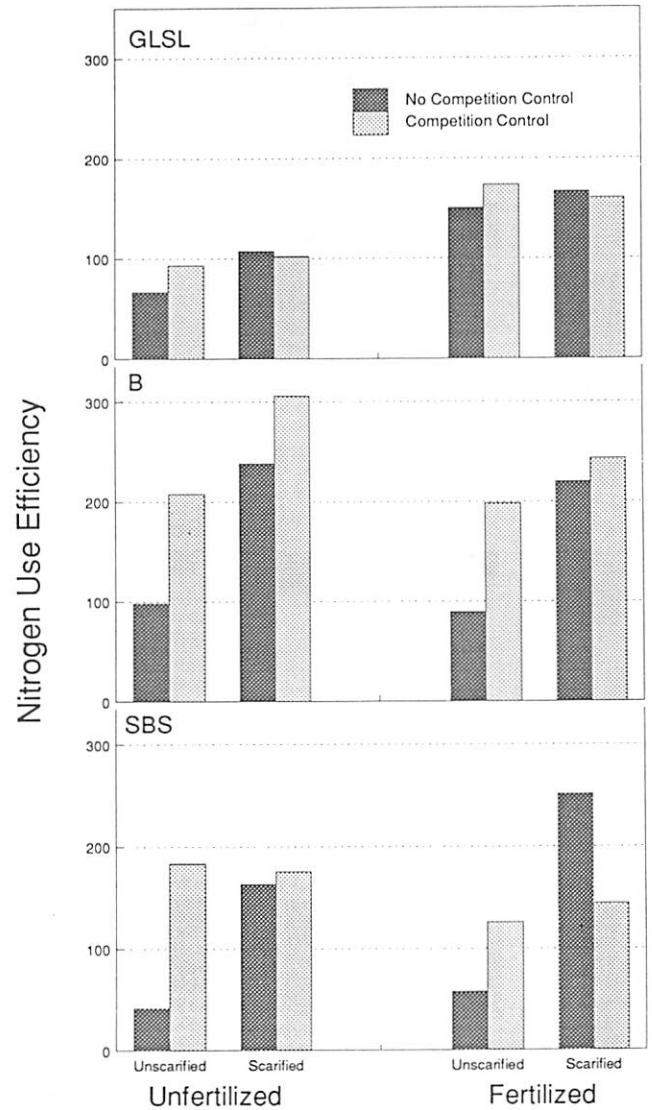

Figure 6. Nitrogen use efficiency (growth per unit foliar nitrogen) of three spruce species in response to experimental treatments.

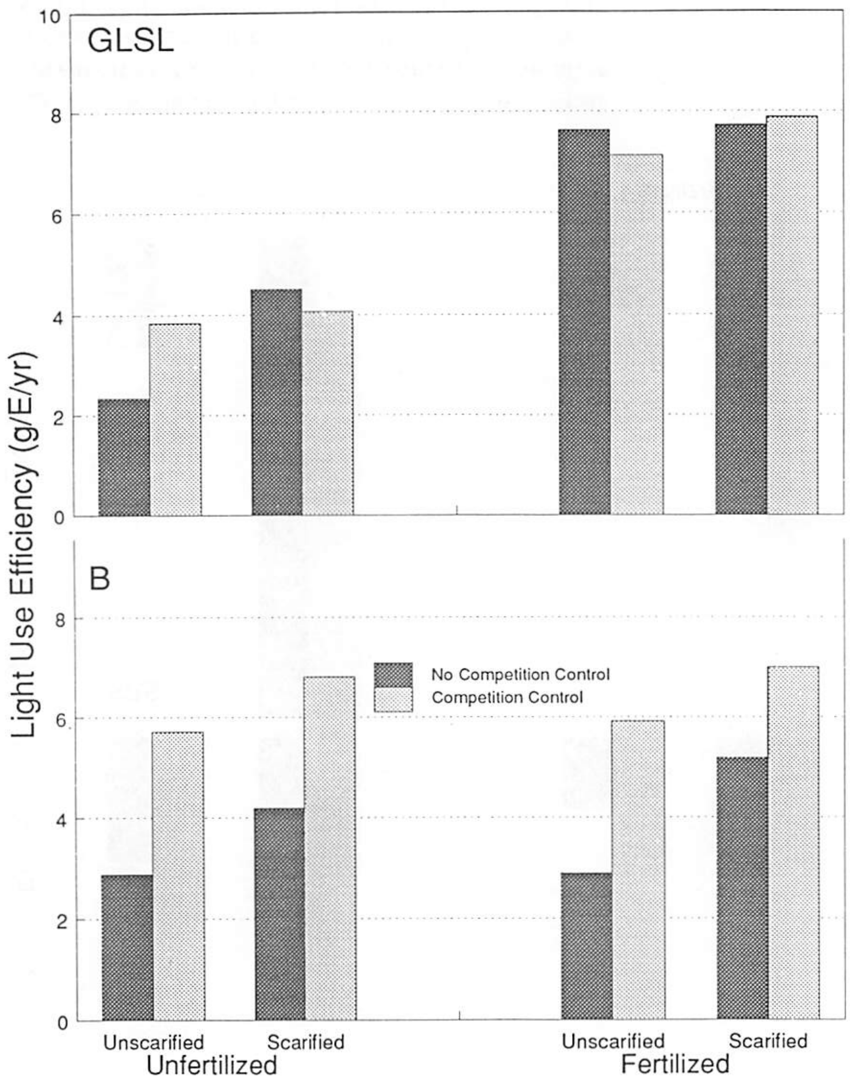

Figure 7. Light use efficiency (growth per unit light intercepted) of two spruce species in response to experimental treatments.

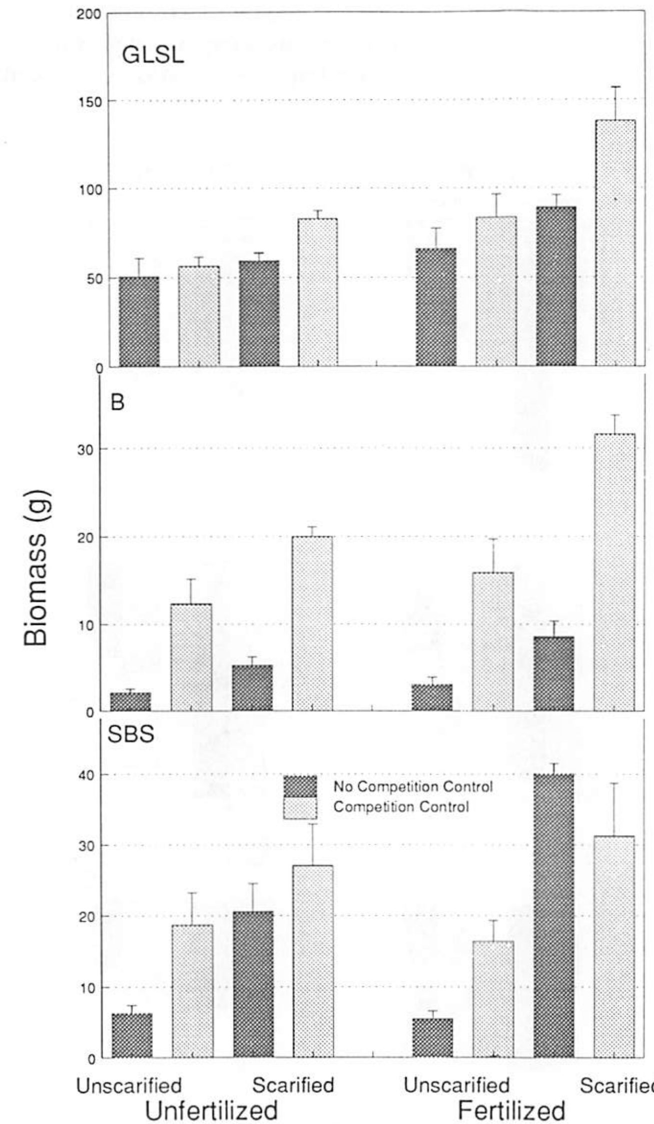

Figure 8. Total biomass of three spruce species after two growing seasons in plots with various experimental treatments.

The B site had heavy competition from low shrubby vegetation that had more effective light interception characteristics than aspen, and this site responded most to brush control. Thinner organic horizons and a more limited distribution of logging debris on this site also led to a diminished soil temperature response to scarification than on the SBS site. The B site also had a silty loam soil and responded strongly ($p = 0.01$) to fertilization. The SBS site had the heaviest brush competition based on light interception (Brand 1989), and also had the deepest organic horizons. Soil temperature modification was the leading factor increasing growth of spruce on this site, but brush control was also important on unscarified sites. Fertilization seemed to be most important in plots which had been scarified, indicating that much of the site's nutrient capital was stored in the organic matter displaced by scarification.

CONCLUSIONS

It is apparent that, despite their stress tolerance, the spruces studied in this experiment respond markedly to positive changes in light, moisture, nutrients, and soil temperature. Growth responses from no treatment to best treatment ranged from 300% for white spruce on the GLSL site to 800% for interior spruce on the SBS site, to 1500% for black spruce on the B site. The spruces showed positive response to all three experimental factors. The magnitude and hierarchy of responses appear to vary from site to site, however, due to differences in the vegetation community competing with the planted trees, the thickness of organic horizons removed by scarification, and nutritional limitations. Because the species studied were on different sites, it is impossible to consider to what extent the differences in response were a function of species differences due to adaptation to stress or site differences in terms of vegetation composition, soil type, and logging history. Nevertheless, all three spruces are shown to be responsive to environmental changes and able to succeed in the early stages of plantation development with appropriate silvicultural treatment. While not as productive as local pine species on these sites (Brand 1989), the three spruce species proved less "resource-conservative" than originally thought and indicate a potential for plantation management. Whether other factors in spruce ecology such as susceptibility to pathogens, soil acidification, or poor stand structure development are exacerbated in spruce monocultures requires consideration of research results other than those presented here.

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POST-CUT BURNING AND BLACK SPRUCE REGENERATION

by

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ABSTRACT

Experimental post-cut burning for black spruce *(Picea mariana* (Mill.) B.S.P.) regeneration was tried in conjunction with natural seeding, artificial seeding, and direct planting. So far, the best results approaching a full spruce stocking were produced by post-cut burning in aid of natural seeding on moist to wet lowland peat sites. Due to reasonable operational costs, ecological compatibility, and consistently acceptable regeneration involved, this particular method is now being extensively used on some areas in the post-cut management of lowland spruce. None of the methods tested on fresh to somewhat moist upland sites produced similarly acceptable regeneration, mainly because both burning and consequent seedbed improvements were inadequate on such sites. This paper provides a brief overview of the current uses of post-cut burning, and then deals specifically with successful black spruce regeneration following lowland burns of two different prescriptions.

INTRODUCTION

Black spruce (*Picea mariana* (Mill.) B.S.P.) usually fails to regenerate in adequate numbers after cutting, mainly because most of the loose, surface forest-floor materials remain undisturbed. The surface materials, consisting often of feather moss (*Pleurozium schreberi* (Brid.) Mitt., occasionally with some *Hylocomium splendens* (Hedw.) B.S.G. and *Ptilium crista-castrensis* (Hedw.) De Not.) and/or various plant litter, are subject to rapid losses of moisture when exposed to increased solar radiation and ventilation (Chrosciewicz 1978, 1980). This alone makes them extremely poor media for seed germination and seedling survival, and the situation is further aggravated by substantial post-cut additions of fresh litter and of logging slash (Heinselman 1957, 1959; Jarvis and Cayford 1961, 1967; Chrosciewicz 1976, 1978, 1980). On such seedbeds, not many of the black spruce seeds that are normally shed by cones in slash on the ground, or are dispersed from cones on residual trees nearby, would have a chance to start a new stand unless mechanical scarification, or controlled burning of the right prescriptions, are carried out to rectify the situation.

These unfavorable post-cut conditions occur both on uplands with mineral soil substrata and on lowlands with organic, or peat, soil substrata. Only where the forest floor on some lowlands predominantly consists of the seemingly always moist *Sphagnum*, the seedbeds may be sufficiently receptive to black spruce regeneration without corrective treatments (Jarvis and Cayford 1961, 1967; Mueller-Dombois 1964; Johnson 1971, 1977; Chrosciewicz 1976; Haavisto 1979; Aksamit and Irving 1983), providing that some of the faster-growing varieties of that moss do not smother the freshly germinated seedlings (LeBarron 1948; Roe 1949; Heinselman 1957, 1959; Losee 1961). In any case, both the living *Sphagnum* and the peat materials derived from *Sphagnum* are nutritionally deficient, and because of this their value as seedbeds may be much less than normally expected (Wilde 1958; Jeglum 1981; Munson and Timmer 1989). Indications are, however, that even this condition, as well as the overall productivity of lowland sites, can be substantially improved by post-cut burning (Mueller-Dombois 1964; Chrosciewicz 1976; Armson 1977), preferably in aid of natural regeneration.

Black spruce is known to regenerate very well on suitable fire-produced seedbeds, particularly where natural seed source is available either in the form of seed trees or as uncut portions of the stand next to the burn (Heinselman 1957, 1959; Dickson and Nickerson 1958; Horton and Lees 1961; Johnson 1971; Chrosciewicz 1976). Controlled fires for silvicultural purposes usually burn the slash, aerial parts of vegetation, surface moss and litter, and depending on site and weather, varying quantities of the underlying

Chrosciewicz, Z. 1990. Post-cut Burning and Black Spruce Regeneration. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 35-44.*

mor or peat. The organic materials remaining after such fires normally include charred stumps and other large pieces of wood, partially burned mor or peat, and unburned plant roots in the residual mor or peat. These conditions are usually adequate for planting the spruce, and if the fires burn deep enough into the mor or peat, they can be favorable also for the reproduction of spruce by either direct or natural seedling. In the latter case, the heat of fires usually helps in seed dissemination by partially opening the otherwise semi-serotinous cones on standing parent trees (Chrosciewicz 1976, 1978, 1980).

As an alternative to mechanical scarification, post-cut burning of clear-cut strips and patches of various sizes was tested on both uplands and lowlands in anticipation of natural seeding from adjoining black spruce stands (Heinselman 1959; Johnson 1971; Haavisto 1979; Aksamit and Irving 1984; Jeglum 1987), and followed either by artificial broadcast and spot seeding (Richardson 1969, 1972; Johnson 1971; Aksamit and Irving 1984) or by direct planting just on uplands (Zasada *et al.* 1987; Arnup 1989). Post-cut burning under black spruce seed trees was also tested on both uplands (Robinson 1970) and lowlands (Chrosciewicz 1976).

The outcome of these tests were highly variable and often inconclusive in terms of black spruce regeneration, particularly on upland sites with respect to natural and artificial seeding. The burning prescriptions for the uplands were simply ineffective in the improvement of seedbeds as the relatively high moisture contents of the forest-floor materials at the time prevented the fires from penetrating sufficiently deep into the mor humus. The black spruce stocking by 4 m^2 quadrats that resulted from these upland burning and seeding tests was totally inadequate at 11-39% (Richardson 1969, 1972; Robinson 1970; Jeglum 1987). The development and growth of planted black spruce on some other burned uplands, however, were quite satisfactory (Zasada *et al.* 1987; Arnup 1989), with the young tree survival being about 68-92% (Zasada *et al.* 1987). Further research is needed to develop suitable burning prescriptions specifically for seedbed improvements on the upland black spruce sites.

The results pertaining to post-burn natural and artificial seeding on lowland sites were considerably better than those on uplands. Summer burning on clear-cut 70-101 m wide strips in anticipation of natural seeding from uncut strips, as well as that on 13-26 ha clear-cut patches followed by broadcast seeding of black spruce with about 247 000 seeds/ha, produced 91% and 80% black spruce stocking 2-6 years later (Johnson 1971). Burning on 40 m wide clear-cut strips in aid of natural seeding also from adjoining uncut strips produced 68% black spruce stocking 4 years later in one area, and 86% black spruce stocking 14 years later in another area (Haavisto 1979). This successful spruce regeneration on lowland sites was attributed to the fact that the burns exposed moist *Sphagnum* from under the slash in some places and at the same time produced other favorable seedbeds by consuming dry feather moss in other places. Burning piled slash in winter was found less practical and more costly than burning scattered slash in summer (Johnson 1971).

In 1967, two burning operations were carried out on one of the lowland cutover sites at latitude 49°34'N and longitude 95°56'W, some 97 km east-southeast of Winnipeg, Manitoba. The objective was to determine whether the predominantly poor feather moss, litter, and slash seedbeds could be sufficiently improved to induce prompt and adequate black spruce regeneration from residual seed sources on the site. The initial results have been published elsewhere (Chrosciewicz 1976), and this report describes the overall outcome of the treatments after 22 growing seasons.

THE SITE

Generally, the site matched Mueller-Dombois' (1964) habitat description as an "oligotrophic (nutritionally poor), very moist, feather moss-*Sphagnum* type on peaty gleysol". It was situated on a gentle transition gradient between a well drained upland and a poorly drained muskeg. The ground was characterized by 25-46 cm high peaty hummocks and intermittent depressions. The upper peat, extending to a depth of about 25 cm below depressions, was mostly a fibrous moss debris that had changed little since accumulation. Immediately below this material was about 41 cm of well decomposed mucky peat, which in turn overlaid a fine-textured mineral gleysol. The average depth to water table between hummocks was about 30 cm, and the soil moisture regime according to Hills' (1955) classification was 6 (Chrosciewicz 1976), or somewhat wet.

Before cutting, the site supported a 100-year-old black spruce forest, averaging 5387 trees/ha. More than a third of the trees were merchantable, with pulpwood yields of nearly 233 m^3/ha. A very few, widely scattered tamarack (*Larix laricina* (Du Roi) K. Koch) grew along with the spruce. The peaty hummocks and depressions were covered by a continuous carpet of moss. About 88% of this carpet was formed by feather moss and the remaining 12% was *Sphagnum*. The

Sphagnum moss occurred in variable-sized colonies that were randomly interspersed throughout the feather moss cover. The overall ground cover by other plants consisted of 10% for various low creeping shrubs and some herbs, 10% for grasses and sedges, and 20% for medium shrubs. Layering was uncommon on this site, and black spruce regeneration originally consisted of 84 seedlings/ha, growing mostly on *Sphagnum* (Chrosciewicz 1976).

A portion of the forest was harvested in the winter of 1964-1965, and the resulting cutover became treatment sections A and B, 2.4 ha and 3.6 ha in area, respectively. The cutting operations removed merchantable timber, and all that remained on these two sections by the time of burning in the spring of 1967 were bare (without needles) logging slash and some 1977 trees/ha that were still standing. These trees were either under-sized or defective ones that loggers could not use. The slash was 25-64 cm deep and provided an intermittent ground cover totalling 52%. Underneath the slash, fallen needles formed a litter mat up to 8 cm thick. Another 2.0 ha portion of the forest was harvested in the winter of 1967-1968, and this cutover, called section C, was kept intact as a control for sections A and B. The conditions resulting from the cutting operations were nearly identical on all three sections (Chrosciewicz 1976).

METHODS

Burning

The individual treatment sections were enclosed by a plowed fire guard 61 cm wide. Section A was burned between 11:20 and 16:40 CST (Central Standard Time) on May 17, 1967, and section B was burned between 10:00 and 15:00 CST on May 29, 1967. Each burn began as a U-shaped backfire and was completed by a series of successive strip head fires. The average flame height for both burns was about 1 m, with occasional trees candling up to 12 m. After normal mop-up operations, the burned sections were patrolled for several days (Chrosciewicz 1976).

Daily weather data for 12:00 CST were obtained from the nearest provincial stations at Hadashville (rainfall) and East Braintree (cloud cover, air temperature, relative humidity, wind speed at 10 m height, and wind direction), 11 and 24 km away from the burning site, respectively. By using these data, various moisture codes (FFMC, fine fuel moisture code; DMC, duff moisture code; DC, drought code) and fire behavior indices (BUI, buildup index; ISI, initial spread index; FWI, fire weather index) for each of the two burns were determined (Chrosciewicz 1976) by standard methods (Canadian Forestry Service 1984). The noon weather, moisture codes, and fire indices on days of burning are shown in Table 1.

The burns were conducted under different degrees of desiccation in the upper peat materials so that, in terms of peat consumption, "light" and "moderate" degrees of burn were obtained. Winds at noon on both days were identical in speed, but May 29 was somewhat warmer and slightly drier than May 17. On both days, fine components of slash, surface litter, feather moss, winter-cured grass, sedge, and herbs were sufficiently dry (FFMC 91) to sustain comparable rates of fire spread (ISI 10). Based on 20 random measurements preceding each burn, the peat under feather moss in more exposed situations was dry to a depth of about 3 cm on May 17 (DMC 22, DC 55) and to a depth of about 8 cm on May 29 (DMC 46, DC 104). This meant that considerably more dry fuel was available to the spreading fire on May 29 (BUI 45) than on May 17 (BUI 21). The total production of thermal energy per unit length of fire front was, therefore, correspondingly greater on May 29 (FWI 21) than on May 17 (FWI 15). Further down the peat profile, the moisture content markedly increased until the materials became completely saturated near the water table. The latter condition provided an effective barrier to excessively deep burning (Chrosciewicz 1976).

The depths of each burn were measured at 40 observation points: 20 on feather moss hummocks and 20 in feather moss depressions. Special steel pins were used to mark the surface of moss or litter at the different points before burning. The pins were placed at random along centre lines traversing each burn. Materials with *Sphagnum* cover were excluded from these measurements because, with their usually high moisture content, they were extremely poor indicators of the overall burning conditions (Chrosciewicz 1976).

Seedbed and Regeneration Surveys

The conditions after burning on sections A and B, and after cutting on section C, were surveyed by means of parallel transects, 20 m apart. The individual transects consisted of single rows of 4 m^2 quadrats, and there were four such transects traversing the middle portion of each section. This resulted in a sampling intensity which for the total section areas ranged between 2.2% and 3.4%. The transects were extended into the residual black spruce forest to provide means for assessing the conditions before cutting (Chrosciewicz 1976).

The individual quadrats within the transects were used, when applicable, for mapping to scale various categories of seedbeds, for making total counts of trees by species and classes of seedbeds, for measuring diameters and/or heights of dominant trees by species on each stocked quadrat, for measuring height growth of dominant black spruce, and for estimating total plant cover by species and groups of species. Seedbeds were surveyed shortly after the treatments, and Table 2 shows their distribution. Otherwise, there were two major surveys along the same transects: the first one was carried out to assess black spruce regeneration after 5 growing seasons, and the second one was carried out to assess the regeneration of all tree species present after 22 growing seasons. The tree species in the second survey included black spruce, white spruce (*Picea glauca* (Moench) Voss), balsam fir (*Abies balsamea* (L.) Mill.), tamarack, white cedar (Thuja occidentalis L.), jack pine (*Pinus banksiana* Lamb.), trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and paper birch (*Betula papyrifera* Marsh.). The results of the first regeneration survey have already been published (Chrosciewicz 1976), and the results of the second survey are presented in this report: regeneration stocking in Table 3, regeneration density in Table 4, regeneration height in Table 5, and black spruce height growth in Table 6. One-way analyses of variance and t-tests were used in making comparisons of mean height growth rates between the treatment sections A, B, and C by tree diameter classes.

RESULTS AND DISCUSSION

Fuel Consumption and Seedbeds

The fires destroyed slash, surface litter, and aerial parts of vegetation, including feather moss and some *Sphagnum*. Varying quantities of peat underneath the feather moss and litter were also destroyed, but stumps and discarded logs remained in their partially burned state. The fires killed residual trees by completely burning the smaller ones and by scorching all others. However, clusters of cones in the upper portions of the scorched crowns were untouched by the flames, resulting in good dispersal of seeds after burning (Chrosciewicz 1976).

The depths of burn into the peat varied from superficial in some of the moister situations to greater than average next to some of the drier stumps and logs. As a result of different degrees of desiccation in the upper peat materials, the depths of burn averaged 8 cm for hummocks and 5 cm for depressions on section A, and 18 cm for hummocks and 10 cm for depressions on section B (Table 2). Burning exposed about 95% of the peat on both sections; the remaining 5% consisted of unburned materials such as 1% *Sphagnum* moss, 3% feather moss, and 1% slash-plus-litter on section A and 3% *Sphagnum* moss, 1% feather moss, and 1% slash-plus-litter on section B. Although the seedbed conditions were improved on both sections, the degree of improvement was directly related to the depth of burn into the peat, greater on section B and lesser on section A. Section B had also, by chance, somewhat greater residual *Sphagnum* cover (Chrosciewicz 1976). In contrast, inferior post-cut seedbeds were much in evidence on section C. About 93% of the section area was characterized by unfavorable conditions, 52% as a result of slash-plus-litter cover, and 41% as a result of feather moss cover. Favorable seedbeds were scarce on this section since only 6% of the area was covered by *Sphagnum* and another 1% had its peat exposed by logging (Table 2) (Chrosciewicz 1976).

Black Spruce Regeneration

Toward the end of the fifth growing season, black spruce stocking by 4 m^2 quadrats was 94% on the moderately burned section B, 70% on the lightly burned section A, and 35% on the unburned control C. The numbers of trees associated with this stocking were 39 856, 7598, and 4690/ha, respectively (Chrosciewicz 1976). Later on, the black spruce stocking increased and its density decreased, until after 22 growing seasons, they were 98% with 31 536 trees/ha on section B, 80% with 6203 trees/ha on section A, and 52% with 4162 trees/ha on control C (Tables 3 and 4). With mean heights of 3.49 m on section B, 3.10 m on section A, and 2.23 m on control C (Table 5), the dominant black spruce trees indicated the same preferential differentiation between the three sections as did both the black spruce stocking (Table 3) and the black spruce density (Table 4). This, however, could not be verified in terms of mean height growth of dominant black spruce trees. When grouped into strict diameter classes, the within-group differences in height growth between the treatment sections A, B, and C, were all consistently not significant (NS) at $p<0.05$ in each of the last three growing seasons, the 20th, the 21st, and the 22nd. Otherwise, the annual rates of mean height growth were quite impressive, particularly for the black spruce trees with large mean diameters (Table 6). Regardless of the rather high stocking and density values, there were numerous black spruce trees that had their tops above all competing vegetation and, therefore, freely growing in full sunlight at excellent annual rates. In fact, height growth rates above 0.5 m per year were quite common, with 0.65 m as the maximum recorded.

Table 1. Weather, moisture codes, and fire indices on days of burning.

Items	Treatment sections: Lightly burned A	Moderately burned B
Date of burn	May 17, 1967	May 29, 1967
Noon weather		
Cloud cover (%)	90	70
Air temperature (°C)	22	24
Relative humidity (%)	32	31
Wind speed (km/h)	14	14
Wind direction	W	SE
Codes and indices[a]		
FFMC (fine fuel moisture code)	91	91
DMC (duff moisture code)	22	46
DC (drought code)	55	104
BUI (buildup index)[b]	21	45
ISI (initial spread index)	10	10
FWI (fire weather index)	15	21

[a] For definitions of the terms used see Canadian Forestry Service (1984) and Van Wagner (1987).

[b] Formerly known as ADMC (adjusted duff moisture code).

Table 2. Post-treatment inventory of seedbeds.

Items	Treatment sections: Lightly burned A	Moderately burned B	Unburned control C
Depths of burn measured (n)	40	40	-
Mean depths of burn			
Hummocks (cm)	8	18	-
Depressions (cm)	5	10	-
4 m^2 quadrats sampled[a] (n)	133	293	167
Area burned (%)	95	95	-
Area by seedbeds			
Exposed peat[b] (%)	95	95	1
Sphagnum moss (%)	1	3	6
Feather moss (%)	3	1	41
Slash-plus-litter (%)	1	1	52

[a] Used for mapping to scale various classes of seedbeds.

[b] Includes fractions of decayed wood.

Table 3. Regeneration stocking after 22 growing seasons.

Tree species	4 m² quadrats stocked (%)[a]		
	Lightly burned A	Moderately burned B	Unburned control C
Black spruce	80	98	52
White spruce	1	28	5
Balsam fir	13	49	25
Tamarack	10	5	7
White cedar	1	2	0
Jack pine	2	0	0
Trembling aspen	27	66	17
Balsam poplar	2	34	1
Paper birch	1	4	4
Any tree species	87	99	68

[a] 4 m² quadrats sampled: 133 in A, 293 in B, and 167 in C. Presence of trees was noted by species on all quadrats.

Table 4. Regeneration density after 22 growing seasons.

Tree species	Living trees (stems/ha)[a]		
	Lightly burned A	Moderately burned B	Unburned control C
Black spruce	6 203	31 536	4 162
White spruce	19	1 015	120
Balsam fir	357	2 312	838
Tamarack	320	154	195
White cedar	19	43	0
Jack pine	38	0	0
Trembling aspen	1 278	4 352	898
Balsam poplar	38	1 502	15
Paper birch	19	128	150
Any tree species	8 291	41 042	6 378

[a] 4 m² quadrats sampled: 133 in A, 293 in B, and 167 in C. Trees were counted by species on all quadrats.

Table 5. Regeneration height after 22 growing seasons.

	Mean heights of dominant trees (m)[a]		
Tree species	Lightly burned A	Moderately burned B	Unburned control C
Black spruce	3.10 (107)	3.49 (287)	2.23 (87)
White spruce	3.91 (1)	2.26 (81)	2.10 (8)
Balsam fir	0.81 (17)	0.44 (145)	1.29 (41)
Tamarack	6.10 (13)	7.72 (16)	1.28 (12)
White cedar	0.07 (1)	0.14 (5)	-
Jack pine	3.80 (2)	-	-
Trembling aspen	6.64 (36)	4.99 (193)	5.15 (29)
Balsam poplar	7.10 (2)	4.62 (100)	1.50 (1)
Paper birch	5.70 (1)	4.82 (11)	5.69 (7)

[a] Heights of tallest trees were measured, one per species per stocked 4 m^2 quadrat. Values in parentheses show the actual numbers of trees so measured.

Regeneration of Companion Tree Species

The rather tall jack pine and the tiny white cedar occurred sporadically after burning on sections A and B. Tamarack trees, with their large sizes being particularly impressive following the burns, were widely scattered throughout the new stands on sections A and B, and on the control C. Balsam fir, which was somewhat shorter on the burned sections A and B than on the control C, occurred as a partial understory on all three sections. The presence of white spruce was numerically much greater on section B than on the other two sections, but the species heights were comparable on the B and C sections (Tables 3-5).

Among the hardwoods, trembling aspen was the numerous companion of black spruce, and was more so than balsam poplar and white birch put together (Tables 3 and 4). All three species were, on the average, much taller than the spruce (Table 5), but this did not appear to have any adverse effect on the growth of spruce (Table 6). In fact, the three hardwood species were numerically much more prominent on section B than elsewhere in the project (Tables 3 and 4), but no significant differences were detected in the growth of black spruce between sections A, B, and C (Table 6).

A similar conclusion can be reached when considering the competition from shrubs. Clumps of willow (mostly *Salix bebbiana* Sarg.), about 4 m tall, were nearly always constant companions of the regenerating black spruce, much more so on section B than on section A, and relatively little on control C. Moreover green alder (*Alnus crispa* (Ait.) Pursh), 4 m tall, and sometimes even speckled alder (*Alnus rugosa* (Du Roi) Spreng. var. *americana* (Regel) Fern.), 5 m tall, occurred sporadically and so they both somewhat increased the already existing competition. Here again, no significant differences could be detected in the growth of black spruce between the sections A, B, and C (Table 6).

In terms of the combined regeneration of all tree species present after 22 growing seasons, the overall stocking and corresponding stand densities were as follows: 99% with 41 042 trees/ha on section B, 87% with 8291 trees/ha on section A, and 68% with 6378 trees/ha on control C. It is premature as yet to speculate which of the treatment sections, A or B, would eventually yield a greater return in usable pulpwood weight, or volume, and by how much in this respect would the control C then lag behind each of the two other sections. Considerably more time will be required before sufficient evidence presents itself to provide concrete answers to these important questions.

THE STATUS OF POST-CUT BURNING

Although the post-cut use of burning for silvicultural purposes is increasing in Canada, much of this is done prior to planting and relatively little prior to direct seeding which, in fact, shows a decline (Kuhnke 1989). There are no reliable statistical data that would, at present, indicate how much of this burning activity is taking place specifically prior to planting or direct seeding of black spruce. Similarly, there are absolutely no data on how much of the post-cut burning is done across Canada in aid of natural black spruce regeneration; the general impression is that, in this respect, much less is done in Canada than in

Table 6. Black spruce height growth by treatment sections and tree diameter classes.

Treatment sections	DBH classes (cm)	Trees measured[a] (n)	Mean DBH[b] (cm)	Mean heights[b] (m)	Mean height growth (m)[b] 20th growing season	21st growing season	22nd growing season
A	≤1.0	8	0.6 ± 0.3	1.58 ± 0.23	0.09 ± 0.04	0.14 ± 0.12	0.15 ± 0.13
			NS	NS	NS	NS	NS
B	≤1.0	8	0.7 ± 0.2 NS	1.70 ± 0.22 NS	0.11 ± 0.04 NS	0.10 ± 0.04 NS	0.13 ± 0.06 NS
			NS	NS	NS	NS	NS
C	≤1.0	5	0.7 ± 0.3	1.63 ± 0.25	0.13 ± 0.06	0.15 ± 0.10	0.16 ± 0.08
A	1.1-3.0	20	2.1 ± 0.5	2.77 ± 0.57	0.20 ± 0.10	0.18 ± 0.11	0.21 ± 0.11
			NS	NS	NS	NS	NS
B	1.1-3.0	118	2.2 ± 0.6 NS	2.98 ± 0.60 NS	0.18 ± 0.08 NS	0.19 ± 0.09 NS	0.22 ± 0.09 NS
			NS	NS	NS	NS	NS
C	1.1-3.0	9	2.1 ± 0.6	2.62± 0.44	0.19 ± 0.07	0.20 ± 0.10	0.23 ± 0.13
A	3.1-5.0	21	4.1 ± 0.5	4.29 ± 0.52	0.30 ± 0.10	0.32 ± 0.15	0.30 ± 0.14
			*	NS	NS	NS	NS
B	3.1-5.0	100	3.8 ± 0.6 NS	4.17 ± 0.55 NS	0.27 ± 0.08 NS	0.31 ± 0.08 NS	0.34 ± 0.08 NS
			NS	NS	NS	NS	NS
C	3.1-5.0	12	3.7 ± 0.8	4.01 ± 0.71	0.29 ± 0.09	0.31 ± 0.11	0.32 ± 0.11
A	5.1-7.0	14	5.8 ± 0.5	5.30 ± 0.67	0.37 ± 0.10	0.36 ± 0.12	0.43 ± 0.07
			NS	NS	NS	NS	NS
B	5.1-7.0	16	5.5 ± 0.4 NS	5.45 ± 0.58 NS	0.37 ± 0.09 NS	0.38 ± 0.10 NS	0.38 ± 0.13 NS
			NS	NS	NS	NS	NS
C	5.1-7.0	10	5.8 ± 0.5	5.39 ± 0.42	0.34 ± 0.11	0.42 ± 0.08	0.38 ± 0.10

[a] Included are dominant, undamaged trees with measurable diameters at 1.30 m (breast height).

[b] Differences between means (with ± standard deviations) are either significant (*) or not significant (NS) at $p<0.05$.

northern Minnesota, for example (Aksamit and Irving 1984). Poor results, high operational costs, and other compelling reasons (Jeglum 1987) may be responsible for this lack of interest in strip burning on black spruce uplands. There is no doubt, however, that this situation can be in time rectified by the development and use of more suitable burning prescriptions than those tried so far on the uplands. It was said not too long ago that "black spruce peatland management (particularly the regeneration aspect of it) is in many respects still in the Dark Ages" (Virgo 1975). This report shows that by now much more is known about the problem and how to solve it. The post-cut burning methods that are designed specifically for the lowlands in aid of natural black spruce regeneration are dependable, ecologically compatible, and cost-effective when compared with other methods serving the same purpose.

ACKNOWLEDGMENTS

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RESPONSE OF PICEA ABIES TO DRAINAGE IN NORTH FINLAND

by

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ABSTRACT

Peatlands cover about 9 million hectares of the 26 million ha of forestry land in Finland. This review paper deals mainly with North Finland which includes 9.8 million ha of land and 3.4 million ha of peatlands. In this area, the average temperature sum does not exceed 1000 degree-days. In the whole of Finland, the area of drained peatland by 1986 was 5.7 million ha with 0.9 million ha of this occuring in North Finland. A brief overview of the peatland classification and peatland forestry practices in Finland is presented. On peatlands in North Finland, *Picea abies* is the dominant tree species on 21% of the forest land area. Hardwood-spruce mires with various mixtures of *Picea abies* and *Betula pubescens* cover 41% of the forest land on peatlands. A considerable response to drainage in the volume increment of mixed hardwood-spruce mire stands is evident up to the southern half of North Finland. However, the growth response of *Picea abies* to drainage seems to be minor when compared to that of *Betula pubescens*, especially in North Finland. It is suggested that in cold climatic conditions *Picea abies* needs a mesotrophic or eutrophic site to be able to respond to drainage.

INTRODUCTION

In the Finnish classification of forest sites, soils are divided into two main groups, mineral soils and peatlands. *Peatland* is defined as a site type where peat-forming vegetation dominates, or an accumulated layer of peat exists. Paludified mineral soil is a term referring to upland sites with insufficient drainage. These sites are lacking a uniform peat layer but the share of wetland vegetation, usually *Sphagnum* species, is 25 to 75 per cent of the ground vegetation. In this paper, *mire* is used as a synonymous term for peatland.

Penttila, T. 1990. Response of Picea abies to Drainage in North Finland. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 45-53.*

Finland lies between latitudes 60° and 70° N. In the boreal zone of Finland, the temperature sum (above 5°C threshold) varies from 650 degree-days in the north to 1400 degree-days in the south. Mean annual precipitation is 500 to 700 mm, but evapotranspiration is only 300 to 350 mm. The moderate sub-maritime climate in Finland is due to the warm Gulf Stream. In most studies Finland is divided into three sub-areas to examine the effects of drainage (Figure 1).

Peatlands cover about 9.0 million ha of the 26 million ha of forestry land in Finland. Since the 1950s the estimated area of peatlands has decreased by some 0.7 million ha, probably due to drainage of shallow-peated peatlands and, to some extent, changes in land use (Paavilainen and Tiihonen 1988). Another 0.7 million ha of peatlands under agricultural use should be included, thus making a total of 10.4 million ha of

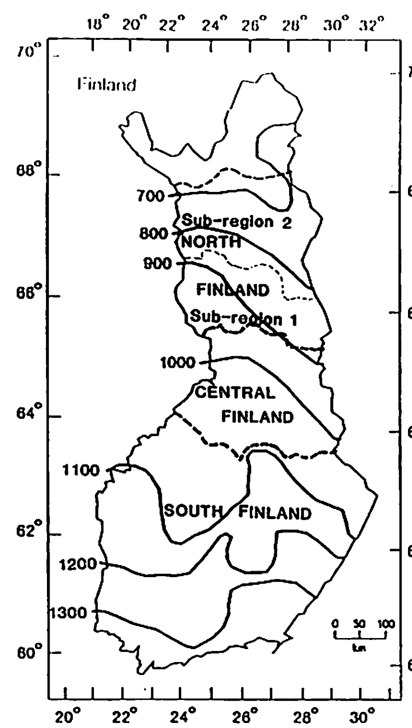

Figure 1. Regions of Finland used in the study, and the aggregate temperature sum (at 5°C threshold).

Table 1. Peatland area and its distribution into land classes in Finland (Paavilainen and Tiihonen 1988)

Region[a]	Land class[b]							
	Forest land		Scrub land		Waste land		All peatland	
	'000 ha	%	'000 ha	%	'000 ha	%	'000 ha	%
South	2687	78	455	13	312	9	3454	100
Central	1226	57	500	24	410	19	2136	100
North	849	25	1208	35	1381	40	3438	100
Whole of Finland	4762	53	2163	24	2103	23	9028	100

[a] See Figure 1.
[b] Forest land - mean annual increment under optimum silvicultural conditions and with normal rotation period at least 1 m^3/ha over bark
Scrub land - mean annual increment at least 0.1 m^3/ha, and less than 1 m^3/ha, respectively
Waste land - mean annual increment below 0.1 m^3/ha, respectively

peatlands in Finland (Päivänen 1984). The distribution of peatlands into forest land, scrub land, and waste land in Finland is shown in Table 1.

The aim of forest drainage is to increase yield by lowering the ground water table, in order to improve the aeration of the surface peat. The ditch depth used in Finland varies from 65 cm for shallow peats to 90 cm for deep peats. The economically optimal ditch spacing is considered to be 30-50 m. Thus, the ditch density is approximately 330-200 m/ha, respectively. In a stand with a high volume of growing stock, and on hardwood-spruce mires in general, a minimum ground water level (30-35 cm below soil surface) can be obtained with a wider ditch spacing than on poor sites with a sparse tree cover.

The most essential silvicultural problem of hardwood-spruce mire stands after drainage is the competition between the main tree species, Norway spruce (*Picea abies* (L.) Karst) and birch (*Betula pubescens* Ehrh.), when grown in mixtures, which is usually the case in Finland. On oligo-mesotrophic and on more fertile peatland sites, birch is known to grow faster than softwoods during the first decades of the rotation period. However, due to its higher commercial value, Norway spruce is the most desirable tree species of hardwood-spruce mire stands.

The post-drainage stand development depends, among other things, on the macroclimate and on the response of the different tree species to drainage. In this paper the response of Norway spruce to drainage is examined especially in North Finland. To give some general background, the peatland classification and some main features of peatland forestry in Finland are first introduced.

PEATLAND CLASSIFICATION

The Finnish peatland classification is based on ground vegetation. According to the peatland classification system outlined by Heikurainen and Pakarinen (1982), a total of 40 site types are distinguished in three major categories. These are hardwood-spruce mires, pine mires and treeless mires. As a minerotrophic species, Norway spruce characterizes the hardwood-spruce mires. Scots pine (*Pinus sylvestris* L.) is the dominant tree species on pine mires. Birch is common on hardwood-spruce mires and on certain pine mires. In the most simplified applications of the classification, for instance the one used in the Finnish National Forest Inventory (NFI), only the major categories and six trophic levels are used to determine the site type.

The drainage condition is described by four classes, undrained mires, newly ditched mires, transforming mires, and transformed mires (see Paavilainen and Tiihonen 1984). Transformed mires have fully reached their potential productivity, and the ground vegetation classified into four drained peatland forest types compares with that of uplands. The nomenclature of the undrained mire types is used on newly ditched and transforming peatland sites. A simplified and more operational classification of drained peatlands has been proposed by Laine (1989).

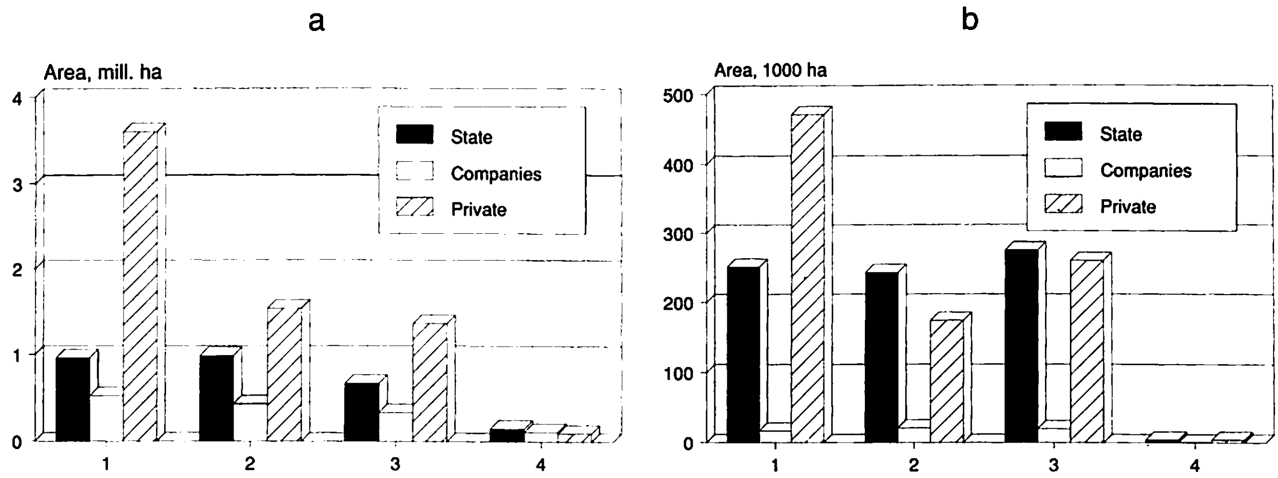

Figure 2. Cumulative area of site preparation, by land owner group, in Finland 1950-1987 (a), and in North Finland 1965-1986 (b). Source: Mr. A. Ritari, the Finnish Forest Research Institute. 1. Drainage, 2. Fertilization, 3. Mechanical preparation, 4. Prescribed burning.

Within the category of hardwood-spruce mires, there exists a wide ecological range from upland vegetation at one end to treeless wet fens at the other end of the scale. Shallow-peated paludified hardwood-spruce forests, true hardwood-spruce mires, and sedge hardwood-spruce mires (transitional to treeless mires) are found mainly on eutrophic, mesotrophic and oligo-mesotrophic sites. An oligotrophic range from poor paludified hardwood-spruce forests to spruce-pine mires is also found. Due to its minor importance only one or two oligotrophic hardwood-spruce mire types are usually distinguished for forestry purposes.

PEATLAND FORESTRY IN FINLAND

In Finland, forest drainage is carried out almost throughout the whole boreal zone, until the aggregate temperature sum decreases below 750 degree days. By 1986, the total area of peatlands and mineral soils drained for forestry was 5.7 million ha in the whole of Finland (Uusitalo 1988). The present aim is to end up with a total of 6.5 million ha of forests drained by the end of the century. The forest drainage area exceeds that of other methods of soil preparation, such as prescribed burning and mechanical site preparation (Figure 2). This holds true for North Finland (Lapland) also, where drainage of peatlands and reforestation of over-aged upland stands may be considered alternative ways for increasing the land base of intensive forestry. In Lapland the latest estimate of the total peatland area on forestry land is 3.4 million ha (Mattila and Penttilä 1987). By 1986, drained peatlands and mineral soils covered 910 000 ha in Lapland (Uusitalo 1988).

Table 2. Dominance of tree species on hardwood-spruce mires on forest land in North Finland, by drainage condition, (after Mattila and Penttilä 1987).

	Dominant tree species % of area			
Drainage condition	O	P	S	B
Undrained	4	8	58	30
Newly ditched	3	12	53	32
Transforming	11	10	41	39
Transformed	11	7	26	56

[a] O - Open area
P - Scots pine
S - Norway spruce
B - Deciduous tree spp., mainly birch

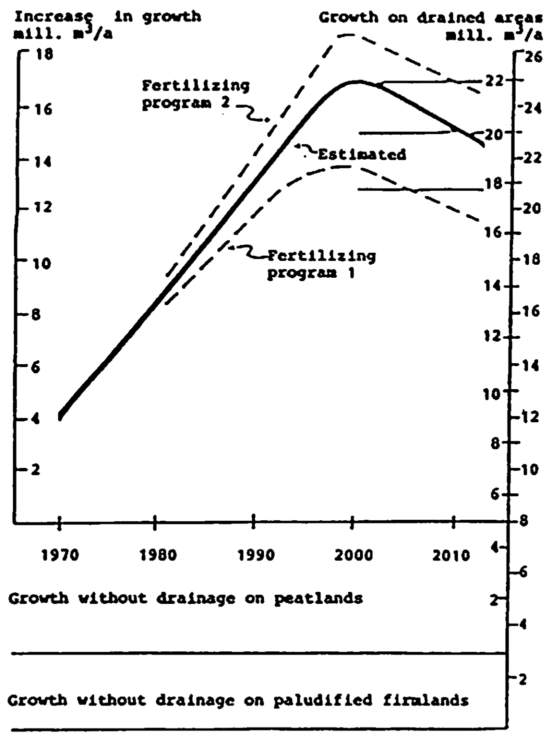

Figure 3. The increase in growth due to forest drainage and the future growth on drained areas in Finland (after Heikurainen 1982).

The aim of this paper requires a more detailed approach to the peatlands in North Finland. In Finland, the proportion of hardwoods in hardwood-spruce mire stands increases northwards (Heikurainen 1959, Keltikangas *et al.* 1986). Hardwood-spruce mires cover 41% of the peatlands on forest land in North Finland. Norway spruce is the dominant tree species on 21% of peatlands on forest land. On hardwood-spruce mires, Norway spruce is the dominating tree species on 47% and hardwoods on 36% of the forest land area, respectively. The remainder consists of pine-dominated stands and open areas. The dominance of hardwoods increases and that of spruce decreases from undrained sites to transformed peatlands (Table 2). On all peatlands on forest land, 30% of the total volume of growing stock is Norway spruce, 35% is Scots pine, and 35% is hardwoods. The shares of annual volume increment are 22%, 39%, and 38%, respectively. (Mattila and Penttilä 1987).

In Finland, drainage has been carried out mainly on naturally treed peatlands. The natural stands are usually considered capable of development after drainage. Hence, the afforestation of peatlands is not necessary on extensive areas. However, oligo-mesotrophic spruce mires should be regenerated with

Table 3. Mean annual stand increment on forest land in Finland according to NFI 7 (after Paavilainen and Tiihonen 1988, Uusitalo 1988).

	Stand increment ($m^3ha^{-1}a^{-1}$)	
Region[a]	Peatlands	Peatlands and uplands
South	3.9	4.6
Central	2.1	2.3
North 1	1.6	1.3
North 2	1.0	
Whole of Finland	2.7	3.4

[a] See Figure 1.

Scots pine or birch following drainage. On drained areas, peatland sites often face the problem of spruce occupying sites which are too oligotrophic under a pine or birch stand. Mature stands on oligo-mesotrophic, or oligotrophic drained sites should be regenerated with Scots pine, or birch, due to the high nutritional demands of Norway spruce. (Kaunisto and Päivänen 1985).

The share of open mires is less than 10 percent of the total forest drainage area (Keltikangas *et al.* 1986). As the open mires are usually poor in potassium and phosphorus the results of drainage and afforestation on treeless mires have not been encouraging (e.g. Kaunisto and Päivänen 1985).

The increase in growth due to forest drainage and fertilization, and the future growth on drained areas has been estimated in several connections. According to Heikurainen (1982) the estimated annual increase in stand increment will be 13-17 million m^3 by the end of the century, depending on the extent of fertilization (Figure 3).

From the data of NFI 7 (carried out in 1977-1984) it has been estimated that the total annual increment in all forests in Finland is 68 million m^3, and in peatland forests it is 15 million m^3. The increase in annual stem wood increment due to drainage exceeds 7 million m^3 for the whole of Finland. In North Finland, the figures are 7.5 million m^3, 1.4 million m^3 and 0.4 million m^3, respectively. (Paavilainen and Tiihonen 1988, Uusitalo 1988). The strong effect of macroclimate on tree growth is also shown in the estimates of mean annual increment of stands in the sub-areas of Finland (Table 3).

Table 4. Stand volume and increment on some undrained and drained hardwood-spruce mire types in Finland according to different studies.

<table>
<tr><th rowspan="2">Mire site type[a]</th><th rowspan="2">Region[b]</th><th colspan="2">Stand volume m^3ha^{-1}</th><th colspan="2">Volume increment $m^3ha^{-1}a^{-1}$</th></tr>
<tr><th>undrained[c]</th><th>drained[d]</th><th>undrained[c]</th><th>drained[d]</th></tr>
<tr><td>LhK</td><td>South</td><td>106</td><td>141</td><td>6.4</td><td>6.7</td></tr>
<tr><td></td><td>Central</td><td rowspan="2">85</td><td rowspan="2">•</td><td rowspan="2">2.8</td><td rowspan="2">•</td></tr>
<tr><td></td><td>North</td></tr>
<tr><td>RhK</td><td>South</td><td>66</td><td>122</td><td>4.2</td><td>5.9</td></tr>
<tr><td></td><td>Central</td><td rowspan="2">54</td><td>47</td><td rowspan="2">1.7</td><td>2.4</td></tr>
<tr><td></td><td>North</td><td>98</td><td>4.6</td></tr>
<tr><td>KgK</td><td>South</td><td>72</td><td>92</td><td>3.3</td><td>4.4</td></tr>
<tr><td></td><td>Central</td><td rowspan="2">49</td><td>37</td><td rowspan="2">1.6</td><td>2.1</td></tr>
<tr><td></td><td>North</td><td>60</td><td>3.0</td></tr>
<tr><td>VK</td><td>South</td><td>69</td><td>115</td><td>2.8</td><td>5.3</td></tr>
<tr><td></td><td>Central</td><td rowspan="2">66</td><td rowspan="2">•</td><td rowspan="2">1.7</td><td>3.2</td></tr>
<tr><td></td><td>North</td><td>2.4</td></tr>
</table>

[a] LhK - Eutrophic paludified hardwood-spruce forest
RhK - Herb rich hardwood-spruce swamp
KgK - Oligo-mesotrophic paludified spruce forest
VK - consists of MK - *V. myrtillus* spruce swamp
PK - *V. vitis-idaea* spruce swamp

[b] See Figure 1.

[c] Undrained peatlands on forest land, NFI3 (Gustavsen and Päivänen 1986)

[d] Peatlands drained for forestry during 1930-1978 (Keltikangas *et al.* 1986)

RESPONSE OF NORWAY SPRUCE TO DRAINAGE

Post-drainage stand increment on different mire types in Finland has been examined in several studies (e.g. Heikurainen 1959, Seppälä 1969, Heikurainen and Seppälä 1973, Keltikangas *et al.* 1986, Paavilainen and Tiihonen 1988). Most of the studies deal with data collected from drainage areas only. To estimate growth responses, it is necessary to know the growth rate of single trees or the development of undrained peatland stands, too. These stands have not been examined as intensively as the drained peatland stands.

On meso-oligotrophic peatland sites in South Finland, single spruce trees respond to drainage a few years after ditching, as the response of pine trees even on oligotrophic pine mires is quite rapid. After reaching the maximum of radial growth, the growth rate of peatland spruce trees corresponds to that of upland spruce trees of the same size (Seppälä 1969).

As regional variation was not considered in depth in Seppälä's (1969) study, Heikurainen and Seppälä (1973) examined the regionality and continuity of tree growth on old drainage areas on the basis of stand increment on different mire types. Tree growth after drainage seemed to continue more or less unchanged, taking into account the normal changes in stand structure. However, the possible difference between the tree species on, for instance, hardwood-spruce mires was not considered.

The average increase in volume increment on certain mire types in different parts of the country was also

Table 5. Distribution of the total stand volume by tree species and by drainage condition, on some hardwood-spruce mire types in Finland.

Mire[a] site type	Drainage[b] conditon	Region[c]					
		South			Central and North		
		Scots pine	Norway spruce	Hard-woods	Scots pine	Norway spruce	Hard-woods
		% of volume					
LhK	Undrained	4	35	61	2	47	51
	Drained	8	69	23	1	40	59
RhK	Undrained	14	28	58	5	40	55
	Drained	10	66	24	3	46	51
KgK	Undrained	20	56	24	16	54	30
	Drained	18	65	17	22	43	35

[a] See Table 4.
[b] Undrained - virgin mires on forest land according to NFI3 (Gustavsen and Päivänen 1986)
Drained - peatlands drained for forestry during 1930 - 1978 (Keltikangas *et al.* 1986)
[c] See Figure 1.

Table 6. Mean volume and increment by tree species[a] on drained and undrained hardwood-spruce mire stands in North Finland (after Mattila and Penttilä 1987).

Region[b]	Drainage Condition	Stand volume (m^3ha^{-1})			Volume increment ($m^3ha^{-1}a^{-1}$)		
		P	S	B	P	S	B
North 1	Undrained	6.0	29.5	20.9	0.15	0.68	0.59
	Drained	3.1	15.8	26.7	0.20	0.74	1.63
North 2	Undrained	3.3	27.3	22.0	0.10	0.49	0.60
	Drained	1.2	13.3	17.2	0.06	0.47	0.67
North Finland	Undrained	4.5	28.3	21.5	0.12	0.57	0.59
	Drained	2.6	15.2	24.2	0.16	0.67	1.38

[a] P - Scots pine
S - Norway spruce
B - Deciduous tree spp., mainly birch
[b] See Figure 1.

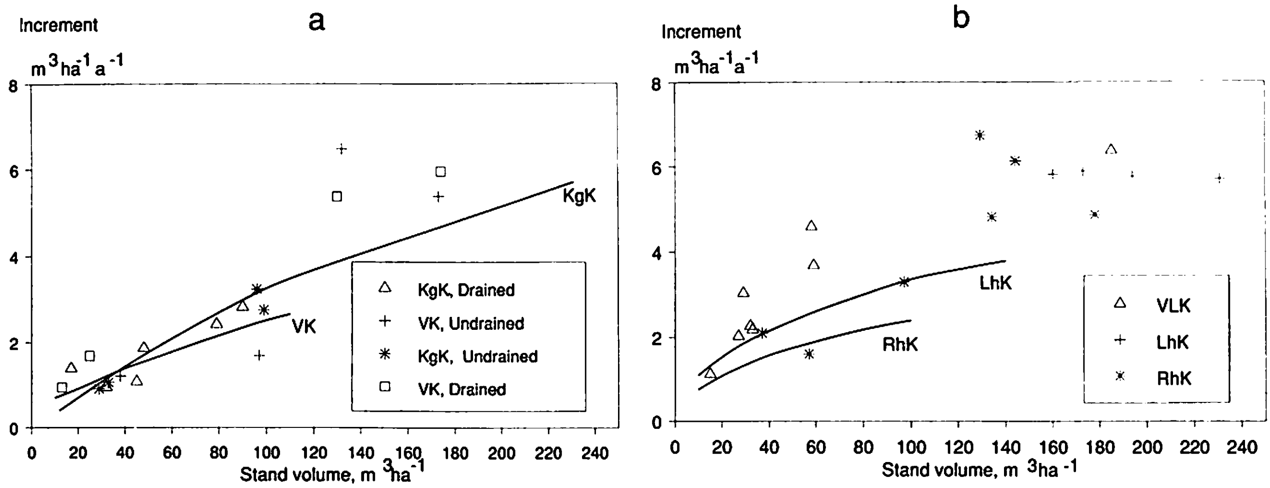

Figure 4. Mean annual increment for the past 5-year period as a function of stand volume, on oligo-mesotrophic (a) and eutrophic (b) hardwood-spruce mire stands in North Finland. Plotted observations (for eutrophic sites drained stands only) are data from permanent sample plots combined with NFI7. The curves indicate undrained stands according to Gustavsen and Päivänen (1986). For mire site type abbreviations, see Table 3.

estimated by Heikurainen and Seppälä (1973). For two representative hardwood-spruce mire types (see Table 4, footnote[a]) it was as follows:

	Volume increment ($m^3ha^{-1}yr^{-1}$)	
	South Finland	North Finland
RhK	5.4	3.6
MK	3.3	1.8

Rough estimates of the response of stands to drainage become available by comparing the data of NFI 3 (carried out in 1951-1953) for undrained sites (Gustavsen and Päivänen 1986) with the present knowledge of drained sites. Some mean values of stand volume and increment on certain undrained and drained hardwood-spruce mire types according to different studies are shown in Table 4. However, this kind of comparison may not be relevant in all cases, as the volume increment of both undrained and drained peatland stands depends greatly on the stand volume (Gustavsen and Päivänen 1986, Laine and Starr 1979). The response of spruce is not properly shown because the hardwoods, mainly birch, play a considerable role in the stands of both undrained and drained hardwood-spruce mires (Table 5).

Regarding North Finland, an attempt was made to estimate the growth response of spruce and birch to drainage on hardwood-spruce mires by comparing the drained and undrained strata of NFI 7 (Mattila and Penttilä 1987). In the southern part of North Finland, birch clearly responded to drainage better than Norway spruce. In the northern part, no response to drainage is apparent (Table 6).

The inventory method of NFI 7 used in North Finland (Mattila 1985) does not enable reliable estimates to be made for small strata such as the increment of different tree species on different trophic levels of hardwood-spruce mires. In order to view the effect of the nutrient status on growth response, preliminary results on stand increment of spruce dominated hardwood-spruce mire stands in North Finland are presented. The data comes from the network of permanent plots on peatlands in North Finland, established by the Finnish Forest Research Institute, Department of Peatland Forestry. The network is a sub-sample of the field sample of NFI 7, stratified on the basis of state of drainage, dominant tree species, and trophic level of the site. Plotting the volume increment versus stand volume (Figure 4) revealed a clear response on drained eutrophic and herb rich hardwood-spruce mire types. On the oligo-mesotrophic mire types, practically no response appeared.

DISCUSSION

Stand increment on peatlands after drainage as well as the profitability of draining is known to depend on the fertility of the site, on the state of the existing growing stock, and on the geographical location of the site. In Finland, the post-drainage stand increment on different mire types has been examined intensively, but less attention has been paid to the response of different tree species when grown in mixtures.

The studies and results referred to previously seem to indicate a better response for birch than for Norway spruce in hardwood-spruce mire stands in North Finland. On the other hand, results indicating decreasing yield due to an increasing share of hardwoods on old drainage areas of fertile hardwood-spruce mires do exist (Huikari *et al.* 1967). The weak response of spruce may thus be only a consequence of neglected silvicultural measures of the stands and natural differences of the growth rate between birch and Norway spruce. However, there are some ecological factors that should be taken into account when regarding wood production on drained peatlands in the northern conditions.

It is possible that birch, due to its deeper root system (Heikurainen 1958), is more effective in the uptake of nutrients than Norway spruce. Hence, birch responds to drainage on relatively poor sites even under cold climatical conditions, while Norway spruce needs a mesotrophic or eutrophic site to be able to respond to the improved aeration due to drainage. This may be in connection with the slow melting of the ground frost on drained peatland sites in North Finland (Eurola 1975) and consequently, insufficient mineralization of nutrients.

The poor aeration due to wetness is probably, in any case, the most important growth limiting factor on undrained hardwood-spruce mires throughout the boreal zone in Finland. However, the ecological features and differences of the main tree species, such as accommodation to growing on cold peat, should be known better at least in North Finland to give a firm basis for silviculture on peatlands.

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DIRECT SEEDING OF PINE AND SPRUCE IN SWEDEN

by

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ABSTRACT

When sown on mineral soil, about 20-30% of live seeds from pine (*Pinus sylvestris* L.) and spruce (*Picea abies* Karst.) produce living seedlings at the end of the first summer. The two species do not differ in this respect. For pine seedlings, 50-70% survive until the age of five years, as compared with 50-60% for spruce. The humus layer must be removed to enhance germination but a shallow scarification seems optimal. Sheltering and covering seeds may increase stocking many fold. Germination and survival vary significantly with the type of site and climate. For direct seeding, spruce is considered to be of less interest operationally than pine. The reasons for this are the lower long-term establishment rate per seed and the unsatisfactory results on "spruce sites" with high fertility. On medium fertile sites it is recommended that spruce seed should be added (40%) to the pine seed. Direct seeding is regarded as a simple and inexpensive regeneration method.

BACKGROUND

In Sweden there is a long tradition of direct seeding of conifers. Forestry textbooks have given specific recommendations concerning direct seeding for over 150 years (Ström 1830). The first large-scale scientific field trials were established in 1905 (Maass 1907). In practical forestry, artificial regeneration by direct seeding was used extensively until the mid-1950s. However, planting programs expanded after this date and, according to recent questionnaires sent to forestry companies in Sweden, direct seeding is used today on only 1% of the artificially regenerated areas (Freij 1989). The method is not recommended on fertile sites where competing vegetation is the major problem. Thus, as spruce is the main species grown on fertile sites, and pine is grown preferably on medium to less fertile sites, direct seeding of spruce is seldom practised in Sweden. However, a mixture of spruce and pine seed is recommended for medium fertile sites (Wahlgren 1922). Given these circumstances, scientific studies on direct seeding have focused on pine rather than on spruce.

Hagner, M. 1990. Direct Seedling of Pine and Spruce in Sweden. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics of Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-217, pp. 55-62.*

Most of the results discussed in this paper have been obtained from Tirén (1952) and from Hagner *et al.* (unpubl.). Tirén examined 80 field trials established between 1943-1949 (latitude 63-67°N, altitude 215-510 m above sea level (m asl), that utilized pine as well as spruce. Hagner *et al.* monitored 154 field trials established with pine between 1980 and 1984 (latitude 56-67°N, altitude 60-650 m asl). From the latter series only the 105 trials north of latitude 60°N form the basis for the results presented here. The two workers monitored seedling development up to the end of the fifth growing season after seeding.

GERMINATION

Provided that seed is sown on mineral soil, 20-30% of live seeds sown form one-summer-old germinants. Maass (1907) found a germination rate of 30%, and Tirén (1952) obtained a germination rate of 20-31% on unburnt ground and 31% on burnt ground. Neither of the studies showed any difference in germination rate between pine and spruce. For pine, Hagner *et al.* (unpubl.) obtained germination rates of 29%, 20%, 21% and 23%, respectively, in four successive years.

SURVIVAL

Despite a high number of plants per hectare, an area cannot be considered successfully regenerated if there are sub-areas totally lacking live plants. The Swedish Forestry Act states that an approved regenerated site must not have more than 10% of six-meter-diameter circular plots completely devoid of seedlings ("zero-circles"). The reason for this is that a considerable loss of production can be expected if seedlings do not occur in an area with a diameter of six meters.

Eneroth (1945) found that the frequency of scarified patches with varying numbers of seedlings could be described by a negative binominal distribution. Tirén (1952) developed this further and found that the frequency of "zero-patches" (i.e. scarified patches with no plants) could be described by

[1] $p = (1+m/r)^{-r}$

where $r = q^2$ and in which q^2 is the disturbance quotient

[2] $q^2 = (s^2/(m^{-1}))/m$

with s^2 = variance and m = mean of number of seedlings per patch. Tirén used this technique to express a permissible "zero-patch frequency" ten years after sowing (Table 1).

To study the frequency of "zero-circles" Hagner *et al.* (unpubl.) arranged field trials using scarified patches at 7 locations 1 meter apart along 6-meter transects. Twenty seeds were sown in each patch. The trials were analyzed with respect to the distribution of "zero-transects" (Figure 1). From these distributions it was obvious that the environment for germination and survival was extremely poor for a certain portion of the seeded transects. Another portion of the transects had an extremely good environment, while the main portion seemed to be of medium quality. Provided the sites could be divided into three such categories, the proportions of these categories could be estimated. The series established in 1980 was found to have 9% of the transects characterized by a 1% probability that one patch contained at least one five-year-old plant (p=0.01). In another 10% the probability was 95%, and in the remaining 81% the probability was 70%. The last figure, which reflects the average environment, was considered to form a sound base for estimations of seeding density.

However, in operational forestry it is the occurrence of "zero-circles" (6 m diameter) and not "zero-transects" (6 m long) that is of interest. Hagner *et al.* (unpubl.) and Bondesson (1988) thus attempted to use the above results for 6-meter transects to predict what would have been the results if 6-meter diameter circles had been used instead.

It is thus important to analyze regeneration trials with respect to the long-term frequency of "zero-areas" rather than to express only figures of number of live seedlings per hectare or stocking of areas as small as 4 square meters. The results also show that a certain portion of the seeded areas have to be considered "hopeless", in that the germination and survival rates will be poor regardless of how high the sowing density is. Of course it is necessary to exclude these areas before estimating seeding density. It is also important to consider whether areas like these should be regenerated by means other than direct seeding.

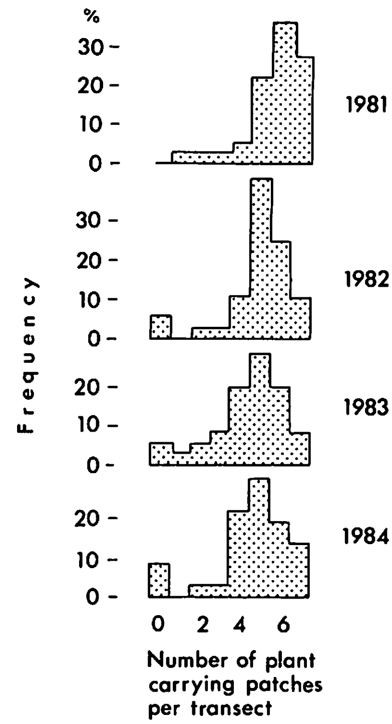

Figure 1. Distribution of 36 transects according to their number of plant-carrying scarified patches. Each transect was 6 m long and comprised 7 scarified patches (11 cm diam, sown with 20 pine seeds/patch) 1 meter apart. Field trials at latitudes 60-66°N established in the spring of 1980. Measurements carried out in the falls of 1981, 1982, 1983 and 1984 (after Hagner *et al.* (unpubl.)).

PINE VERSUS SPRUCE

Textbooks dating back to 1830 have stated that direct seeding is a convenient method for regenerating sites with medium to low fertility and characterized by scarce vegetation (Ström 1830). Pine is considered better adapted to poor and medium sites than spruce, and thus direct seeding is usually carried out with pine. However, as most sites are a mosaic made up of both fertile and infertile areas, it is clear that pine alone cannot always be used to ensure adequate restocking of a complete site. A mixture of seed from pine (60%) and spruce (40%) was therefore used as the standard regeneration method on clearcut areas in the northern half of Sweden until the Second World War. Today, however, the choice between the two species is strongly influenced by the existence of a very large moose population, as pine is much more affected by browsing than spruce. Many forest owners prefer spruce despite the fact that theoretically the highest production can be obtained with pine. When direct seeding is used, a mixture of the two species thus seems logical, to

Table 1. Mean number of seedlings obtained in the first fall after direct seeding in square scarified patches on unburnt ground. An equal (but undefined) volume of seed was sown in each scarified patch. Altitudes above 400 m asl (after Tirén 1952).

	Pine		Spruce	
Year	no. of plots	plants/patch	no. of plots	plants/patch
1943	1	17.0	2	15.1
1944	1	7.2	1	6.2
1945	2	7.0	2	6.8
1946	7	21.5	7	19.3
1947	1	9.6	-	-
1948	6	3.2	2	6.1
1949	2	5.4	2	8.2

overcome the effect of differences in fertility across a single site, and the damage to pines due to browsing.

Most research has clearly shown that spruce and pine have a fairly similar survival rate when considering the number of germinants in the first fall (Maass 1907, Eneroth 1941, Tirén 1952). Climatic differences between years seem to have the same influence upon the two species (Table 1).

Detailed studies on the long-term survival of one-summer-old germinants have led to the functions presented in Figure 2. For pine on unburnt ground Tirén (1952) found a survival of 68% after five years. The corresponding figure for spruce was only 49%, i.e. 72% of that for pine. However, Eneroth (1941) found no great differences between the two species when considering the number of "zero-patches" nine years after sowing.

SHELTER AND COVER

Sheltering of the seedbed is considered advantageous. Trees, shrubs, rocks, stumps, sticks, and dead branches have all been mentioned as providing beneficial shelter. A cover sprinkled out on top of the seed is also recommended (Eneroth 1945, Wiksten 1948, Tirén 1952, Jakabffy 1963, Hagner and Lundmark 1982). The material should ideally be coarse and non-capillary, such as ant hill matter, coarse humus, ground surface vegetation, dead needles and gravel. However, gravel is considered best because it prevents dehydration of seeds and the soil surface, and it is heavy enough to lessen erosion. The use of top soil or other materials able to transport capillary water have been found to have a negative effect on seed germination in wet years.

Artificial shelters made of plastic have been used in large field trials. Hagner and Sahlén (1977) found 6 cm-high cones to be most beneficial. This "cone seeding" method is recommended for practice today (Hagner 1984).

Plastic funnels pressed down into the humus layer and covered by a plastic cone proved to give an extraordinarily high and even germination rate for pine (Hagner and de Jong 1982). Unfortunately, the long term survival rate was fairly low and the "funnel seeding" method is not recommended for practical use in Sweden today.

SCARIFICATION

A common experience from many field trials is that germination is hampered as soon as seeds are separated from the mineral soil by material unable to transport capillary water. Accordingly, most authors propose removal of the humus layer, and it is recommended that the soil surface should be compacted either by foot or by mechanical measures. For an additional advantage, indentations could be formed on the soil surface (Hagner 1976, Bergsten 1988). Hagner *et al.* (unpubl.) found that a light scarification with a disc trencher, leaving 50% fine humus and 50% mineral soil, gave somewhat better germination than that observed for bare mineral soil.

Besides scarification, prescribed burning before seeding is also recommended under certain conditions (Wahlgren 1922). Tirén (1952) proved this to be advantageous for the establishment and survival of pine and spruce (Figure 2).

SITE DIFFERENCES

Aside from the effect of the scarification mentioned above it has been found that the following features can have a negative influence on the final number of plants:

1. latitude lower than 60°N (Hagner *et al.* (unpubl.))
2. altitude higher than 400 m asl (Ström 1830, Tirén 1952 and Hagner *et al.* (unpubl.))
3. dry site (Tirén 1952 and Hagner *et al.* (unpubl.))
4. steep slope (transect 6 cm) (Hagner *et al.* (unpubl.))
5. steep slope (transect 20 cm) (Hagner *et al.* (unpubl.))
6. steep sunny slope (Ström 1830)
7. soil characterized by frost heaving (Ström 1830)
8. grass or herbs close to or in the patch (Ström 1830, Wahlgren 1922, Hagner *et al.* (unpubl.))
9. more than one year between scarification and sowing (Hagner *et al.* (unpubl.))
10. high site index (Hagner *et al.* (unpubl.)).

RECOMMENDED NUMBER OF SEEDS

Swedish textbooks have long recommended a quantity of 4 to 100 seeds per scarified patch. Naturally, over the decades the desired final number of trees per hectare has varied to a high degree. The first mentioned figure was 100 seeds/patch at a patch spacing of 1 m with 25 cm square patches (Ström 1830). Ström also theoretically examined the effect of having smaller patches (12 cm square), closer spacing (60 cm) and seeding with a smaller number of seeds (20), thinking that this would produce similar results with just 80% of the otherwise required amount of seed.

The first large series of scientific experiments (Maass 1907) resulted in recommendations of 10-20 seeds (pine and spruce, germination percentage 70%, spacing 1.2 m). Maass tested different numbers of seeds per scarified patch and found that the frequency of patches with live two-year-old seedlings increased from 58% to 87% when seeding was increased from 5 to 20 seeds (Table 2).

Wahlgren (1922) recommended the use of 5500-7000 scarified patches per hectare and 9 seeds per patch. This corresponds to 0.25 kg of seed/ha but Wahlgren stated that practical experience had shown that this amount should be increased to 0.8-1.0 kg.

Tirén (1952) estimated the recommended number of seeds per scarified patch from the average figures for germination, seedling survival and "permissible zero-patch frequency" (Table 3). In addition, he used a "seed correction factor" derived from the variation among different field trials. This factor was added to bring down the frequency of unsatisfactory regeneration from 50% to a reasonable level.

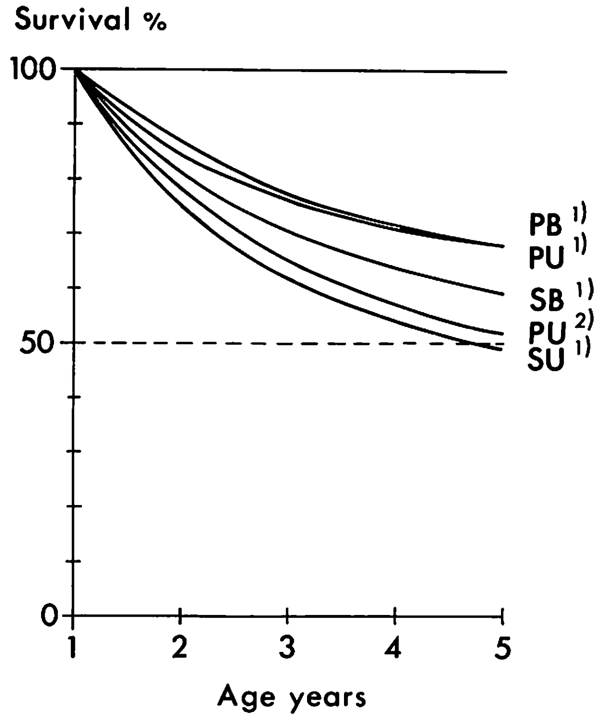

Figure 2. Survival percentages (S) for one-summer-old seedlings as a function of age (t = years).

PU, Pine unburnt ground[a]	S = 0.509 + 0.950/t - 0.459/t
PB, Pine burnt[a]	S = 0.555 + 0.675/t - 0.213/t
SU, Spruce unburnt[a]	S = 0.275 + 1.174/t - 0.449/t
SB, Spruce burnt[a]	S = 0.405 + 1.032/t - 0.437/t
PU, Pine unburnt[b]	S = 0.300 + 1.212/t - 0.512/t

[a] after Tirén (1952) and [b] Hagner *et al.* (unpubl.).

Hagner *et al.* (unpubl.) studied direct seeding after disc trenching and found that it was adequate with 18.5 live seeds/meter (placed in circular clusters with diameter 11 cm at spacing of one meter), corresponding to 72 000 seeds/ha, if 1800 five-year-old seedlings/ha were required (unsatisfactory on 6-25% of the trancects). This sowing rate is in keeping with the findings of Maass (1907). However, Hagner *et al.* considered sowing in patches to be a very poor idea. Instead, they recommended that seeds be dispersed as evenly as possible over the whole trench. Calculations show (Bondesson 1988) that a good dispersal of seeds might lower the required number of seeds significantly.

Table 2. Frequency of scarified patches with two-year-old seedlings after direct seeding with varying numbers of seeds per patch (after Maass 1907).

Species	Number of seeds sown	Percent of patches with live seedlings
Pine	5	62
Pine	10	80
Pine	20	87
Spruce	5	58
Spruce	10	74
Spruce	20	79

Table 3. Permissible percentage of "zero-patches" in the tenth autumn after sowing for different numbers of seed-patches per hectare (after Tirén 1952).

Patches per ha	"Zero-patch" percentage
1000	5.0
1500	8.4
2000	11.2
2500	13.5
3500	16.8
5000	19.5

SEED QUALITY AND FIELD GERMINATION

Most research has been carried out with seed of high quality in spite of the fact that direct seeding tends to be practised with seed that is not good enough to be used in the nursery.

To estimate the correct number of seeds required for sowing, the germination percentage under optimal conditions in the laboratory must first be determined. Wahlgren (1922) suggests that this figure should be multiplied by the germination energy (percent germinated after 7 days). Hagner (1985) discusses the different factors to be considered for seeds in the nursery and the field, respectively. He concludes that, contrary to the requirement for rapid and even germination in the nursery, seed in the field should preferably germinate successively over a long time period. This would decrease the negative effects of periods with adverse climatic conditions. It would also lead to a large variation in size among seedlings, which is considered advantageous for long-term value production in the stand. Accordingly, Hagner (1985) recommends that seed for the nursery and field, respectively, should be exposed to very different pretreatments. A special mixture of rapidly and slowly germinating seeds might be ideal for sowing in the field.

SPECIES MIXTURE

Where pine is the main crop species, a seed mixture of pine and spruce is actually recommended by Wahlgren (1922). The spruce seems unable to develop into a tall tree in a scarified patch where the pine survives. The spruce then functions as an "insurance seedling" in patches where the pine is injured or killed. Hagner (unpubl.) examined a 35-year-old stand resulting from direct seeding with a mixture of seeds from both species (60% pine, 40% spruce), and found that the two species had germinated and grown in their own ecological niches (Figure 3). This study also indicated that the spruce caused no thinning problems in patches where both species survived. Gemmel and Örlander (1989) sowed pine and spruce in the same container and thus planted out plugs each containing one pine and one spruce seedling. The five-year results from this study confirm that the use of mixtures increases the overall survival per scarified patch.

GROWTH

In comparison with seedlings from a nursery, germinants from direct seeding develop more slowly during the first years. Most comparisons have shown that planted pine is normally two to three years ahead of seedlings resulting from direct seeding (Näslund 1983, Hagner 1984). Practical experience shows that this difference increases on sites with large establishment problems. When artificial regeneration with pine is carried out many years after clearcutting or many years after prescribed burning, the development of seedlings resulting from direct seeding appears to be more delayed than that of planted seedlings.

The growth of pine and spruce were compared in one trial established in 1930 in central Sweden (Eneroth 1941). Ten growing seasons after sowing, the dominant height in patches sown with pure pine was 95 cm while that in patches sown with pure spruce was 43 cm.

CARE OF SOWN STANDS

In the Swedish Forestry Act it is recommended that dense seedling clumps resulting from direct seeding of pine in scarified patches should be thinned to one stem per patch before they have reached a height of one meter. Thinning experiments have shown that a single

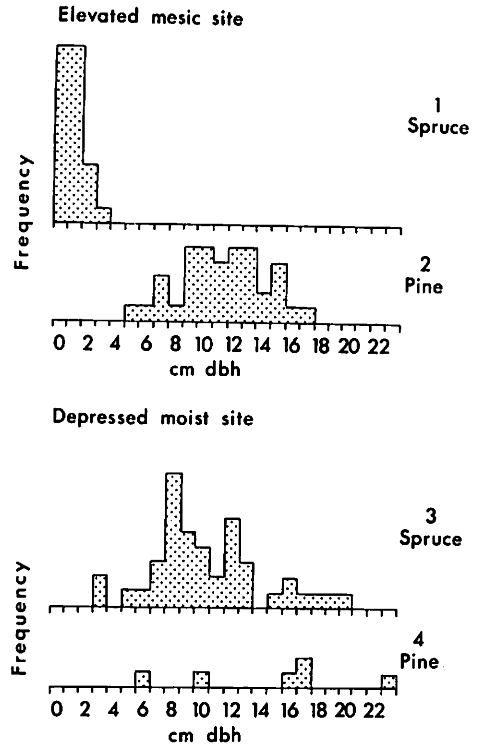

Figure 3. Frequency distribution of trees by diameter (dbh) in two areas (elevated mesic, and depressed moist respectively) in a 35-year-old stand (latitude 63°30'N, altitude 200 m asl) established through direct seeding in scarified patches with a mixture of seeds from pine (60%) and spruce (40%).

stem left from a thinned patch is able to grow almost as fast as the untouched clump of stems would have done (Näslund 1983). However, Sirén (1956) and Hagner (1984) have shown that the growth rate for the dominant stem in groups is much more rapid (two fold increase) than for single stems. This growth difference can still be observed at age 40. Accordingly, it is recommended that dense seedling clumps should not be thinned to leave a single stem. They should rather be treated in such a way that a dominating stem will occur within each clump.

ECONOMY

Manual seeding following disc trenching is an uncomplicated task, and one person can seed over two hectares a day (Ulriksson 1983). Totally mechanized systems have been developed using a seeder on a disc trencher. Although extremely convenient, the results of mechanized seeding have been unfavourable so far due to technical problems resulting from equipment failure. Accordingly, the manual method is recommended (de Jong *et al.* 1982). The total cost of regeneration by manual row seeding is estimated to be 43% of the average cost of planting (Ericsson and Rådström 1984).

DIRECT SEEDING COMPARED TO PLANTING

Planting is widely held to be a more reliable method of artificial regeneration than seeding, and to give a faster growth from an early age. However, when used with a satisfactory density of seeds, direct seeding is found to be reliable on most common site types in northern Sweden (Hagner *et al.* unpubl.). Additionally, this type of regeneration method is simple and does not require highly trained personnel (Hagner 1989). Tirén (1952) implied that it was foolproof. However, practical experience shows that many poor results have been obtained by direct seeding on sites with high fertility, grass, high moisture, high altitudes and frost heaving soil. Other reasons for unsuccessful attempts are that too small amounts of seed as well as unsatisfactory seeding apparatus have been used.

CONCLUSIONS

1. Direct seeding is recommended on sites of medium to low fertility. On sites with high fertility and strong development of grass and herbs, the small germinants are unable to develop. As spruce is the main species occupying these richer sites, direct seeding is seldom used to introduce stands of spruce. However, it is recommended that spruce seed be added to pine seed when direct seeding is carried out on medium quality sites in the northern half of Sweden.

2. The germination potential is the same for spruce and pine and 20-30% of the seed will give rise to one-summer-old seedlings.

3. The survival of these seedlings until the age of five years is somewhat lower (80%) for spruce than for pine. The survival rate for five-year-old pines is 50-70% of the stocking occuring after one summer.

4. Shelter and cover is most advantageous and may increase germination many fold.

5. Scarification is necessary to place the seed in close contact with capillary water.

6. The recommended number of seeds for pine is 72 000/ha if sown in patches one meter apart with 18.5 seeds/patch. However, it is recommended that seed should be spread out as evenly as possible on all the exposed mineral soil.

7. Seed quality considerations for direct seeding are different from those for seeding in nurseries. After

direct seeding the germination should preferably be spread out over time.

8. Simplicity is a characteristic feature of direct seeding.

9. The economy of direct seeding is good and the total cost can be half of what is normal for planting.

10. Site differences and climate strongly influence germination and survival. Some sites give an adverse result. However, used with discernment direct seeding is considered foolproof by some researchers.

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ARTIFICIAL REGENERATION OF KOREAN SPRUCE IN THE NORTHEAST OF CHINA

by

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ABSTRACT

Korean spruce has been used for artificial regeneration in China since the 1960s, and became one of the four most important species in the Northeast Forestry Region of China in the 1970s. Korean spruce is a timber species with a wide range of adaptation to site conditions, high survival rate, and low susceptibility to diseases, frost damage and pests. Thirty years of experience has demonstrated that regeneration with Korean spruce is successful, and prospects for future use of this species in plantations are optimistic.

INTRODUCTION

The northeast of China includes the administrative provinces of Liaoning, Jilin and Heilongjiang. The Northeast Forestry Region of China includes these three provinces and the Great Xingan Mountains in the Inner Mongolian Autonomous Region (Figure 1). This forestry region is one of the most important forest areas and sources of timber production in all of China. There are two species of spruce which grow naturally in the northeast of China: scale, or jezo spruce (*Picea jezoensis* Carr.) and Korean spruce (*Picea koraiensis* Nakai). These two species are found on different sites (Wu 1987). Scale spruce is found at the mid-elevations of high mountains above 600-800 m above sea level (m asl). Korean spruce is found at mid-and lower elevations below 600-800 m asl, and accounts for only 1% of the total forested area in the region. Artificial regeneration is frequently carried out on sites on plains and in valleys with convenient access for transportation. Korean spruce, which is adapted to lower elevation conditions, is thus chosen for artificial regeneration. All artificial regeneration of Korean spruce is done within its natural range.

Zhan, H.Z., Zhang, T.W. and Wang, F.Y. 1990. Artifical Regeneration of Korean Spruce in the Northeast of China. In: B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 63-66.

The role of Korean spruce in artificial regeneration programs in the Northeast Forestry Region has increased in recent years. Spruce was not used for regeneration or planting in the 1950s because it was considered to be a shade-tolerant and slow growing species. It was also believed then that the species would acidify the soil. Korean spruce began to be planted on harvested areas in the 1960s, but only on a small scale. However, some features of regenerating Korean spruce, such as its high survival rate, good growth rate and resistance to diseases and pests, were recognized by forestry institutions as this species began to be more widely used and an understanding of spruce silvics developed. The area regenerated with Korean spruce has increased significantly since the late 1970s. The area planted in the Lesser Xingan Mountains in Heilongjiang Province was about 1% of the total in the 1960s, but increased linearly to 20% by the late 1970s (Figure 2). The ratio of spruce used in regeneration by the forestry bureau owned by Heilonjiang Forest Industrial System as compared to other species has also increased annually. At present, Korean spruce, Xingan larch (*Larix gmelinii* Rupr.), Scots pine (*Pinus sylvestris* var. *mongolica* Litv.), and Korean pine (*Pinus koraiensis* Seib. et Zucc.) are the four main species used for planting and regeneration programs in the region. From Table 1 it can be seen that the area planted with spruce has increased from 2.0% in 1980 to 17.0% of the total area planted in 1988.

FEATURES OF ARTIFICIAL REGENERATION WITH KOREAN SPRUCE

There is a long interval, generally 5-9 years, between two successive seed years for Korean spruce in natural forests in the Northeast Forestry Region. The areas regenerated annually in the 1960s fluctuated periodically because of the effect of seed years and problems with long-term storage of seed. However, problems of seed storage have now been largely solved.

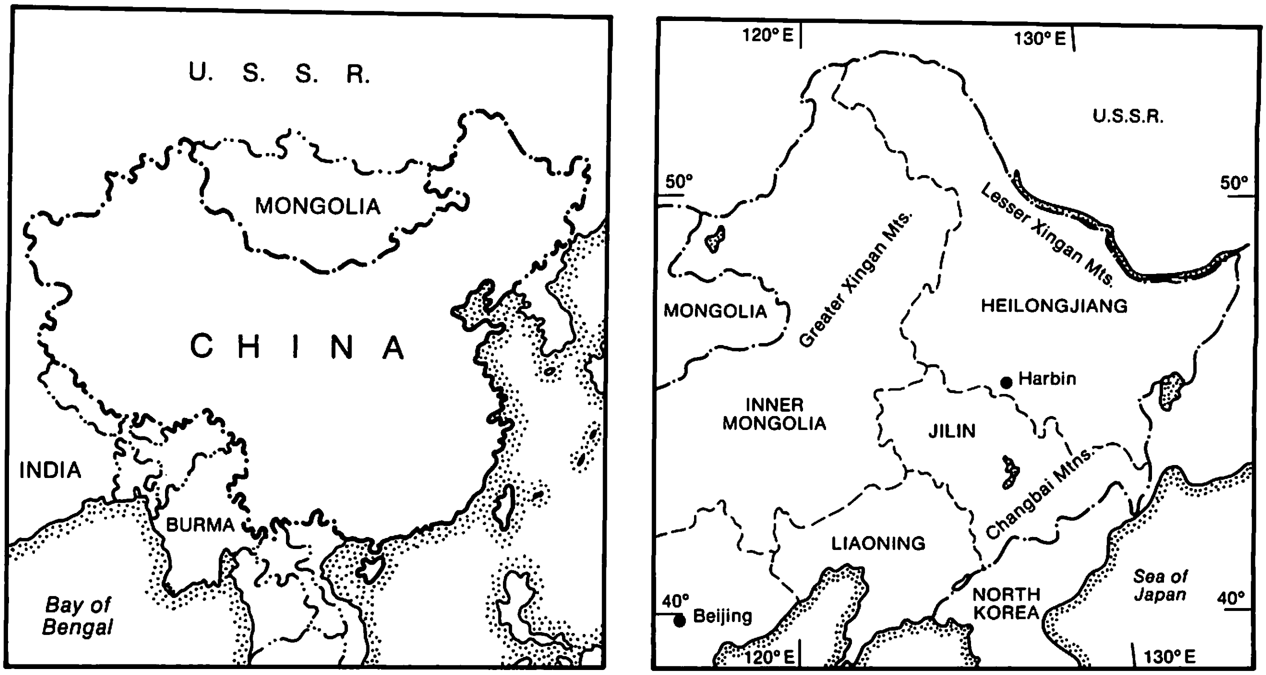

Figure 1. The geographic position of the northeast of China (after Burger and Zhao 1988).

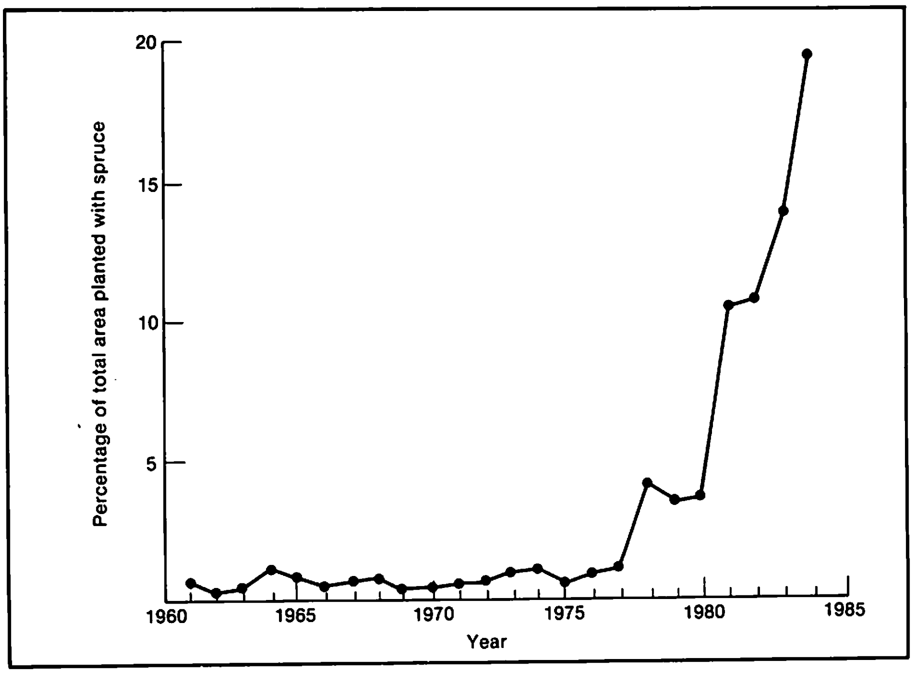

Figure 2. The change in the amount of Korean spruce used in plantations in the Lesser Xingan Mountains, northeast China, as a percent of total area planted.

Table 1. **Area planted by species in the Forestry Bureau run by the Heilongjiang Forestry Industrial System, as a percent of the total area regenerated annually (%).**

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988
spruce	2.0	2.1	2.4	4.5	5.3	7.4	11.7	18.2	17.0
Korean pine	38.8	39.5	39.3	37.2	31.3	25.0	27.3	30.0	29.0
larch	18.5	20.2	24.1	32.4	32.8	43.9	40.1	38.2	41.2
Scots pine	2.0	2.1	0.9	1.4	3.0	1.7	1.5	1.0	1.2

Germination rates are still 40% after 10 years of storage under suitable conditions with a temperature of 0-3°C and a humidity of 40%. There is thus now a stable seed source because of full storage of seeds in seed storehouses to meet regeneration needs.

Growing Seedlings Under Full Light

Shade and prevention of frost damage were once thought to be required for successfully growing spruce seedlings because foresters used to believe that Korean spruce was a shade-tolerant species. However, experience has shown that Korean spruce grows well under sunny conditions, even though it is shade-tolerant. It is thus feasible to grow seedlings under full light conditions, except at the beginning of the first growing season when some form of artificial shading is used, if the amount and frequency of irrigation can be controlled adequately to prevent the surface soil from extreme drying and heat. Spruce seedlings grown under full light have healthy xylems in the autumn and are thus frost hardy, and other steps to prevent frost damage over the winter are now not required. The broad range of ecological adaptability of Korean spruce to varying sunlight conditions is thus of great benefit to operational forestry practice.

Site Requirements

Although Korean spruce has some tolerance to shade, artificially regenerated seedlings require full light conditions to grow normally. Korean spruce can thus grow well on clear-cut, burned, and abandoned areas (Wu 1986). The spruce is planted either the year of harvesting or one year after harvesting using 2+1 stock. Korean spruce requires deep, fertile soil. Planting with this species is successful at mid- and lower elevations on well drained soils if the water supply can meet the needs of the growing seedlings, and the soil is not too coarse textured. Artificial regeneration is not successful on extremely dry or wet sites, or if there is not adequate sunlight due to shading.

Survival Rates

The key reason that Korean spruce is widely accepted for use as a species for artificial regeneration is that it has a high survival rate. The survival rate of Korean spruce seedlings after the first year is generally above 95%, with 90% of seedlings remaining three years after planting, and 80% after canopy closure (Zhan 1987). There are two main reasons for the high survival rate: one is the high shoot:root ratio of seedlings which ensures initial survival on planting, and the other is the ability of Korean spruce roots to re-sprout. Korean spruce is a shallow rooting species, and although the main root does not develop very well, there are many fine roots. These fine roots can sprout new roots soon after planting.

Growth Rates

Korean spruce grows slowly in the early stages of stand development, but the growth rate of plantations is still higher than that of natural forests. This period of slow growth lasts for about ten years. The annual height increment of young trees can increase from 60 cm/yr to 80 cm/yr after ten years. Stand volume can reach 100 m^3/ha with an average annual increment of 5 m^3/ha at 20 years of age. In the early stages of development, Korean spruce grows more slowly than Xingan larch and Scots pine, but faster than Korean pine. The difference in growth rates between Korean spruce and fast-growing species such as Xingan larch and Scots pine is, however, not significant by 20 years of age because of the high initial planting density (4,400 seedlings/ha) and high survival rate of the spruce.

PROBLEMS IN YOUNG PLANTATIONS

Disease and Mouse Damage

Diseases, pests, and mouse damage are more serious in young plantations than in natural forests, and some degree of pest control is required. Among the species used for artificial regeneration, Xingan larch and Korean pine can suffer serious disease and pest damage, but Korean spruce and Scots pine are seldom affected. The most common diseases in plantations include *Mycospharella laricileptolepis* K. Ito et K. Sato, *Coleosporium salidaginie* (Schw) Thiim, *Trichoscyphella willkommii* (Hart.) Nonnf. and *Physalospora laricina* Sanada in Xingan larch plantations, *Cronartium ribicola* J.G. Fischer and *Cenangium ferruginosum* Fr. ex Fr. in Korean pine plantations, and *Cronartium quercum* (Berk) Miyabe in Scots pine plantations. The most serious damage by mice occurs in Scots pine forests, where sapling growth can be threatened. Xingan larch and Korean spruce also suffer from mice damage, but this does not lead to serious consequences, and thus no control measures have been taken for these two species in operational forestry practice.

Frost Damage

One problem found in young plantations of Korean spruce is damage to seedlings and saplings by late frosts in the spring. There is a dry spring with little rain every 3 or 4 years in the northeast of China. Under these conditions, the temperature can drop below zero during the night from May 20 to early June, and minimums of -8°C can be reached. However, flushing in Korean spruce begins in the middle of May, and thus frost damage may occur while the temperature is below zero. Frost damage results in the death of new needles and shoots, but more new branches will form later. Frost damage can affect current-year growth and tree form, but has no serious effect on the long-term development of spruce plantations. Generally, frost damage occurs in young stands that have not closed canopy, and at forest edges.

It is now known that there are two phenological types of Korean spruce, an early-flushing type and a later-flushing type. The former begins flushing in the middle of May, and the latter begins flushing 1-2 weeks later and does not suffer from frost damage. The later-flushing type should be chosen for the establishment of seed orchards to provide seeds for regeneration and planting programs to help prevent the occurrence of frost damage in young plantations.

Branching in Spruce Plantations

Branches and twigs of Korean spruce are luxuriant in plantations because of the strong shade tolerance of this species. Natural branch pruning does not take place very well in natural forests, which may affect timber quality in the future. Two approaches must be taken to solve this problem: one is to delay tending and thinning until 20 years of age and then to thin forests at a low intensity, leaving more living stems in the stands; the other approach is to use artificial pruning to remove both dead and living branches below 4 metres above the ground in stages.

CONCLUSION

Thirty years of experience have successfully demonstrated that artificial regeneration with Korean spruce gives rise to healthy plantations, and that this species has great potential for future use in the Northeast Forestry Region of China. The present trend is that the proportion of artificial regeneration with Xingan larch and Scots pine will decrease, and that of Korean pine and Korean spruce will increase. Selection of seed source, establishment of fast growing plantations that will produce high quality timber, and improvement of pruning techniques are the main spruce plantation research topics for the future.

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NITROGEN AVAILABILITY AND DECLINE IN WHITE SPRUCE PLANTATIONS

by

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ABSTRACT

Increment cores were obtained from five apparently healthy dominant white spruce (*Picea glauca* (Moench) Voss) trees in each of 37 permanent sample plots in plantations established at the Petawawa National Forestry Institute between 1924 and 1940. The difference between mean annual basal area increment for 1973-1987 and for 1958-1972, used as an index of relative growth or decline, ranged from -7.4 to 3.6 $cm^2 yr^{-1}$, with a mean of -1.8 $cm^2 yr^{-1}$. This index was positively correlated ($r = 0.473$, $p < .005$) with NH_4-N formation in mineral soil (0 - 15 cm), assayed using 6-week aerobic incubations at 30 °C. Growth decline was most evident where NH_4-N production rates were less than 0.5 mg kg^{-1} d^{-1}. White spruce may be unstable as a plantation species due to its tendency to acidify the soil. This initially promotes growth by increasing the availability of N in organic matter accumulated during previous stand growth, but eventually leads to depletion of N and other essential elements by uptake and/or leaching.

INTRODUCTION

Many factors have been suggested as causes of decline in European spruce plantations. Cramer (1984), reviewing earlier work, concluded that pure stands of Norway spruce (*Picea abies*) promote acidification, podzolization, and compaction of soil, which lead to decreased rooting depth, susceptibility to drought, and limited nutrient uptake. Another frequently cited problem in spruce plantations is the accumulation of "raw humus", poorly decayed litter with considerable organic N but little N mineralization activity. Slow litter decay promotes acidification (Nilsson *et al.* 1982, van Breemen *et al.* 1983), which may cause leaching of essential cations such as Ca, Mg, and K. Pollution-derived acid compounds in precipitation can accelerate cation leaching (Schulze 1989), and may also contain excessive amounts of nitrogen, leading to nutritional imbalances, lack of winter hardiness, and disease (Skeffington and Wilson 1988). Both insufficient soil N supplies and excess atmospheric N inputs have been blamed for spruce decline.

Canada's first extensive white spruce (*Picea glauca* (Moench) Voss) plantations were established between 1920 and 1932 on abandoned agricultural land near Grand'Mere, Quebec. Poor growth in many of the Grand'Mere plantations has been attributed to soil nutrient deficiencies, shallow rooting, repeated attacks of spruce budworm (*Choristoneura fumiferana*), and various pathogenic fungi (Gagnon 1978). Despite these problems, Gagnon (1972) maintained that establishment of white spruce plantations on the better sites at Grand'Mere represented "sound forest management". In contrast, Paine (1960) argued that "the lack of success with these plantations must seriously jeapordize the future of reforestation programs in eastern Canada." These conflicting views underscore the need for more studies of the factors affecting the growth of mature white spruce plantations.

Between 1924 and 1940, a number of white spruce plantations were established near Chalk River, Ontario. Scientists at the Petawawa National Forestry Institute have closely monitored volume growth and effects of thinning in these plantations (Stiell 1970, Stiell and Berry 1973, Berry 1987). Unlike the Grand'Mere plantations in Quebec, no extensive soil studies have been conducted at Petawawa. This report presents initial results from a 1988 sampling of soils in the Petawawa white spruce plantations, and examines some relationships among soil properties and indices of growth and decline.

Hendrickson, O.Q. 1990. Nitrogen Availability and Decline in White Spruce Plantations. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 67-73.*

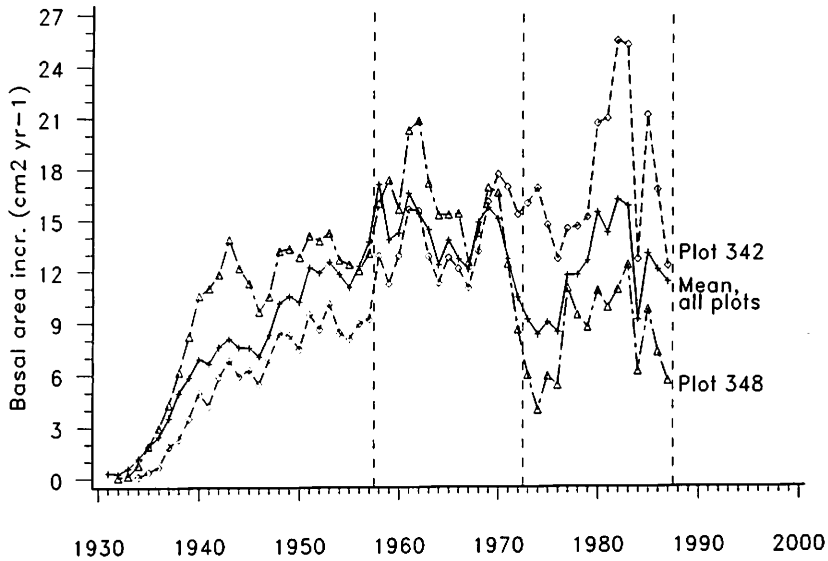

Figure 1. Annual basal area increments (cm² yr⁻¹) in the Petawawa white spruce plantations, based on increment coring of dominant trees. Mean trends for all plots, and trends for individual plots with the most and the least decline in the past 15 years are shown.

METHODS

Eight forest floor samples (20 cm x 20 cm) and eight mineral soil cores (7.2 cm diam. x 15 cm) were collected along the longer central axis through each of 37 permanent sample plots. The plots, varying in size from 0.04 to 0.10 ha, were located in pre-1941 white spruce plantations at the Petawawa National Forestry Institute (46°00'N, 77°26'W). Samples were pooled within each plot and depth. Subsamples were sieved (4 mm for forest floor, 2 mm for mineral soil) and assayed for moisture (dried at 80°C), organic matter (ashed 5 h at 500 °C), and pH (of a 1:1 or 1:2 slurry of mineral soil or forest floor in distilled water). Ammonium-N and nitrate-N contents of 19 g (dry weight equivalent) forest floor samples and 38 g mineral soil samples incubated aerobically in 500 mL canning jars for 0, 2, 4, and 6 weeks at 30 °C and 60% saturation water contents were determined by extraction with 1M KCl followed by steam distillation (Keeney and Nelson 1982). Air-dried subsamples were assayed for total N, total P, Bray-extractable P, and NH_4OAc-extractable Ca, Mg, and K by the Analytical Services Laboratory at the University of Guelph, Guelph, Ontario.

After the 1987 growing season, two increment cores were taken from five dominant trees in each of the 37 plots. Ring widths were measured to the nearest 0.1 mm and corrected for missed centers. Cores were cross-dated using computer programs and careful visual analysis. The permanent sample plot data were used to find the mean height and d.b.h. of all dominant trees (largest 400 ha^{-1}) at an index age of 40 years. These data were also used to derive annual basal area and volume increments on a whole-plot basis, calculated from year of planting to the year for which the most recent height data were available (41 to 57 years).

RESULTS

Considerable mortality has occurred in the Petawawa plantations. By age 40, numbers of stems averaged 2200 ha^{-1} in unthinned plots and 1100 ha^{-1} in thinned plots, compared to the 3315 stems ha^{-1} present at the time of the first measurement (Table 1). Thinning reduced natural mortality, and increased annual basal area production, but did not increase total annual volume production in the thinned plots (including volume removed and volume remaining).

Annual basal area increments, averaged for the 37 plots, have declined in recent years, although trends for individual plots vary greatly (Figure 1). The difference in annual basal area increment for 1973-1987 and for 1958-1972, derived from the five dominant trees in each plot sampled by increment coring, was chosen as an index of growth decline (or increase). This index varied from -7.4 to 3.6 $cm^2\ yr^{-1}$, with a mean of -1.8 $cm^2\ yr^{-1}$, and was negatively correlated with overall plot mean d.b.h. (r = -0.40, p = 0.015) or mean height of dominants (r = -0.32, p = 0.050). This indicates that plots which initially had better growth rates later showed steeper growth rate declines.

The mean height of dominants at age 40, used as an index of site quality, was positively correlated with the pH of the organic horizon, the Ca concentration in

Table 1. Growth variation in the Petawawa white spruce plantations.

Variable	Thinned plots (n = 22)		Unthinned plots (n = 15)
Height (m) of dominants, age 40	16.0 (13.5-19.4)		16.6 (14.5-19.1)
D.b.h. (cm) of dominants, age 40	21.6 (17.9-23.8)		21.9 (18.8-24.9)
Density (stems ha^{-1}), 1st meast.	3315 (1914-6474		3315 (2038-4912
Annual mortality (%)	0.79 (0.03-2.03)	*	2.24 (1.34-3.12)
Basal area increment (m^2 ha^{-1} yr^{-1})	1.04 (0.84-1.24)	*	0.83 (0.51-1.05)
Volume increment (m^3 ha^{-1} yr^{-1})	6.67 (4.77-9.54)		6.66 (4.51-9.04)

Note: Values are means, with ranges in parentheses. Asterisks indicate that means differ for the thinned and unthinned plots (t-test, $p < 0.05$).

Table 2. Correlation coefficients between site index or decline index and chemical properties of forest floor and mineral soil.

	Site index		Decline index	
	For. floor	Min. soil	For. floor	Min. soil
pH	0.463 ***	0.175	-0.120	-0.214
Total N	-0.248	-0.034	0.035	0.275 *
Total P	-0.035	0.235	-0.136	-0.085
Available P	0.044	-0.113	-0.460 ***	0.114
Available K	-0.105	-0.134	0.146	0.378 **
Available Ca	-0.118	0.414 **	0.096	0.123
Available Mg	0.102	0.255	0.020	0.305 *
NH_4-N production	-0.333 **	-0.400 **	0.060	0.438 ***
NO_3-N production	-0.125	0.505 ***	0.187	-0.245

Note: Site index is mean height (m) of the largest 400 trees ha^{-1} at age 40, and decline index is the difference in mean annual basal area increment (cm^2 yr^{-1}) between 1973-1981 and 1958-1972 for five healthy dominant trees. Values followed by single, double, and triple asterisks are significant at the 10%, 5%, and 1% levels, respectively.

mineral soil, and the NO_3-N production rate in mineral soil (Table 2). While negative correlations between site quality and NH_4-N production rates were found both in forest floor and mineral soil samples, it is possible that available N was depleted in the more productive plots. It should be noted that these chemical analyses were performed more than 40 years after the date of plantation establishment.

The decline index (described above) was positively correlated with K, Mg, and total-N concentrations and the rate of NH_4-N production rate in mineral soil (Table 2). Plots with steeper growth rate declines had lower amounts of essential nutrients (but not always the same ones which were related to site quality). In general, the chemical properties of the mineral soil were better predictors of growth declines than the properties of the forest floor.

Forest floor N mineralization rates decreased markedly over the 6-week incubation, with samples releasing little additional N after the first two weeks (Figure 2). Nitrification activity was absent in the forest floor. Mineral soil ammonium production rates were nearly linear over time. A substantial fraction of the total N mineralized was nitrified in mineral soil, and this activity increased with time.

Greatest declines in annual basal area increment occurred in plots where the net rate of mineral soil NH_4-N production was less than 0.5 mg kg^{-1} d^{-1} over the entire 6-week incubation period, although the data show considerable variation (Figure 3). Nitrification activity was not related to growth decline, and when NO_3-N and NH_4-N were summed to produce a measure of total N mineralization activity, the relationship with growth decline was weaker than for NH_4-N alone but still significant (Table 2).

DISCUSSION

Trends in the current study are comparable to those observed in the studies of the Grand'Mere plantations in Quebec: increasing mortality of the planted spruce through time, and unsatisfactory growth in many areas. Some of the mortality in the Petawawa plantations can be attributed to outbreaks of the root rotting fungus *Ionatus tomentosus* (Fr.) Gilbertson (Berry 1987). Nutrient availability also appears to play a key role in causing unsatisfactory growth in both the Petawawa and the Grand'Mere plantations.

Earlier work by Brand *et al.* (1987) in these same plots found substantial decreases in soil pH over time, as is commonly found in spruce plantations (e.g. Nihlgard 1971). Results of the present study suggest that this decline would reduce site quality for subsequent rotations of white spruce, since the factors associated with increased height growth (forest floor pH, mineral soil Ca, mineral soil nitrification activity) are all closely related to pH.

Nitrification is an acidifying process. Although it was once thought that nitrification is absent in very acid soils, European studies suggest that it does occur and may in fact play a key role in the "general forest decline" (van Breemen and van Dijk 1988). The susceptibility of nitrate to leaching promotes the concomitant loss of essential cations (K, Mg, Ca) which appear to be related to growth and decline in the Petawawa plantations.

Other factors besides nitrification contribute to acidification and cation loss in spruce stands. Increased weathering under spruce compared to beech, and associated loss of Mg, has been demonstrated by comparing changes in abundance of clay minerals with quartz after 80 years (Sohet et al. 1988). Alban (1982) noted that spruce decomposition products are generally more acid than those of other species, and showed that white spruce plantations had lower mineral soil Ca contents than adjacent pine plantations or natural stands of aspen. White spruce tends to accumulate more Ca and K in wood, bark, and foliage than other species with which it commonly occurs (Alban 1982, Hendrickson *et al.* 1987). It is also slow to shed dead lower branches, preventing their nutrients from returning to soil and displacing hydrogen from exchange sites.

Why does white spruce acidify the site, when this process is likely to deplete the soil of essential cations? One possibility is that acidification temporarily increases nitrogen availability in mixed stands where white spruce often occurs. Fisher and Stone (1969) found that conifers growing in old fields obtain nitrogen from previously inaccessible sources. Addition of acid to natural conifer stands enhances nitrogen turnover in humus (Tamm *et al.* 1977, Popovic 1984). In forest floor material taken from a mixed stand containing white spruce, increasing amounts of HCl greatly stimulated the release of mineral-N while inhibiting the release of CO_2-C (Figure 4). These effects would be magnified in white spruce monocultures, and could in time deplete available nitrogen and cause the accumulation of excessive amounts of carbon in surface horizons. Pastor *et al.* (1987) proposed a similar sequence of changes in nitrogen availability to explain the predisposition of natural spruce stands to decline or dieback.

These findings suggest that white spruce will be difficult to manage, particularly in pure stands under repeated rotations. Acidification and nutrient depletion problems might be less severe in stands of spruce mixed with hardwoods such as aspen or birch, where litter turnover rates would be faster and deeper root penetration could minimize nutrient leaching losses. Managers should be aware that any of a number of nutrient deficiencies may reduce the productivity of their white spruce plantations.

ACKNOWLEDGEMENTS

I would like to thank Dr. Jim Harrington for providing access to the white spruce increment core data set, and Dr. Dave Brand and Mr. Craig Robinson for providing access to the permanent sample plot records.

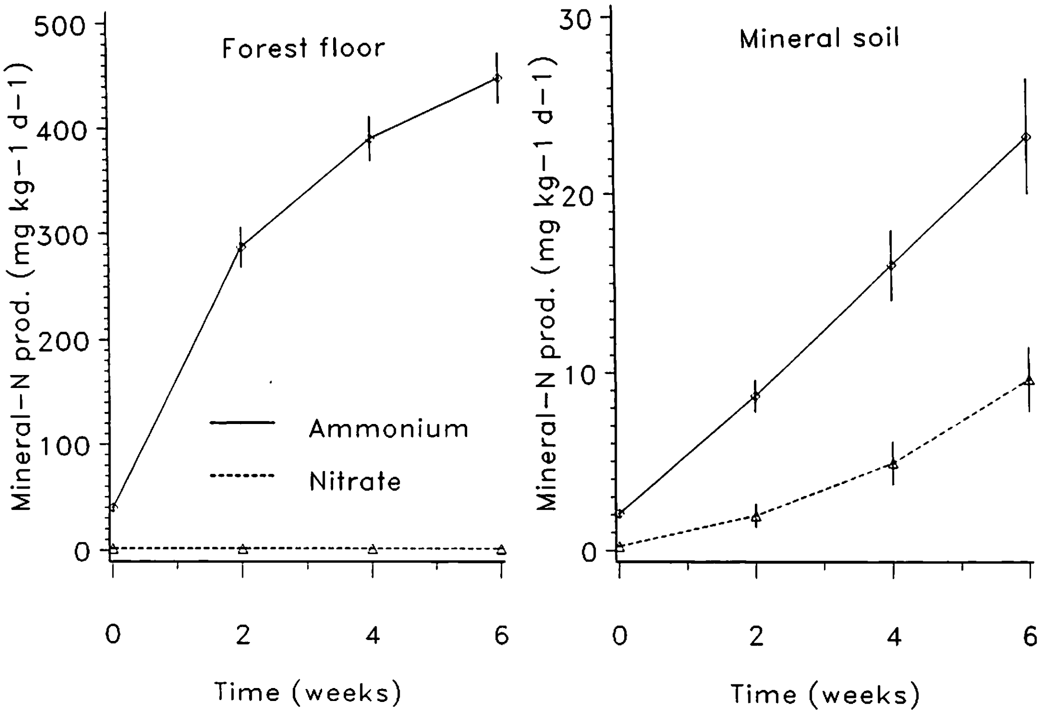

Figure 2. Forest floor and mineral soil NH_4-N and NO_3-N production in soil from the Petawawa white spruce plantations. Values are means (with SE) for all 37 plots.

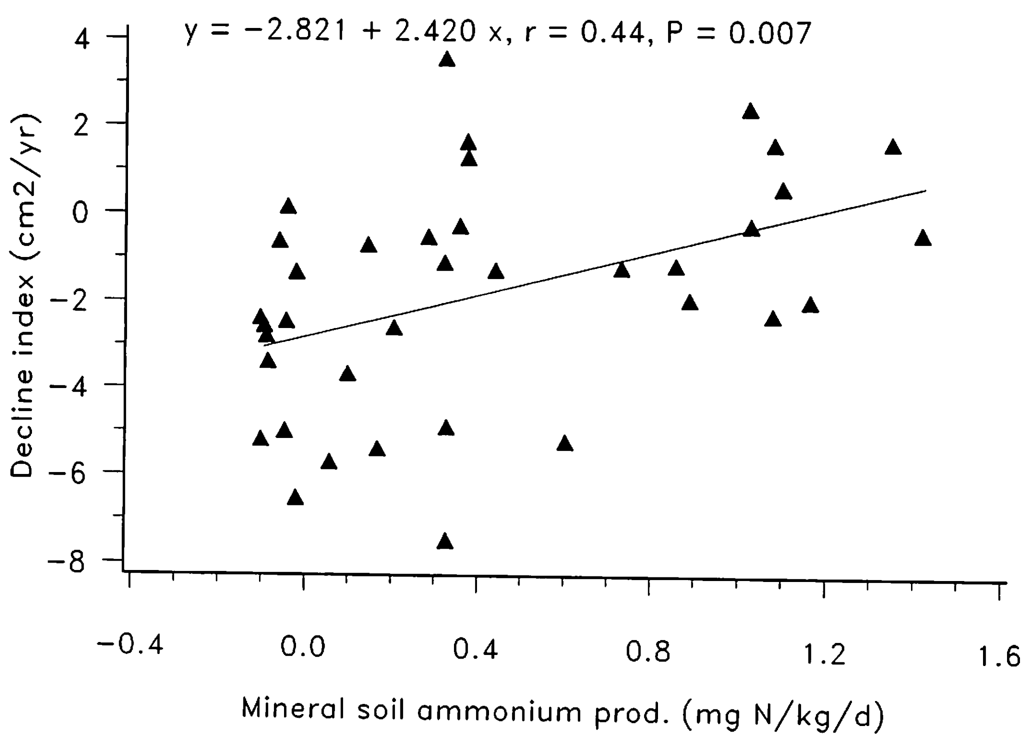

Figure 3. Relationship between growth decline (or increase) and NH_4-N production in mineral soil.

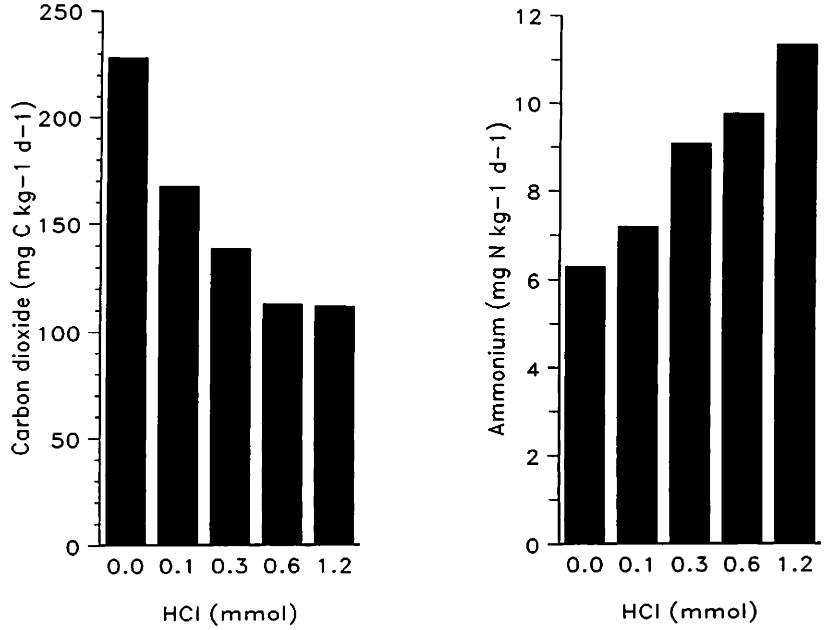

Figure 4. Effects of increasing acidity on N and C mineralization in forest floor from a mixed conifer-hardwood stand. Data are from Hendrickson (1985).

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THE EFFECTS OF HARDWOODS ON SOFTWOOD GROWTH IN MIXED STANDS IN FENNOSCANDIA

by

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ABSTRACT

Most studies of mixed softwood-hardwood stands in Fennoscandia concern Norway spruce (*Picea abies*) or Scots pine (*Pinus silvestris*), mixed with silver birch (*Betula pendula*) or downy birch (*B. pubescens*).

Birch admixture in conifer stands can have a positive influence both upon stand health and long-term soil development. However, birch can also be a competitor with conifers. Silver birch is a stronger competitor than spruce in young and middle-aged stands. During the first decades its height growth is greater than that of spruce. Downy birch is a more equal, or even weaker competitor than spruce. Its height growth is closer to that of spruce. When spruce sites are left to natural succession, Norway spruce, as a climax species, eventually becomes dominating.

Most studies indicate that the total volume yield of mixed birch-softwood stands is approximately equal to that of pure softwood stands. With a silver birch admixture, yield can be slightly better. However, an admixture of downy birch can give a slight growth loss. Under the present Finnish conditions, mixed stands of softwoods and silver birch are financially superior to pure softwood stands. The optimal birch proportion during the first 50 years of the rotation seems to be 20-60% by volume, depending on the conifer species. After this stage, the birch proportion should be strongly reduced by thinning.

Frivold, L.H and Mielikäinen, K. 1990. The Effects of Hardwoods on Softwood Growth in Mixed Stands in Fennoscandia. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 75-82.*

INTRODUCTION

Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) are the most abundant tree species in Fennoscandia. The most common hardwoods are downy birch (*Betula pubescens* Ehrh.), silver birch (*B. pendula* Roth), aspen (*Populus tremula* L.) and grey alder (*Alnus incana* Moench.). Norway spruce is a climax species, and on suitable sites it will eventually grow through the pioneer hardwood canopy and become dominant.

While the commercial value of spruce and pine has been unquestioned for more than a hundred years, the demand for hardwoods has fluctuated. Large dimension birch has always been valuable for the sawmilling and plywood industry, at least in Finland. The demand for small-sized hardwoods has often been inadequate. However, recently, both the economic and multiple-use importance of hardwoods has clearly increased in all three countries.

In spite of silvicultural practices that favour conifers, hardwoods have always been successful in the forest ecosystem. Shifting cultivation in the past and clearcutting today have guaranteed the survival of hardwoods.

The most common types of mixed stands in Fennoscandia are spruce-pine mixtures, and mixtures of conifers and birch. Both Scots pine and birch are light demanding tree species. Mixed stands of pine and birch thus tend to be single-storied. Mixtures of Norway spruce and birch can form both one- and two-storied stands, because of their different patterns of height growth and the ability of Norway spruce to tolerate shade.

Several approaches have been utilized in Fennoscandian yield research in mixed birch-conifer stands. Research in pure stands has however had priority. Studies in older stands are thus most often non-experimental, while series of experiments are established in younger stands. There are few studies in mixed stands with hardwood species other than birch.

ECOLOGICAL EFFECTS OF HARDWOODS

The hardwoods in question shed their leaves every autumn. Decomposition of the litter improves soil properties. Mälkönen (1977) found that the dry matter production of leaves in a birch stand was 2900 kg/ha/year. The stem volume growth was of about the same magnitude in this stand (2740 kg/ha/year). The high calcium content of birch leaves increases microbial activity and hence the rate of nutrient cycling in the soil (Mikola 1985). On peatlands, common birch helps conifer growth by lowering the soil water content through increased transpiration and by transporting oxygen into the soil via its roots (Huikari 1954).

The potential effect of hardwoods on soil acidity has been discussed by Troedsson (1985), who examined a large number of samples from conifer stands with various admixture proportions of birch from all over Sweden. He found that the pH of the upper layer of the soil was highest in stands with a high proportion of birch. However, a problem inherent in this survey was the question of whether the birch had indeed improved the soil, or whether the birch had merely regenerated on soils with a high pH. Preliminary results from a study of soil properties under natural birch stands and planted spruce stands in West Norway also indicate a higher pH under birch than under spruce (Frank 1989). This material was collected entirely outside the range of natural spruce, suggesting that birch is a reason for higher soil pH, rather than a result of it.

Mixed stands are considered to be healthier than monocultures. The main reason for this is that fewer root and crown connections between trees of the same species occur. In the stands examined by Rennerfelt (1946), root rot of Norway spruce was considerably more frequent in monocultures than in mixed stands

The microclimate of a mixed stand can be unfavourable to certain insects. Ozols (1960) found that Pine bark bug (*Aradus cinnamomeus* Pz.) was five times more frequent in pure pine stands than in pine-birch mixtures. Also, damage to one tree species in a mixed stand can be compensated for by improved growth conditions for the other species.

THE EFFECT OF COMPETITION IN YOUNG MIXED STANDS

Solem (1982) studied the development of 200 planted spruce trees growing in competition with younger downy birch. Birch reduced height growth of spruce significantly when the mean distance to the spruce tree was less than 1 m, birch was taller than spruce, and crown projection percentage of hardwoods was greater than 50%. Diameter increments of spruce were more sensitive than height growth to hardwood competition.

A small-scale cleaning study from northern latitudes gave varying results (Folkesson and Bärring 1982). In one plot, cleaning of birch improved spruce growth considerably, in another moderately, while in the third plot spruce was growing better under a birch canopy. In the latter case, protection by the birch canopy from frost damage was thought to be the reason for improved spruce growth.

In a group of young, mixed stands chosen for a cleaning experiment, silver birch grew 60-80 cm/year, and spruce and downy birch grew 20-40 cm annually (Braathe 1988). The difference in height increment between species is believed to determine the future development of the mixed stands. In plots with dense hardwood canopies, height increment of spruce was less than in plots with all hardwoods removed. In many stands the height increments in plots with a small amount of birch left after cleaning were greater than in completely cleaned plots. This can be ascribed either to differences in initial site quality (Braathe 1988, p. 5), or to positive influences from birch.

Tham (1987) observed retarded height growth in 75% of the spruces in young mixed stands with spruce and birch prior to their cleaning. Between 1 and 11% of the spruces had dead tops due to mechanical damage (friction). There was little mortality among spruce in these stands.

THE EFFECT OF BIRCH ADMIXTURE ON STAND VOLUME GROWTH

Competition of trees in mixed stands

In both pure and mixed stands, trees compete below ground for water and nutrients. The different rooting depths of tree species thus decreases below ground competition in mixed stands. Fast growing birch, on the other hand, increases crown competition.

Lappi-Seppälä (1930) and Jonsson (1962) concluded that an admixture with birch improves both diameter and height growth of conifers. Silver birch and downy birch were not differentiated in these studies. Silver birch grows faster and competes more strongly than downy birch.

Mielikäinen (1980, 1985) found that an increasing proportion of silver birch in the stand decreased the growth of pine, spruce and birch itself (Figure 1). Downy birch had no effect on conifer growth.

One-or multi-storied stands

The following studies all utilized temporary sample plots in middle-aged to mature stands. The results reveal direct effects of inter-tree competition on growth and yield of mixed stands. To study long-term effects of hardwood admixture on soil development, permanent experiments are needed. The results thus might underestimate the growth of mixed stands.

The first Nordic study in this field was that of Lappi-Seppälä (1930), who compared the total yield of unthinned mixed stands of Scots pine and birch to yield tables for pine. Pine grew better in mixed stands than in pure stands. The optimum proportion of birch was 20% of total stand volume (see also Jonsson 1962).

Frivold (1982) studied a number of sample plots in natural, more or less multi-storied mixed stands of birch and spruce. In most plots, the mean height of spruce reached well into the crown of birches, and the birch was slightly younger than the spruce. Damage from friction (whipping) was recorded in about 10% of the spruce trees. There were no significant correlations between percentage of friction damage and factors such as stand density index or mean height relationship of birch and spruce. Birch admixture did not seem to contribute to self-thinning in spruce, except at a few very drought-susceptible sites. Top height/age site indices were used to compare results with yield tables for pure stands. The volume yield of spruce and birch together was closer to yield table values for pure birch stands than to those for pure spruce stands. Reflecting the growth rhythm of the species, the mean annual increment in birch-dominated mixed stands could compete with that for pure spruce stands up to the age of 40-60 years. In older plots, the increment of the mixed stands was inferior.

According to Mielikäinen (1980), young mixed stands of Scots pine and silver birch in Finland grow best as a 50-50 mixture. In old pine stands, birch admixture leads to a growth loss. A sparse silver birch admixture leads to an increase of growth both in young and old Norway spruce stands (Mielikäinen 1985). This may be explained by differences in the growth rhythms of the tree species and changes in the microclimate of the stands (Figure 2).

The effects of a birch admixture on the total growth over a full rotation are presented in Table 1. The results for pine and birch are simulated by using stand growth models (Mielikäinen 1980). The initial stand was a young pine stand with 50% silver birch by

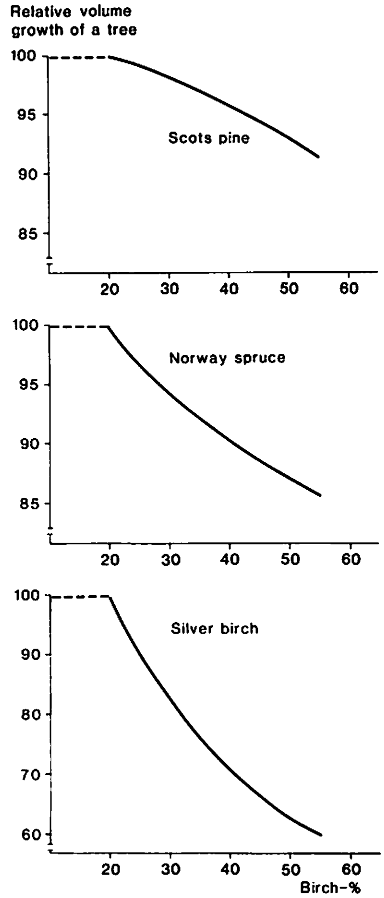

Figure 1. The effect of silver birch on the relative volume growth of trees. Pure conifer stand = 100 (after Mielikäinen 1980, 1985).

volume. Thinnings in the model are directed mainly at birch, and convert the pine-birch stand to a pure pine stand towards the end of rotation. The growth of spruce-birch stands was simulated by tree models (Mielikäinen 1985). The initial stand here was a first thinning spruce stand with a 25% birch admixture. The degree of mixture has been kept constant in all thinnings.

The yield of a mixed stand of Scots pine and silver birch was similar to or slightly better than the yield of a pure pine stand (Table 1). A prerequisite for high growth rates in the mixed stand is intensive silviculture and thinnings directed at birch.

A small amount of silver birch in a spruce stand resulted in a growth increase of 3-5% over the whole rotation (Table 1). The saw timber production was 6-9% and the dry matter production was 9-11% higher in the mixed stand.

Stands containing downy birch produced slightly lower yields than pure pine and spruce stands. Nevertheless, downy birch is often the only supplementing tree

Table 1. The effect of tree species composition (thinning programme) on the total production of stemwood, saw timber and dry weight in mixed stands of birch and conifers in Finland. Rotation 80 years. (After Mielikäinen 1980, 1985).

Alternative	Total yield (%)	Saw timber (%)	Dry weight (%)
Norway Spruce - *B. Pendula*			
Site index (H_{100}) = 30			
Spruce stand	100	100	100
25% birch mixture	105	109	111
50% birch mixture	103	102	115
Norway Spruce - *B. Pubescens*			
Spruce stand	100	100	100
25% birch mixture	96	91	102
50% birch mixture	99	91	108
Scots Pine - *B. Pendula*			
Site index (H_{100}) = 28			
Pine stand	100	100	100
B. pendula stand	80	54	96
50% birch mixture	100	86	110
0-50% birch mixture	102	94	110

species in Fennoscandian conifer stands, and might be valuable in maintaining long-term soil productivity. Further, conifer growth is less likely to be reduced in that downy birch is not as strong a competitor as silver birch.

Agestam (1985) used a great number of temporary sample plots in various kinds of stands to construct a growth simulation model for mixed stands of pine, spruce and birch. The growth simulation did not reveal any explicit effect of birch admixture on total volume yield. This need not be in contradiction with the results of Mielikäinen cited above, however, as Agestam's model did not differentiate between the two birch species.

Two-storied stands

A large yield study in first-measurement plots of silver birch of various ages included an investigation of spruce undergrowth (Fries 1964). The study comprises data from 1272 spruce trees in 78 plots. The results suggest that height development of spruce undergrowth is not severely influenced by the sheltering birches. However, Fries (1964) expected a conflict between the two species when spruce grew into the birch canopy.

Tham (1988) studied the growth of Norway spruce under birch shelter. The study consisted of permanent experiments, the oldest of which had been measured for 37 years. Growth simulations were made using tree competition models based on mapped data. According to this study, a Norway spruce stand with birch shelter clearly produces more wood than a pure spruce stand (Figure 3). A birch shelter of 500-600 stems/ha did not decrease the growth of spruce over a 50 year period (birch was removed at the age of 25 years in this simulation). The total growth of both tree species together was greatest when the density of the sheltering birches was 800 stems/ha. The total growth of birch over 25 years was 50-80 m^3/ha, depending on the birch species.

In the coastlands of northern Norway, beyond the natural range of spruce, Bergan (1987) studied the influence of birch shelterwood on planted spruce. Experiments were laid out in natural birch forests with spruce underplanting. It was concluded that a shelterwood is necessary to achieve a satisfying result on sites rich in grasses and herbs, in areas exposed to early and late frosts, and in steep terrain with a deep snow cover (> 1 m). On good sites the height development of spruce seedlings was better under shelter in the first years after planting. About 150 shelter trees per hectare seems to be sufficient, and

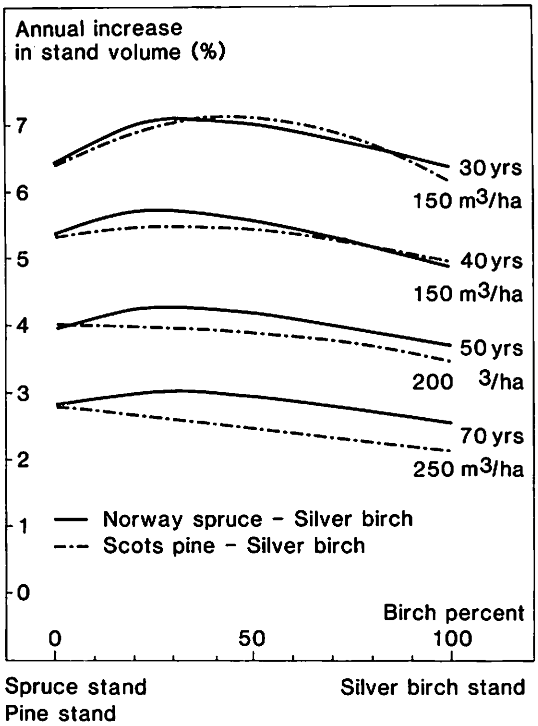

Figure 2. The annual volume growth during the future 5-year period in mixed stands of silver birch and the conifers as a function of stand age, stand volume and birch admixture (after Mielikäinen 1980, 1985).

shelter trees may be removed when spruce trees reach a mean height of 1 - 3 m. In steep terrain with a deep snow cover a denser shelterwood is recommended, and shelter trees should be kept longer.

There are few studies in Fennoscandia concerning the admixture of hardwood species other than birch. An analysis of a single, planted mixed aspen-spruce stand in southern Norway (Hegre and Langhammer 1967) supports the hypothesis that the effect of aspen on spruce is not profoundly different from the effect of birch on spruce.

ECONOMY OF MIXED STANDS OF HARDWOODS AND SOFTWOODS

The economies of growing a mixed stand depend upon volume production, wood prices and the cost of growing and harvesting stands. Valsta and Mielikäinen (1987) and Valsta (1988) studied the economics of mixed stands of Scots pine, Norway spruce and silver birch in Finland using dynamic programming. The simulations show that a mixed stand is financially superior to a pure stand. The optimal birch proportion during the first 50 years of the rotation is 20-60%, depending on the conifer species being grown. After this age, thinnings must be mainly directed at birch to convert the stand into a clearly pine or spruce dominated stand before the final cut (Figure 4).

A study from Sweden, where birch pulpwood now plays an important part in the timber market, concludes that leaving birch as fill-in trees in conifer regenerations is profitable (Hägg 1988).

Some reduction in diameter growth of conifers by competition from, for example birch, can be beneficial for wood quality both in spruce (Braathe 1988) and pine (Hägg 1988). Wide initial spacings (2 - 2.5 m) are common in conifer cultures in Fennoscandia.

CONCLUSIONS

Our conclusions from the cited studies are:

1. Norway spruce is well able to survive and grow in mixtures with birch, except on very dry sites.

2. Silver birch is a stronger competitor than spruce in young and middle-aged stands. In the first decades after stand establishment the height growth of silver birch is greater than that of spruce, giving rise to a two-storied phase during the development of even-aged stands.

3. Downy birch is a more equal, or even weaker competitor than spruce. Its height growth is closer to that of spruce. In even-aged stands, the two-storied phase can be less pronounced than with silver birch.

4. Both birch species are light-demanding, and tend to live shorter than Norway spruce. Birch cannot regenerate under a spruce canopy. If mixed stands are left undisturbed, they will therefore eventually turn into more or less pure spruce stands.

5. Results vary concerning the effects of birch admixtures on the height development of spruce. Several surveys of older mixed stands suggest that the top height of spruce is not severely influenced. Surveys of younger mixed stands, however, indicate that a dense canopy of birch slows down height growth of spruce. A slight admixture of birch can increase height growth of spruce, according to some studies.

6. Birch shelterwood has a definite positive effect on the growth of young spruce on sites susceptible to summer frost. The same has been reported on sites rich in grasses and herbs in northern latitudes.

7. The effect of silver birch on diameter growth of spruce is greater than the effect on height growth. When competition is significant, this reduces volume production in spruce. Results vary concerning the

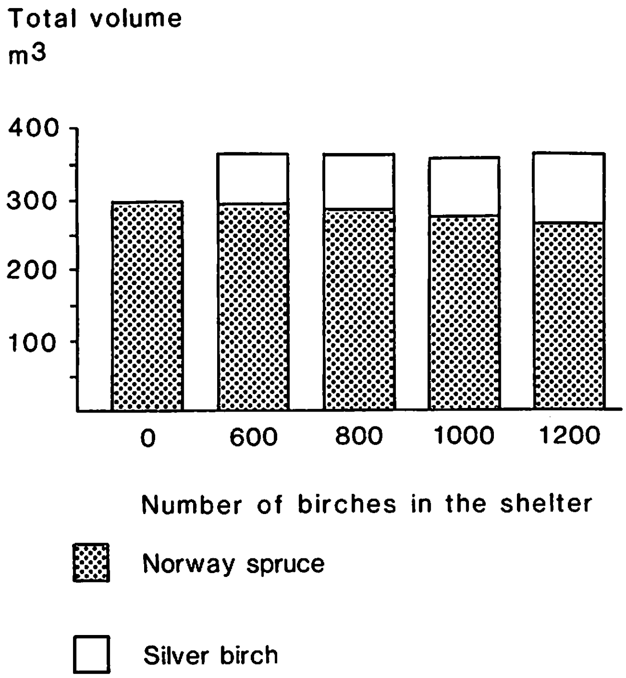

Figure 3. The total yield of Norway spruce and silver birch in 50 years with five combinations of managed birch shelters. 1600 Norway spruce (after Tham 1988).

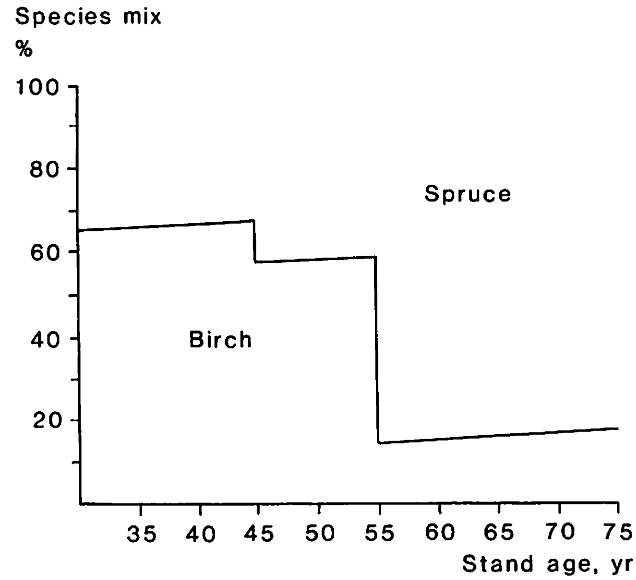

Figure 4. The optimal species composition (percent of stand volume) when maximizing soil expectation value at a 3% interest rate (after Valsta 1988).

effects of downy birch. Leaving birch as fill-in trees in widely spaced conifer cultures is likely to improve the wood quality of conifers.

8. Damage to spruce from mechanical friction (whipping) varies considerably among stands. Surveys which included this feature suggest an overall frequency of severe friction damage in approximately 10% of the spruce trees.

9. Finnish investigations show that total volume yield of all species in mixed birch-spruce stands surpass that of pure spruce stands if the birch species is silver birch. Under Finnish conditions, mixed stands of spruce and silver birch are financially superior to pure stands. With downy birch, volume yield of mixed stands is less than that of pure spruce stands. If dry weight is considered instead of volume, some admixture of any of the birch species increases total yield.

10. For Scots pine stands, some authors report an increase in growth of pine from birch admixtures, others report no influence (from downy birch) or a decrease (from silver birch). The total volume yield of all species in mixed birch-pine stands can be equal to or surpass that of pure pine stands if the birch species is silver birch, and thinnings are directed at birch. Under Finnish conditions, such mixed stands are financially superior to pure stands. With downy birch, total volume yield is slightly inferior.

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THE EFFECTS OF ERICACEOUS PLANTS ON FOREST PRODUCTIVITY

by

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ABSTRACT

Ericaceous plants are associated with heathland conditions where conifer regeneration is often slowly established and chlorotic, or even excluded. The reasons for the growth check and lower fertility are reviewed, including the heather check syndrome in the U.K., the evidence for allelopathy, soil acidification and paludification, and changes in humus decomposition. The management implications for Canadian *Kalmia*, *Ledum*, *Vaccinium* and *Gaultheria* dominated cutovers are also reviewed. It is concluded that prevention of heath invasion is preferable to the slow and costly ploughing, hoeing and fertilization treatments usually required to regenerate ericaceous dominated cutovers and burns.

DISTRIBUTION OF ERICACEOUS PLANTS IN THE NORTHERN HEMISPHERE

Ericaceous plants are one of the most ecologically successful plants in the Northern Hemisphere, with representatives dominating vast areas of heathlands. The term "heathland" is used to describe territories in which trees or tall shrubs are sparse or absent, and in which the dominant life-form is that of the ericaceous dwarf shrub, as represented by the order Ericales, particularly of the family Ericaceae, which comprises about seventy genera and more than 1900 species. Specht (1978) has enumerated the common traits for worldwide heathlands as follows: (*i*) their evergreen sclerophyllous nature; (*ii*) the presence, but not necessarily the dominance, of the heath families in the stand - Diapensiaceae, Empetracaea, Epacridaceae, Ericaceae, Grubbiàceae, Prionotaceae, Vaccinicaeae; (*iii*) their ecological restriction to soils very low in plant nutrients. These infertile soils may be well-drained (supporting dry-heathlands or "sand-heath") or seasonally waterlogged (supporting wet-heathland).

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The conditions favouring the dominance of heathlands involve a combination of a relatively cool temperate regime, high humidity throughout most of the year, and rather freely-drained soil not conducive to formation of peat. In addition, some factor, whether climatic, edaphic, biotic or anthropogenic, must operate to initially remove, or exclude the development of taller shrubs and trees. This type of environment may be expected in three main categories of situations (Gimingham 1972): (*i*) where for any reason forest is excluded in the strongly oceanic regions of the cool-temperate belt; (*ii*) in certain parts of sub-arctic and sub-antarctic territory; and (*iii*) where adequate humidity prevails at sub-alpine or low-alpine altitudes on mountains. Of the three situations, the first is of particular economic and land-use importance in developed countries and will be the focus of this paper.

Oceanic heathlands are most widely represented in western Europe, South Africa, Eastern Canada and U.S.A. In Europe, the heath region belongs essentially to the oceanic and sub-oceanic regions of west Europe, particularly the broad west European coastal plain in countries bordering the North Sea and the English Channel. The most prominent genera are *Erica* and *Calluna*. In Canada, the heathlands predominate in Nova Scotia, Newfoundland and coastal British Columbia, while in U.S.A., mainly along the extreme eastern coastline from Maine to South Carolina and the Alaska panhandle; the prominent genera are *Vaccinium, Gaylussacia, Gaultheria, Rhododendron, Kalmia and Arctostaphylos.*

Heathlands of the cool-temperate oceanic region are believed to have arisen from pre-existing forests following human settlement and land cultivation. Pollen analytical studies indicate the expansion of ericaceous pollen in relation to tree pollen in Denmark (Jonassen 1950) and Norway (Kaland 1986). Historical land use studies indicate repeated cutting and burning for agricultural land use effectively maintained and perpetuated the heath vegetation over considerable areas of Britain (Conway 1947), Sweden and Denmark (Romell 1952), Norway (Kaland 1986) and Newfoundland (Meades 1986). Similarly, clearcut logging and slashburning on northern and western Vancouver Island has stimulated the productivity of *Gaultheria shallon* Pursh. which appears to be excluding forest tree regeneration (Weetman *et al.* 1990).

THE EFFECTS OF THE ERICACEAE

The Heather Check Syndrome

The effect of ericaceous plants on trees was first observed between *Calluna vulgaris* (L.) Hull. and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Scotland by Muller (1897) who commented that although cultivation of the heathland soil by ploughing and harrowing several times in the course of three years resulted in satisfactory growth of spruce, this was only maintained so long as heather did not re-invade the sites. Prevention of re-invasion by heather allowed the spruce to continue to grow but once the heather covered the site again, stagnation of the spruce ensued; this effect was more pronounced where there had been more rapid growth of the spruce following cultivation of the soil.

In early trials of afforestation on the heathlands, it was noted that "heather-sensitive" species such as Sitka spruce, Norway spruce (*Picea abies* (L.) Karst.), Douglas-fir (*Pseudotsuga menziessii* (Mirb.) Franco), silver fir (*Abies amabalis* (Dougl.) Forbes), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and Lawson cypress (*Chamaecyparis lawsoniana* (A. Murr.) Parl.), virtually ceased growth when planted in *Calluna* swards. Pioneer species such as pines and larches, did not suffer this "check" to their growth (Weatherall 1953).

Fertilizer applications led to the belief that stagnation of Sitka spruce on heather-dominated sites was the result of direct competition by heather for water and nutrients, especially nitrogen (N) and phosphorus (P). However, the elimination of heather did not always alleviate the checked condition, particularly on sites deficient in N and P. Fertilization of these sites with N and P resulted in a temporary growth response, but it soon became apparent that further fertilization was necessary. Thus, the *Calluna* check was caused by more than just a nutrient deficiency (Malcolm 1975).

Braathe (1950) suggested unfavourable soil conditions, excessive soil acidity, deficiency of trace elements in the soil, deficiency of mycorrhizal fungi and severe competition from *Calluna* as being responsible for the inhibition of growth of spruce on heathlands. He found it very difficult to believe that the soil could change so markedly in two to three years, or that the *Calluna* at the time of invasion could monopolize all the nutrients so completely. He therefore concluded that *Calluna* had a biological effect on spruce and suggested that a substance was produced which in some way inhibits the growth of spruce.

Circumstantial evidence for allelopathy by the Ericaceae was gathered in Scotland where it was noted that species sensitive to heather competition did not develop the branched mycorrhizal root systems typical of the normal condition of actively growing plants. This led to the speculation that some factor closely associated with the *Calluna* plant prevented the development of the ectomycorrhizal association in the trees. Handley (1963) found that aqueous extracts of mor from stands of vigorous *Calluna* could inhibit the growth of a range of mycorrhizae-forming fungus, whereas extracts from other soils of similar acidity and nutritional status did not. Some fungi, including those that formed mycorrhizal associations with pine, were not inhibited. The inhibition was less pronounced where the mor sample came from shaded *Calluna* or was less acid. There seemed to be some variation in the resistance of fungi to the inhibitory factor, suggesting that some strains of fungus could form ectomycorrhizal associations with trees such as pines, that could apparently tolerate the *Calluna* competition. The disappearance of the factor inhibitory to the mycorrhizae when the *Calluna* was suppressed suggested that it must be continuously produced to maintain an inhibitory level.

Handley's work did not achieve immediate acceptance, and as late as 1970 researchers were still suggesting that direct competition of *Calluna* was inhibiting the growth of trees (Bjorkman 1970). However, the ability of "heather-sensitive" species to compete with other vegetation, some of which is more demanding in its water and nutrient demands than *Calluna*, would seem to relegate direct competition to a somewhat lesser role.

According to Read (1984), toxicity of heathland soils occurs as a result of the ability of *Calluna* to modify the soil environment in its favour. Interactions between the high organic acid content of humus, low pH, and low base status produce phytotoxicity sufficient to exclude or debilitate most would-be competitors. The success of ericaceous species therefore must be examined in terms of all interacting effects.

Evidence for Allelopathy

Phenolic compounds are the most likely class of compounds implicated in allelopathy of ericaceous plants. Harborne and Williams (1973) found that simple phenols were abundant in the Ericaceae, particularly hydroxybenzoic, cinnamic, gentisic, vanillic, p-coumaric acid, and caffeic acids. Catechol and salicylic acids were found by Towers *et al.* (1966) to be important markers in *Gaultheria.* Of the common flavonols, quercitin is found to occur in all species, while both kaempferol and myrcitin are of more limited occurrence. Myrcitin is found in more woody members of the family such as Rhododendroideae, Ericoideae, Vaccinoideae, and Cassiopeae, while a predominance of kaempferol occurs in the more herbaceous members such as Pyroloideae and Monotropoideae (Harborne and Williams 1973).

The occurrence of phenolic compounds in living tissue does not prove an allelopathic effect exists, or even that these compounds are released into the soil environment. Furthermore, the release of plant-produced phytotoxins and correlated toxic qualities of the environment does not mean that the original toxic product acts, in unchanged condition, as the allelopathic agent. Some factors of the environment that affect retention or alteration of allelochemicals include redox potential of the soil, its fixation on clay or humus, the presence of metallic ions for chelation reactions, and the composition of the soil solution and atmosphere (Vaughan *et al.* 1983; Haider and Martin 1975; Huang *et al.* 1977). For example, levels of phenolic acids have been shown to vary seasonally in soils under *Erica australis* L. (Carballeira and Cuervo 1980) and *Calluna vulgaris* (Jalal and Read 1983a and b) ranging from very low levels in late summer months to maximum levels of 0.12 mM in early summer months. The seasonal nature of phenolic acid concentration was felt to be associated with accumulation during cold, wet winter months; increasing aeration and temperature in spring leading to more rapid breakdown by microbial and fungal metabolism and growth, and increased production of phenolics at the roots in spring (Jalal *et al.* 1982).

The high concentrations of phenolics in the Ericaceae and/or the allelopathic interaction between ericaceous and non-ericaceous species has been examined for *Erica scoparia* L. and *E. australis* L. in Spain (Ballester *et al.* 1977; Carballeira 1980; Carballeira and Cuervo 1980); for *Arctostaphylos glauca* Lindl. and *A. glandulosa* Lindl. in the California chaparral (Muller *et al.* 1968; Chou and Muller 1972); for *Calluna vulgaris* in Scotland (Handley 1963; Robinson 1972; Jalal *et al.*, 1982; Jalal and Read 1983a and b); and for *Kalmia angustifolia* L. in Newfoundland (Mallik, 1987).

In contrast to the idea of a direct release of phenols from the ericaceous plant, Read, working with the ericoid mycorrhizae of ericaceous species, proposes that the ericoid mycorrhizae produces exoenzymes which cleave off smaller phenolic molecules from the complex organic media on which the ericaceous plants grow (D.J. Read, Department of Botany, University of Sheffield, U.K., S10 2TN, *pers. comm.*, 1989). In this way the fungi is readily able to obtain a carbohydrate and nutrient source, while enriching the availability of simple phenolics in the root environment of competitors.

The mechanisms by which organic acids act as allelochemicals is still unknown. Glass (1973, 1974, 1975, 1976) and Glass and Dunlop (1974) concluded that a likely mechanism is that the phenolic acids partition themselves between the aqueous medium and the lipid component of the cell according to their lipid solubilities. The membrane then becomes permeable to both anions and cations. This resultant loss of ions rapidly depolarizes the membrane potential by increasing the permeability coefficients of the ions and by reducing the imbalance of ion concentrations across the cell membrane. The dysfunctioning of the plasma membrane then leads to the failure of cells to maintain proper mineral nutrition. This could then lead to the inefficiency of the energy systems of respiration and photosynthesis in plants which demand precise membrane organization, charge separation, and the work of membrane-associated proteins.

A somewhat similar effect on growth as occurs with membrane dysfunctioning, could occur with impairment of the establishment of a mycorrhizal association by trees growing on these nutrient deficient, acidic sites. Several studies have shown the fungi toxic effect of *Calluna* on mycorrhizal associations of competing species. Handley's (1963) experiments showed that *Calluna* or its ericoid mycorrhizae were responsible for the release of a factor inhibitory to the formation of ectotrophic mycorrhizal associations of competing trees. The prevention of the mycorrhizal association was due not to lack of fungal inoculum, but to the prevention of growth and inoculation by the fungus, because any factor which restricted growth of *Calluna* was conducive to the formation of mycorrhizae by the checked trees. When Handley grew saprophytic soil microorganisms in aerated extracts of *Calluna* raw humus inhibitory to the mycorrhizal fungus, the inhibitory effect disappeared; he concluded that the toxin must be continuously produced. Robinson (1972) confirmed Handley's observations.

The inability to properly absorb nutrients at the membrane, or to form mycorrhizal associations, can then have far-reaching implications for overall plant growth. Alterations of the mineral content of plants subjected to nonspecific allelopathic conditions has been shown in more than a dozen investigations (Rice 1984), but it is difficult to generalize about changes in mineral content incurred from allelopathic interference. Phosphorus contents are frequently reduced, while nitrogen, potassium and magnesium uptake may be increased or decreased. Consistent with these findings of nutrient imbalance is that tree species "sensitive" to ericaceous plants often show symptoms of N and P deficiency (Malcolm 1975; Weetman *et al.* 1989). Fertilizer applications to overcome allelochemical induced growth suppression have been shown in laboratory experiments, as well as with field experiments using "sensitive" trees.

Soil or substrate fertility can affect the toxicity and rate of breakdown of phenolics; higher fertility leads to a more rapid breakdown and less toxic conditions. This was shown in a study by Stowe and Osborn (1980) where phenolic toxicity appeared to depend intimately on nutrient concentrations; the phenolic acids were uniformly and significantly inhibitory only at low nutrient concentrations. Since phenolics are more likely to be produced in a plant under stress (Rice 1984) it appears that allelopathy with phenolics is more likely in nutrient poor soils.

Soil Acidification and Paludification

Heathland flora is generally indicative of oligotrophic, acidic soils, but more significantly, ericaceous plants may actually contribute to the process of soil acidification, which may be one reason why they are capable of invading and dominating more complex vegetation types. Pollen analysis of heath soils by Dimbleby (1962) has shown that the rise of dominance of *Calluna* is closely linked with increasing soil acidification, the disappearance of deep-burrowing earthworms and the subsequent accumulation of raw humus. Similarly, Webley *et al.* (1952) have shown marked reductions in bacteria and increases in fungi when a fixed *Ammophila* sand dune community was succeeded by a dune heath dominated by *Calluna*. Grubb *et al.* (1969), found a strong correlation between the size of *Calluna* bushes and the soil pH beneath their centres; also between distance from the centre and pH both at the soil surface and below. More direct evidence for soil acidification by ericaceous plants was shown in a study with *Calluna* and *Rhododendron*, which dominate soils of very low pH in the range 3-4. When grown in sand with mineral nutrient solution at pH 4.5, *Calluna* and *Rhododendron* acidified the medium to below pH 4.0 in 8 weeks, and to 3.5 in a subsequent 2 month period (Read 1984). The increase in acidity was felt to be due to production of organic acids and to the depletion of the soil base status.

The presence of well developed heath vegetation is associated with soil podsolization, in which sesquioxides are eluviated to lower mineral horizons (Soil Survey Staff 1975). The solubility of iron, aluminum and manganese are greater under the more acidic conditions, and the organic acids associated with heath vegetation then chelate with the metal ions and are leached down the soil profile to the lower horizons. In many cases iron-podsols form, in which the iron is deposited in the form of a thin, hard iron pan (placic horizon or fragipan) leading to a consequent rise in the perched water table, and ultimately in widespread paludification (Damman 1965; McKeague *et al.* 1968). The formation of pans under heathlands has been noted in north England and Scotland under *Calluna* (Gimingham 1972),in Newfoundland under *Kalmia* (McKeague *et al.* 1968), on western Vancouver Island under *Gaultheria* (R.E. Carter, Research Associate, Dept. Soil Sci., U.B.C., Vancouver, B.C., *pers. comm.*, 1988) and in southeast Alaska under *Vaccinium* and *Menziesia* (Ugolini and Mann 1979). If such sites are left undisturbed, the high water table can lead to reductions in forest productivity and changes in vegetation through accumulation of forest humus resulting in wetter, colder soils and a reduction in tree rooting depths.

Humus Decomposition

A further effect of the apparent accumulation of phenolic acids under ericaceous plants may be the tanning effect of the phenolics on humus. The efficiency of tanning is associated with the molecular dimensions of the tanning agent, since the tannin has to form a stable cross link with the protein molecule. Tannin molecules below a critical size cannot form these cross links, and those above this size will combine only at easily accessible outer sites producing a case-hardening or surface combination. It appears that the tannins formed between pH 3 and 5 are of about the right molecular size to afford adequate protection to the protein. Outside of this pH range, the molecular size is probably too great and the protein is not adequately protected (Gustaven 1956). These results suggest that acid conditions, such as those associated with mor sites, will favour the formation of stable protein-tannin complexes so that mineralization of the protein is delayed.

Tannins can also slow the decomposition of nonproteins such as cellulose and hemicellulose because the tannin-protein complexes coat and permeate cell walls, making them considerably resistant to microbial attack (Benoit and Starkey 1968a and b). Tannins also affect decomposition through inactivation of certain enzymes important to the process of decomposition of large molecular weight compounds such as proteins, cellulose, hemicellulose and other polysaccharides and lipids (Benoit and Starkey 1968b).

The mor humus forms associated with ericaceous species are characteristically deep and unhumified, and not conducive to rapid decomposition. Not surprisingly then, these same sites show very low rates of mineralization of nitrogen, phosphorus and sometimes sulphur, and consequently there are overall deficiencies of these important nutrients. It may be that phenols released by ericaceous species polymerize into tannins which greatly reduce the mineralization of organic nitrogen and phosphorus.

MANAGEMENT IMPLICATIONS FOR CANADIAN FORESTS

Following clearcutting or burning without prompt regeneration of conifers, it is common for old growth forests with ericaceous plants already in the understorey, to become heath plant dominated cutovers. Some examples are: (*i*) *Kalmia* barrens in Newfoundland following cutting of black spruce, (*ii*) *Vaccinium*, *Kalmia*, and *Ledum* heaths in Nova Scotia or the boreal forests following cutting of jack pine or black spruce on low productivity soils, (*iii*) *Gaultheria* dominated cutovers following clearcutting of old growth western red cedar forests in the coastal forests of British Columbia.

Once established it is very difficult to eradicate heath vegetation. Herbicides are not usually both effective and licensed for use. Planting trees into dense heath cover is not feasible. Burning usually stimulates further heath plant sprouting and renews their vigour. In some cases the dominance of heath plants can be very long-term and represent a permanent exclusion of forest cover, as seen in British heathlands and in Newfoundland and Nova Scotian barrens. For boreal and westcoast heathlands, evidence suggests slow invasion by trees and eventual forest re-establishment.

In some British heathlands where pure Sitka spruce stands suffer growth check and nitrogen shortages, mixed spruce and pine or spruce and larch stands show vigorous growth and no shortage of nitrogen (Malcolm 1975). To date, there is no North American evidence for this "nurse crop" or mixed species effect.

Evidence from Alaska and B.C. coastal hemlock forests suggests that periodic natural windthrow which uproots old trees and buries the humus layer is an important factor in maintaining soil fertility.

Reforestation of heathlands usually requires ploughing or use of backhoes to physically turn over or rip out the heath plants, usually followed by nitrogen and phosphorus fertilization prescribed on a site specific basis. Current work with chlorotic, slow growing Sitka spruce, western hemlock and western red cedar regeneration on *Gaultheria* dominated cutovers indicates that nitrogen and phosphorus provide an immediate but temporary release of growth check, whether applied at time of planting or later.

European experience with attempts to reforest established heathlands indicate it is difficult, slow and expensive as compared to preventative measures. Therefore, the most appropriate actions are those designed to avoid establishment of heath plants such as (*i*) prevention of fires on naturally regenerated cutovers; (*ii*) seed bed preparation for prompt natural regeneration; and (*iii*) rapid planting, supplemented where necessary by fertilization.

SUMMARY

Throughout the northern hemisphere, the presence of ericaceous plants can greatly affect forest productivity through a number of complex interacting mechanisms, as illustrated in Figure 1. Ericaceous plants have been found to be associated with phenolic compounds in soils which are phytotoxic to plants, probably through their effects on root membrane permeabilities or mycorrhizal infections, leading to a failure of cells to maintain adequate mineral nutrition, and the inefficiency of the energy systems of respiration and photosynthesis. The phenolic compounds can polymerize and chelate with iron and aluminum in soils forming organo-metallic complexes which migrate and precipitate in lower mineral horizons leading to podsolization and possibly the formation of iron pans, thereby impeding drainage and rooting. The polyphenolics can also form tannin-like compounds with proteins and enzymes resulting in decreased decomposition and mineralization of organic material and the accumulation of raw humus. The overall result is a decrease in the productivity of forests.

Land management which allows the establishment of heathlands results in expensive site specific efforts at rehabilitation which are rarely fully effective. Therefore, the most appropriate actions are those designed to avoid establishment of heath plants such as (*i*) prevention of fires on naturally regenerated cutovers; (*ii*) seed bed preparation for prompt natural regeneration; and (*iii*) rapid planting, supplemented where necessary by fertilization.

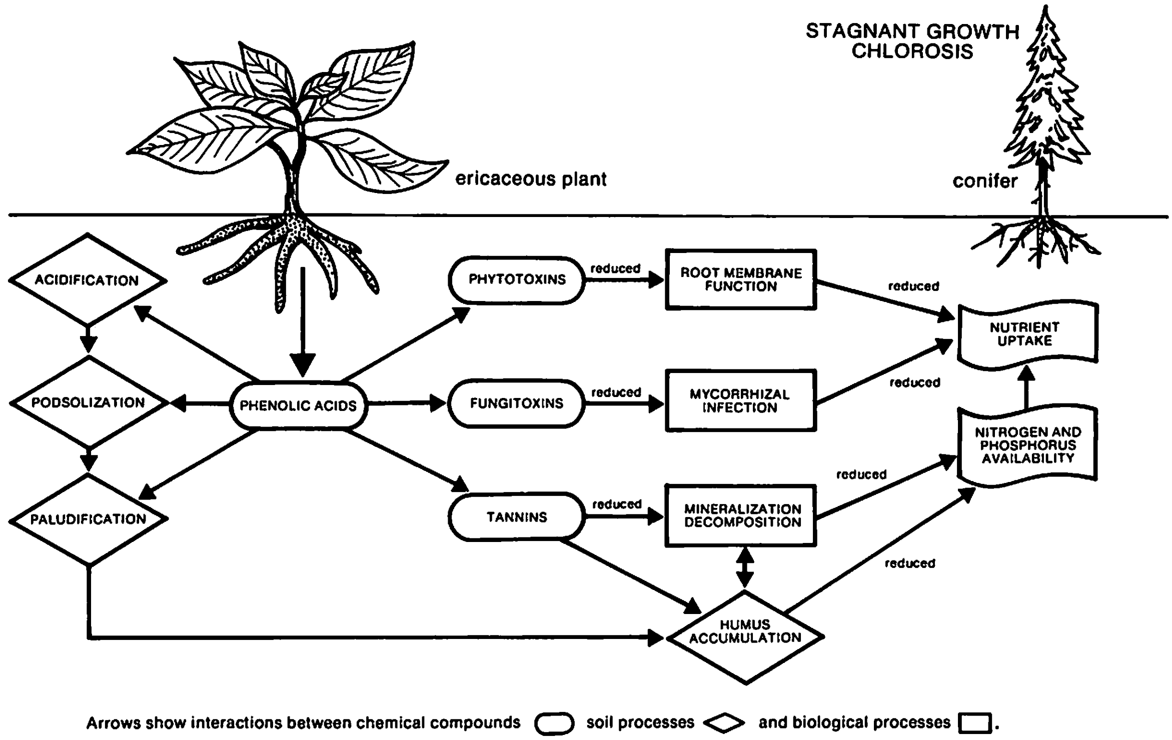

Figure 1. Possible effects of ericaceous plants on ecosystem processes and growth of conifers.

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SPRUCE FORESTS IN NORTHEAST CHINA

by

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ABSTRACT

China is rich in species of the spruce (*Picea*) genus. There are two species of spruce in northeast China, Korean spruce (*Picea koraiensis*) and jezo spruce (*Picea jezoensis*). The former is found mainly on bottom lands and the latter in the subalpine zone. Both are very important commercial tree species, and are used mainly for pulpwood. The distribution, composition, establishment, and growth of the two species are discussed in this paper.

INTRODUCTION

About 40 species of the spruce (*Picea*) genus are widely spread throughout the Northern Hemisphere, with half of the species occurring in China. The main forest species include *Picea koraiensis* Nakai and *P. jezoensis* Carr. in the northeast, *P. meyeri* Rehd. et Wils. and *P. wilsonii* Mast. in the north, *P. crassifolia* Kom., *P. asperata* Mast., *P. obovata* Ledeb., and *P. schrenkiana* Fisch. et Mey. in the northwest, and *P. likiangensis* (Franch.) Pritz., *P. purpurea* Mast., *P. brachytyla* (Franch.) Pritz., and *P. spinulosa* (Griff.) Henry in the southwest (Cheng 1983, Zhou 1986) (*Figure 1*). All are found in mountainous areas.

In the northeast of China, Korean spruce (*P. koraiensis*) and jezo spruce (*P. jezoensis*) are distributed throughout the eastern part of the area. The Korean spruce forests, or bottom land spruce forests, are largely located at lower elevations between 300-500 m above sea level (m asl), growing on the poorly drained soil of flats and humid valleys, adjacent to streams. Above the flats, where the soils are deeper and better drained, the proportion of Korean pine (*Pinus koraiensis* Sieb. et Zucc.) and hardwood species is greater. The jezo spruce forests, or subalpine spruce forests, occur in the subalpine zone between 1110-1700 m asl in the Changbai Mountains (the highest peak of 2691 m asl is situated on the border between China and Korea), and between 700-1100 m asl on a few peaks in the north of the Lesser Xingan Mountains. The composition of the jezo spruce forests ranges from essentially pure stands at the higher elevations through varying mixtures with Korean pine and other hardwood species until the softwood climax merges into the Korean pine-hardwood zone at lower elevations (Zhou and Li 1964, Zhao 1980) (Figure 2).

Li, J.W., Zhan, H.Z. and Ge, J.P. 1990. Spruce Forests in Northeast China. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 91-95.*

Stand Composition

In contrast to the rich composition of species found in the Korean pine-hardwood forests in the eastern part of Northeast China, the spruce forests contain fewer species. Both Korean spruce and jezo spruce (exceptionally large individuals can attain diameters of 1-1.5 m dbh at 35-40 m height) are always associated with Xingan fir (*Abies nephrolepis* Nakai), forming various spruce-fir forest types. Other softwood species are occasionally found in these forest types, principally *Larix olgensis* Henry and *Taxus cuspidata* Sieb. et Zucc. (a rare species in the Changbai Mountains), *Larix gmelinii* (Rupr.) Rupr. in both the Lesser Xingan Mountains, and Great Xingan Mountains. *Betula costata* Trautv., *B. platyphlla* Suk., *Tilia amurensis* Rupr., *Acer mono* Maxim., *Ulmus propinqua* Koidz., and various species of *Populus* can comprise a small proportion of the overstory. The spruce-fir forest types are usually 2-3 layered, or continuous multi-layered in structure, with a stem density of 700-900 stems/ha and a stocking density of 300-400 m^3/ha in mature stands. The small trees and shrubs below the canopy include *Acer tegmentosum* Maxim., *Acer ukurenduense* Trautv., *Lonicera caerulea* L. var. *edulis* Regel, *Lonicera maximowiczii* (Rupr.) Maxim. and *Ribes maximowiczianum* Kom. The herbaceous plants (commonly *Oxalis acetosella* L., *Pyrola incarnata* Fisch. and *Mitella nuda* L.) are scattered, while clumps of ferns and sedges grow on wet and soggy sites. Mosses such as *Rhytidiadelphus triquetrus* (L.) Warst. and *Hylocomium proliferum* (L.) Lindb. are well developed and usually form continuous sheets on the forest floor, reaching a cover presence of 80% by area. *Usnea longissima* Ach. often drapes the branches of conifers (Wu 1980).

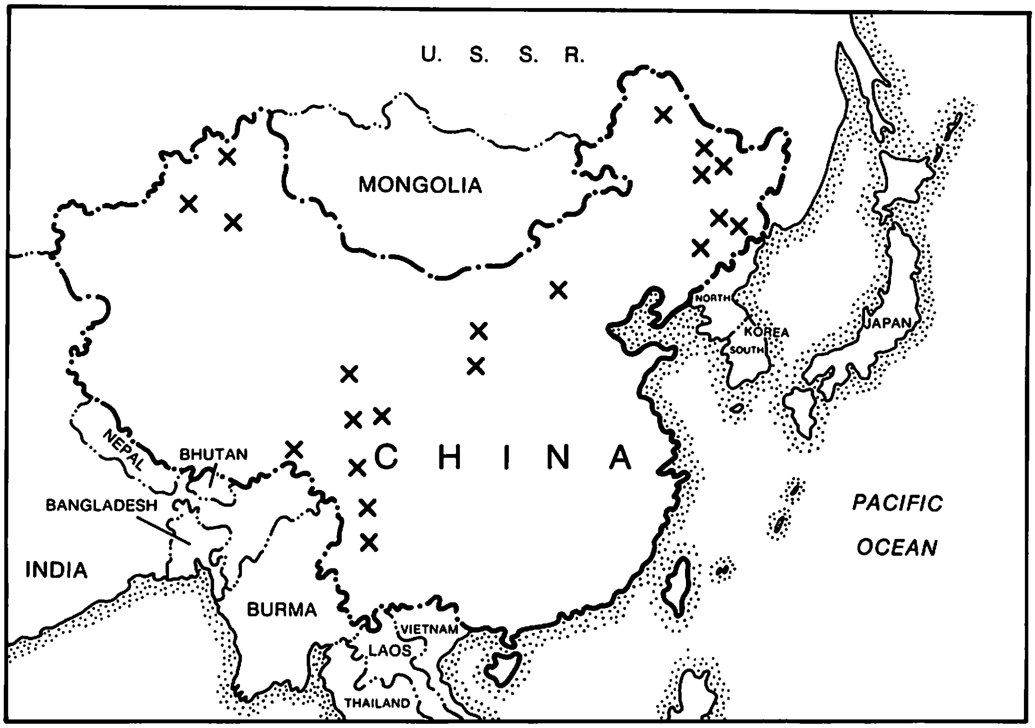

Figure 1. The main distribution of spruce in China.

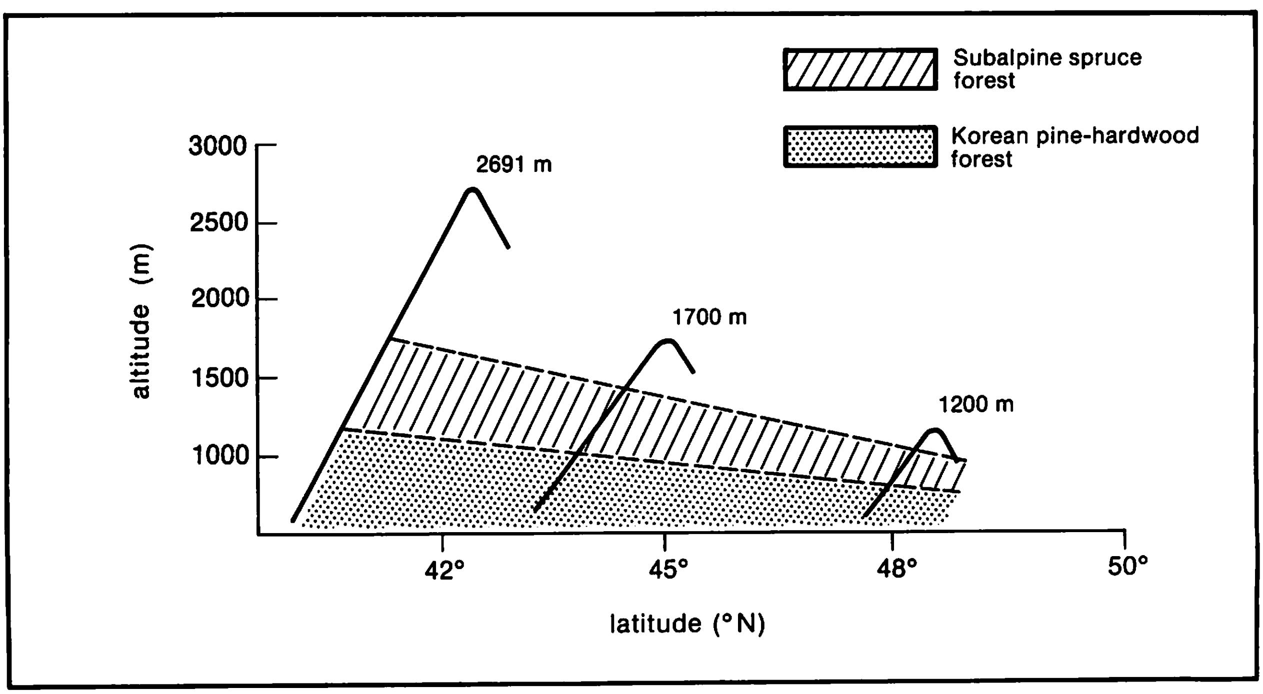

Figure 2. The decrease in altitude of the subalpine spruce forest zone from the south to the north in northeast China.

Table 1. Some silvical characteristics of spruce and other associated conifers.

Silvical characteristics	Species				
	Abies nephrolepis	*Picea jezoensis*	*Picea koraiensis*	*Pinus koraiensis*	*Larix gmelinii*
Relative shade tolerance	Very Tolerant	Tolerant	Tolerant	Medium	Intolerant
Relative growth rate of young tree	Slow	Slow	Slow	Very Slow	Much Faster
Age of fruition[a] (yr)	80-160	80-160	80-160	140-240	60-160
Good cone crop frequency (yr)	2-3	2-4	2-4	3-5	2-3
Weight of 1000 seeds (g)	10.00	2.10	4.68	55.6	4.0
Effective seed dispersal (m)	30	30-50 (120)	30-50 (120)	-	30-50 (120)
Method of seed dispersal	Wind	Wind	Wind	Bird or Squirrel	Wind

[a] Age at which tree bears abundant cones

Stand Establishment

The basic requirements for successful natural spruce-fir regeneration include an adequate seed supply, a proper seedbed, and light, temperature, and moisture conditions that are conducive to seed germination and seedling survival. Seed production begins when trees are about 40 years old, but significant production does not usually begin until the trees are 80-100 years old (Wu 1987). Very few viable seeds can be stored in the forest floor for more than one year. Silvical characteristics of several of the species are given in Table 1.

In the original spruce forests, natural regeneration generally occurs on fallen dead wood and rotten logs and mineral soil, where ample moisture is available and temperatures are moderate. Typically, 60-80% of the total regeneration in these forests occurs on fallen dead wood and logs which cover 7-10% of the ground surface area. Litter and humus are poorer seedbeds because they are likely to be drier. Severe competition makes heavy sod the poorest seedbed. Growth of seedlings and saplings is very slow under a closed canopy (Table 2), and shaded, unreleased seedlings usually reach a maximum of 40 cm in height before dying at about age 13 because they have grown too large to be supported by the low understory light levels and their photosynthesis:respiration ratio has dropped below one (P/R<1). However, if a canopy opening is made by windfall, the already-present plants will survive past the age of 13 (Wu 1987). The light intensity controlled by the size of gaps is a very important factor affecting regeneration in spruce forests. Light intensity will determine which species will regenerate, and will also control their growth rate. The continual cycle of gap creation and closure causes the release, growth, reproduction, and mortality of the spruce population and determines survival patterns.

Table 2. The age and height of the ten tallest seedlings and saplings under a closed canopy Korean spruce stand.

Age (yr)	Height (cm)
10	16.2
10	22.1
10	27.5
10	33.0
11	30.0
12	29.2
12	33.0
13	36.1
13	42.5
13	44.2

Table 3. Stand characteristics of natural Korean spruce stands of increasing age in the Lesser Xingan Mountains.

Age (yrs)	Mean height (m)	Mean dbh (cm)	Growing Stock Per Ha			Vol. Increment (m^3/ha/yr)	
			No. of trees	Basal area (m^2)	Vol. (m^3)	Mean	Annual
30	3.4	2.6	-	10.0	30	1.0	-
40	5.8	4.5	11 195	17.8	75	1.9	4.5
50	8.3	6.7	7 280	25.7	137	2.7	6.2
60	11.0	9.5	4 626	32.8	215	3.6	7.8
70	13.6	12.5	3 024	37.1	286	4.1	7.1
80	15.7	15.7	2 066	40.0	344	4.3	5.8
90	17.3	18.8	1 517	42.1	390	4.3	4.6
100	18.6	21.5	1 198	43.5	424	4.2	3.4
110	19.6	24.1	978	44.6	449	4.1	2.5
120	20.4	26.4	829	45.4	470	3.9	2.1
130	21.1	28.5	723	46.1	487	3.8	1.7
140	21.7	30.2	652	46.7	502	3.6	1.5
150	22.2	31.7	598	47.2	513	3.4	1.1
160	22.6	33.0	555	47.5	522	3.3	0.9
170	23.0	34.2	521	47.9	531	3.1	0.9
180	23.4	35.2	495	48.2	540	3.0	0.9
190	23.7	36.1	474	48.5	547	2.9	0.7
200	24.0	36.9	456	48.8	554	2.8	0.7

Stand Growth

Natural spruce stands vary greatly in growth rate, depending upon differences in site quality, density of stocking, and whether the stand is pure or a mixture of two or more species. From studies in the Lesser Xingan Mountains (Table 3), it is known that Korean spruce stands on medium sites will approach a height of 3.4 m, mean dbh of 2.6 cm, and growing stock of 30 m^3/ha when about 30 years old. Thereafter, growth will continue at a reduced rate until stands attain an average height of 24 m, diameter of 37 cm and volume of 554 m^3/ha at about 200 years. The dominant trees in these stands can attain heights of 30 m and diameters of 50 cm by this age.

Table 4. The growth of man-made plantations of Korean spruce up to age 24 years on good sites in Suiling County, Heilongjiang Province.

Age (yrs)	Mean height (m)	Mean dbh (cm)
10	1.82	1.20
15	3.82	3.61
20	6.42	6.23
24	8.94	8.00

In man-made Korean spruce plantations, the growth of trees is fast (Table 4). Twenty-four-year-old stands are usually 9 m tall with diameters of 8 cm, and have volumes of more than 100 m^3/ha. At age 24 they are comparable with 50- to 60-year-old natural stands.

In Heilongjiang province, Korean spruce is now a very important plantation species. For example, in Suiling County about 10 000 ha has been planted, of which nearly 2000 ha is fully stocked with volumes of more than 30 m^3/ha.

SUMMARY

The northeast of China has large areas of old growth timber which form an important base for forest resources in China. Natural forests are dominated by species of *Pinus*, *Picea*, *Abies*, *Larix*, and many hardwoods. The coniferous forests extend throughout the higher mountains. The mixed conifer-hardwood forests are located at lower elevations. Both forests are often invaded by species of hardwoods, especially *Betula* and *Populus*, in seral stages. This decrease in conifers and increase in hardwoods due to exploitation over a long time period have changed the composition of the forests for the worse. Attempts to achieve natural regeneration of conifers have not often been successful in these forests, so artificial regeneration by

planting on the cutover land is now emphasized. The principal species planted are Korean pine, Scots pine, larch, and poplars. The spruces were often neglected in the past. However, the high survival rate, rapid growth rate, and ability of Korean spruce to adapt to a variety of forest sites has attracted the attention of foresters since the beginning of the 1960s, and the use of Korean spruce in plantations appears promising. Jezo spruce has also been planted, but its use is restricted to small plantations and to experimental plots, mainly at relatively high altitudes and in the north part of the area.

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PERFORMANCE OF PICEA MARIANA IN NORWAY

by

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ABSTRACT

Since 1960, 33 field experiments with 29 *Picea mariana* provenances have been established in Norway. The latitudinal range of the trials is 58°-69°N, at altitudes ranging from 40 to 820 m above sea level. Interest in *Picea mariana* arose because of frost problems in plantations of *Picea abies*.

The provenances tested performed poorly in near-coastal areas (<20 km from the coastline). Black spruce from Ontario and Manitoba grew reasonably well on low altitude sites in southern Norway. In some cases height growth was comparable to that of Norway spruce. Stem quality, however, was often unsatisfactory. A provenance from Duck Mountain, Manitoba, has performed excellently on one inland site at latitude 64°N. Its height growth there was better than that of seven other species tested, and its stem quality was good. This particular provenance has been tested from latitude 58°-69°N, and an optimum zone for climatic adaptation has been identified.

The renewed interest in black spruce in Norway in the 1980s resulted in a search for suitable provenances from western Canada and Alaska. Before new field trials are established, genetic screening of provenances should be carried out.

The species, however, will probably never become a competitor to Norway spruce on upland sites with a good microclimate and an ample store of nutrients.

INTRODUCTION

The interest in black spruce (*Picea mariana* (Mill.) B.S.P.) as an exotic species in Norwegian forestry has been based on several conditions. The species has a wide natural range in North America (latitude 41°-69°N; longitude 54°-163°W), which indicates a broad genotypic variation. It is frost hardy, has modest demands for site quality, and makes good pulp. The genotypic variation in its natural range is predominantly clinal with rather low within-stand variation. Photoperiod and temperature are obviously the major factors of natural selection (Morgenstern 1978).

In Norway radiation frost during the vegetation period frequently damages plantations of Norway spruce (*Picea abies* (L.) Karst.) on flatlands, especially in valley-bottoms. This problem initiated the search for more hardy species. Black spruce was chosen as one of the test species, and the first trials were established on drained peatland in 1960. However, planting of black spruce by private forest companies had been done earlier. Since the provenance choice was casual in most of the earliest plantations, and also in some of the field trials, the results were often discouraging.

The first test program on growth rhythms and hardiness of black spruce in nursery beds was started in 1966 (Dietrichson 1969). This test included 80 half-sib families from 21 stands in nine areas, mostly in Ontario. The results were used to screen and choose species for seven field experiments, which were planted in 1969. Height and survival at age 17 years in four of the trials on drained peatland have been published by Brække (1984). The results from three upland sites are summarized by Kaasen and Dietrichson (1987). The growth performance of plants from two commercial seedlots in four drained peatland trials on the SW coast of Norway has been published by Arnøy (1986).

The main purpose of this report is to evaluate available data on black spruce in Norway, taking into consideration some of the results from the other Nordic countries.

DISTRIBUTION OF TRIALS AND GENERAL EVALUATION

The geographic distribution of trials with black spruce in Norway is depicted in Figure 1, and descriptions are summarized in Table 1. Altogether, 33 field trials have been established, four on mineral soil and 29 on drained peatland. All trials, except one, were established between 1960 and 1969. Latitudinal

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Brække, F.H. 1990. Performance of Picea Mariana in Norway. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc. Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 97-106.*

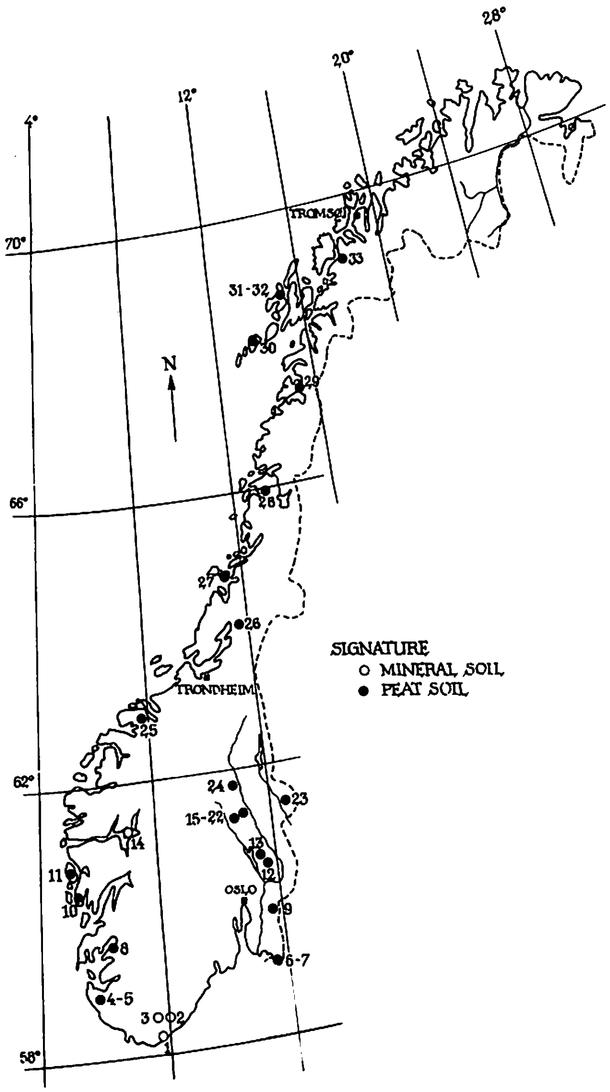

Figure 1. Distribution of trials with black spruce in Norway. All trials have block or split plot design with two or more replicates. In most cases several provenances of black spruce have been tested together with other species.

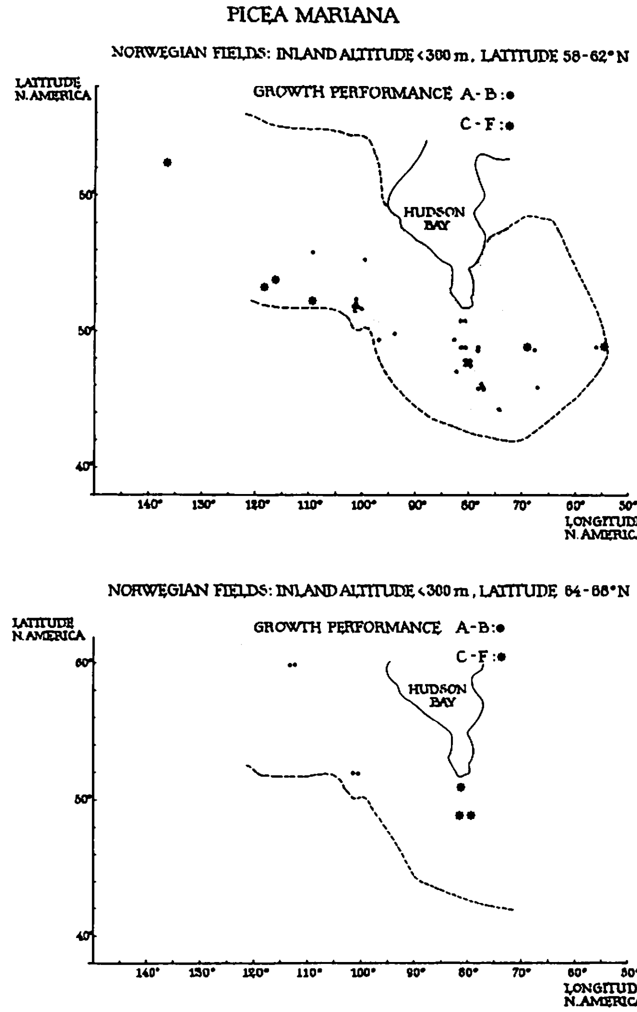

Figure 2. Relation between growth performance of black spruce in Norway and its geographical origin in the United States and Canada. Definition of growth performance codes is given in Table 2.

positions range from 58°-69°N, and the altitudinal range is 20 to 820 m above sea level (m asl). Seven field trials are located on sites characterized as coastal (i.e., having oceanic climate with low frequencies of frost in the vegetation period). For practical reasons the coastal species *Picea sitchensis* (Bong) Carr., which is susceptible to frost, was used as an indicator species of such conditions (see Table 1).

According to available records a total of 29 different provenances of black spruce have been tested in field trials (Table 2). The height growth and survival of black spruce are evaluated on each of these trials according to four categories: excellent, reasonable, not satifactory, and failure (see Table 2 for definitions). Generally the species has performed poorly in coastal areas. Although there might be suitable genotypes from the east coast of Canada, it is not advisable to put much effort into such tests, because there are excellent provenances of Sitka spruce available for these areas. All tests on higher altitude sites (> 300 m asl) failed, and one obvious reason is that the choice of provenances was wrong. Growth performance is related to origin in Figure 2. All tested provenances from the longitudinal range 70°-115°W in Canada and the United States have performed excellently or reasonably well at test sites between latitudes 58° and 62°N in Norway. The best height and diameter growth

Table 1. Field trials with *Picea mariana* in Norway.

Location		Established	Soil	Latitude (N)	Longitude (E)	Altitude (m)	Coast/ Inland[a]	Institute[b]
1	Dømmesmoen	1969	Mineral	58°21'	8°34'	70	Coast	NISK
2	Jerpedalslia	1969	"	58°39'	8°34'	270	Inland	"
3	Epletveitlia	1969	"	58°47'	8°31	230	"	"
4 - 5	Røyslandsmyr	1968	Organic	58°40'	6°00'	250	"	"
6 - 7	Rødkleivmyr	1960	"	59°00'	11°35'	170	"	NLH
8	Øksmyr	1967	"	59°29'	6°12'	120	"	NISK
9	Skøyenmyra	1962	"	60°02'	11°39'	310	"	"
10	Osmyra	1965	"	60°12'	5°28'	40	Coast	"
11	Hundvenmyra	1967	"	60°42'	5°11'	60	"	"
12	Jengårdsmyra	1963	"	60°55'	11°09'	590	Inland	"
13	Prestsætermyra	1961	"	61°05'	11°03'	620	"	"
14	Amla	1982	Mineral	61°10'	7°16'	"	"	"
15 - 17	Pålsmyra	1964	Organic	61°17'	10°44'	820	"	"
18 - 22	Slåttmyra	1964	"	61°18'	10°46'	750	"	"
23	Almyra	1964	"	61°22'	12°21'	640	"	"
24	Hullbekkmyra	1962	"	61°43'	10°40'	650	"	"
25	Angvikmyr	1965	"	62°50'	8°00'	140	Coast	"
26	Brandseggmyra	1968	"	64°00'	11°42'	110	Inland	"
27	Ryumsklaven	1965	"	64°53'	11°13'	70	Coast	"
28	Straumsmyra	1969	"	65°57'	13°24'	45	Inland	"
29	Vassryggmyra	1969	"	67°21'	15°30'	40	"	"
30	Borgmyra	1969	"	68°14'	13°45'	60	Coast	"
31 - 32	Vikeid	1965	"	68°46'	15°16'	20	"	"
33	Kongomyr	1969	"	69°14'	18°24'	35	Inland	"

[a] Coast: Sites where the coastal species *Picea sitchensis* performs well.
Inland: All other sites.

[b] NISK: The Norwegian Forest Research Institute.
NLH: The Agricultural University of Norway.

Table 2. Specifications of *Picea mariana* seed lots used in Norwegian trials with evaluation of height growth at total age from 9 to 21 years.

Location	Provenance	Latitude (N)	Longitude (W)	Altitude (m)	Evaluation[a]
1 - 3	Chalk River, Ontario	46°02'	77°28'	<100	C(1),A(2),B(3)
	Kenogami Lake, Ontario	48°00'	80°08'	<100	"
	Kenogami Lake, Ontario	47°59'	80°09'	<100	"
	Potter, Ontario	48°53'	80°54'	<100	"
	Moosonee, Ontario	51°06'	80°	<100	"
	Duck Mt. Manitoba	51°53'	100°51'	<730	"
4 - 5	Duck Mt. Manitoba	51°53'	100°51'	<730	A
6 - 7	Kapuskasing, Ontario	49°25'	82°26'	200-500	B
	Chalk River, Ontario	46°02'	77°28'	<100	A
	Baie Comeau, Quebec	49°12'	68°10'	<100	C
	Fredericton, New Brunswick	45°57'	66°40'	<100	B
	Matane, Quebec	48°50'	67°31'	<100	B
	Grand Falls, Newfoundland	48°57'	55°40'	200-500	C
8	Lake Placid, New York State	44°18'	74°01'	600	A
9	Adirondack Mnt.	44°	74°	(600)	F
10	Lake Placid, New York State	44°18'	74°01'	600	A
11	Lake Placid, New York State	44°18'	74°01'	600	C
12	Adirondack Mnt. ?	44°	74°	(600)	F
13	Adirondack Mnt. ?	44°	74°	(600)	F
14	Sandy Brook, Newfoundland	48°47'	56°07'	260	B
	Co. Abitibi Est. Quebec	48°50'	78°08'	320	B
	Ont. Dept. of Land and Forests Site Region 4E, Ontario	46°30' - 48°00'	79°30' - 84°30'	320 - 390	B
	Ont. Dept. Land and Forests Site Region 4S, Ontario	49°30' - 50°30'	91°45' - 95°10'	400 - 420	A
	Pulp. River, Manitoba	51°48'	100°12'	290	A
	Birch River, "	52°23'	101°07'	340	B
	Paint River, "	55°30'	98°40'	220	B
	N.W. Angle Forest Reserve, Manit.	49°17'	96°18'	370	A
	Peter Pond Lake, Saskatchewan	56°03'	108°42'	460	B
	Sec. 27.T.40,R. 30 W, Porcupine Mountain, Saskatchewan	52°30'	108°43'	645	C
	Sec. 32-33, T.51-25-5, R.25, Alberta	53°27'	117°38'	1225	C
	Sec. 22, T.55, R.12,"	53°45'	115°43'	810	C
	Mile 120, Hwy. Whitehorse Mayo Yukon Territory	62°22'	136°25'	810	C
15 - 22	Port Hope Simpson, Labrador	52°20'	56°18'	<200	(B)
	Adirondack, New York	44°	74°	(600)	F
23	Northern New York State	44°	74°	(600)	F
24	Adirondack Mnt. ?	44°	74°	(600)	F
25	Lake Placid, New York State	44°	73°	600	B
26	Duck Mt. Manitoba	51°53'	100°51'	<730	A
27	Duck Mt. Manitoba	51°53'	100°51'	<730	C
28	Nighthawk Lake, Ontario	48°50'	80°50'	300	C
	Duck Mt. Manitoba	51°53'	100°51'	<730	A
	Northwest Territory	60°03'	112°46'	200	B
29	Nighthawk Lake, Ontario	48°50'	80°50'	300	F
	Moosonee, Ontario	51°06'	80°52'	<100	C
	Northwest Territory	60°03'	112°46'	200	B
30	Nighthawk Lake, Ontario	48°50'	80°50'	300	F
	Moosonee, Ontario	51°06'	80°52'	<100	F
	Duck Mt. Manitoba	51°53'	100°51'	<730	F
31 - 32	Northern New York State	44°	74°	(600)	F
	Lake Placid, New York State	44°18'	74°01'	600	F
33	Moosonee, Ontario	51°06'	80°52'	<100	F
	Duck Mt. Manitoba	51°53'	100°51'	<730	F
	Northwest Territory	60°03'	112°46'	200	F

[a] EVALUATION CODES
- A: Establishment and height growth > other tested *Picea* spp.
- B: Establishment and height growth = other tested *Picea* spp.
- C: Establishment and height growth < other tested *Picea* spp.
- F: Failure

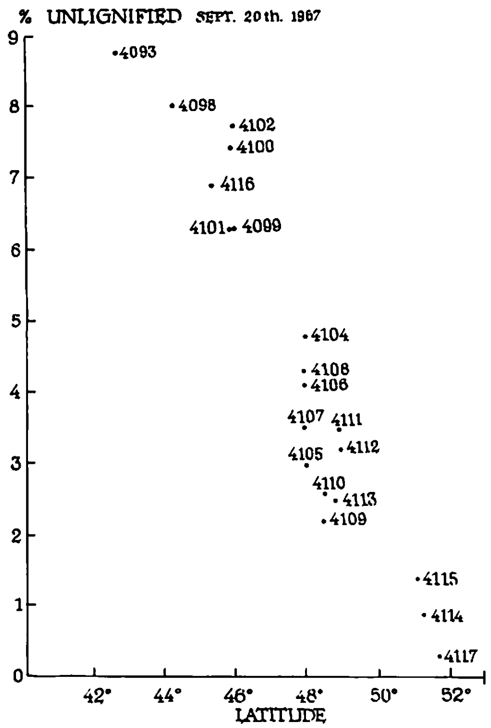

Figure 3. Relationship between the northern origin of black spruce seed source and percent unlignified year ring on 20 Sept. 1967. The test was done on 4-year-old plants in nursery beds (from Dietrichson 1969).

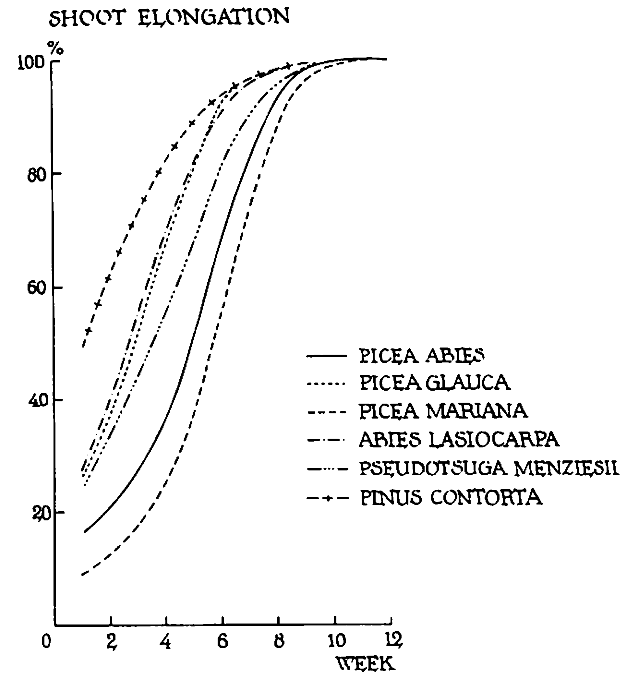

Figure 4. Mean top shoot extension of tree species in trials 1-3 (see Figure 1). Extension is given as percent of total shoot length in the autumn of 1972. Measurements were done over a ten-week period starting on 29 May 1972 (from Kaasen and Dietrichson 1987).

at latitude 59°N were shown by a provenance from Chalk River, Ontario. On test sites situated at 64°-68°N, however, the Ontario provenances failed, while provenances from Manitoba and the Northwest Territories performed well. The small number of tested provenances, however, excludes any firm conclusions from being drawn.

GROWTH RHYTHM AND HARDINESS TESTS

Genetic variation in frost susceptibility, growth rhythms and height growth of different genotypes of 4-year-old black spruce seedlings were studied in 1967 by Dietrichson (1969). Except for the families from Duck Mountain, Manitoba, the others had been collected along a transect in Ontario (longitude 80°W) from Lake Erie to Moosonee. Significant gradients with latitude were found for growth initiation, height at four-years, winter damage, frost ring frequency, and lignification progress in autumn. The northern families flushed earliest in spring and terminated growth first in the autumn. They showed less height growth, but also less autumn/winter damage.

The lignification progression in autumn is shown in Figure 3. On 20 September 1967 the families from Duck Mountain and Moosonee were nearly fully lignified, while the ones from the Lake Erie area had almost 9% of the annual rings unlignified. Height growth and autumn/winter damage were positively correlated to the lignification parameter, whereas the relationship between early flushing and lignification was reversed. Component analyses confirmed that fast-growing families enter dormancy later, sustain more winter damage, and show higher frequencies of frost rings than slower growing plants with earlier growth cessation. A study of Norway spruce (Dietrichson 1967) showed that family variation was greater in this species than in black spruce.

The half-sib families within six of the areas were selected for further field tests on three different sites (see Figure 1, sites 1-3) together with five other species (Table 3). Shoot elongation curves for the species are given for 1972 in Figure 4. Black spruce showed delayed bud burst compared to Norway spruce, while cessation of growth occurred at about the same time for both species. This feature is generally noticed in black spruce plantations in Norway, irrespective of

Table 3. Specifications of origin for the provenances used in trials no. 1-3 (after Kaasen and Dietrichson 1987).

No.	Species	Provenances	Latitude (N)	Longitude (E or W)	Altitude (m)
1	*Picea abies*	Brosteni, Romania	47°05'	25°40'E	950
2	" "	Frasin, Romania	47°30'	25°45'E	700
3	" "	Moldovita, Romania	47°25'	25°30E	850
4	" "	Brasov, Romania	45°30'	25°40'E	1050
5	" "	Westerhof, W. Germany	51°42'	10°18'E	300
6[a]	" "	Sund, Aremark, Norway	59°08'	11°41'E	150
7	*Picea glauca*	Peterborough, Ontario	44°20'	78°20'W	250
8	" "	Swastica, Ontario	48°06'	80°07'W	30
9	" "	Enns, Alberta	54°35'	117°45'W	880
10	" "	Peace River, B.C.	55°40'	122°12'W	630
11	" "	Boundary Creek, B.C.	49°05'	116°45'W	1440
12	" "	Birch Island, B.C.	51°35'	119°51'W	440
13	*Picea mariana*	Chalk River, Ontario	46°02'	77°22'W	<100
14	" "	Kenogami Lake, Ontario	48°00'	80°08'W	<100
15	" "	Kenogami Lake, Ontario	47°59'	80°09'W	<100
16	" "	Potter, Ontario	48°53'	80°54'W	<100
17	" "	Moosonee, Ontario	51°06'	80°52'W	<100
18	" "	Duck Mt., Manitoba	51°53'	100°51'W	<730
19	*Abies lasiocarpa*	White Rock, Idaho	47°00'	116°32'W	1520
20	" "	Deary, Idaho	46°48'	116°32'W	870
21	" "	Simonette River, Alberta	54°36'	117°44'W	760
22	" "	Pinchi Lake, B.C.	54°38'	124°22'W	750
23	" "	Aleza Lake, B.C.	54°04'	122°08'W	640
24	" "	Aleza Lake, B.C.	54°06'	121°40'W	850
25	*Pseudotsuga menziesii*	Radium Hot Springs, B.C.	50°34'	116°40'W	unknown
26	" "	Townsen, Montana	46°18'	111°34'W	1250
27	" "	Pinchi Lake, B.C.	54°34'	124°20'W	750
28	" "	Pinchi Lake, B.C.	54°34'	124°20'W	750
29	" "	Stuart Lake, B.C.	54°32'	124°28'W	700
30	" "	Stuart Lake, B.C.	54°32'	124°28'W	700
31	*Pinus contorta*	Terrace, B.C.	45°67'	128°75'W	150
32	" "	Vancouver Island, B.C.	49°25'	124°83'W	160
33	" "	Duthie Mine Rd., B.C.	54°13'	127°05'W	1000
34	" "	Crowsnest, Alberta	49°55'	114°63'W	1400
35	" "	Park Brothers, Alberta	54°50'	118°08'W	800
36	" "	Medicine Bow, Wyoming	41°34'	107°67'W	3000

[a] Progeny from one tree.

Table 4. Average occurence of different damage categories in 1984, as percent of living trees (after Kaasen and Dietrichson 1987).

Tree species	Stem failure damage (%)	Spring frost (%)	Browsing damage (%)
Abies lasicocarpa	11.3	4.4	1.9
Picea abies	12.5	2.1	0.1
Picea glauca	21.6	4.3	0.4
Pseudotsuga menziesii	24.5	2.1	1.4
Picea mariana	24.7	0.6	0.1
Pinus cortorta	58.7	-	9.4

provenance. The early burst, rapid initial elongation, but rather long cessation period of the lodgepole pine provenances should also be mentioned.

Figure 5 gives the arithmetic mean height 16 years after establishment of the trials. At Dømmesmoen (coastal climate) Norway spruce was the most successful species, while at Jerpedalslia and Epletveitlia lodgepole pine was best. Compared to Norway spruce on these sites, black spruce ranked second, first, and equal, respectively. At the two inland sites, the Chalk River provenance grew best, whereas that from Duck Mountain had the slowest growth rate. This is in agreement with the results from the early test in the nursery, and indicates that the Duck Mountain provenance was a little too hardy for the prevailing climate. However, the differences in height growth were not great.

When the commercial value of an introduced species is evaluated, parameters other than simply height must be considered. Table 4 shows that lodgepole pine is very susceptible to stem failure (forked and crooked stems) and browse damage (by moose), which cannot make up for the better height growth. Black spruce, white spruce, and Douglas fir showed about 25% stem failure, compared to 12.5% for Norway spruce. One of the drawbacks with black spruce is its tendency to form forked and sometimes also spiral stems, but this weakness seems to be partly related to provenance choice. Black spruce also has a slower diameter growth than Norway spruce, even at equal height growth.

HEIGHT GROWTH AND SURVIVAL ON A LATITUDINAL TRANSECT IN NORWAY

The provenance from Duck Mountain, Manitoba, has been planted in six different trials, from latitudes 58°39'N to 69°14'N. Figure 6 shows the latitudinal variation in height multiplied by percent survival at total age 21 years, percent survival, and mean synoptic air temperature for June-September (tetraterm). Height growth for this provenance has not been significantly different over a range of five latitude degrees, despite slightly higher air temperatures at the southern sites. The same was true for survival. The data indicate an optimum zone at latitude 64°N, where the tetraterm (1931-60) is 12.2°C. Beyond this latitude height growth

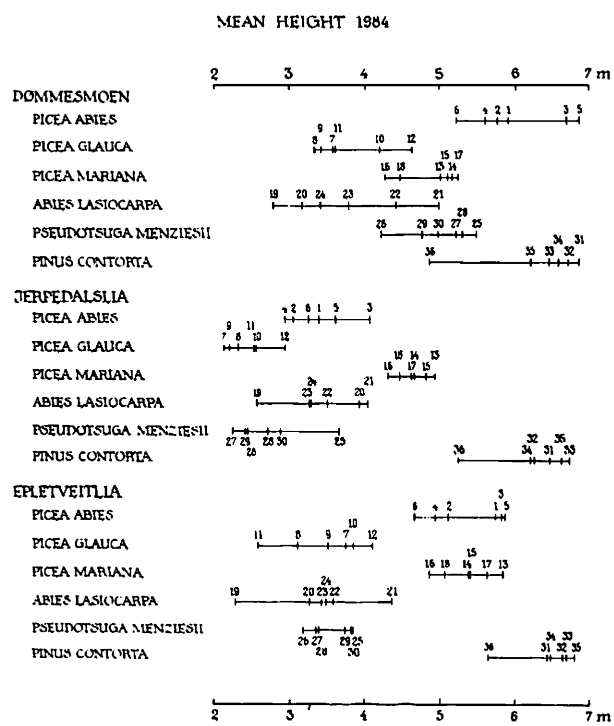

Figure 5. Mean heights in autumn 1984 of the 36 provenances tested in trials 1-3. Provenance descriptions are given in Table 3 (from Kaasen and Dietrichson 1987).

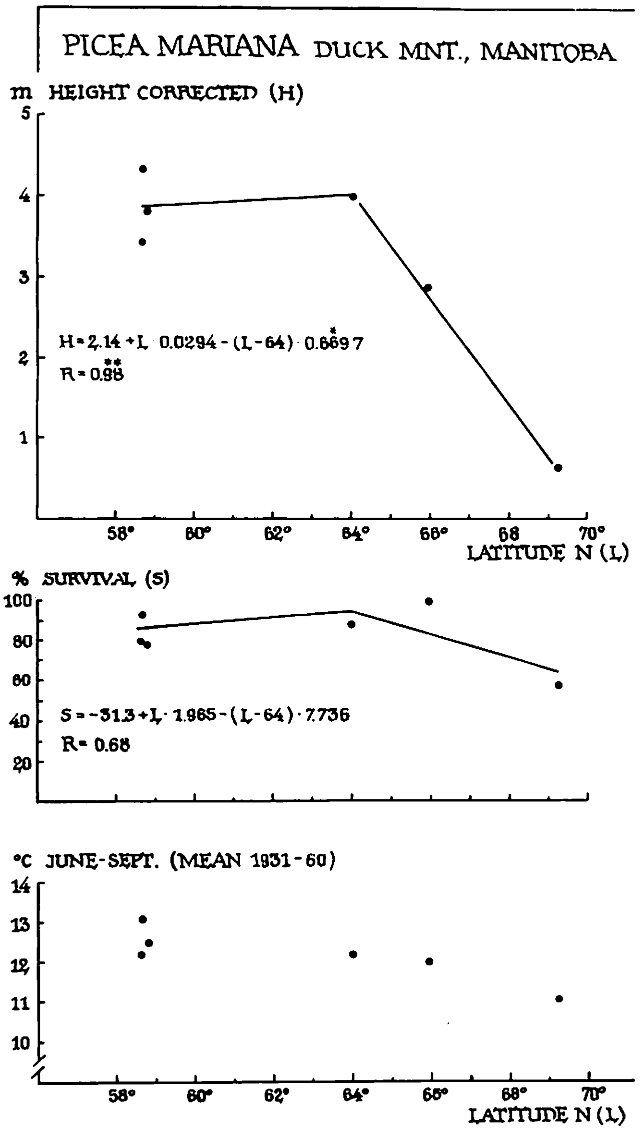

Figure 6. Height growth and survival of the Duck Mountain provenance on a transect from latitude 59° to 69°N in Norway. Height corrected is the arithmetic mean height at age 21 years multiplied by percent survival.

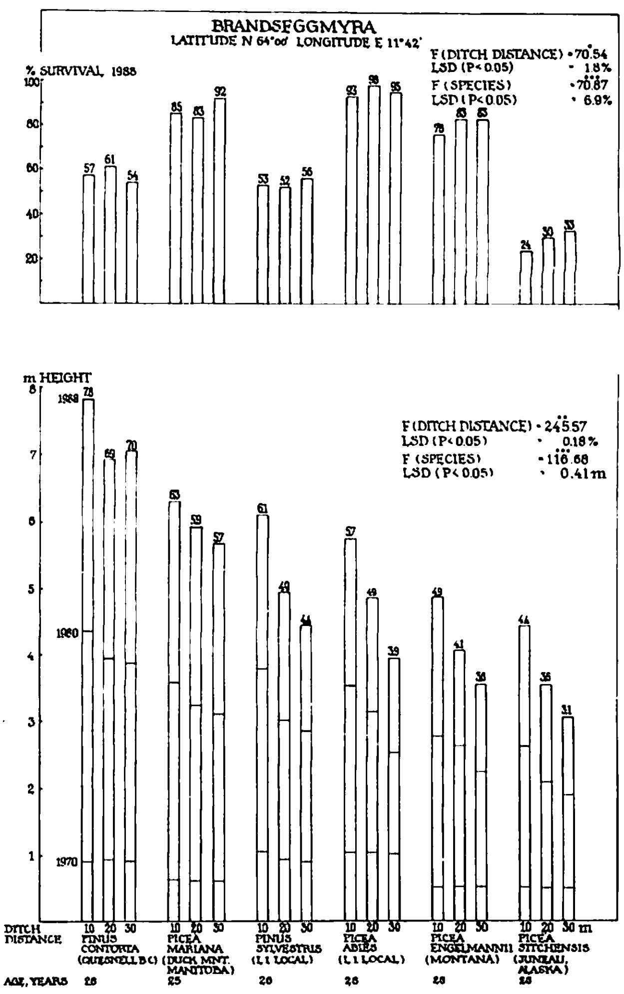

Figure 7. Height and survival of six species tested at different drainage intensities on an ombrotrophic bog (site 26). The fertilization program included N, K, P, Mg, and B.

has been significantly reduced, and at latitude 69° the provenance failed. It seems surprising that such small marginal changes in the growing season temperature could have such drastic effects. A more plausible explanation could be that photoperiodic interruption due to short or no dark periods combined with relatively low initiation temperatures in spring, early frost in autumn, and semi-maritime winter climate led to poor survival. If this is the case, black spruce from its southern extension must have a different response to these environmental factors than, for example, Norway spruce.

Figure 7 gives more results from the trial in which black spruce showed its best performance. The low survival rate of lodgepole and Scots pine was due to heavy moose browsing, which is a general problem for these species in Norway. In addition, the lodgepole pine had a high frequency of stem failure, so the tested provenance cannot be recommended for commercial plantations, despite its vigorous growth. The Sitka spruce did not tolerate the inland climate and suffered from summer/autumn frosts. This also damaged the Engelmann spruce, although to a lesser extent. The black spruce was planted three years after the Norway spruce, because the first planting failed for technical reasons. In the autumn of 1988 the black spruce was significantly higher ($p<0.01$) than Norway spruce at ditch distances of 20 and 30 meters. It is a characteristic feature of black spruce that it tolerates high water table levels better than most other tree species. This is probably genetically conditioned, since the species is adapted to boggy sites in its natural habitat. Although stem quality parameters have not been evaluated at Brandseggmyra, it should be emphasized that frequecies of forked and spiral stems are rather low. This should mean that the provenance seems better adapted to this than to the other sites tested.

CONCLUSIONS

Black spruce provenances tested in near-coastal areas in Norway have not performed well. More suitable genotypes might exist in the eastern maritime climatic zone in Canada. However, since a well-adapted maritime species, Sitka spruce, is available, there should be no need for more testing of black spruce provenances in maritime climate areas in Norway.

At some distance from the coastline, where radiation frost limits the extension of Sitka spruce, black spruce seems to be an alternative to the indigenous species, especially in depressions with high water table levels and frequent summer radiation frosts. It is surprising, however, that black spruce from the cold continental climatic zone of Canada performs well in the semi-continental climate of Norway, which includes most of the forested areas. A cold continental climate prevails only at higher altitudes along the Swedish border. Unfortunately, none of the hardy genotypes from Ontario and Manitoba have been tested in these areas, where they should fit better than in the semi-continental climatic zone.

The test results indicate that the optimum zone for collecting seed lots shifts to the northwest in Canada when planting in Sweden and Norway is done from latitude 57° to 68°N. Persson and Ganered (1981) reported successful growth of black spruce provenances from longitude 62°-68°W on drained peatland in Halland, Sweden (latitude 56°50'N). These provenances grew significantly better than black spruce from central and western Canada, and also better than the local provenances of Norway spruce. For latitudes 58°-62°N in Norway, black spruce provenances from longitude 70°-105°W grew best. This optimum zone of origin was moved further NW in Canada for provenances to be planted at latitudes 64°-68° in Norway. Logically, one should expect to find the best provenances adaptable for Norway in the western semi-continental zone in British Columbia and Alaska, from about latitudes 54° to 62°N, assuming that photoperiodic response is similar in black, white and Sitka spruce. There is reason to believe that black spruce from the interior of Alaska is generally unsuitable, because they have been selected under an extremely cold continental climate. To test such provenances, regions with a cold continental climate in Norway should be used.

The most successful provenance tested in Norway so far (Duck Mountain) has at age 25 years outgrown the local provenances of Norway spruce and Scots pine. The dominant height (the arithmetic mean of the 100 tallest trees per ha) is 8.4 meters. Presupposing a growth rate in the future as in the last 10 years, the dominant height could be about 17-18 meters at a total age of 50 years. This estimate refers to plots with 10 meter ditch spacing, but the growth is almost as good on the 20 and 30 meter broad strips.

One disadvantage of black spruce is the high frequency of forked stems, which makes it less suitable for sawmill processing than the indigenous species. Less diameter growth has also been registered, which means that black spruce normally cannot compete in stem volume production. However, for pulp processing a 20% lower volume production than Norway spruce can be accepted because of the higher density of black spruce.

Lahde *et al.* (1984) examined 15 older stands (51-53 years) in southernmost Finland and showed that black spruce performed poorly, except for one stand at Solböle. The provenance tested was from Olds, Alberta, and total production at age 53 years was 310 m^3/ha, with a dominant height of 15.5 m. Previous damage in the Finnish field trials was mainly caused by drought and fungal diseases, principally *Sclerophoma pityophila*, on shoots.

Martinson and Winsa (1986) have evaluated the research data on black spruce in Sweden and concluded that the provenance choice in most cases had been wrong. They recommend expanded research on the species, especially on abandoned agricultural peatland sites with frost problems. The potential for future use of black spruce in Norway depends on the availability of proper provenances for sites considered marginal for Norway spruce and Scots pine. These include, among others, the cold continental sites, depressions with high frequencies of summer frosts, and oligotrophic peatlands in the semi- and the cold continental areas.

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GENETIC ASPECTS OF BLACK SPRUCE SILVICULTURE

by

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ABSTRACT

Black spruce (*Picea mariana* (Mill.) B.S.P.) is a genetically variable species and this variability must be taken into account in seed collection, distribution and development of selection programs. Clinal variation is found in phenology and growth parallel to gradients in photoperiod and temperature, with regional deviation from this general pattern due to inbreeding and other genetic processes. As a result of the importance of black spruce in silviculture, particularly in eastern Canada, large-scale selection and breeding programs have been initiated, and improved seed is already available.

INTRODUCTION

Black spruce (*Picea mariana* (Mill.) B.S.P.) is an important species of north-temperate and boreal forests in North America. Its ecological and genetic characteristics can be summarized in three words: flexibility, adaptability and variability. Black spruce excels in all of these. It regenerates by seed and layering, is sufficiently light tolerant to develop in uneven-aged pure and mixed stands in competition with a variety of associates, yet can also grow as a pioneer on open areas following cutting, fire or other natural catastrophes (Heinselman 1957). In boreal forests it produces merchantable volumes of high-quality pulpwood on sites ranging from stony, shallow and dry uplands to moist and wet lowlands and bogs. Many such difficult sites can be utilized effectively only by black spruce - our "Cinderella species" (Hearnden 1975). At the same time it is affected very little by insects or fungus diseases (Basham and Morawski 1964, Canadian Forestry Service 1976). Because of its economic value and broad adaptability, black spruce is artificially regenerated on a large scale. A survey of nurseries in Canada shows that it ranks first in numbers of seedlings grown in all provinces from Manitoba to the Atlantic (Smyth and Brownright 1986). We estimate that in the U.S.A. and Canada at least 80 million seedlings are established on about 40,000 ha each year by planting alone and that these figures are still increasing. It is therefore very important to consider the genetic composition of the seed used because failure to do so may well lead to losses in adaptability to local conditions and productivity of plantations. This paper summarizes the most essential information on the genetics of the species and describes the application of such knowledge in tree improvement and silviculture.

Morgenstern, E.K. and Hall, J.P. 1990. Genetic Aspects of Black Spruce Silviculture. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 107-111.*

THE ORIGIN OF GENETIC VARIATION

Several genetic processes operate in populations of a species to produce genetic variability within and among them. *Mutation* is the process that creates new genes or changes in chromosome structure. Individuals thus affected transmit these new gene or gene combinations through *migration* of pollen and seed. *Natural selection* removes weak and poorly adapted members of the population during all stages of reproduction and development. *Inbreeding*, i.e. mating of genetically related individuals, leads to greater uniformity within a population and usually loss of vigour. *Introgressive hybridization* is the exchange of genes between two closely related species in areas where their ranges overlap, leading to greater variability of one or both of the species but usually not the disappearance of the pure species (Wilson and Bossert 1971).

All of these processes influence the variation of black spruce but their impact differs in time and space and can never be fully determined. As a rule, however, *natural selection* is the dominant process and can be most easily demonstrated (Morgenstern 1969).

POPULATION STRUCTURE

The interplay of genetic processes such as mutation, migration and selection affects levels of genetic variation within and among populations. Population structure is studied by collecting seed from individual trees in several populations following open or controlled pollination and subsequent electrophoretic analyses of enzymes in the laboratory or testing of seedlings in various environments to study morphological and physiological traits.

Hypotheses on population structure have been concerned with the possibility of black spruce bog and upland ecotypes. Morgenstern (1969) found that progeny from sites ranging from bogs to uplands in six regions of Ontario differed little when tested in a variety of environments. Fowler and Mullin (1977) discovered differences among stands but these were not related to upland or bog habitats, even when experiments were conducted in the field for a period of 10 years. O'Reilly *et al.* (1985) demonstrated greater genetic distances among upland than among lowland stands but there was a broad range of overlap in genotype frequencies from these two habitats. Since populations in the central part of the Boreal Forest Règion (Rowe 1972) are large and continuous, there is little isolation and much migration of genes among populations. Edaphic ecotypes have probably not developed. Even in parts of the Acadian Forest Region where black spruce is found in large stands, as in central New Brunswick, genetic differences among stands were very small (Boyle and Morgenstern 1986).

In contrast, where populations are small and isolated, inbreeding is more likely to occur (Falconer 1981). This generally leads to reduced seed set and low survival and depressed vigor of the progeny (Park and Fowler 1983). In three regions of southern Ontario where black spruce is found in small isolated stands, the inbreeding coefficient, F, was 0.08 but in three regions of northern Ontario with its larger stands it dropped to 0.03 (Morgenstern 1972). Even stronger effects of inbreeding have been determined in Alberta where F was as large as 0.23 for the progeny population (Sproule 1988). In Nova Scotia, provenance experiments demonstrated poor growth of native Cape Breton Highland populations when compared to introduced populations (Fowler and Park 1982). A study by McCurdy (1988) based on electrophoresis confirmed in breeding with F ranging from 0.08 to 0.17 in the p. Studies of population structure can therefore yield results which can be applied in silviculture. In this last case, for example, they indicate that the small local Cape Breton Highland populations are undesirable for the regeneration of the Highlands following spruce budworm (*Choristoneura fumiferana* Clem.) defoliation.

GEOGRAPHIC VARIATION

Broader aspects of variation across the range or parts of the range of a species are usually explored by the traditional seed-source or provenance experiments. Although these may begin in the greenhouse and nursery, they are usually continued by means of long-term field experiments. Field experiments are more expensive and difficult to handle. Because of less control over more complex physical and biological factors than are found in the nursery, the results are often not as clear and easy to interpret (Snaydon 1980).

Early results from greenhouse and nursery experiments indicated that variation in central populations was clinal in seedling phenology and growth in response to natural selection along the gradients of photoperiod and temperature (Dietrichson 1969, Morgenstern 1969, Pollard and Logan 1976). In range-wide material, experiments in Ontario showed a similar variation pattern (Morgenstern 1978). Experiments in Newfoundland with native populations revealed a relationship to the forest regions of the Island and the variation pattern was termed ecotypic (Khalil 1973).

In field experiments up to 15 years from seed, results have been similar but often general trends have not been as clear. In Newfoundland, range-wide experiments showed weak south-north and east-west trends in height (Khalil 1986). Regional experiments in Newfoundland generally demonstrated stronger correlations of height and latitude at age 15 than at age 10 and therefore a clearer clinal variation pattern, but in two extreme environments, the Northern Peninsula and the Avalon Peninsula, the pattern expressed was ecotypic (Hall 1986). In the Maritime Provinces, Quebec and Ontario, the clinal pattern discovered in nursery experiments was still evident at age 15 in some locations in the field but not in others, and each experiment varied in the degree to which differences in height and survival were expressed and correlated with geographic and climatic variables. Considerable changes in rank are still taking place (Fowler and Park 1982, Boyle 1985, Morgenstern *et al.* 1987, Park and Fowler 1988, Beaulieu *et al.* 1989). In the Lake States experiments, correlations with geographic and climatic variables declined with age and early selection was not considered promising (Merrill *et al.* 1983, Nienstaedt 1984).

Considering that all of the experiments in the range-wide study have results from trees only 15 years old, it is too early to draw final conclusions. In all regions the negative correlation of height with latitude suggests the possibility of gaining growth by moving provenances to the north, but the correlation with survival is often positive, particularly in boreal regions, and therefore calls for movement to the south. This conflict cannot be resolved until longer records are available. The importance of survival cannot be underestimated since it influences volume production. Volume production per hectare depends as much upon good tree survival (i.e. stocking) as upon tree height, but survival differences usually require several decades of testing before they are fully expressed (Oleksyn and Giertych 1984).

An aspect of black spruce geographic variation which occasionally causes problems in identification is introgressive hybridization with red spruce (*Picea rubens* Sarg.) (Manley 1972). The ranges of black spruce and red spruce overlap from Pennsylvania north through the New England States to the Maritime Provinces and in eastern Ontario and Quebec (Hosie 1969). Black spruce individuals which carry some red spruce genes are more susceptible to the spruce budworm than pure black spruce (Manley and Fowler 1969).

SELECTION AND BREEDING

In any silvicultural program based on seeding and planting it is necessary to pay attention to the quality of seed used. The first method applied to achieve some degree of control over seed is the delineation of seed zones. Seed zones assure that only adapted genotypes from the same zone are used in regeneration to achieve good growth and survival of plantations. Usually they are based on ecological regions but modifications are possible once results from provenance experiments are available. Seed zones have been delineated in all provinces (Morgenstern and Carlson 1979).

The second method used for seed control is the seed production area, i.e. a natural stand of high quality which is reserved from cutting or cut in good seed years. These stands, if regenerated from their own seed naturally or artificially, can also serve the purpose of gene conservation. When seed production areas are selected it is important to avoid stands that have been regenerated by layering. Layering creates groups of closely related individuals (clones) which produce large quantities of inbred seed. Cone collections in such stands will therefore yield only small quantities of good seed and are wasteful and inefficient. In some provinces seed production areas are being tested in a series of regional provenance experiments (Coles 1981).

If long-term provenance tests have shown that productivity can be increased by growing seed from neighboring regions (provenance selection), then seed can be introduced from those regions. In tests in the Maritime Provinces there is some evidence that black spruce seed can be transferred across several of the seed zones established at an earlier date (Fowler and MacGillivray 1967, Park and Fowler 1988).

Small-scale selection or "tree improvement" programs for black spruce have been underway in Canada for 30 years, but during the last 10 years there has been a significant acceleration (Morgenstern and Carlson 1979, McPherson *et al.* 1982). A survey of provincial activities indicated that the total of 167 ha of black spruce seed orchards established by 1984 was expected to increase to 954 ha by 1988. If this area is now in fact as large as planned, then black spruce orchards make up 46.9% of the total area of seed orchards in Canada for all species (2 036 ha) (Morgenstern 1986).

Any selection program must be carefully planned taking many factors into account (Fowler 1986). The first operational activity in such a program is plus-tree selection. Since black spruce exhibits relatively little variation in stem and crown form and is utilized primarily for pulp and paper, selection is concentrated on rate of growth (Morgenstern *et al.* 1975). This permits relatively rapid selection of trees in natural stands but must be followed by establishment of progeny tests which in this case are better described as family tests. The progeny of an individual, open-pollinated tree constitutes a half-sib family. Seedling seed orchards are planted in the same year and about 10-15 years later the orchards are rogued on the basis of results from the family tests. In the next three generations (40 years) recurrent selection will be practiced by means of controlled crosses and progeny tests, and increasingly more valuable seed will come from seed orchards (Fowler 1986).

Economic analyses show that this family selection - seedling orchard strategy is sound and will yield appreciable genetic gain in the first generation (Cornelius and Morgenstern 1986). It has been adopted for black spruce in most programs in the U.S.A. and Canada (Carter 1988). Its success has recently been demonstrated in New Brunswick where the first substantial seed crop (about 41 million seeds) was obtained from the unrogued seedling orchards only 11 years after the program was initiated (Simpson 1989).

Genetic improvement of our native species, such as black spruce, is not an end in itself but is an integral part of silviculture. Genetic insights and methods will make future forests vigorous and productive. This is being recognized in Newfoundland as much as elsewhere in North America (Harrison 1988).

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LONG TERM DEVELOPMENT OF BLACK SPRUCE ADVANCE GROWTH RELEASED BY CUTTING

by

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ABSTRACT

Second-growth black spruce stands originating after logging in the first half of this century were sampled throughout the commercial range of black spruce in Québec. Most of the trees forming the present stands had originated before harvesting, and evidence of layer origin was found for most dominant trees whose root system was excavated. Trees of all height classes responded to release. Maximum height growth rates occurred from 20 to 30 years after release and they were inversely proportional to height at time of release. Productivity of most of these stands was equal to or even greater than that of Site I as depicted in black spruce yield tables for Ontario and Québec.

RÉSUMÉ

Des peuplements d'épinette noire établis à la suite des activités d'exploitation de la première moitié de ce siècle ont été échantillonnés à différents endroits de l'aire commerciale de l'épinette noire. La grande majorité des tiges provenait de la régénération préétablie que la coupe du peuplement précédent avait dégagée. La plupart des tiges dominantes dont on a étudié le système racinaire étaient des marcottes. Des tiges de toutes les classes de hauteur ont bénéficié du dégagement provoqué par la coupe. Le taux de croissance maximal en hauteur a été atteint entre 20 et 30 ans après la coupe et il était inversement proportionel à la hauteur au moment de la coupe. Ces peuplements ont produit un volume ligneux équivalent ou supérieur à celui d'une station de première qualité, tel que donné par les tables de rendement du Québec et de l'Ontario.

Doucet, R. 1990. Long Term Development of Black Spruce Advance Growth Released by Cutting. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep., N-X-271, pp. 113-121.*

INTRODUCTION

Black spruce (*Picea mariana* (Mill.) BSP) is widely distributed accross Canada (Hosie 1969). It is used extensively for pulpwood and small lumber, and the usual logging method is clearcutting. In Quebec alone, it is estimated that for the next ten years, about 117 000 ha will be logged annually in the black spruce type of the public domain (Tremblay *et al.* 1987). This represents over 50 percent of the total area that will be cut in all forest types. Much effort will thus be needed to ensure that these stands are adequately regenerated.

Black spruce regeneration is often present under mature stands (Bellefeuille 1935; Linteau 1959). A recent survey of over 200 stands (Doucet 1988a) showed that more than 70 percent were adequately stocked with advance regeneration (stocking ≥ 75 percent based on 4 m quadrats). Layering usually comprises 80 percent or more of this advance regeneration (Frisque and Vézina 1977; Groot 1984; Heinselman 1959; Richardson 1981) and seedlings are often totally lacking (Bellefeuille 1935; Hatcher 1963; Linteau 1959).

The potential of advance growth in general, and of layers in particular has been questioned (Roy 1940) because height growth is slow and form is poor (Groot 1984; Jarvis and Cayford 1961). Moreover, empirical evidence of the production attained by second-growth stands originating from cutting is lacking, because most mature stands of the boreal forest originated after fire (Cogbill 1985; Van Wagner 1984). However, with the extension of logging into the black spruce type in the early part of this century and successful fire protection, second-growth stands approaching maturity are now available for study.

The objectives of this study are (*i*) to evaluate the importance of advance growth in the overall regeneration of old clearcuts, (*ii*) to establish its growth pattern and, (*iii*) to ascertain its origin.

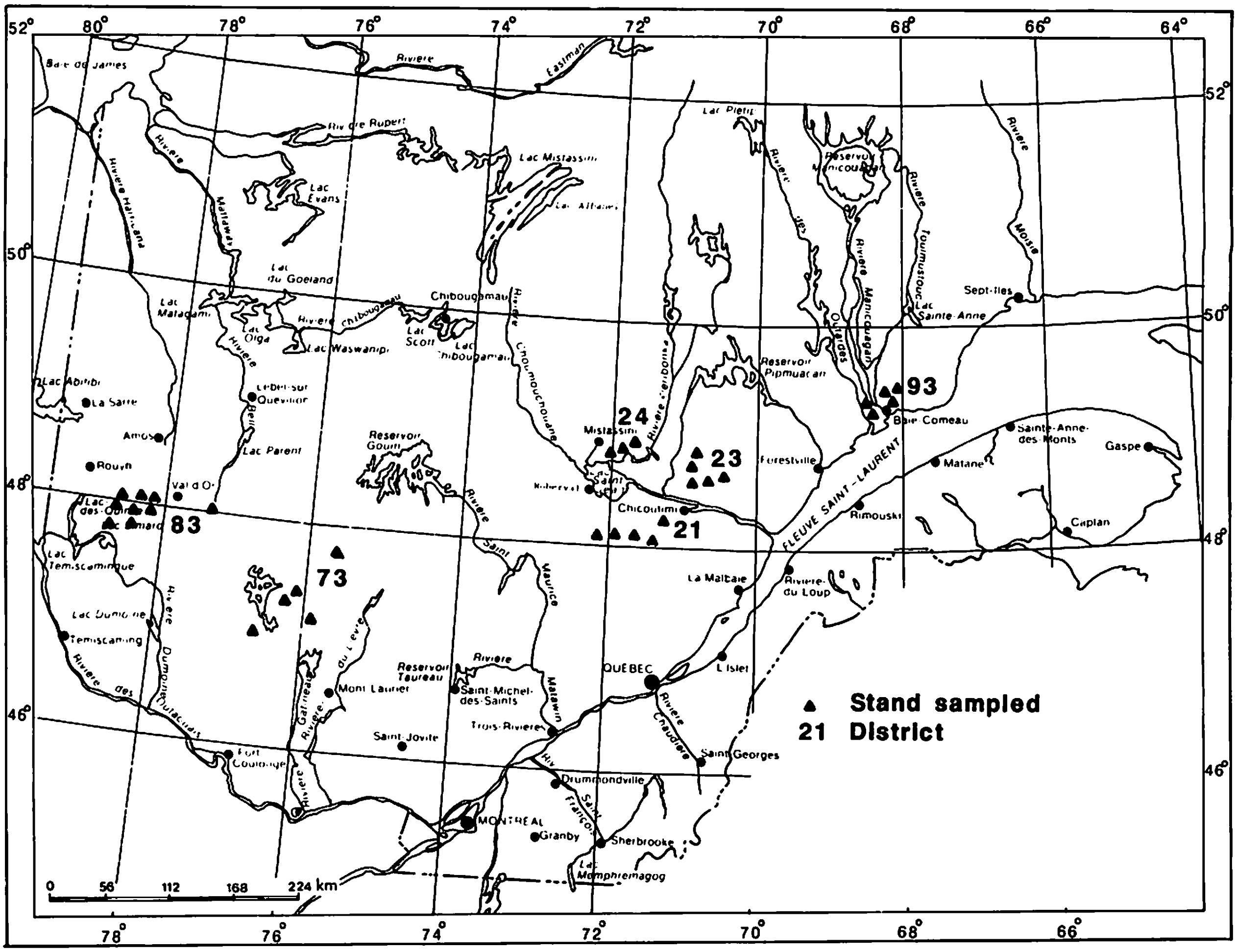

Figure 1. Location of the stands sampled.

METHODS

Thirty-two stands originating from old clearcuts were located throughout the range of black spruce in Quebec (Figure 1). The information on cut location was gathered from several sources. The year of logging was sometimes available from old forest maps but in other cases only the location of logging activities by decade was provided. Recent forest type maps were also used to ensure that these areas had actually regenerated to black spruce.

Evidence of cutting activities was ascertained in the field from remains of old stumps, and year of cutting was verified by dating wounds on advance regeneration and growth reactions that followed cutting.

Three to five sample plots covering an area of 0.04 ha each were located in each stand. No effort was made to select the densest parts of the stands, but openings that would have occupied more than one third of the plot area were avoided. The diameter at 1.30 m (dbh) of all stems with dbh larger than 1.0 cm was measured to the nearest millimetre, and 15 stems evenly distributed over the range of dbh were felled. Total height was measured as well as diameter at the stump (15 cm from the ground) and at 50, 130, 200 cm and every metre thereafter. A disk was cut at the stump for age determination. Additional disks were collected at the above-mentioned intervals on five of the felled trees, one in each of the five largest diameter classes. Annual height growth was also measured for the last ten years.

Drainage and soil texture classes of each sample plot were evaluated according to the canadian system of classification (Day and McMenamin 1982). Topographic location (upland or lowland) was also noted and depth of the humus layer was measured.

The stump-root system of the largest tree in each plot was excavated to determine whether it originated from layering. When the branch connection was found, an attempt was made to follow it for the maximum distance possible. Otherwise a disk was cut from each

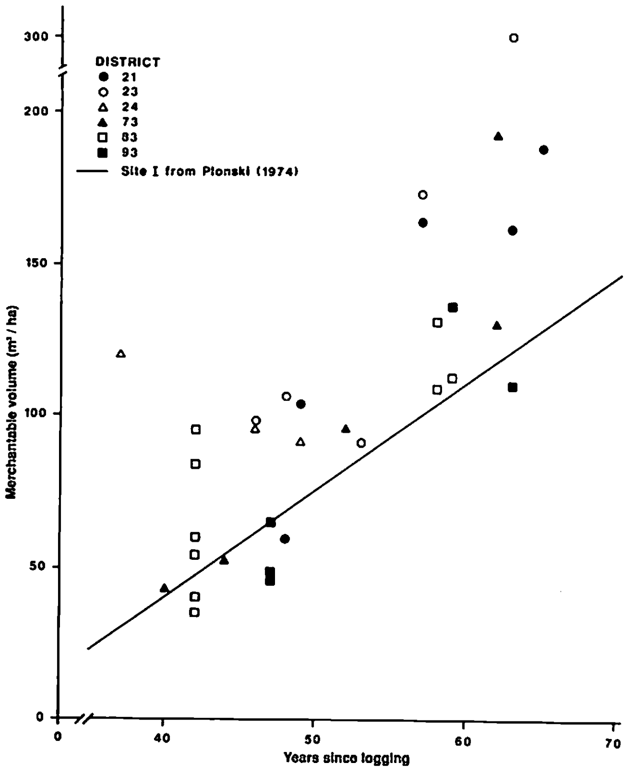

Figure 2. Yield of merchantable volume (dbh >9.0 cm) of second-growth stands as compared to Plonski's (1974) yield tables.

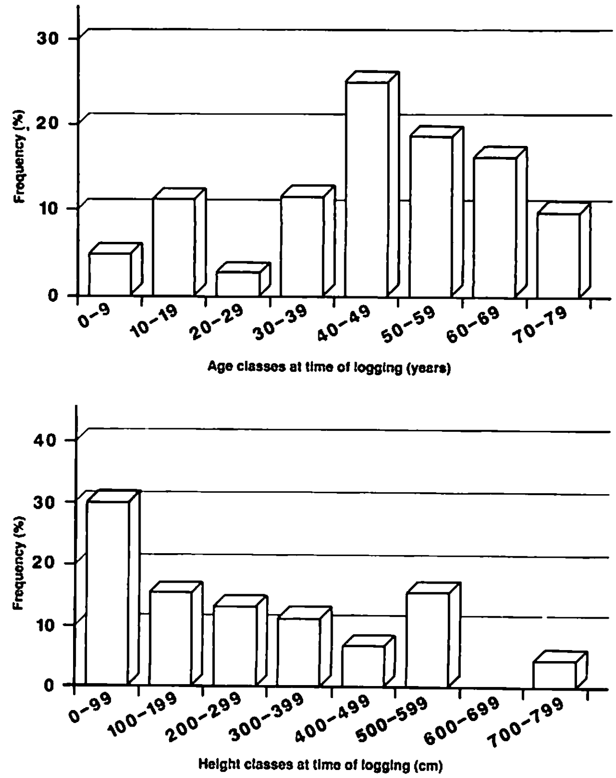

Figure 3. Age and height structures of stand 93-1 at time of logging.

root at some distance from the stump for study under magnification with a microscope.

Volume of each felled tree was calculated by using a taper equation developed by Désaulniers (1985). These data served as the basis for deriving local volume tables for each stand, based on 45 to 75 sample trees (15 per plot), which were applied to plot tallies to obtain total and merchantable volumes. The age of each sample disk was counted and height at time of release, when applicable, was determined by linear interpolation between the two levels that contained it, using the method described by Carmean (1972), which gives more accurate results than several other methods (Dyer and Bailey 1987). Height growth curves were calculated for each stem by means of non linear regressions of the form:

$$Y = (x + 1)^{B_1} \epsilon^{(B_2 + B_3X + B_4X^2)} - 1$$

where: Y = height in metres

X = age at given height

ϵ = base of neperian logarithms

using the height and age data obtained by stem analysis. This model gave better fit than polynomials at both ends of the range of data. Separate curves were fitted for growth periods before and after logging. Growth rates could then be calculated for any given age by using the first derivative of the regression.

Histograms of stem age at time of logging were prepared for some of the stands. Linear correlations between present height, dbh, height growth, and height and age at time of logging were also calculated. Data analysis is still in progress for the other stands.

STUDY AREA DESCRIPTION

Most stands sampled were located on upland sites (Table 1). Drainage was usually good to rapid and humus depth often less than 30 cm. Understory vegetation was dominated by feather mosses (*Pleurozium schreberi* (BSG) Mitt., *Hylocomium splendens* (Hedw.) BSG, *Ptilium crista-castrensis* (Hedw) De Not.). Tree species other than black spruce included balsam fir (*Abies balsamea* (L.) Mill.) and occasionally tamarack (*Larix laricina* (Du Roi) K. Koch), jack pine (*Pinus banksiana* Lamb.), white birch (*Betula papyrifera* Marsh), or trembling aspen (*Populus tremuloides* Michx) depending on the stand.

Number of years since logging varied from 37 to 65 years. In a few cases, two major disturbances seemed to have taken place, as evidenced by growth reactions

Table 1. Site and stand characteristics.

District	Stand	Years Since cutting	Topographic position	Humus depth (cm)	Drainage class	Soil textural class	Number of stems/ha	Basal Area m²/ha	Basal Area % black spruce	Total volume (m³/ha)	Average dbh (cm)	Dominant height (m)
21	1	48	Upland	25	Good	Sandy loam	4317	21	98	93	7.9	10.8
	2	65	Upland	18	Rapid	Sand	2700	36	99	216	12.9	14.1
	3	63	Upland	13	Good	Loamy sand	1508	28	99	177	15.2	15.1
	4	57	Upland	15	Good	Loamy sand	2292	31	100	187	13.0	14.2
	5	49	Lowland	>100	Poor	Organic	4175	28	100	136	9.3	11.5
23	1	46	Upland	18	Good	Loamy sand	6150	32	92	150	8.2	11.8
	2	48	Upland	22	Rapid	Medium sand	7433	37	95	168	8.0	11.1
	3	54	Upland	24	Good	Sandy loam	5350	27	94	131	8.1	12.3
	4	57	Upland	27	Good	Sandy loam	3083	32	94	194	11.5	15.1
	5	63	Upland	30	Good	Sandy loam	2500	41	93	326	14.5	18.6
24	1	37	Upland	37	Rapid	Sandy clay loam	3806	33	96	170	10.4	12.4
	2	46	Upland	55	Good	Sandy clay loam	6025	32	98	145	8.2	11.5
	3	49	Upland	33	Rapid	Sandy loam	5450	31	99	145	8.5	11.6
73	1	40	Upland	16	Rapid	Sandy loam	5265	21	93	78	7.1	9.3
	2	62	Lowland	>100	Very poor	Organic	3475	27	82	159	9.9	14.8
	3	52	Upland	10	Rapid	Loamy sand	3708	25	97	131	9.2	12.2
	4	44	Lowland	48	Poor	Organic	4525	21	82	87	7.7	10.3
	5	62	Upland	18	Good	Loamy sand	2850	35	96	222	12.6	14.8
83	1	42	Upland	12	Good	Loamy sand	3900	26	90	138	9.2	12.5
	2	42	Upland	14	Good	Loam	4983	16	93	66	6.3	11.3
	3	42	Upland	12	Good	Sandy loam	3913	20	96	98	8.1	11.7
	4	42	Upland	30	Moderate	Loam	5900	19	97	80	6.4	10.7
	5	42	Upland	13	Good	Fine sand	3808	20	95	90	8.2	11.2
	6	42	Upland	17	Good	Sandy loam	2867	23	94	112	10.0	11.8
	7	59	Upland	15	Moderate	Loamy clay	3110	27	96	143	10.4	12.9
	8	58	Upland	19	Good	Loamy clay	2033	26	90	157	12.7	14.3
	9	58	Upland	11	Good	Loamy sand	2075	22	98	130	11.6	14.3
93	1	47	Upland	20	Good	Sandy loam	6150	24	99	103	7.1	10.2
	2	47	Upland	20	Rapid	Sandy loam	8233	26	95	100	6.4	9.6
	3	47	Upland	22	Rapid	Sandy loam	9867	29	98	99	6.1	9.0
	4	59	Upland	35	Good	Sandy loam	5008	39	83	179	9.7	11.3
	5	63	Upland	23	Good	Sandy loam	6042	33	99	153	8.4	11.2

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on some of the stems. The last one was the clearcut that had given rise to the present stand while the former was probably a partial cut, for which no documentation could be found. Stand characteristics such as number of stems, average dbh, basal area and volume per unit area were highly variable (Table 1, Figure 2).

RESULTS

In most cases, the vast majority of stems forming the present stand had originated before cutting (Table 2). This was especially true for merchantable stems, that is those having a dbh larger than 9.0 cm. Age and height of stems within stands were highly variable (Figure 3). The oldest and largest residual stems were often more than 80 years old (Table 2) and taller than 8 m at the time of cutting.

The layer origin of one or more dominant stems could be established for most stands; in several instances the layered branch that had given rise to the stem could still be followed for a considerable distance (Table 2).

The relationship between present height and height at time of cutting was relatively strong in most cases, though variations within a given class were large. This was especially the case for those stems that were smaller at time of cutting: some of them attained the dominant or codominant crown class while other remained suppressed (Figure 4). The same was true for present height vs age at time of cutting.

Growth rates of those residual stems that eventually formed the main canopy was strongly affected by cutting. Growth reaction occured rapidly and maximum growth rates were, in most cases, inversely related to height at time of cutting (Figure 5). Growth rates were declining when stands were sampled 37 to 65 years after cutting and were about the same for all stems of the main canopy, regardless of their height and age at time of release.

DISCUSSION

An adequate means of assessing the productivity of stands originating from advance growth released by logging would have been to compare them with stands of fire origin of the same age growing in their immediate vicinity. However such a situation could not be found. Comparison of stands growing in different areas was hampered by the lack of an adequate method for assessing site productivity. Site Index is recognized as one of the best methods (Tesch 1981), but its use implies that dominant stems have been free of suppression throughout their life, which clearly was not the case here. Classifications based on site

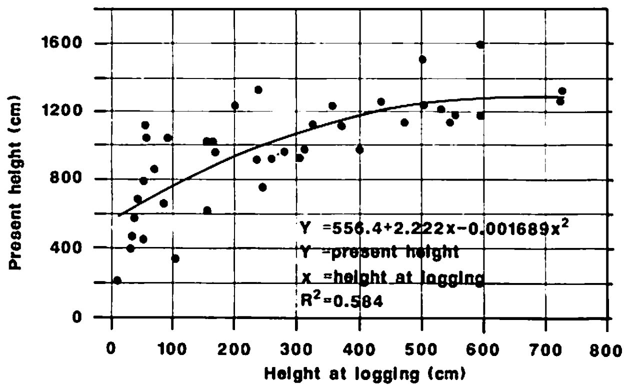

Figure 4. Present height vs height at time of logging for stand 93-1.

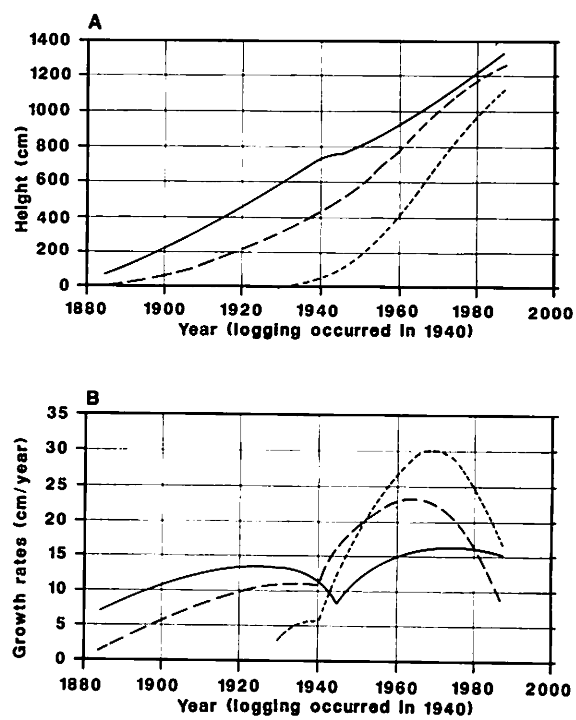

Figure 5. Height growth (a) and growth rates (b) of three representative stems of the main canopy of stand 93-1.

characteristics such as soil and topography are useful to define broad categories, but species-specific regional studies are needed to obtain accurate results (Schmidt and Carmean 1988). Existing yield tables thus remained the only basis for evaluation. In most cases, yield of sampled stands, as measured by merchantable

Table 2. Age structure of sampled trees and length of the layer connection of a dominant stem.

District	Stand	% advance growth		Age of advance growth at time of cutting (years)		Length of layer connection (cm)
		all stems	dbh>9.0 cm	average	maximum	
21	1	92	97	37.9	119	130
	2	100	100	54.5	105	171
	3	90	100	24.6	84	225
	4	91	100	37.2	104	115
	5	100	100	63.1	137	75
23	1	88	97	40.6	99	115
	2	90	93	42.6	113	120
	3	75	86	29.8	58	120
	4	93	97	58.2	107	100
	5	97	100	35.5	87	50
24	1	98	100	64.2	174	130
	2	100	100	47.9	80	95
	3	92	97	50.2	80	73
73	1	78	92	25.3	51	52
	2	84	97	34.2	65	26
	3	70	87	32.6	89	45
	4	18	32	58.9	98	65
	5	43	48	34.2	65	234
83	1	96	100	9.9	49	46
	2	92	95	59.3	87	85
	3	92	95	16.8	86	200
	4	61	90	51.9	85	180
	5	82	96	27.9	67	*
	6	90	96	42.6	108	68
	7	85	96	34.3	162	146
	8	69	88	31.4	104	217
	9	83	100	34.0	74	56
93	1	100	100	44.6	72	21
	2	92	100	34.2	85	76
	3	97	100	34.0	78	157
	4	88	100	33.2	92	63
	5	100	100	42.9	73	110

* not found

volume, was equal to or better than site class I of normal yield tables for Ontario (Plonski 1974), as can be seen in Figure 2. It was also equal to or better than the best site (site class II in this case) of normal yield tables for Québec (Vézina and Linteau 1968) and of variable density yield tables for Québec (Boudoux 1978). The same trend was evident when total volume was used for comparison, although more stands fell between the means for site classes I and II.

One might argue that these comparisons are invalid because these tables portray the development of stands that established after disturbance (fire) while our stands came from regeneration already established at the time of logging. However, from a management point of view, one would have to decide either to accept advance growth or to begin anew with natural or planted seedlings established after cutting. Year of cutting should thus be considered as the beginning of the rotation.

Height growth potential seemed to be related more closely to the relative position of the respective stems at time of release rather than to age. Frequently, small stems reacted more strongly to release but they attained their maximum growth rate at about the same time as the larger ones. Maximum growth occured from 20 to 30 years after logging and this rate declined rapidly thereafter (Figure 5), even though they were several years younger. The same result was obtained in west-central Alberta (Johnstone 1976), and parallels the development depicted in Plonski's (1974) yield tables for dominant stems in the early years after establishment, even though these latter stems likely did not suffer from a period of suppression. This is consistent with the assumption that increasing height provides a limitation to growth because of increased difficulties with translocation, especially of water (Mäkelä 1986). Physiological age would thus be more important than chronological age, as evidenced by the fact that current growth rates of dominant stems, 40 to 60 years after release, were the same regardless of their height and age at time of release. Some of these stems, when sampled, were approaching the maximum longevity currently accepted for black spruce (Loehle 1988) and appeared to be able to survive for several more years. Strictly speaking, these stands were uneven aged but they behaved like even aged stands of medium age.

Not all stems responded similarly to release, especially in the smaller height class. Inter-tree competition was probably responsible for this: some of these stems were effectively released while others probably still suffered from the presence of taller stems in their immediate vicinity. A study of the growth of black spruce clumps in the first few years after their release by logging has shown that several stems initially responded, but as one member of the clump gradually gained dominance, height growth of the others was unfavorably affected (Doucet 1988b; Doucet and Boily 1988).

There is evidence that some stems did survive two distinct periods of suppression and still resumed fast enough growth to be part of the main canopy. This is important since non-merchantable trees that could be left to form the next stand are numerous and many of them were already established when the stand was logged for the first time 40 to 60 years ago.

The layer origin of only a few stems was ascertained, but it is most likely that the majority of stems were layers. Several studies have shown that layers formed 80 percent or more of the advance growth of mature black spruce stands (Frisque and Vézina 1977; Richardson 1981; Groot 1984). Seedlings were often completely lacking regardless of the site (Linteau 1959; Hatcher 1963). In recent clearcuts, where identification is easier than in old stands, layers were more prevalent than seedlings in the regenerating stands (Hatcher 1964). In one such study of a 20-year-old clearcut, 97 percent of all stems sampled were positively identified as layers (Doucet 1988b). Mallik and Newton (1988) have shown that a seedbed substrate consisting of organic matter from black spruce stands inhibited growth and development of seedlings. In old clearcuts, the proportion of layers has been estimated at a minimum of 30 percent based on basal sweep (Horton and Groot 1987). This however may be a gross underestimate: seedlings can also have basal sweep (Vincent 1965) and the form of fast growing layers improves with age (Stanek 1968). The degree of basal sweep also depends on the size of the branch that has layered.

The stands sampled are not necessarily representative of the average black spruce stand. They are a sample of the stands that were logged in the first half of this century in such a manner that advance growth was protected. It is likely that other stands did not regenerate to black spruce either because advance growth was absent or was largely destroyed by logging. It can also be argued that in these early days of logging in the black spruce forest, better than average sites were selected for logging, as evidenced by site characteristics. This problem is alleviated however when yields are compared with better sites of normal yield tables. These comparisons confirm the results obtained in second-growth black spruce peatlands in northeastern Ontario (Horton and Groot 1988) and extend them to a much larger area.

The role of black spruce advance growth in the regeneration of logged stands has largely been disregarded. Regeneration survey guidelines in some provinces specifically exclude layers from acceptable reproduction (Alberta Forest Service 1979; Paquet 1984). Others set standards of quality and growth rates that would probably exclude much of the advance growth when surveys are conducted either before logging or in the first few years thereafter (Manitoba Forestry Branch 1980; Chaudry 1981). While this study did show that black spruce advance growth can in fact produce commercial trees, not all stems can survive and grow well. Differentiation of good versus poor growth and survival requires further research into vegetative reproduction to decide which regeneration system will be used in future forest management.

Another problem with advance growth is that it is largely destroyed in the course of usual logging practices (Webber *et al.* 1969). However observations made in 20 year old and younger clearcuts (Doucet 1988b; Doucet and Boily in press; unpublished data) have shown that a fair proportion of the smaller advance growth is often preserved even when no special efforts are made. Methods such as directional felling and wide spacing between skid trails can improve survival substantially (Canuel 1987). Greater care may be needed to preserve larger stems, but the potential benefit should provide an incentive to devise appropriate logging methods.

SUMMARY AND CONCLUSION

Black spruce stands that had been logged in the first half of this century were sampled to determine how they had evolved after disturbance. It was found that most had regenerated from advance growth, often of layer origin. Stems that formed the main canopy 40 to 60 years after logging varied widely in age and height when the previous stand was cut. Small stems reacted more strongly to release but their growth rate declined 25 to 35 years later so that larger individuals were able to maintain a dominant position. These findings show that advance growth, including relatively large residual stems, will respond to release if preserved during logging and develop into stands as productive as those described by currently available yield tables.

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MODIFIED HARVESTING TO PROMOTE NATURAL REGENERATION OF BLACK SPRUCE

by

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ABSTRACT

Black spruce (*Picea mariana* (Mill.) B.S.P.) has evolved two reproduction characteristics that can be utilized by foresters to obtain natural regeneration by modified harvesting. It produces an abundant supply of seed that is released slowly from the semi-serotinous cones over a number of years, and it regenerates readily by layering. As well, black spruce stands that are moderately open-canopied or overmature often develop an understory of advance growth. This paper considers the forestry situation in Ontario, the ecological and silvical features of black spruce that lend themselves to natural regeneration, modified harvesting methods to achieve natural regeneration, and the need to develop appropriate harvesting machines and techniques to achieve natural regeneration.

INTRODUCTION

Ontario has a large amount of merchantable black spruce (*Picea mariana* (Mill.) B.S.P.), which grows predominantly in the Boreal Forest Region. Black spruce is the most important commercial tree species in Ontario, and accounts for some 40% of the province's total productive forest area (Ketcheson and Jeglum 1972). Of this area, 54% is on upland sites and 46% is on peatlands ("uplands" in this paper refers to mineral soils, while "peatlands" refers to organic soils cf. Canada Soil Survey Committee, Subcommittee on Soil Classification 1978). Currently, more than 80% of the allowable cut for black spruce is harvested annually.

Because of its importance, and because of the need to improve the levels of regeneration in clearcut black spruce forests, Forestry Canada, Ontario Region has been conducting a long-term research project entitled "Black Spruce Ecosystem Silviculture". This project has emphasized research into natural regeneration of black spruce, both from seed and from residual growth remaining after harvesting (Jeglum and Leblanc 1988).

Jeglum, J.K. 1990. Modified Harvesting to Promote Natural Regeneration of Black Spruce. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 123-129.*

This paper presents an overview of the use of modified harvesting to promote natural regeneration of black spruce in Ontario. Because there is not enough money available under the current mechanism of funding regeneration to regenerate all cutovers by planting, we need to use more fully other techniques such as direct seeding and modified harvesting.

The main topics to be considered in this paper are: (*i*) the forestry situation in Ontario, (*ii*) ecological and silvicultural attributes of black spruce, (*iii*) modified harvesting/ regeneration methods used in Ontario, and (*iv*) development of machines and harvesting techniques to match site and stand conditions.

THE FORESTRY SITUATION IN ONTARIO

In Ontario, most of the forest land is publicly owned crown land, administered by the Ontario Ministry of Natural Resources (OMNR), and forest industries license or lease the land from the province. The industries pay the province stumpage for the wood harvested, and taxes on earnings. In turn, the public funds the regeneration of cutover crown land in large part through forest management agreements (FMAs) with the companies. In these agreements, ground rules for methods of regeneration and rates of compensation are negotiated. The situation with respect to regeneration in Ontario is as follows:

- Current statistics suggest that we are regenerating only 50 to 60% of the land harvested annually (Anon. 1988, Jeglum and Leblanc 1988). There are large areas of "backlog" (un-regenerated or inadequately regenerated lands) that have accumulated over the years.

- Regeneration budgets for OMNR are being capped or reduced, owing to competition with other government expenditures. Seedling production ceilings have been established.

- Availability of regeneration dollars will determine how much of the harvested area will be addressed. A current concern is that of stretching available regeneration dollars as far as possible.

- Various classifications, such as the Forest Ecosystem Classification (Jones *et al.* 1983) and prime land/prime site classifications, are designed, in part, to identify ways of allocating regeneration dollars. Management plans are attempting to direct high-cost regeneration toward the most productive sites, and medium- and low-cost regeneration toward the moderately productive and least productive sites.

- Because of limited regeneration budgets, we cannot address every hectare with the high-cost planting option of clearcut and plant. Consequently, we must consider cheaper alternatives to obtain acceptable regeneration on the 40 to 50% of the harvest area that cannot be planted.

ECOLOGY AND SILVICS OF BLACK SPRUCE

Much of the effort in the Black Spruce Project has been devoted over the years to natural regeneration of black spruce by modified harvesting (e.g., Fleming and Groot 1984, Groot 1984, Groot 1987, Haavisto 1979, Haavisto *et al.* 1988, Jeglum and Leblanc 1988). This emphasis has necessitated a study of the species' ecological and silvical characteristics. Some of the main ecological characteristics of black spruce that pertain to natural regeneration are as follows:

- It is found mainly on wet and moist organic soils, and on dry, shallow soil over bedrock sites. After wildfire, it spreads from the wet and shallow-soil sites onto adjacent mineral soils of moist and fresh moisture regimes, where it achieves its best growth.

- Its root systems are generally shallow and wide-spreading. Windthrow is common in older stands and in shallow or unstable soils. In peatlands, adventitious roots are produced on stems as moss and peat grow upwards.

- It has two main mechanisms for natural regeneration: seeding and layering (rooting of low-lying branches in moss, with the tips growing upwards and eventually becoming independent stems).

- It produces seed prolifically, and is adapted to areas in which there are frequent wildfires. Tops with densely clustered semi-serotinous cones not completely burned in fires disperse millions of seeds per hectare. Fire-origin stands are usually even-aged.

- Favorable seedbeds include *Sphagnum* moss and peat, exposed mineral soil, shallow humus over mineral soil, thin pioneer moss on mineral soil, and rotten wood.

- Successful seedling establishment requires abundant light (Curtis 1959). However, in overmature stands and open-canopied peatland and shallow-soil upland forests, there can be considerable advance growth.

- As the canopy of the juvenile stand closes and the moss layer develops, considerable in-filling may occur in the first few decades by layering and/or seeding.

- Seedling growth is slow, and there is competition from faster growing broadleaved trees and shrubs. Black spruce is often seen under jack pine (*Pinus banksiana* Lamb.), where it may be the same age and have the same time of origin or it may be successional.

- Of all North American spruces, it survives and reproduces with the smallest nutrient supply, even in ombrotrophic bog. It tolerates low soil temperatures beneath dense canopies and in peatlands.

MODIFIED HARVESTING/REGENERATION SYSTEMS

When the standard clearcutting operation is modified to promote natural regeneration, this is modified harvesting. Usually modified harvesting results in clearcutting, although careful logging, which leaves advance growth seedlings, saplings, and small trees, is also a method of modified harvesting.

The main reason for modified harvesting is to obtain natural regeneration more cheaply than by planting. The idea is to spend money in the harvesting phase in order to obtain cheaper regeneration in the regeneration phase. In this view, the extra cost of harvesting, in comparison with what it would have been with clearcutting, is regarded as part of the cost of regeneration. In this presentation, I will give a few examples of where extra costs of harvesting have been estimated for some kinds of modified harvesting.

Natural Regeneration with Clearcutting

A certain proportion of clearcuts do regenerate naturally, although not necessarily to desired species or to levels of stocking that would yield high merchantable volumes at rotation. Frequently there are compositional changes after harvesting of conifer-dominated stands towards more broadleaf composition, trembling aspen (*Populus tremuloides* Michx.) and birch (*Betula* spp.) (Jeglum 1983).

Alternate-Strip Clearcutting

There are three well known requirements for successful regeneration from seed after strip cutting and patch cutting. One must ensure that there is (*i*) an adequate viable seed supply, (*ii*) enough receptive seedbed, and (*iii*) some protection from excessive drying. Usually, regeneration failure can be explained by the lack of one of these major requirements.

A long-term cooperative project on alternate-strip clearcutting in upland black spruce near Nipigon, Ontario has been in progress since 1974 (Jeglum in press). One main objective of this project was to determine the influence of strip widths, leave time and receptive seedbed on regeneration of black spruce. Results from this study suggested that strip widths up to 80 m (4 chains) would yield desirable levels of regeneration, and that a 4-year leave time was preferable to the 2-year leave time for obtaining desirable levels of regeneration at the 80-m width (Jeglum 1987). It is essential to scarify the upland sites to provide receptive seedbed for seed germination and seedling establishment (Jeglum 1984).

In an economics study, Johnson and Smyth (1988) dealt with the overall cost-effectiveness of strip cutting and the total cost of harvesting and regeneration. This study compared strip cutting with clearcutting for numerous options of planting and direct seeding. If one compares clearcutting and planting with strip cutting and planting the second-cut strips, considerable net savings can be achieved by strip cutting. For example, if natural regeneration can be achieved with a 3- to 5-year leave time, and my studies suggest that it can (Jeglum 1987, in press), then it is possible to achieve a net savings of between $200 and $600 per hectare! If strip depths are increased, thereby decreasing the density of roads, it is possible to increase the savings even more (Johnson and Smyth 1988).

In Ontario this technique is prescribed mainly for black spruce sites with poor productivity, poor accessibility, or "fragile soils" that are particularly susceptible to damage, especially shallow-soil uplands and wet swamps. Environmental reasons for strip cutting include minimizing soil erosion, reducing the level of run-off and flooding, creating diversity of habitat and increasing the amount of edge effect for wildlife, and aesthetic considerations.

Patch and Block Cutting

Various sizes of small clearcut areas have also been tried to promote natural regeneration by seed. Some of the earliest trials in Ontario were those of Losee (1966), who used relatively small group cuttings connected by narrow skid lines. Block cuts with diameters of 100 to 200 m have also been used. Patches and small blocks are regenerated naturally by seed according to the same principles that apply to strip cutting.

Groups of Seed Trees

With this method, relatively small patches of living, seed-producing trees are left to provide seed for natural regeneration of the harvested area. The usual practice has been to use groups 10 to 15 m in diameter approximately 90 m apart. The system has been used in both mineral-soil uplands and organic soils. It has also been applied to regenerate the second-cut strips in alternate-strip clearcutting. Site preparation is necessary, except when there is abundant *Sphagnum*.

The application of this method is inexpensive, since all that is required is the marking of the groups of seed trees prior to cutting, and the sacrifice of a small proportion of the harvest. However, it is not certain just how effective the seed trees actually are. One study (Burnside 1984), and other unpublished data (K. Virgo, Spruce Falls Power and Paper, P.O. Box 100, Kapuskasing, Ontario, P5N 2Y2, pers. comm.) suggest that seedling stocking is highly variable, from desirable to inadequate, but most of the time it is in the 40 to 60% range. The method is probably not as effective as strip cutting because of rapid blowdown, lower seed supply, and less protection.

Careful Logging to Conserve Advance Growth

This is the most important method of natural regeneration used in Ontario at the present time. The idea for this came from the "horse-logging" system, used in the early part of the 20th century. This system preserved a large proportion of the advance growth, resulting in a new stand with seedlings and saplings that were already several years into the next rotation. Some of these forests, cut in the 1920s and 1930s, are now being harvested for the second time. With the advent of the wheeled skidder and year-round logging after World War II, clearcutting destroyed much of the advance growth, and summer logging resulted in considerable areas of rutting and churning of wet mineral and organic soils, which became "untreatable" for regeneration.

In recent years, machinery with low ground pressure has been introduced, as well as logging systems intended to preserve as much advance growth as possible, and to minimize rutting and churning of the peat (Virgo 1975). Initially, regular skidders were modified to accept wide tires for logging low, wet ground in the summer. Most recently, the industry is converting to large grapple or clam-bunk skidders that carry large bunches of trees, thereby requiring fewer passes on the skid trail. With this technique, the main weight of the bunches is supported, but the tops of the bunches still drag on the ground and cause some damage to the advance growth.

The industry and OMNR recognize, in the FMA negotiations, that careful logging is a regeneration cost. By saving and utilizing existing advance growth, it is possible to obtain cheaper regeneration, even if the site must still be partially regenerated by fill-in planting or seeding.

Different approaches to compensation for careful logging have been used in the Clay Belt. In one of these the company requested that for certain designated low ground sites with enough advance growth, they should be given a per-hectare compensation rate for regeneration, and they would then be responsible for obtaining adequate regeneration. They developed a technique of careful logging that saved a certain proportion of the small advance growth, and then did fill-in planting or aerial seeding to regenerate the skid trails. The rate of compensation, about $350 per hectare, was less than half the per-hectare rate if the normal site preparation and plant option had been used, at a cost of about $800. And of course far fewer seedlings were required for any additional fill-in planting.

In another case, a careful logging agreement was based on an estimate of how much of a particular area would lend itself to careful logging. On the basis of this estimate, it was agreed to compensate at $650 per hectare rather than the normal $800. Careful logging was conducted by an experienced operator who had used the procedure before. No lines were laid out, since this would incur additional cost. The operator was instructed to take additional care and make an effort not to knock down the small trees and saplings when they were present. It was a winter operation, so the snow was covering much of the lower advance growth.

Shearblading, the common site preparation in the Clay Belt, was applied along the feller-buncher/skidder trails in both the carefully logged patches and the clearcut areas. However, 60 to 65% of the area is sheared in clearcut areas, whereas with careful logging, only 30 to 40% is sheared because the objective is to save the advance growth and site prepare only the feller-buncher trails. Hence, there are potential savings by reducing, through the use of careful logging, the shearblading area required. Planting is to be done in both clearcut and carefully logged areas, but the latter requires only 50 to 60% of the trees required for planting the clearcut areas.

In the above operation, more area was carefully logged than had been anticipated, about 75% rather than 50%. In the case of overmature forests in which a large proportion of the harvest is projected to have advance growth, a better way to compensate would be to pay for careful logging for all black spruce that is cut. In this way, additional advance growth under the snow would be saved. Careful logging might cost about $60 to $70 per hectare. After the logging the area requiring site preparation and planting could be assessed, and compensation made for the areas treated in different ways. With this approach, payment would be made for careful logging even on those areas that ended up being clearcut, shearbladed and planted. However, this would be offset by the low-cost natural regeneration obtained on the carefully logged portions.

For the areas that are carefully logged, the following options are possible: (*i*) shearblade the feller-buncher trails and fill-in plant, (*ii*) shearblade and allow natural regeneration by seed from remaining advance growth, or (*iii*) do not shearblade if the area already has considerable *Sphagnum* seedbeds. All these options would result in lower costs and in net savings, and would permit limited regeneration dollars to be spent elsewhere.

It is anticipated that careful logging and utilization of already-established advance growth will reduce the rotation period. However, this is based on the assumption that the advance growth will recover and grow well enough to produce the next stand in an acceptable time (e.g., Vincent 1965). Recent studies in Ontario have focused on: (*i*) determining the recovery in growth of black spruce advance growth after harvesting, and (*ii*) assessing the growth and yield of second-growth stands of black spruce that were horse-logged several decades ago, and apparently originated largely from advance growth (for further information, contact A. Groot, Forestry Canada, Ontario Region, P.O. Box 490, Sault Ste. Marie, Ontario P6A 5M7).

DEVELOPMENT OF MACHINES AND TECHNIQUES

In Ontario, harvesting methods for black spruce have evolved considerably since the days of ground cutters and horse-skidding. One early modification of this procedure was the use of high-mast cable-yarders for extracting the wood. In the 1950s companies began using rubber-tired skidders to extract bunches of trees. When the skidders were used in summer operations, there was much damage to advance growth, and also to organic and wet mineral soils.

Currently, the trend is toward feller-bunchers, with extraction of full trees by means of large grapple and clam-bunk skidders, and delimbing at roadside. These methods have reduced the need for ground cutters, and they permit more efficient extraction of the wood, the primary objective of the logger. By happy coincidence, these methods employ low-ground-pressure machines, and the size of the clam-bunk skidders reduces the number of passes along any one skid trail, thereby reducing disturbance to the soil and to the advance growth.

Alternate-strip clearcutting has progressed from the system of ground loggers, delimbing in the bush and skidding tree-length, to feller-bunchers with full-tree skidding and delimbing at roadside. Tree-length logging consists of felling the tree, delimbing and detopping in the bush by the ground worker, and then extracting bunches of trees with cable skidders. Full-tree logging consists of felling the tree with a feller-buncher, extracting bunches of trees to roadside with skidders, and delimbing/detopping at roadside. In this development, it should be recognized that the shallow-soil sites are particularly susceptible to nutrient depletion by delimbing at the roadside (e.g., Foster and Morrison 1987). It has been argued that it is better to use full-tree logging because then slash will not impede site preparation. However, it is suggested that the amount of slash loading for these sites often will not be prohibitive. Feller-bunchers that delimb in the bush should be used in logging shallow-soil sites.

Site preparation and creation of sufficient well distributed, receptive seedbed is critical to achieving successful regeneration with strip cutting or small patch cutting. It is necessary to purchase site preparation equipment capable of penetrating the slash and providing seedbed. Equipment already exists for this purpose, e.g., hydraulically powered discs or cones, with the capability to apply ground pressure.

In site preparation for strip cutting, low, wet, *Sphagnum*-rich areas should not be scarified (Jeglum 1984). Operators need to be taught to recognize these areas so as to avoid the need for marking out before scarification.

Careful logging should be undertaken primarily in the wet and peaty areas. However, in some other areas, such as overmature uplands that have developed considerable understory, it may be undertaken as well. With careful logging, the main problems relate to obtaining appropriate machinery and to operator skill and experience. Feller-bunchers may be used with varying degrees of care in extracting the harvestable pieces, and operators need to be concerned with minimizing disturbance of the advance growth and residual small trees. Without this care, considerable numbers of the larger residual saplings will be knocked down by the boom, and by the extraction of bunches of trees. In extracting the trees, one should attempt to lift the trees and place them parallel to and at the side of the trail, rather than in piles across the regenerating strips. This would reduce damage to the advance growth.

The Finnish forester who planned and implemented the Wally Creek Area Forest Drainage Project has observed that some modifications could be made readily to ensure even more careful logging (Koivisto 1986). The most important is developing or obtaining feller-bunchers with longer booms. Machines with multiple-task abilities such as felling, delimbing and bucking should also be considered. This would allow the widening of the strips between the machine trails, and more preservation of advance growth. Koivisto also recommended the use of load-carrying forwarders, the standard practice in the Scandinavian countries, rather than dragging the tops, which would serve to minimize damage to advance growth.

All of this care takes extra time, of course, and incentives should be provided for machine operators. The extra expenses incurred in careful logging should be regarded as a cost of regeneration, since a proportion of the regeneration of the next stand will come from the advance growth and natural seeding from the residual saplings and small trees that are saved. This effort requires that foresters become knowledgeable about how to manipulate and direct the ecosystem to achieve optimal natural regeneration.

CONCLUSION

Despite the great increase in the numbers of seedlings planted and areas regenerated in Ontario, there is still a majority of the annual cut that cannot be addressed by artificial regeneration. Ceilings are being placed on the amount of stock to be produced. It appears that a high proportion of the annual harvest will not be planted simply because of ceilings on the number of seedlings for planting and on funds for conducting the planting.

It will be necessary to develop several harvesting and regeneration strategies. These will consist of a mix of methods ranging from inexpensive to very expensive, and including such options as planting, modified harvest for natural regeneration, and seeding. Since the extra costs of modified harvesting methods are considerably less than those of conventional planting of nursery stock, increasingly the natural regenerative powers of the forest must be utilized. As a logical extension of this, it will be necessary to stratify the projected harvested area into treatment blocks that will be treated with various harvesting/regeneration strategies.

The success of modified harvesting techniques is dependent upon the development of machines and techniques that will favor natural seeding and/or preservation of existing advance growth. Management foresters, technicians and machine operators must be provided with more information about harvesting and site preparation so that they can utilize the natural regenerative capabilities of the forest. As well, they require simple case studies on economics to determine the net cost of the various harvesting/regeneration options to assist them in choosing the most efficient combination of methods for achieving regeneration goals.

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STAND AND SITE CONDITIONS ASSOCIATED WITH THE OCCURRENCE AND ABUNDANCE OF BLACK SPRUCE ADVANCE GROWTH IN NORTH CENTRAL ONTARIO

by

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ABSTRACT

The occurrence and abundance of black spruce (*Picea mariana* (Mill.) B.S.P.) advance growth (seedlings and layerings) was assessed on each of 236 Forest Ecosystem Classification (F.E.C.) plots selected to represent the range of ecosystem conditions in north central Ontario. Layering stems accounted for 96% of the total advance growth stems; seedlings 4%. Although most pine and black spruce dominated ecosystems were stocked to some degree, stocking levels were generally low (<40%) and exhibited extreme variability. The variability within the ecosystem types was partly attributed to the inherent class heterogeneity of the various modal site and stand conditions used to define the ecosystems.

Ecosystem stand types with the greatest potential for black spruce advance growth were wet, organic lowland types typically associated with *Sphagnum* organic soils or conifer-dominated, nutrient poor upland sites, often occurring on soils with less than 20 cm mineral soil and a 5-20 cm LFH horizon. Upland, hardwood mixedwood ecosystems with diverse and abundant herb and shrub components exhibited limited potential for black spruce advance growth. Individual variables having the greatest positive correlation with black spruce advance growth stocking included: the percent cover by *Sphagnum* moss or *Ledum groenlandicum* L., the proportion of black spruce in total stand basal area, and the age of the stand. Negative correlations with stocking were observed for the percent cover by herbaceous species, broadleaf litter, and the percent canopy closure.

A predictive key and interpretive ordination diagram was prepared for the field manager using the results and trend graphs from the analyses.

Wickware, G.M., Towill, W.D. and Sims, R.A. 1990. Stand and Site Conditions Associated with the Occurrence and Abundance of Black Spruce Advance Growth in North Central Ontario. In: B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 131-142.

INTRODUCTION

Black spruce (*Picea mariana* (Mill.) B.S.P.) is economically the most important tree species in Ontario, accounting for half of the annual volume and value harvested on Crown land (approximately 8.4 million m^3 in 1986; Smyth and Campbell 1987). There are about 17.5 million ha of black spruce dominated forest in Ontario, constituting 41% of the province's total production forest (Anon. 1986). Black spruce grows on a wide variety of sites ranging from very wet, organic lowlands, to very dry and rocky hillcrests. About one-half of Ontario's black spruce forests occur as relatively pure stands on peatlands, while the other half are pure to mixed stands on upland mineral soils.

Artificial regeneration of black spruce by planting or seeding following its harvest is an expensive activity. Advance growth remaining on the site following harvesting is a potential source of "stocking" in the "new" forest and planning for its use might help to reduce artificial regeneration costs. It can provide either a means to supplement planting stock on certain sites or a method by which the sustained productivity of difficult to regenerate sites is ensured.

In recent years, significant improvements have occurred in the overall regeneration effort for all species. In 1986, for example, there was a 19% increase in the total area treated (i.e. 288,500 ha) over either 1984 or 1985. In 1986, some 18,700 ha were seeded, 61,300 ha were planted, 76,800 ha were tended (thinned, herbicided, cleaned, etc.) and 94,700 ha were site prepared (OMNR 1987).

To identify those site and stand conditions where black spruce advance growth can be expected to occur, it is first necessary to have an ecological site classification system. The Northwestern Ontario Forest Ecosystem Classification (NWO-FEC) has recently been completed (Sims *et al.* 1989). The classification provides a framework for setting regeneration objectives and strategies, when the abundance of advance growth of the commercially important tree species within types are known.

THE NORTHWESTERN ONTARIO FOREST ECOSYSTEM CLASSIFICATION (NWO-FEC)

The NWO-FEC includes 38 modal vegetation types (V-types) and 22 modal soil types (S-types). Although only recently implemented, the system is already being used to: (*i*) organize site-specific site and stand productivity information for the major commercial tree species of the region (Carmean 1987), (*ii*) conduct pre-cut surveys (Towill *et al.* 1988), and (*iii*) develop management interpretations for various combinations of vegetation and soil conditions (Racey *et al.* 1989).

The occurrence and abundance of advance growth were not used to define vegetation types, but the state of advance growth was thought to be dissimilar among vegetation types. Preliminary NWO-FEC investigations of shrub cover data (Sims *et al.* 1989) suggest that black spruce advance growth occurs over a range of vegetation and soil/site conditions throughout the Region.

STUDY OBJECTIVES

The study objectives included:

(*i*) description of the average physical condition, abundance, type and size of advance growth encountered on those stand and site conditions;

(*ii*) analysis of the distribution and abundance of advance growth, as related to stand and site attributes; and the development of a predictive function for the occurrence of advance growth.

STUDY AREA

The North Central Region of Ontario (Figure 1) is one of four northern administrative areas of the Ontario Ministry of Natural Resources. From 49 to 58 degrees North latitude, this region contains 65,630 square kilometres of production forest. The economically viable portion of the production forest is limited mainly to the southern half of the region. This area is underlain by a variety of bedrock conditions, mostly pre-Cambrian (Pye 1969). The pattern of glacially-associated landforms is distinct and complex owing to

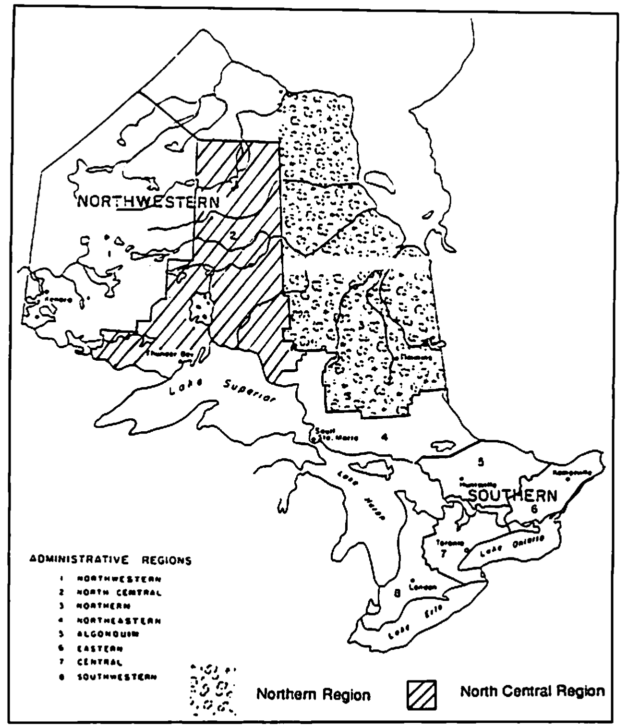


Figure 1. North central region of Ontario with administrative forest district boundaries.

the intense and sometimes repetitive nature of the glacial processes which occurred 11,700 years ago (Zoltai 1965, 1967). Common glacial landforms include eskers, outwash plains, glacio-lacustrine deposits, undulating ablation and basal tills, and morainal and drumlin features (Noble 1979).

The climate, according to the Thornthwaite system is microthermal (C'21 to C'22) and humid (B^1 to B^3-B^4) (Sanderson 1948). There are two climatic gradients across the region: (*i*) seasonal temperatures are moderated to the south by the influence of Lake Superior, and (*ii*) humidity and precipitation are drier in the west and more moist in the east (Chapman and Thomas 1968).

According to Rowe (1972) most of the area belongs to the expansive Boreal Forest Region (Sections B.8, B.9, B.10, and B.11) and is characterized by a mosaic of stand ages and compositions. Black spruce (Sb), white spruce (*Picea glauca* (Moench) Voss) (Sw), jack pine (*Pinus banksiana* Lamb.) (Pj) , red pine (*Pinus resinosa* Ait.) (Pr), white pine (*Pinus strobus* L.) (Pw), trembling aspen (*Populus tremuloides* Michx.) (Pot), balsam poplar (*Populus balsamifera* L.) (POb), white birch (*Betula papyrifera* Marsh.) (Bw) and balsam fir (*Abies balsamea* (L.) Mill.) (Bf) all occur either singly or in combination throughout the forests.

METHODS

Vegetation Sampling

Information from a sub-set of 238 plots contained in the original NWO-FEC dataset, as well as supplementary advance growth data, comprise the study data base. The NWO-FEC dataset consists of vegetation, soil, site and mensurational data collected from 2,100 semi-permanent sample plots (10 x 10m) located in mature, natural stands representing the broad range of ecological conditions in northwestern Ontario. Vegetation information includes an estimate of percent cover for all species and strata (trees, shrubs, herbs, graminoids, mosses and lichens). A comprehensive soil profile description at each plot is based on Canadian System of Soil Classification (CSSC) standards (Canadian Soil Survey Committee 1978). Detailed soil geochemistry is also available for selected representative plots.

Black Spruce Advance Growth Data

Plot selection: During 1988, black spruce advance growth information was collected from the sub-set of 238 NWO-FEC plots originally chosen because they represented all jack pine and black spruce dominated V-types (V8-11, V17-20, V27-38), the lowland cedar (lc) (V22) and larch (L) types (V23). The V-types sampled in this survey included the following:

V2	Black ash hardwood and mixed wood
V5	Aspen hardwood
V8	Trembling aspen (white birch)/mountain maple
V9	Trembling aspen mixedwood
V10	Trembling aspen - black spruce - jack pine/low shrub
V11	Trembling aspen conifer/blueberry/feathermoss
V17	Jack pine mixedwood/shrub rich
V18	Jack pine mixedwood/feathermoss
V19	Black spruce mixedwood/herb rich
V20	Black spruce mixedwood/feathermoss
V27	Red pine conifer
V28	Jack pine/low shrub
V29	Jack pine/ericaceous shrub/feathermoss
V30	Jack pine - black spruce/blueberry/lichen
V31	Black spruce - jack pine/tall shrub/feathermoss
V32	Jack pine - black spruce/ericaceous shrub/feathermoss
V33	Black spruce/feathermoss
V34	Black spruce/Labrador tea/feathermoss (Sphagnum)
V35	Black spruce/speckled alder/Sphagnum
V36	Black spruce/bunchberry/Sphagnum (feathermoss)
V37	Black spruce/ericaceous shrub/Sphagnum
V38	Black spruce/leatherleaf/Sphagnum

These V-types typically had 50% or greater occurrence of black spruce in the shrub layer. Two hardwood V-types (V2 and V5) were also included in the sample group.

The plots were located on a variety of soil and site conditions. The S-types encountered in this survey included the following:

(*i*) Deep soils > 1.0 m

S1	Dry/course sandy
S2	Fresh/fine sandy
S3	Fresh/coarse loamy
S4	Fresh/silty - silt loamy
S5	Fresh/fine loamy
S6	Fresh/clayey
S7	Moist/sandy
S8	Moist/coarse loamy
S9	Moist/silty - silt loamy
S10	Moist/fine loamy - clayey
S11	Moist/peaty phase
S12S	Wet/organic (feathermoss)
S12F	Wet/organic (Sphagnum spp.)

and (*ii*) Shallow soils < 1.0 m

SS1	Discontinuous organic mat on bedrock
SS2	Extremely shallow soil on bedrock
SS3	Very shallow soil on bedrock
SS5	Shallow - moderately deep/sandy
SS6	Shallow - moderately deep/coarse loamy
SS7	Shallow - moderately deep/silty - fine loamy - clay
SS8	Shallow - moderately deep/mottle - gley

Stand sampling: On each 10 x 10 m NWO-FEC plot, a select number of vegetation, soil, site and stand features were recorded. The following were measured in each plot: the V- and S-type, humus form and thickness, depth of mineral soil, percent of the plot covered by surface stones, percent exposed bedrock, feathermoss and *Sphagnum* species, and cover estimates (%) for Labrador tea, green alder (*Alnus crispa* (Ait.) Pursh), speckled alder (*A. rugosa* (Du Roi) Spreng.), and for all other shrubs combined. An ocular estimate of the percent crown closure for each species was also recorded. Stand age was determined from breast height core samples of five dominant/codominant trees on or near the plot. Stocking was determined from a prism sweep (BAF2 wedge prism) taken at plot centre.

Advance growth in each of the 20 quadrats (2 x 2 m) established along the perimeter of each plot was tallied. Four species were recorded: black spruce, white spruce, jack pine, and balsam fir. Each stem of advance growth was tallied into one of four height classes: (*i*) 0 to 9.9 cm, (*ii*) 10.0 to 49.9 cm, (*iii*) 50.0 to 199.9 cm, or (*iv*) 200.0 cm in height to 2.5 cm DBH.

Black spruce advance growth on each plot was also classified as a layer or a seedling based on their appearance. Stems were classified as layers if the bottom portion of the stem curved from the horizontal to the vertical (Groot 1984). Advance growth type was occasionally verified by identifying the layer's branch connection.

The form of the black spruce advance growth was also described and defined as either upright, bent or oppressed. An upright stem was one growing vertically with a straight stem, even if the base was curved as in a layered stem; a bent stem had gross curvatures along its length; and an oppressed stem had a non-vigorous appearance.

Data analysis: All advance growth data was analyzed both as an independent dataset and in conjunction with the NWO-FEC data, using multivariate and ANOVA statistical techniques. Data was summarized by V-type using SAS (SAS Institute Inc. 1985) and BMDP (BMDP Statistical Software 1983) programs. Simple univariate analyses included sample frequencies for each V- and S-type, and the distribution of seedlings and layers across all sampled types.

Stocking, used as a measure of distribution and defined as the proportion of 2 m x 2 m quadrats having at least one advance growth stem (Groot 1984), was calculated for each stand. Density, defined as the number of advance growth stems per hectare (Groot 1984), was used as a measure of the abundance of advance growth. Average stocking and density of black spruce advance growth were calculated for each V-type and S-type.

Four stocking classes were defined using Robinson's (1974) criteria for black spruce stocking levels: (*i*) 0 to 40%, (*ii*) 41 to 60%, (*iii*) 61 to 80%, and (*iv*) greater than 80%. All plots were assigned to a stocking class, and frequency distributions determined for each V-type. This analysis was requested for advance growth stems belonging to the four height classes: (*i*) 0 to 9.9 cm, (*ii*) 10 to 49.9 cm, (*iii*) 50 to 199.9 cm, and (*iv*) 200.0 cm height to 2.5 cm DBH.

Ordination overlays using Decorana (Hill 1979) were used to define trends in the occurrence of black spruce advance growth. Individual values of soil and site variables were superimposed onto this ordination diagram to examine vegetation and soil/site relationships.

Simple correlation and multiple linear regression analyses were then used to assess relationships between advance growth stocking and density, and stand, soil or site parameters. Variables from both the NWO-FEC and advance growth datasets were used in this analysis. Stepwise discriminant analysis was used to determine the vegetation, soil and site features that best predicted the four stocking classes.

From these analyses, a preliminary model for predicting the occurrence of black spruce advance growth for each NWO-FEC V-type was developed.

RESULTS AND DISCUSSION

Relationship of Black Spruce Advance Growth to NWO-FEC Vegetation Types (V-Type)

Layering stems accounted for 96% and seedlings 4%, of the 6,272 black spruce advance growth stems counted on the 238 plots. The mean stocking and stem densities of black spruce advance growth within NWO-FEC V-types are given in Table 1. Stocking levels were generally low and extremely variable (Figure 2). Mean stocking levels exceeded 60% only in V38 - an unmerchantable black spruce type. Three other V-types, V20, V34, V37, were stocked to above 40%. Stocking levels were highly variable in these V-types, ranging from 0 to 90%. These four V-types are all predominantly black spruce in the overstory and they occur on moister sites with thick feathermoss over mineral soil or *Sphagnum*-dominated organic soils.

The variability of stocking levels within V-types can be explained partly by the heterogeneity inherent to the V- and S-types. Each of the NWO-FEC classes reflects a range of conditions which may be significant for some application (Sims *et al.* 1989).

To better define the occurrence and distribution of advance growth, each of the 238 sampled sites were assigned to the previously defined stocking classes. The number of plots within each V-type across the four stocking classes is shown in Table 2.

Most plots were in stocking class 1, having less than 40% stocking to black spruce advance growth. In Ontario, 60% stocking is required for full stocking of black spruce. Less than 40% stocking is considered to be inadequately regenerated (Robinson 1974), although Haavisto (1979) has suggested that stocking in the 41% to 60% range is acceptable since most mature stands fall in that range. This stocking range should also be acceptable for peatlands. Of the five lowland V-types (V34 to V38), three (V34, 37, 38) attained mean stocking levels within that acceptable range (Table 2). V38, an unmerchantable type, is the only V-type to exceed the standards, with 86% stocking to black spruce advance growth (Table 1). Black spruce advance

Table 1. Comparison of black spruce advance growth stocking and stem densities for the NWO-FEC vegetation (V)-types.

Stand cover	V-type	Percent stocking[a]	Density (stems/ha)
Mainly hardwood	4	6	3900
	5	3	200
	7	0	0
	8	3	100
	9	10	900
	10	8	700
	11	17	1200
Conifer mixedwood	15	5	100
	16	3	100
	17	15	1100
	18	27	3600
	19	23	1900
	20	41	6600
Conifer	21	0	0
	22	21	1600
	23	18	900
	24	0	0
	25	0	0
	28	6	300
	29	34	4700
	30	34	5700
	31	19	1000
	32	32	3100
	33	24	2500
	34	40	3100
	35	34	2800
	36	38	3100
	37	43	4500
	38	86	9900

[a] Based upon proportion of 2 m x 2 m quadrats having at least one stem of black spruce advance growth

Table 2. Number of plots within each NWO-FEC Vegetation (V)-types containing black spruce advance growth stratified by stocking class.

Stand cover	V-type	Stocking class 1 (0 to 40%)	2 (41 to 60%)	3 (61 to 80%)	4 (>80%)
Mainly hardwood	4	7	-	-	-
	5	9	-	-	-
	7	1	-	-	-
	8	4	-	-	-
	9	4	-	-	-
	10	11	-	-	-
Conifer mixedwood	11	16	-	1	-
	15	1	-	-	-
	16	3	-	-	-
	17	11	-	-	-
	18	8	1	-	1
	19	9	-	1	-
	20	5	4	2	-
Conifer	21	1	-	-	-
	22	9	1	-	-
	23	8	-	-	1
	24	1	-	-	-
	25	1	-	-	-
	28	7	-	-	
	29	9	-	2	-
	30	6	2	2	-
	31	11	1	-	-
	32	10	5	1	-
	33	8	-	-	2
	34	6	2	2	2
	35	6	3	1	-
	36	6	2	3	-
	37	7	3	3	1
	38	-	-	1	3
TOTAL		185	24	19	10

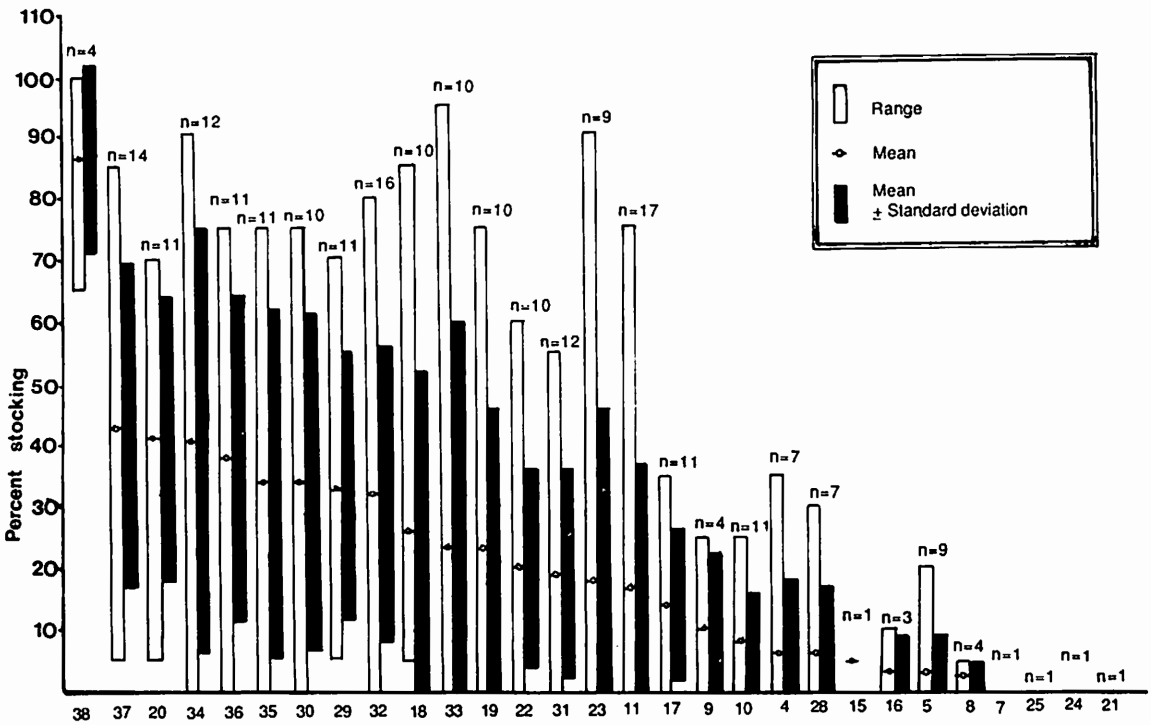


Figure 2. Black spruce advance growth stocking levels for Northwestern Ontario FEC vegetation (V)-types.

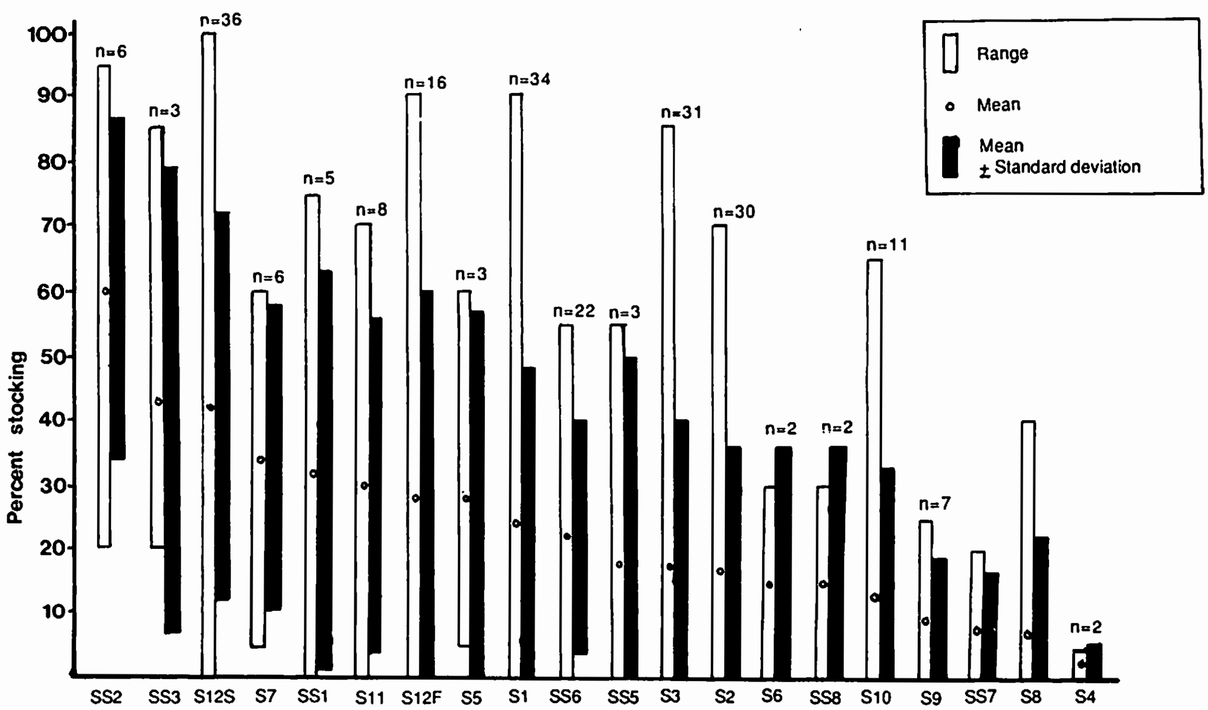


Figure 3. Black spruce advance growth stocking levels on the NW0-FEC soil (S) - types.

growth can only be considered as a supplemental regeneration source, rather than a primary source.

Densities of stems, particularly in the pure conifer V-types (V29 to V38), as well as V-types 4, 18 and 20, were typically high and frequently exceeded the Ontario regeneration standard of 2,000 stems/ha (Table 1) However, stocking levels (a measure of the distribution of the stems) were typically low for these same V-types. Wickware and Walsh (1989) have shown that clumping is a characteristic feature of the advance growth in most V-types.

Relationship of Black Spruce Advance Growth to NWO-FEC Soil Types (S-Type)

Only three S-types, SS2, SS3 and S12S, attained a stocking level exceeding 40% (Figure 3). SS2, a shallow soil condition with <5 cm mineral soil and a 5-20 cm organic layer, had the highest mean stocking, at 60%. S12S is a deep peaty organic soil derived primarily from *Sphagnum* mosses. Jeglum (1981, 1984) and Johnston (1971) report *Sphagnum* peat to be an ideal seedbed for black spruce germination and establishment. Considerable range in actual stocking levels is associated with most S-types (Figure 3). These large ranges reflect the inherent variation associated within S-types. Other S-types, such as S11, S12F, S1, S2, S3 and S10, exhibited relatively high stem densities. Stems, however, tended to be clumped and stocking levels low, giving rise to a potentially misleading perception of advance growth potential.

Stocking and Density Relationships Between NWO-FEC Vegetation Types and Black Spruce Advance Growth

Relationships between NWO-FEC V-types and stocking and density of black spruce advance growth were evaluated using detrended correspondence analysis ordination techniques (Hill 1979). Each plot was represented on the ordination diagram by a single point (Figure 4) which represents the V-type, with the position of each point reflecting the relative similarities (or dissimilarities) between V-types. In this ordination, the vertical axis generally defines a moisture gradient (wet to dry, upward along the axis), and a nutrient gradient (poor to rich, from left to right along the horizontal axis).

V-types with substantial amounts of black spruce advance growth at least occasionally are on wet, organic lowland or nutrient-poor upland types (Figure 5). They are characterized by a moderately abundant shrub layer dominated by ericaceous or conifer species, herb-poor understory conditions and an expansive feathermoss mat (Figure 6). Advance growth

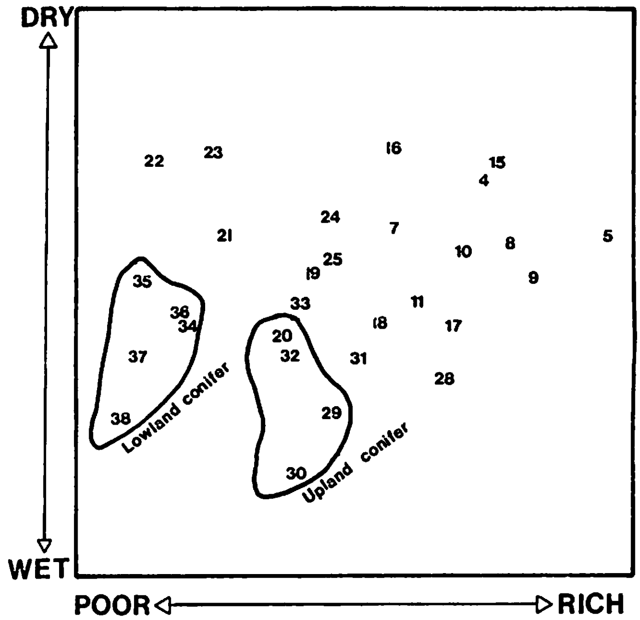


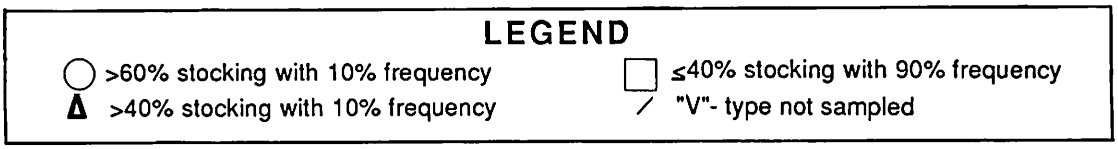
Figure 4. Ordination of NWO-FEC vegetation (V) - types sampled in the 1988 black spruce advance growth project study.

occurrence data, superimposed on the ordination, illustrate that any occurrences of black spruce advance growth stocking at levels greater than 40% are associated with those V-types on the left side of the diagram. These types occur across a range of moisture conditions (vertical axis) but tend to have relatively poorer stand nutrient conditions (horizontal axis) (Figures 7 and 8).

Upland, hardwood mixedwood stands that have a diverse and abundant herb and shrub component exhibited less substantial stocking of black spruce advance growth. Vegetation cover in V30 is typically sparse as a result of the significant bedrock exposure associated with these sites (Sims *et al.* 1989).

Prediction of Black Spruce Advance Growth Using Soil/Site Parameters

The percent cover by *Sphagnum* moss or Labrador tea and the proportion of black spruce in the total stand basal area had the greatest positive correlation with black spruce and advance growth stocking. These factors were also significant in a report by Groot (1984) and generally characterize lowland stand conditions with peaty organic soils, and significant cover by Labrador tea and other ericaceous shrubs (e.g. leatherleaf (*Chamaedaphne calyculata* (L.) Moench)).



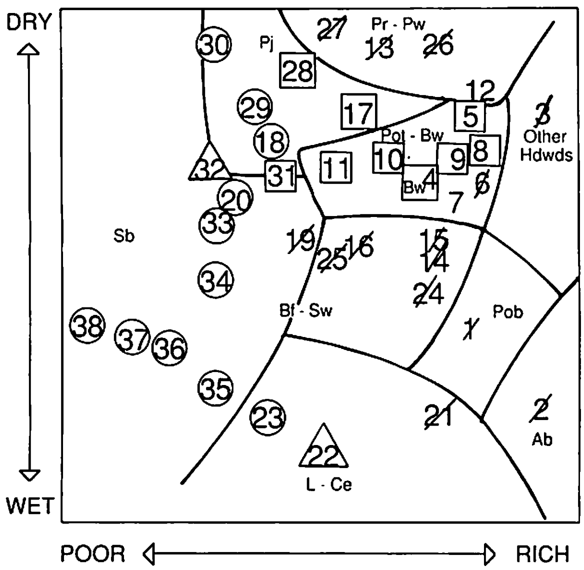


Figure 5. Frequency occurrence of black spruce advance growth stocking for Northwestern Ontario FEC vegetation (V) - types. Ordination based on all V-types (after Sims *et al.* 1989). Lines dividing ordination into zones indicate dominant tree species/species groupings.

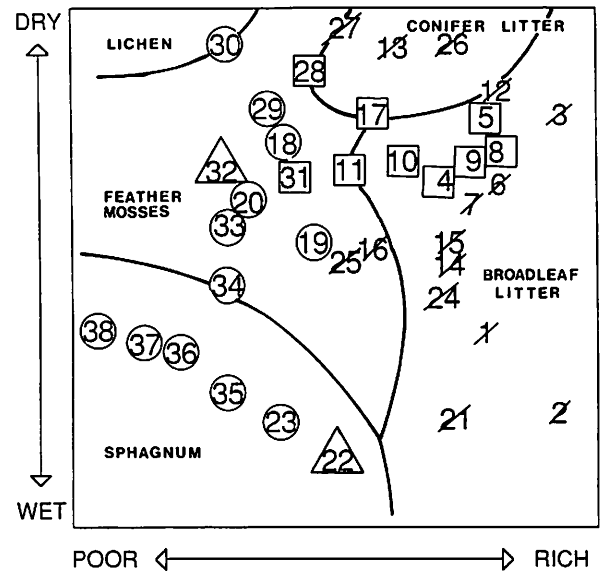


Figure 6. Frequency occurrence of black spurce advance growth stocking for Northwestern Ontario FEC vegetation (V) - types stratified by seedbed condition. Ordination as in Figure 5; lines dividing zones of dominant forest floor cover.

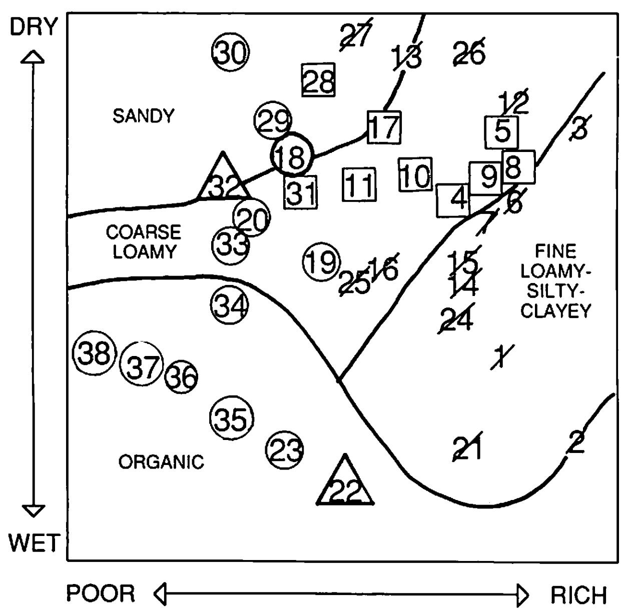


Figure 7. Frequency occurrence of black spruce advance growth stocking for Northwestern Ontario FEC vegetation (V) - types. Ordination as in Figure 5; lines divide major texture class groupings for soil parent material (C-horizon).

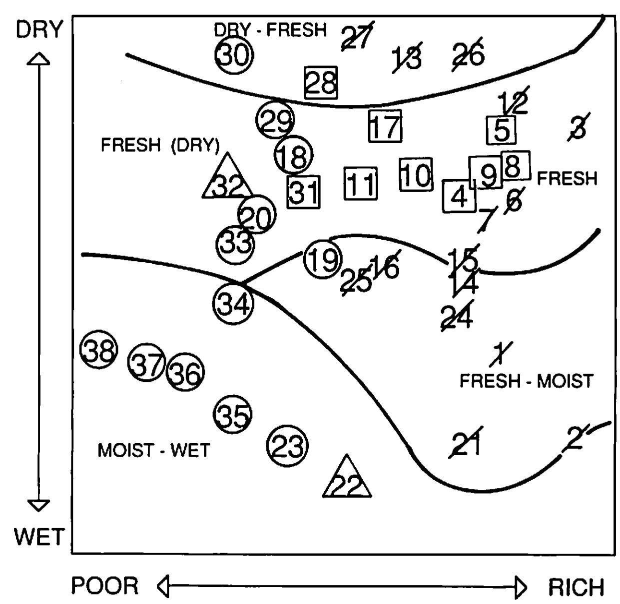


Figure 8. Frequency occurrence of black spruce advance growth stocking for Northwestern Ontario FEC vegetation (V) - types. Ordination as in Figure 5; lines divide main soil moisture regime groupings.

Negative correlations with advance growth stocking were observed for percent cover by herbaceous species, broadleaf litter and the percent canopy closure. These variables are typically associated with upland stand conditions where understory floristic diversity is highest and a significant hardwood component is present in the main canopy. Such stand conditions are not favourable for advance growth of black spruce.

Abundant advance growth was only found under pure conifer cover types dominated by black spruce and/or jack pine. The forest floor supporting advance growth was covered by extensive mats of feathermoss on upland sites and of *Sphagnum* spp. on lowland sites. Typically the abundance and diversity of herb species in these V-types is low. Diversity of shrub species is also limited, with the most abundant species being labrador tea and other ericaceous shrubs.

A simple "key" has been developed to show the potential of V-types for predicting stocking of black spruce advance growth (Figure 9). Field application and testing will be used to refine the key as additional stands are evaluated.

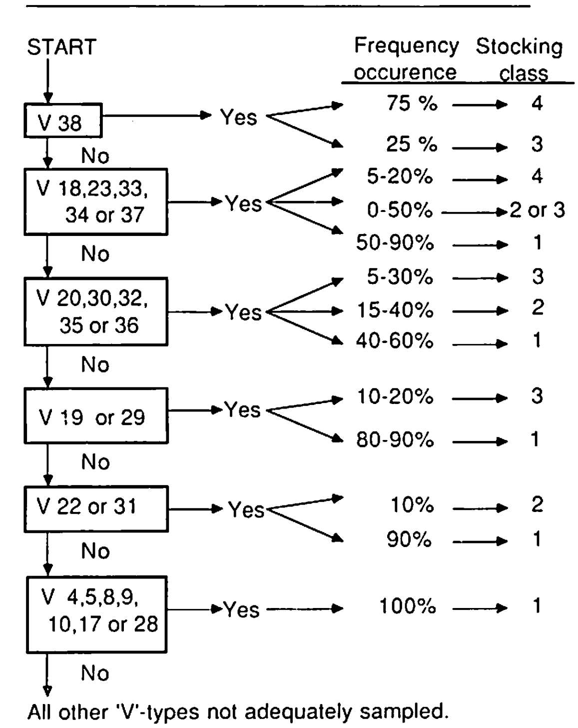


Figure 9. Key to evaluating the occurrence of black spruce advance growth in north central Ontario.

SUMMARY AND CONCLUSIONS

Black spruce advance growth commonly occurs across a range of vegetation and soil conditions in the North Central Region. Though not yet widely recognized, its potential contribution to post-harvest stocking requirements cannot be ignored, especially in view of increasing demand for more cost-efficient regeneration of forest stands. Advance growth is not yet relied upon as part of the future crop because stand and site conditions associated with abundant advance growth are poorly defined and the advance growth is subject to considerable loss during the harvest phase.

Black spruce advance growth was found to be primarily of layer origin. Seedlings accounted for less than 5% of the total black spruce advance growth potential. Most stems were growing upright to a dominant height of 50 cm.

Black spruce advance growth occurs, to some degree, in most V- and S-types. Since there is considerable variation within any one type in the amount of advance growth encountered, accurate mathematical prediction of black spruce advance growth occurrence was extremely limited. The stagnant, unmerchantable stands of V38 proved to have the greatest occurrence of black spruce advance growth. Fourteen additional V-types have potential for black spruce advance growth to a stocking level greater than 40%. The frequency of such occurrences is typically low.

Black spruce advance growth occurs in V-types that span the range of moisture conditions, from wet lowland types to drier upland types. The abundance of black spruce advance growth tends to be greater in those stands having black spruce in the overstory, lacking species-richness and having an extensive moss mat. V-types characterized as shrub and/or herb rich mixedwoods tend not to have black spruce advance growth at greater than 40% stocking levels.

The trends in black spruce advance growth occurrence are incorporated into a simple key derived from the stand frequencies in four stocking classes for each V-type. This model, though not based on probabilities of occurrence, is useful in evaluating the potential for abundant black spruce advance growth in a stand of a known V-type. Since the determination of NWO-FEC V-types is already, or can easily be incorporated into existing pre-cut survey methods, this key ensures that such advance growth evaluations remain uncomplicated.

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COMBINATION OF PLANTED SEEDLINGS AND ADVANCE GROWTH OF NORWAY SPRUCE IN A REGENERATION TRIAL AT A HIGH ALTITUDE IN NORTHERN SWEDEN

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ABSTRACT

Seedling survival is a major problem in forest regeneration at high altitudes in Northern Sweden. The main reasons for this are considered to be poor climatical conditions or detrimental weather. Results from a 17-year-old experiment established at a high altitude (500-570 m asl) in Northern Sweden show that advance growth of Norway spruce (*Picea abies* (L.) Karst.) is a valuable complement to planted seedlings in forest regeneration. A method is suggested where naturally regenerated spruce taller than approximately 2 m are cut 5-10 years after planting. The number of seedlings planted must be related to the abundance and condition of the advance growth.

INTRODUCTION

Seedling survival is a major problem in forest regeneration at high altitudes in Northern Sweden. The main reasons for this are considered to be poor climatical conditions or detrimental weather. One method of improving regeneration in these areas is by using advance growth in combination with planted seedlings. Prerequisites for this method to work are that a sufficient number of the advance growth seedlings must survive harvesting and grow at satisfactory rates, and the growth of planted seedlings must not suffer too much from competition from the advance growth. In this paper, survival and height development of planted seedlings and advance growth of Norway spruce (*Picea abies* (L.) Karst.) is presented from a 17-year-old experiment in Northern Sweden. Effects of competition on height increment and survival of planted seedlings are also investigated.

Fries, C. 1990. Combination of Planted Seedlings and Advance Growth of Norway Spruce in a Regeneration Trial at a High Altitude in Northern Sweden. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 143-150.*

MATERIALS AND METHODS

The experiment is located in the province of Lapland (65°53' N, 18°21' E), at an altitude of 500-570 m above sea level (m asl) on a NW-exposed site with an average slope of 6%. The mean annual temperature is -0.5° C, the temperature sum is 540-620 degree days and the length of the growing season is approximately 125 days (Odin *et al.* 1983). The mean annual precipitation is 520 mm. According to a system developed by Hägglund (1979) site index (dominant height at 100 years) for Norway spruce is 13 m. The soil moisture class is mesic (Lundmark 1974) and the soil type is sandy to fine sand. The field layer is dominated by *Vaccinium myrtillus* L. The previous stand, with a total volume over bark of 80 m^3ha^{-1}, consisted of uneven-aged Norway spruce with scattered European birch (*Betula pubescens* Ehrh.). The previous stand was clear-felled in the winter of 1966/67.

The experiment was laid out in randomized blocks with five treatments and six replications (three of them at 500-520 m asl and three at 550-570 m asl). In this paper results from two treatments are presented:

Regeneration Method 1: No site clearing (spruces with a dbhob less than 8 cm and all birches [approximately 70 ha^{-1} with a mean height of 5.5 m] were left); scarification and planting.

Regeneration Method 2: Site clearing (spruces higher than 1 m were felled and all birches were notched) followed by scarification and planting.

Scarification was done manually as patches in connection with planting in July 1969. 2-year-old balled seedlings of Norway spruce were then planted in straight rows (Table 1). The provenance (approximately 65° N, 300 m asl) is appropriate for the site.

Height was measured on all advance growth of spruce taller than 10 cm in 1969 two years after clear-felling, prior to site clearing and planting (Table 1 and Figure

Table 1. Mean density of planted seedlings and advance spruce growth before site clearing in 1969 (±SE) and mean height (m; ±SD) of advance spruce gowth in 1969 for the two regeneration methods and for the six replicates at the higher and lower elevations in experimental area.

	Seedling origin		
	Planted	Advance growth	
	density (stems ha^{-1})	density (stems ha^{-1})	height (m)
No site clearing	774 ± 467	623 ± 29	1.7 ± 1.8
Site clearing	943 ± 50	447 ± 13	2.2 ± 2.0
Higher elevation	(not given)	297 ± 4	2.3 ± 2.0
Lower elevation	(not given)	773 ± 21	1.8 ± 1.8

1). The experiment was surveyed for response of planted spruce in the autumns of 1970, 1971, 1972, 1974, 1975, and 1986 (2, 3, 4, 6, 7, and 18 growing seasons, respectively, after planting). In each treatment plot (50 m x 50 m) the regeneration in 20 permanently marked circular plots with a radius of 2 m was recorded. The circular plots were systematically placed (4 x 5 plots) in the treatment plots with 10 m between plot centres. The distances between plot centres and the borders of the treatment plots were 5 m in one direction and 10 m in the other. When surveyed, height and annual increment of the planted seedlings were measured and the most severe damage on each occasion was registered. Three classes were used for damage (undamaged, slightly damaged and severely damaged). Slight damage was subjectively assumed to cause less than one year, and severe damage more than one year's reduced height increment. When the last survey was made (1986) the same data were collected for the naturally regenerated spruces as for the planted ones. It was assumed that the sheltering birches had grown 1 m from 1969 to 1986.

Survival rates for advance growth spruce were determined by comparing the number of naturally regenerated seedlings in 1969 with those in 1986. However, it was first necessary to estimate which seedlings measured in 1986 were indeed advance growth, and which had become established since clear-felling 20 growing seasons earlier. A single regression of annual height increment in 1986 over total height was thus developed for all advance growth seedlings (data from both treatments was pooled; data from seedlings that were either > 1 m in height or severely damaged were excluded). From the regression, it was estimated that the annual increment of a 50 cm high seedling was 4.9 cm. If all seedlings grew at 5 cm per year, a seedling 20 years old would be 1 m high in 1986. All seedlings less than 1 m were thus assumed to have become established since clear-felling, and were omitted from subsequent data analysis.

Data for planted seedlings in the 20 circular plots were used to calculate mean values for height, length of leading shoot and survival for each treatment plot. The mean values were compared using analysis of variance. The relationship between seedling height and annual increment at the last inventory was evaluated for both planted and naturally regenerated seedlings using linear regression, using seedlings from the height interval 1-5 m only (severely damaged seedlings were excluded). A significance level of $p<0.05$ was used in both analyses.

When analysing the results of the two regeneration methods it is reasonable to compare spruce stocking by height interval and damage class. The interval of 1-5 m was chosen and severely damaged seedlings were excluded, in that it was difficult to predict the development of especially the smaller planted seedlings, since a large proportion of them (approximately 60%) were severely damaged by pathogens such as snow blight (*Lophophaciduim hyperboreum* Lagerb.). Another reason is that, without making any further calculations, it was presumed that a height difference of maximally 4 m would lead to an acceptable stand development in these young stands with a relatively low number of stems per hectares.

RESULTS AND DISCUSSION

The survival rates of spruce advance growth are fairly high (Table 2). They must be regarded as rough estimates, however, considering the way in which this experiment was laid out, surveyed, and the number of new natural regeneration calculated. The advance growth was first examined two years after clear-felling. As the mortality for Norway spruce seedlings less than 30 cm in height can be more than 50% over the first two years after clear-felling (Skoklefald 1967), it is likely that the actual survival rates, from clear-felling to the inventory in 1986, are lower than those presented in Table 2. In any case a large number of the advance growth survived clear-felling and several subsequent years. As no spruce higher than 1 m was found dead at the inventory in 1986 it can be assumed that the mortality among seedlings taller than 1 m is now very low.

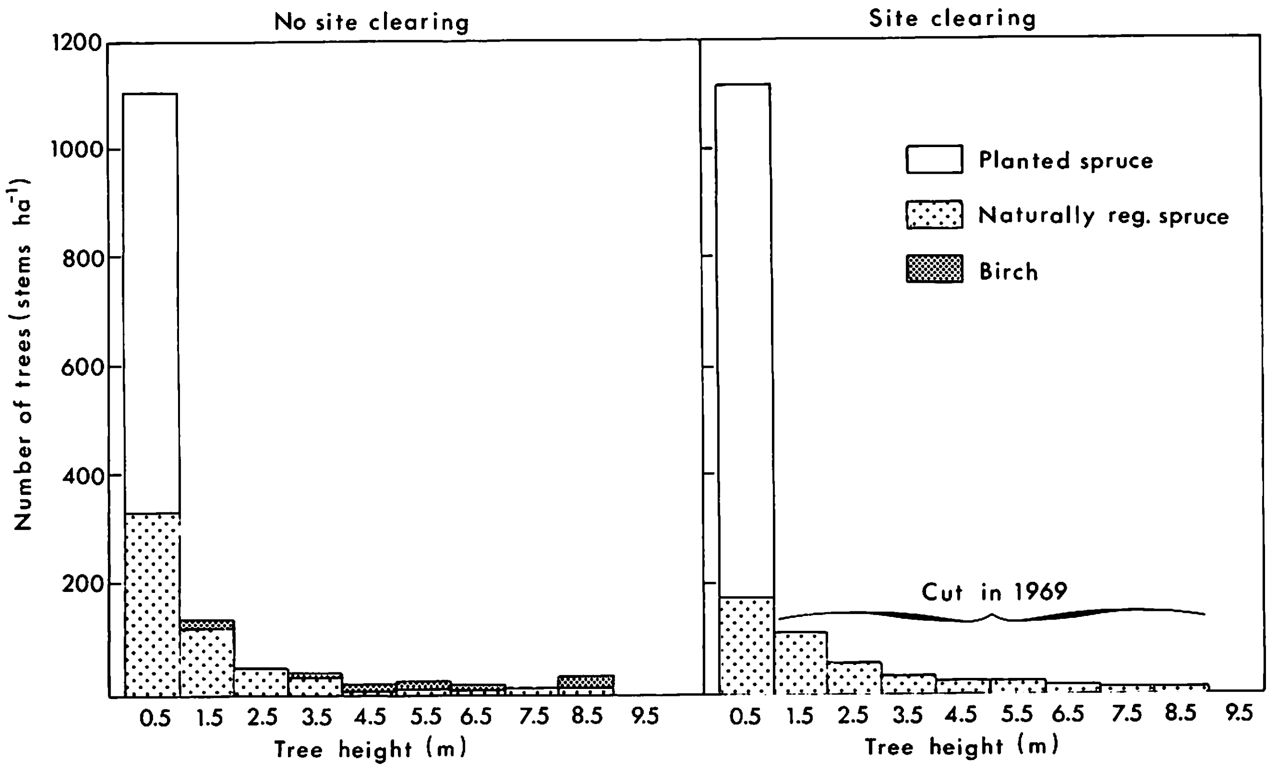

Figure 1. Number of planted and naturally regenerated spruces and sheltering birches (birches only shown in regeneration method 1) before site clearing in the year of planting (1969), divided into height classes for the two regeneration methods.

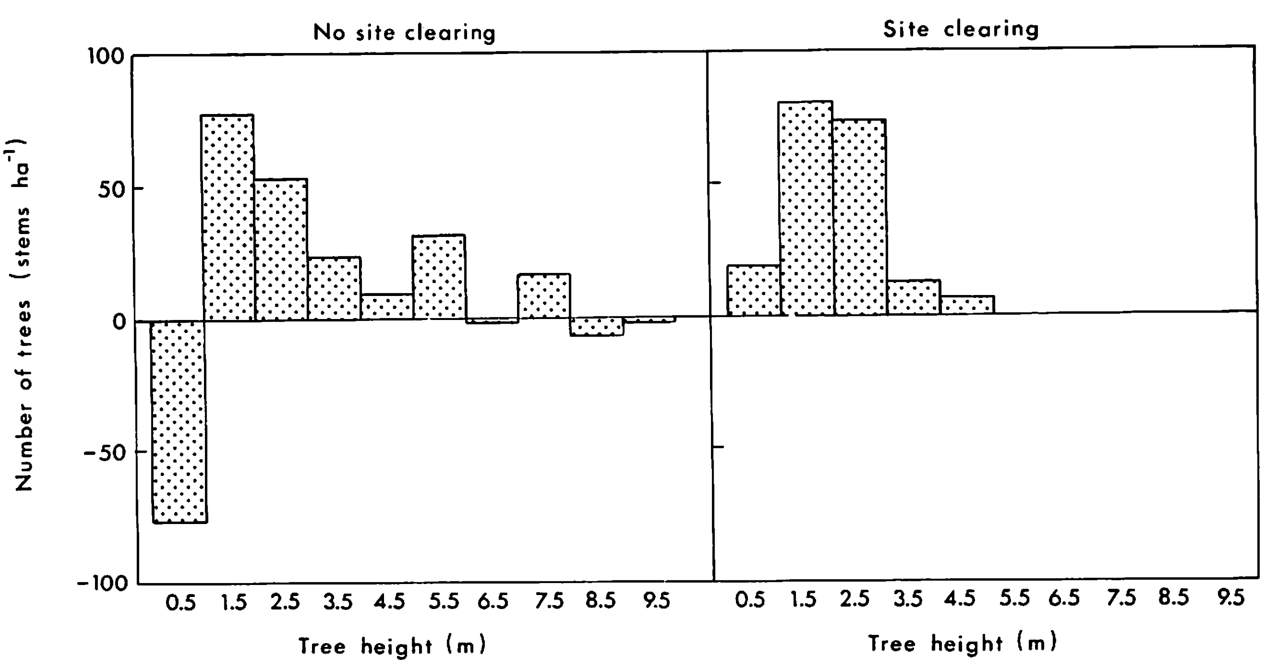

Figure 2. Differences between the total number of naturally regenerated spruce in 1969 (after site clearing) and in 1986 for different height classes for the two regeneration methods.

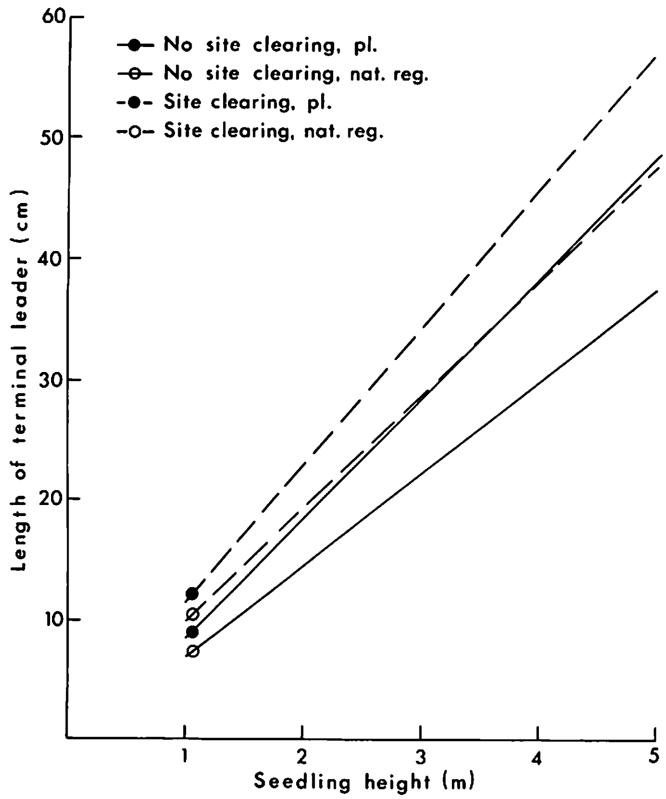

Figure 3. Linear regressions of length of terminal leader over seedling height for undamaged and slightly damaged planted and naturally regenerated spruce in the height interval 1.01-5.00 m at the survey 18 growing seasons after planting for the two regeneration methods.

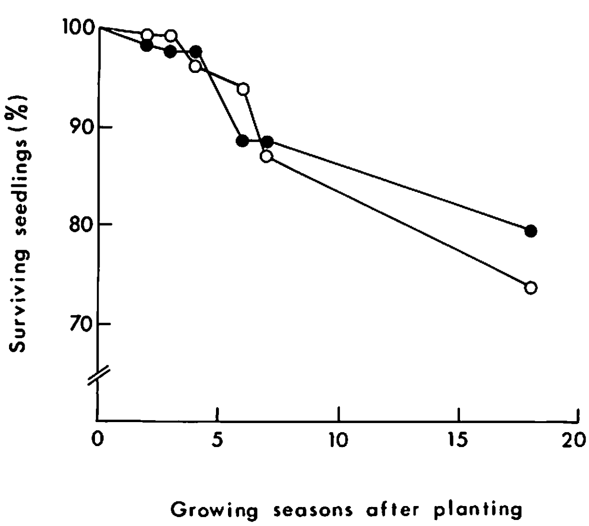

Figure 4. Percent survival of planted seedlings 2-18 growing seasons after planting. Site clearing (filled circles) and no site clearing (unfilled circles).

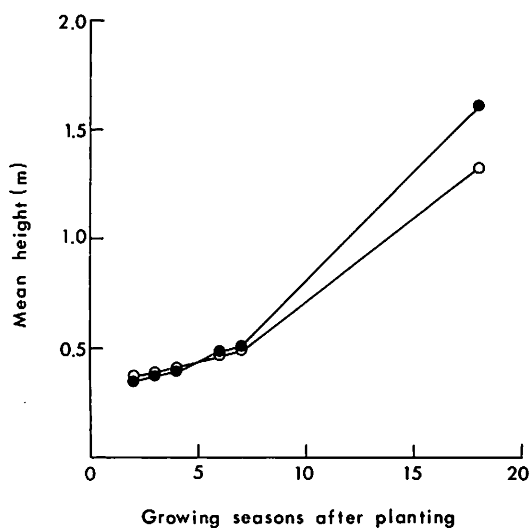

Figure 5. Mean height development for planted seedlings 2-18 growing seasons after planting. Site clearing (filled circles) and no site clearing (unfilled circles).

In the regeneration method without site clearing the number of naturally regenerated spruce was generally higher in 1969 than in 1986 for height classes greater than 1 m (Figure 2). The decrease in the number of seedlings in the < 1 m class is 23% and can probably be explained by the high mortality among smaller seedlings during the first years after clear-felling, as well as the error inherent in using two different sampling methods in 1969 and 1986. In the regeneration method with site clearing the number of naturally regenerated seedlings had increased in the time between the inventories of 1969 and 1986. From Figure 2 it is evident that a large proportion of the advance spruce growth had increased in height, in some cases more than 3 m in 17 years. Several Scandinavian studies confirm this finding, although Nilsen (1988) found it difficult to predict the reaction of advance spruce growth after clear-felling. In Finland, however, Cajander (1934) found that taller seedlings reacted faster with increased height increment after clear-felling than lower ones.

The terminal leaders in 1986 were generally longer for planted spruce than for naturally regenerated spruce, although the difference between regression coefficients is significant only in the regeneration method without site clearing (Figure 3 and Table 3). This suggests that the sheltering birches, and possibly also the taller advance spruce growth, have had a negative influence on the height development of planted spruce. Although the terminal leaders in 1986 were significantly longer for planted than for naturally regenerated seedlings in

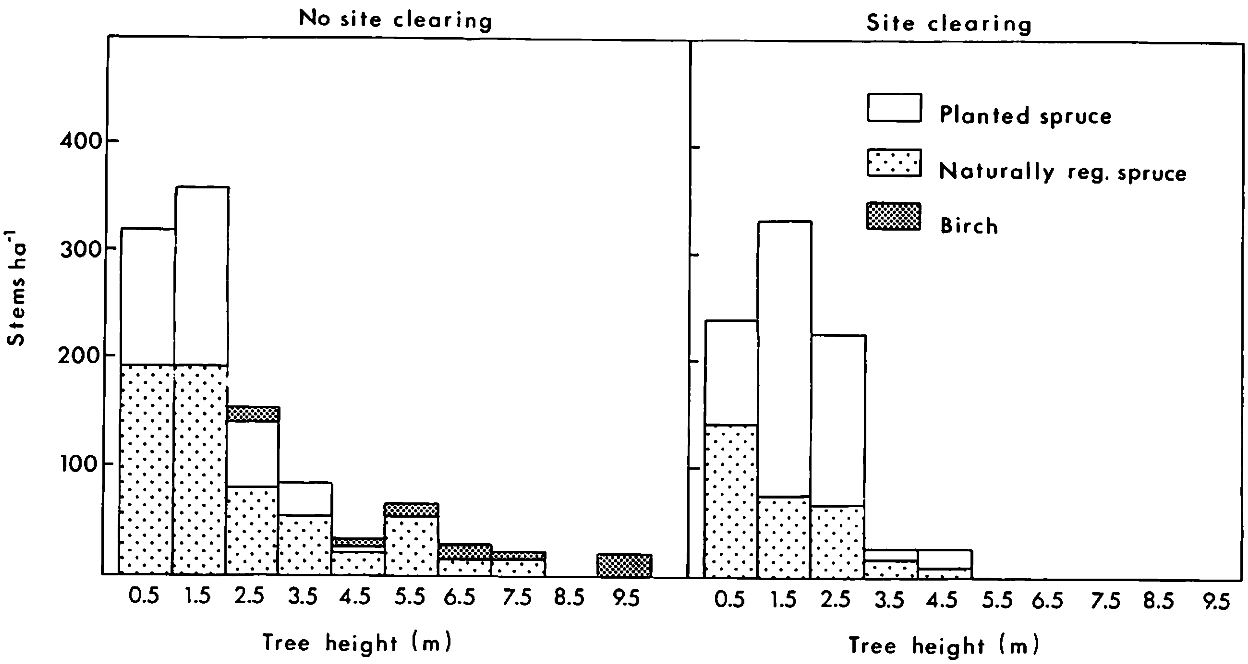

Figure 6. Number of undamaged and slightly damaged planted and naturally regenerated spruces and sheltering birches per height class 18 growing seasons after planting (1986) for the two regeneration methods.

the regeneration method with site clearing, the regression coefficients for length of terminal leader over total seedling height do not differ significantly. However, a significant difference between regression coefficients was found for naturally regenerated seedlings when the regeneration methods are compared. It is not possible to show whether or not these differences in height growth between planted and naturally regenerated spruce are small enough to enable the two types of seedlings to develop together and form a stand of homogeneous height. In any case, with a height difference of 1-5 m and the annual height increment strongly positively correlated with seedling height, it is obvious that the future stands in the two regeneration methods will contain trees with an even greater height distribution.

Neither survival (Figure 4) nor mean height (Figure 5) for planted seedlings differ significantly between the two regeneration methods at any inventory. Consequently, the sheltering birches and the advance growth spruce have not caused a significantly higher mortality or a significantly slower height development for planted spruce during the first 18 growing seasons after planting. However, there is a tendency for higher mortality and poorer height development for planted seedlings where site clearing had not been done.

The total numbers of undamaged and slightly damaged seedlings after 18 growing seasons are 850 and 1000 per hectare in the regeneration methods with and without site clearing, respectively. In the height interval 1-5 m there are approximately 610 undamaged or slightly damaged seedlings per hectare in both methods. In the regeneration method without site clearing, the height intervals 0-1 and 1-2 m have the highest numbers of planted seedlings, while the height intervals 1-2 and 2-3 m have the highest numbers in the regeneration method with site clearing (Figure 6). The number of naturally regenerated seedlings is generally highest in the lower height classes. About 93% of the examined circular plots of 12.6 m^2 where site clearing had not been done contained spruce seedlings after 18 growing seasons (Figure 7). Approximately 44% of the plots contained undamaged or slightly damaged seedlings in the height interval 1-5 m (Figure 8). In the regeneration method with site clearing the corresponding proportions are were 92% and 54%, respectively. This means that in this experiment, site clearing resulted in a young stand with 150 less seedlings ha^{-1} but with 10% more of the site covered with undamaged or slightly damaged seedlings 1-5 m in height than would have been expected if the site had not been cleared. It has also resulted in a young stand with a more even height distribution, although the

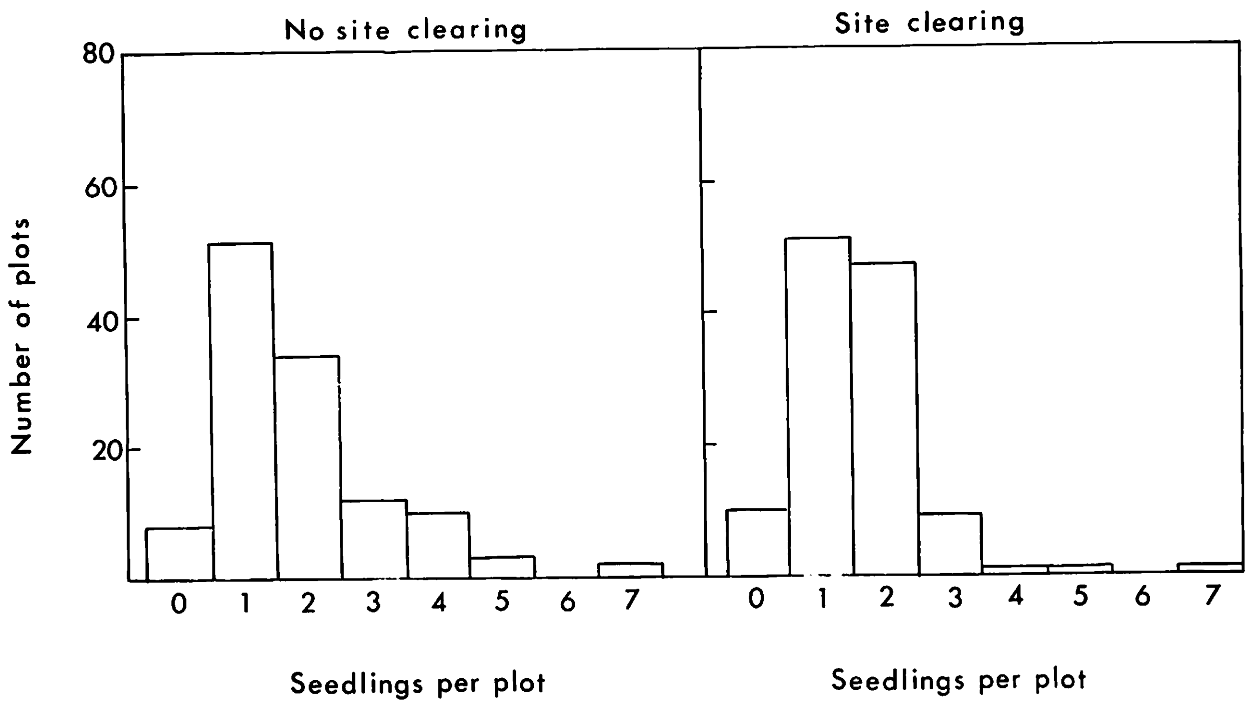

Figure 7. Frequency distribution of the number of circular plots (area 12.6 m²) with different numbers of spruces 18 growing seasons after planting for the two regeneration methods.

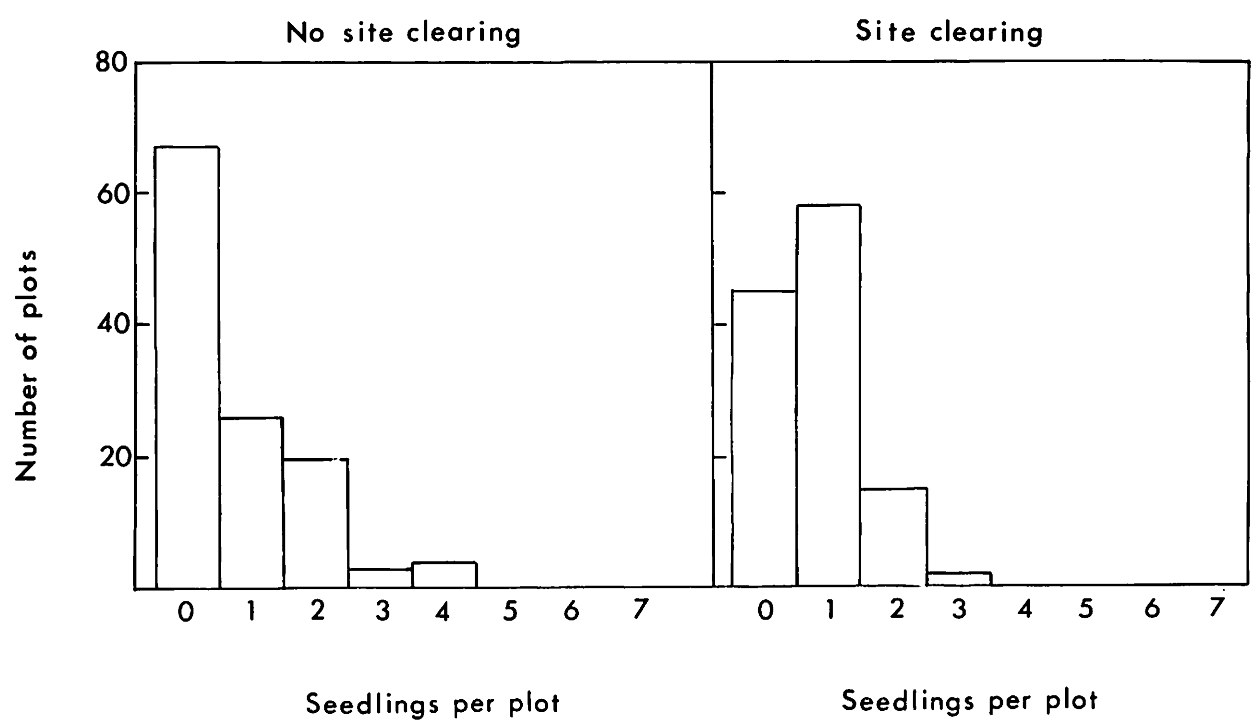

Figure 8. Frequency distribution of the number of circular plots (area 12.6 m²) with different numbers of undamaged and slightly damaged spruces in the height interval 1.01-5.00 m 18 growing seasons after planting for the two regeneration methods.

Table 2. Estimated survival rates for advance spruce growth during the period 2 to 20 growing seasons after clear-felling.

	Density of naturally regenerated spruce seedlings (stems ha^{-1})		Estimated survival rates (%)
	1969 All (A)	1986 >1 m (B)	100 x B/A
No site clearing	620	490	79
Site clearing	170	169	99

Table 3. Values of coefficients, R^2 and SE of regression coefficients (b) for the four regression lines (length of terminal leader (cm) = a + b x seedling height (m)).

	a	b	R^2	SE_b
No site clearing, planted seedlings	-1.58	0.099	0.47	0.017
No site clearing, nat. reg. seedlings	1.56	0.053	0.40	0.009
Site clearing, planted seedlings	0.06	0.114	0.46	0.015
Site clearing, nat. reg. seedlings	-0.72	0.097	0.50	0.020

Table 4. Number of naturally regenerated spruce (±SE) with a maximum height of 1 m at the inventory 20 growing seasons after clear-felling for the two regeneration methods and for the six replicates in the higher and lower elevations in the experimental area.

	stems ha^{-1}
No site clearing	252 ± 59
Site clearing	195 ± 54
Higher elevation	133 ± 43
Lower elevation	312 ± 40

mean height is lower than that obtained without site clearing.

It is not clear why the mean number of estimated new naturally regenerated spruce is higher on the uncleared sites (Table 4). It is possible that the climatic conditions for seed germination and seedling development were less favourable after site clearing. It is also possible that the largest spruces have functioned as seed trees. Findings by Tirén (1951) support the latter hypothesis. The lower mean values for the number of advance spruce growth two years after clear-felling (Table 1), and for new naturally regenerated spruce at the higher elevation site (Table 4) correspond with results presented by Tirén (1949) and Nilsen (1988).

CONCLUSIONS AND PRACTICAL APPLICATIONS

The most important finding in this study is that it is possible to use planted and advance growth spruce combined, to complement each other in forest regeneration on certain high elevation sites. If the development (survival and height increment) of the advance growth on a site can be predicted, the number of planted seedlings can be adjusted so that the total desired number of seedlings per hectare capable of forming the future stand is obtained.

In this experiment, the relative height increment is somewhat lower for naturally regenerated spruce than for planted spruce. One conclusion to be drawn is that it would be possible to save even taller and, subsequently, more advance spruce growth than in this experiment (e.g. 2 m in height) from being cleared. Using a heavier scarification method (e.g. mounding) than was used in this experiment would probably lead to an even greater height increment for planted seedlings (Söderström 1976). Heavy scarification will certainly destroy some of the advance growth. Experiments and experience from Swedish forestry also show that the development of Norway spruce seedlings is promoted by some sort of shelter, especially under harsh climatic conditions (F. Bergman, Swedish University of Agricultural Sciences, Faculty of Forestry, S-901 83 Umeå, Sweden, pers. comm., 1989). It might therefore be advantageous to do site clearing 5-10 years after planting. By then, it would probably be easier to choose the correct seedlings to cut. There would seem to be no advantage in leaving a birch shelterwood when regenerating Norway spruce on sites similar to those described in this study.

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THE IUFRO WORKING PARTY S1.05-12 SYMPOSIUM "THE SILVICS AND ECOLOGY OF BOREAL SPRUCES": AN OVERVIEW

by

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INTRODUCTION

Our individual responses to what we have experienced and heard about during this symposium will vary widely, and I offer nothing more than a personal opinion. A Newfoundlander might well dismiss this with the comment "Your tawts are too far aft", a colorful way of suggesting unbalance, as when a canoeist positions himself too close to the stern (English 1955). The equivalent "Away" expression might be "You're all wet".

First, I would offer a few comments on the role of the Working Party, especially about the role of these annual meetings. Three main elements can be distinguished: the experience of boreal forests; formal exchange of information; and cultivation of contacts.

THE EXPERIENCE OF BOREAL FORESTS

The meetings give participants the opportunity to experience parts of the boreal forest with which they might be unfamiliar. Nothing can fully substitute for first-hand experience. Our guides and mentors here in Newfoundland have been indefatigable and exceptionally able in helping us draw maximum benefit from our visit. We are greatly indebted to them.

My brief acquaintance with the forests of Newfoundland during this symposium has impressed me with the severity of the constraints that influence tree growth here. Various edaphic, meteorologic, and biotic constraining factors combine to produce substantial limitations on tree growth over extensive areas of the province. The *Kalmia* problem is one aspect of this.

Sutton, R.F. 1990. The IUFRO Working Group S1.05-12 Symposium "The Silvics and Ecology of Boreal Spruces": An Overview. In: B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 151-155.

The deep concern of silviculturists and forest managers in central Newfoundland about the proliferation of the ericaceous shrub lambkill (*Kalmia angustifolia* L.) after forest disturbance is clearly apparent; black spruce regeneration in areas dominated by *Kalmia* is unthrifty, often to the point of seeming to preclude economic stand establishment. The problem resembles that of spruce "check" associated with heather (*Calluna* (Salisb.)/*Erica* (L.)) in Europe. Similarly, in British Columbia, coniferous regeneration is found to stagnate in the presence of the ericaceous shrub salal (*Gaultheria shallon* Pursh.) (Oran 1989, Pemberton 1989, FRDA Projects #F-52-41-112 and #F-52-31-009). The phenomenon is widespread. The field study initiated in central Newfoundland by Titus and Meades (1988) to investigate methods of controlling *Kalmia* and the effects of these methods on the subsequent performance of outplanted conifers will therefore attract much more than local attention.

FORMAL EXCHANGE OF INFORMATION

The second role of these annual meetings is to provide a forum for the formal exchange of information through papers and posters. This exchange increases our knowledge about the boreal forest and might well suggest new hypotheses and new approaches to experimentation, analysis, or interpretation. The papers and posters presented during the current symposium have reached high standards, and the visual aids (the "snaps") have been particularly effective. However, the formal presentation of information is completed only with publication of the proceedings. The recent appearance of the proceedings of the 1985 meeting (Martinsson *et al.* 1989) is to be applauded. Every effort should be made to publish the backlog of proceedings with a minimum of further delay.

An overview of the current symposium's theme, "the Silvics and Ecology of Boreal Spruces", could have provided a useful backdrop for the other formal papers. I believe that such a paper was sought by the Organizing Committee. Certainly, a thorough review is a valuable document, both scientifically and from the standpoint of technology transfer. Unfortunately, the preparation of a major review requires the expenditure of great amounts of time and effort. Furthermore, such a review does not readily find a publisher, though the proceedings would seem to offer an appropriate vehicle in this regard. Organizers of future symposia might be encouraged to include an overview/review of the topic in the program, but two years of lead-time would not be too much to allow the author(s) to prepare such a review.

However, the subject of the 1989 S1.05-12 Working Group Symposium is perhaps too broad to bring into focus within the confines of an annual meeting. The ecophysiology/silviculture/management of just one of the major boreal spruces would provide a subject amply broad to occupy one of our workshops. A lack of focus militates against the detection of inter-relationships and the coordination of research.

Thus, the boreal spruces as a whole are not addressed in any of the papers at this symposium. Spruces belong to the Family Pinaceae, Subfamily Abietoideae (van Gelderen and van Hoey Smith 1986) and are widely distributed in the temperate and boreal regions of the northern hemisphere, occurring in Europe, Asia Minor, the Caucasus, Siberia, China, Japan, the Himalayas, and North America. About 50 species (van Gelderen and van Hoey Smith 1986) have been described, but "some of the newer Chinese species are very difficult to separate" (Dallimore and Jackson 1961). *Picea koraiensis*, discussed in the papers that were to be presented here by Zhan *et al.* and Li *et al.*, was not recognized by Dallimore and Jackson.

The spruces, in the terminology of Dallimore and Jackson (1961) and van Gelderen and van Hoey Smith (1986), include:

Picea abies (L.) Karst.	Northern, central, and southeastern Europe
P. alcoquiana Carr.	Japan
P. asperata Mast.	China
P. brachytyla Pritz.	central and western China
P. breweriana S. Wats.	northwestern California, southwestern Oregon
P. engelmannii Parry	western USA
P. glauca (Moench) Voss	Canada, northeastern and northcentral USA
P. glehnii Mast.	Japan
P. jezoensis Carr.	Manchuria, northeastern Asia (Scale spruce)
P. jezoensis var. *hondoensis* Rehd.	Japan
P. koyamai Shiras	central Japan
P. likiangensis Pritz.	western China
P. mariana B.S.P.	North America
P. obovata Ledeb.	northern Europe
P. omorika Purk.	Yugoslavia
P. orientalis Link.	Asia Minor, Caucasus
P. polita Carr.	Japan
P. pungens Engelm.	southwestern USA
P. rubens Sarg.	northeastern North America
P. schrenkiana Fish. et Mey.	central Asia
P. sitchensis Carr.	western north America
P. smithiana Boiss.	western Himalayas
P. spinulosa Henry	eastern Himalayas
P. wilsonii Mast.	central and western China

Only 14 of these species are listed by the Commonwealth Agricultural Bureaux (CAB) International (CAB 1988). Only five or six species of spruce are mentioned in papers presented during our symposium.

The geographical distributions of the listed species are mostly drawn from Vaucher (1986). However, Vaucher's "NE USA" for the range of *P. glauca* requires amending. Disconcertingly, van Gelderen and van Hoey Smith (1986) also stand in need of correction with their unamplified "In Canada, near the Pacific coast, *P. glauca* is an important species as is *P. sitchensis* in Alaska". These lapses are surprising in view of such authoritative descriptions of the distribution of *P. glauca* as that of Fowells (1965): "White spruce [*Picea glauca*]...grows naturally from Newfoundland and Labrador west across Canada along the northern limit of trees to Hudson Bay, Northwest Territories, Yukon, and northwestern Alaska. In British Columbia it is found east of the main range of the coastal mountains; through Alberta and Manitoba; and through northern parts of Minnesota and Wisconsin, central Michigan, northeastern New York and Maine. Outlying populations grow in the Black Hills of South Dakota and in Montana and Wyoming". One of the functions of an overview would be to flag misleading literature and point to reliable information.

Together with a consideration of the implications of climatic change, an overview of the climate of spruce forests could also have made a valuable unifying contribution to the topic.

The paper presented here by de Montigny and Weetman, though addressing a topic much more circumscribed than that of the symposium, well illustrates the value of a good, critical review. It is helpful to see a local problem in the context of a wider framework. The problems stemming from salal, heather, and lambkill, for example, are not unrelated. Formulation of hypotheses, and the devising of experimentation and remedial treatments, are promoted by the broader perspective.

Also valuable are presentations of the consolidated results from a body of experimental evidence directed towards a common objective, such as we have heard from Mats Hagner about direct seeding trials in Sweden, Finn Brække about black spruce provenance trials in Norway, and George Chrosciewicz about fire and black spruce regeneration in Manitoba.

Reports of individual experiments, such as those that might be called the "mainframe" studies reported here by Lorne Bedford and David Brand, and the study of advance growth presented by René Doucet, are valued contributions, too.

In my view, the annual formal exchange of information should include a mix of reports of single experiments and groups or series of experiments, reviews of specific topics, and an authoritative overview of the symposium theme.

CULTIVATION OF CONTACTS

The third element of the annual meetings is the fostering of contacts among foresters and scientists faced with similar, often interrelated, sets of problems. These meetings have served well this important purpose.

FUTURE DIRECTIONS

In seeking experimental solutions to problems, the researcher must conduct experimentation that is statistically valid. That should go without saying, but, even after statistically valid results have been obtained, there remains the problem of extrapolation. The applicability of the results of an experiment to situations other than that in which the results were generated is often very limited. In fact, in forest experimentation, it is extraordinarily difficult to get the same result twice running from experimentation that attempts replication in time. Even the results derived from a well designed, well conducted experiment cannot be extrapolated incautiously. This is where chaos theory might help.

Chaos, a mathematical concept "difficult to define precisely", can be thought of as deterministic randomness -- "deterministic", because it arises from intrinsic causes and not from extraneous noise or interference, and "randomness", because of seemingly irregular, unpredictable behavior (Pool 1989). As Pool observed, scientists in many diverse fields have come to realize over the past 15 years that nature is not as orderly as was once assumed. The particularly appealing aspect of chaos is that it offers a way to understand complicated behavior as something that is purposeful and structured instead of extrinsic and accidental. Pool credited Paul Martin, Dean of Applied Sciences at Harvard University, with the observation that the contribution of chaos theory has been to give researchers an appreciation of just how little complexity in a system is needed to produce complicated phenomena.

This, I believe, is the crux of the difficulty experienced by silviculturists who attempt temporal replication. An apparently inconsequential or unsuspected perturbation at some stage during the course of experimentation can significantly affect the results obtained.

Thus, before extrapolating the results of even mainframe experimentation, supportive, corroborative data are needed in amounts that depend on the variability -- the degree of chaos -- encountered.

Among the many topics that could with advantage be investigated here in central Newfoundland are: the nutritional relationships (deficiencies, levels, and cycling) for the main crop species; ecophysiology of crop/heath vegetation (including biochemistry and allelopathies); crop/mammal/insect interactions (physiological and pathological); determination of the main regional constraints on tree growth, and evaluation of ameliorative or avoidance treatments; provenance trials of promising forestation species, especially Scots pine *(Pinus sylvestris* L.), *Larix L.* spp., and, possibly, Norway spruce (*Picea abies* Karst.) and red pine (*Pinus resinosa* Ait.), with the potential for increasing productivity and diversity; stand dynamics; and the silviculture of mixtures.

DEVELOPING A RESEARCH PROGRAM

On the question of developing a research program, Jeffers (1987) made some perceptive comments, e.g., "the timescale necessary for scientific research into long-lived organisms like trees imposes a difficulty that can only be overcome by equally long-term planning and financial support"; and "the rational development of a strategy for research and management of... forest, requires a set of clear objectives for the future". Jeffers suggested we need look no further than the World Conservation Strategy (Allen 1980) for objectives to sharpen the focus of our present and future research:

maintain essential ecological processes and life-support systems; preserve genetic diversity; and utilize species and the forest ecosystem as a whole on a sustainable basis only. The essential ecological processes range from global phenomena, such as the cycling of oxygen and carbon, to local ones such as the production and dispersal of seed by trees and other forest plants. Many other processes between these extremes are essential for the survival of the forest, notably soil formation, cycling of nutrients, and vegetation succession following the clearance of forest or damage by fire. The widest possible range of the genetic variation in all parts of the forest ecosystem needs to be preserved to sustain and improve timber and fiber production, through breeding programs for forest crops and forage plants, as well as for plants that have medicinal or aesthetic uses. The preservation of genetic diversity is a form of insurance and an investment against harmful environmental change. Research is necessary, therefore, to characterize variability and to find ways in which that variability can be preserved in living plants and animals. The concept of sustainability is a simple one, but sustainability is difficult to achieve because the difference between sustained use and exploitation leading to extinction is sometimes very small, particularly in ecosystems that undergo periodic fluctuations because of climate or succession. Research is therefore necessary to define the limits within which the exploitation of the forest resources can be permitted so as to ensure that the forest itself, and the many species that make up that forest, will survive. Such research also has to be linked to the economic and social factors that govern the use of the forest and its resources. Jeffers was referring to temperate forest ecosystems, but his remarks are equally applicable to boreal forest ecosystems.

SUMMARY AND CONCLUSIONS

The role of the Working Party, especially the role of its annual symposia, is threefold: provision of opportunities to experience of the boreal forest; promotion of formal exchange of information about boreal forests and forestry; and betterment of contact among scientists involved in research related to forests and forestry in boreal and sub-boreal regions. The current symposium in central Newfoundland has filled all three roles remarkably well.

Forest experimentation must conform with sound statistical principles, but the useful extrapolation of results remains problematical. Temporal replication of silvicultural experimentation often yields dissimilar conclusions. The crux of the problem might well be the lack of appreciation of just how little complexity in a system is needed to produce complicated phenomena. An apparently inconsequential or unsuspected perturbation at some stage during the course of experimentation can significantly affect the results obtained. This is the problem addressed by chaos theory.

Many problems in the forests of central Newfoundland cry out for investigation. The major experimentation recently initiated (Titus and Meades 1988) to study methods of controlling *Kalmia* and to evaluate coniferous crop response will be followed with interest by anyone concerned with interaction between members of the Ericaceae and conifers. Other topics that could with advantage be researched include: the nutritional relationships for the main crop species; crop/mammal/insect interactions; determination of the main regional constraints on tree growth, and evaluation of ameliorative or avoidance treatments. Systematic provenance trials of forestation species with potentials for increasing productivity and diversity are highly desirable.

In closing, I am sure I speak for everyone when I express heartfelt thanks to all, including Chairman Ed Packee, who have helped organize this most worthwhile symposium. Brian Titus and his team have done us proud. Our time in central Newfoundland has been full of interest and replete with food for thought. Our Newfoundland hosts, IUFRO and otherwise, have been thoughtful, thorough, and indefatigable in catering to our ease, education, and edification, throughout the symposium.

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POSTER ABSTRACTS

IDS-SEPARATION OF WHITE SPRUCE (*PICEA GLAUCA* [MOENCH] VOSS) SEED: WHY SOW DEAD SEED WHEN PRODUCING CONTAINERIZED SEEDLINGS?

by

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Dead white spruce seed can be separated from live seed thereby decreasing the amount used in nurseries to produce a given number of seedlings. Such separations using the IDS-separation techniques (Incubation-Dried-Separated) result in portions of seed lots that can be used for single seed sowing resulting in decreased costs.

Incubation of a seed lot of good and one of poor germinability of white spruce from New Brunswick took place for 21 days at 5° C under moist conditions (moist prechilling). This incubation broke eventual dormancy requirements while allowing imbibed water to become bound in physiological, pregermination processes in live seed. Incubation increased germination percentage from 36.4 to 50.2% (ns)[1] and from 74.0 to 94.5%* in before and after incubation contrasts for the poor and good seed lots respectively. Mean germination time decreased from 14.4 to 8.9* and from 13.8 to 6.7* days before and after incubation for these same seed lots.

Density curves were obtained for storage dry seed revealing that this species' seed had a specific gravity lower than that of water. However, after the standard incubation mentioned above, all seed from both seed lots sank in water, indicating that the separation step could be carried out in this medium. The percentage of dead seeds in the consignments was calculated through cut tests performed after Jacobson germination tests.

The incubated seed lots were then dried and separated into a floating and a sinking fraction in the separation step of the IDS-separation technique. This technique resulted in a further improvement in germination percentage from 50.2% to 86.0%* and from 94.5.% to 99.5% (ns) when the controls and bottom fractions within the poor and good seed lots respectively were compared. Mean germination time was reduced from 8.9 to 7.5 (ns) days for the poor seed lot while there was no difference in germination time for the good seed lot. Additionally, it was found that a 24 hour drying period after separation increased mean germination time slightly but had no effect on germination percentages.

The economical and biological advantages are considerable in culling dead seed from seed lots with poor germinability. The IDS-technique can even be used to increase the germinability of portions of seed lots of very good inherent viability and vigor a few percent. Incubation drastically increases the germination percent and shortens the mean germination time of the provenances tested. Finally, drying the seed after separation did not affect germination percent, indicating that it is probably possible to store separated seed lots after drying to suitable storage moisture contents, without having to restratify the seed before sowing.

[1] Scheffe's multiple pairwise comparisons were performed to establish significance.

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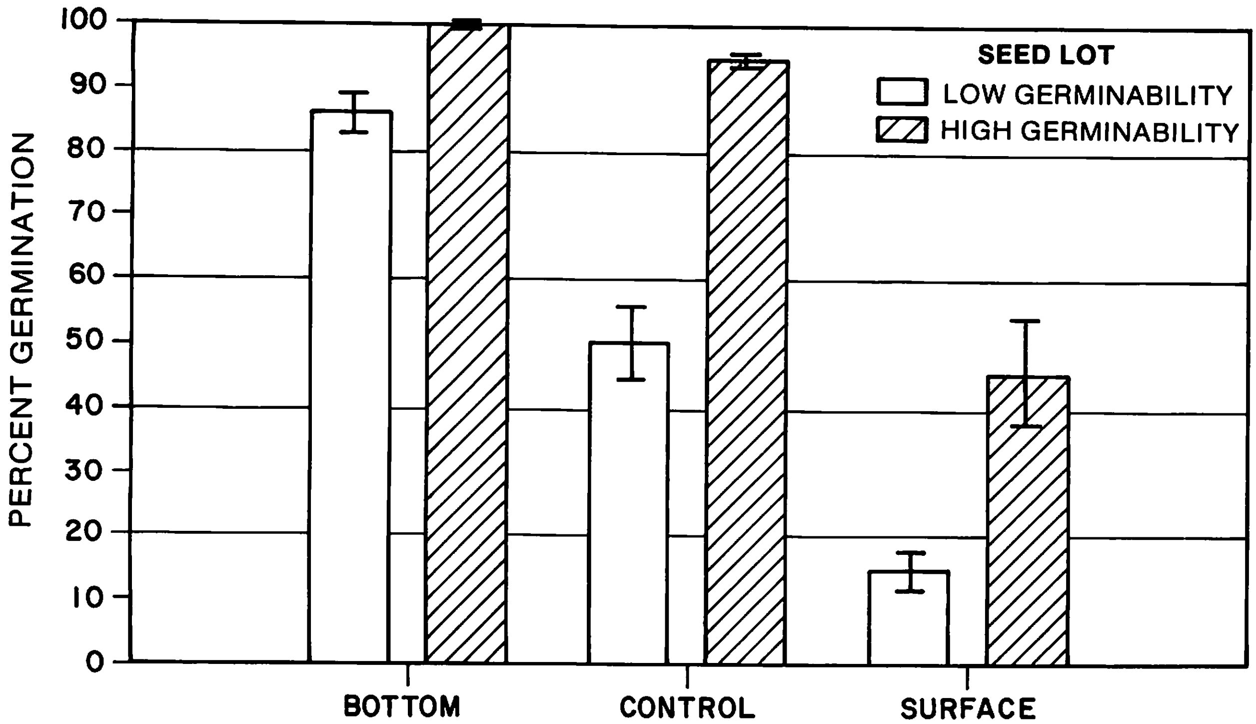

Figure 1. Percent germination after IDS treatment of two provenances of white spruce from New Brunswick, Canada (supplied by N.B. Ministry of Natural Resources).

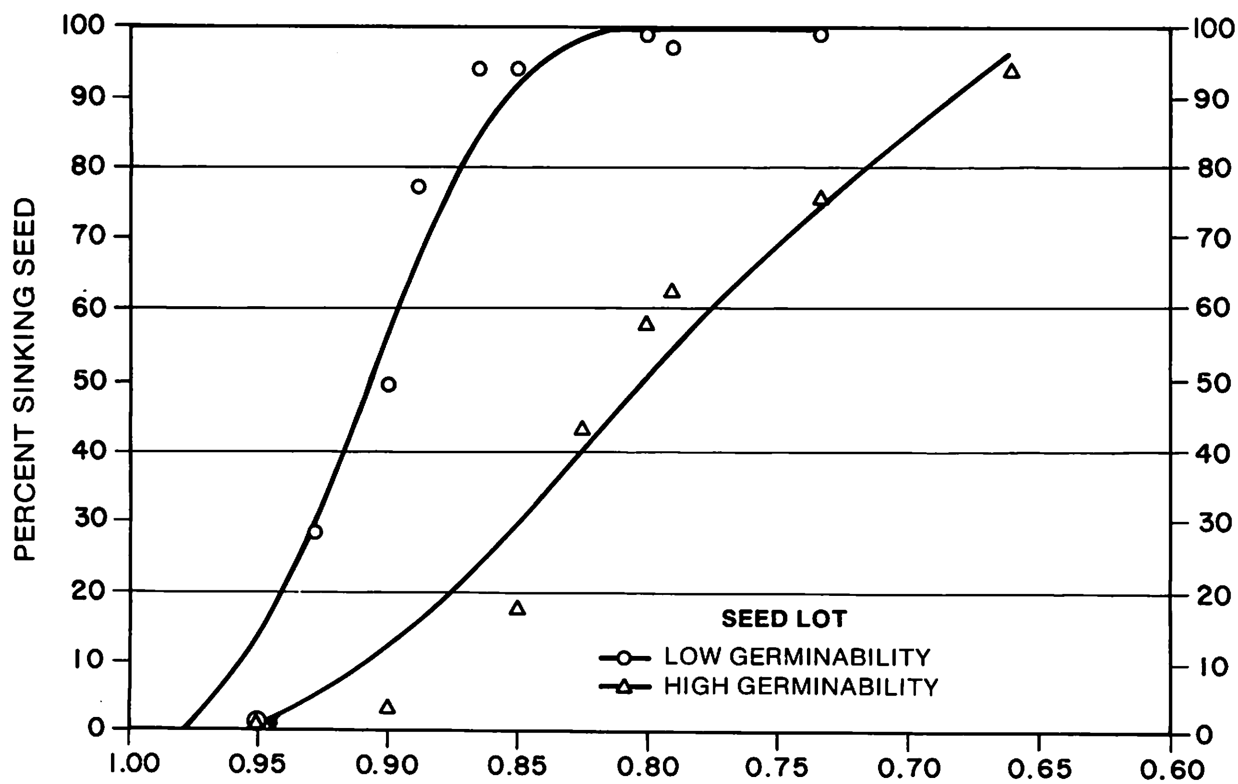

Figure 2. Seed density curves at moisture contents of 5.9 and 8.1%.

SURVIVAL AND GROWTH OF SPRUCE SEEDLINGS AFTER RADICAL SITE PREPARATION

by

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Background: Swedish foresters maintain that radical site preparation methods affect soils by reducing water retention ability and increasing nutrient losses. On poor sites, radical site preparation is definitely not recommended. Today, aesthetic concerns have, in addition, made radical site preparation methods even less attractive.

Methods: In 1964-65 various provenances of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* (L.)) were planted on a lichen pine site in Anundsjo (63°40'N) Sweden. Before planting, the soil had been ploughed to 20 cm depth, burnt or left untreated.

In 1987 the height of all trees in the trial was measured. Since the plots were not replicated, no significant differences could be distinguished. Despite this fact the age of this trial and the extremely poor site with frequent summer frosts make the trial interesting.

Results and Discussion: The mean height of the spruces was 144 cm on the ploughed plot, 38 cm on the burnt and 63 cm on the untreated (Figure 1). Survival was 98% on the ploughed plot, 82% on the burnt and 62% on the untreated plot (Figure 1). The Scots pine have reacted similarly to the different site treatments. But the mean height of the pines is more than twice that of the spruces (4.5 m on the ploughed plot and 3 m on the untreated plot).

The height increment of the spruces on the untreated plot corresponds to a site index of approximately 11 m (dominant height at 100 years breast height). The spruce site index varies between 10 and 40 m on forest sites occurring in Sweden. This trial indicates that, even on a site as poor as the one in Anundsjo, ploughing can improve the early growth of Norway spruce.

Considering that canopy closure has not yet been obtained within the spruce plots, 25 years after clear cutting an overall nutrient loss regardless of treatment is suspected. The chlorotic appearance of most spruces in the trial indicates nutrient deficiency.

The superior performance of the Norway spruces on the ploughed plot is probably the combined result of a more favorable microclimate and improved nutrient availability compared to the untreated plot. The poor development on the burnt plot could be explained by nitrogen (gas) losses as well as by the transformation of organically bound nitrogen to easily leached nitrate during combustion.

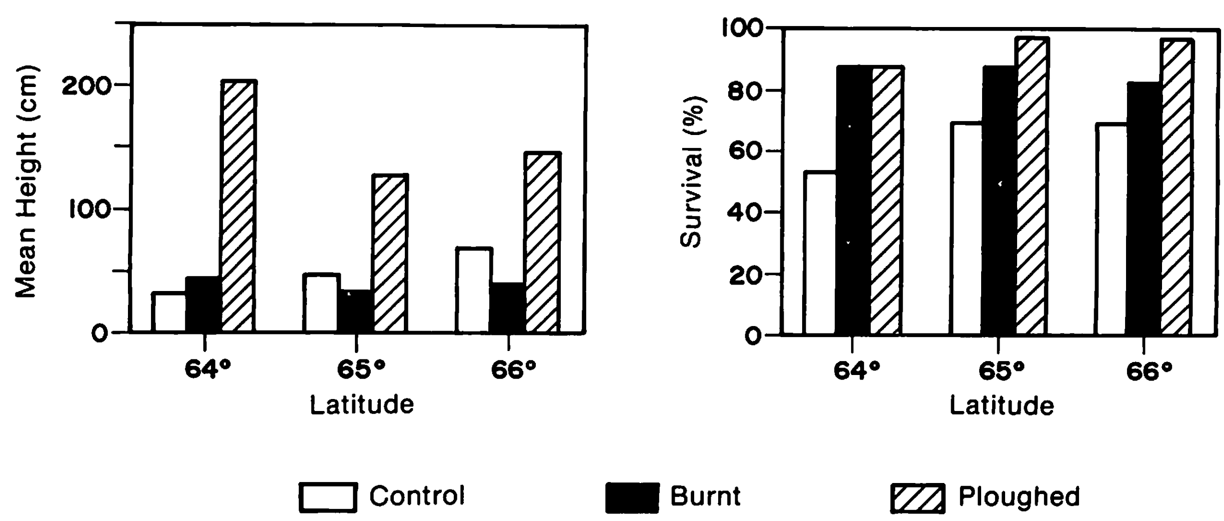

Figure 1. Mean height (left) and survival (right) of Norway spruce of three different provenances 22 and 23 years after planting (SD = standard deviation).

ALLELOPATHY AND THE COMPETITIVE ADVANTAGE OF *KALMIA ANGUSTIFOLIA* OVER BLACK SPRUCE

by

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Introduction: Northern sheep laurel, *Kalmia angustifolia* var. *angustifoila*, is an abundant ericaceous shrub in the forests and heathlands of Newfoundland. This native shrub grows vigorously following disturbances such as forest clear cut and burning. Long-term occupancy of *Kalmia* may bring about irreversible soil deterioration by nutrient "lock up" in the organic horizon, increasing soil acidity, iron pan formation and by accumulating growth inhibitory factor(s) in the organic matter. Rapid spread of this plant following disturbance and its inhibitory effects on softwood tree seedlings can turn fairly productive forest land into a "stable" unproductive ericaceous heath precluding forest regeneration. The present study examines: (*i*) the allelopathic growth inhibition, and (*ii*) the mechanism of competitive dominance of *Kalmia* over black spruce. Results of a greenhouse experiment on *Kalmia* control by herbicide applications, cutting, burning, and mulching is also presented.

Allelopathy: Primary root growth and development of black spruce was inhibited dramatically when seedlings were grown directly on *Kalmia*-dominated forest organic matter. The inhibited seedlings did not produce root hairs like control seedlings. Water extracts of various plant components and organic soil from a *Kalmia* site were tested against black spruce germinants. The greatest significant root growth inhibition was obtained in seedlings treated with litter extracts followed by soil and root extracts of *Kalmia*. It is possible to extract the growth inhibitory component of *Kalmia* humus by solvent extraction methods using ethyl acetate and chloroform. Extracts of both the solvents used were strongly inhibitory to root growth of black spruce. The extracted materials lose their active principle fairly quickly and the compound(s) were not recognizable in thin layer chromatography (TLC) plate. Further research is required to isolate and identify the compounds.

A stair-step-pot experiment was performed where 2+0 black spruce seedlings were grown in sand culture with and without *Kalmia* soil monolith interruption. Three months later, growth and biomass of the black spruce seedlings receiving *Kalmia* leachates were found to be significantly less as compared to the control seedlings.

Habitat Influence on *Kalmia* Growth and Reproduction: Plant height, stem density, specific leaf area, current year's foliage biomass, fruit, and seed production of *Kalmia* per m^2 were determined from eight different habitat types; closed canopy black spruce forest, open canopy black spruce forest, forest-heath ecotone, cutover black spruce forest, cutover and burnt-over black spruce forest, burnt-over red pine forest, and *Kalmia* dominated heath and bog. *Kalmia* was most vigorous in open canopy black spruce forest and least vigorous in the bog. *Kalmia* produced the largest quantity of seeds in the burnt-over site and least under the closed canopy forest site. However, most of the seeds produced under forest cover were viable whereas about 50% or more seeds produced in the burnt-over site, heaths and bogs were empty. Specific leaf area of *Kalmia* was highest under forest cover and lowest in the bog and heath sites.

Spread and Regrowth: The vegetative regeneration strategy of *Kalmia* was studied by examining the rhizome system of the plant. *Kalmia* regenerates mainly by vegetative sprouts originating from stem bases and underground rhizomes. Layering may occur to a limited extent in relatively undisturbed site under forest cover where *Kalmia* grows taller and older than on the exposed habitats. Three types of rhizomes, primary secondary and tertiary rhizomes have been recognized and described. Secondary rhizomes are the main organs by which the plant spreads vegetatively. The vegetative buds on the rhizomes remain protected by bud scales. The large number of vegetative buds occur at the stem bases and also on the rhizomes. Individual length of rhizomes may vary from 5 cm to a metre. The rhizomes grow in all directions in the organic horizon and show characteristic apical dominance.

Chronological Growth Dynamics: Age dependent above and below ground biomass allocation was determined by excavating 14 isolated bushes of *Kalmia* of different age groups. In the first five years of growth the plant produces fairly proportionate above and below ground biomass followed by a phase (5-8 years) when more foliage and concomitantly less rhizomes are produced. In this phase the plant spreads itself most vigorously and coalesces with other adjacent bushes. Towards the end of this phase intra-specific competition and self thinning of stems takes place. From eight years onward *Kalmia* attains some degree of stability following the intra-specific competition and readjustment of the above and below ground biomass allocation and thus establishes itself quite firmly in the habitat.

Kalmia Control: Greenhouse experiments were conducted to control *Kalmia* using herbicides, cutting, burning and mulching treatments. Among the five herbicides used, Garlon 3A effectively killed *Kalmia* and Velpar application defoliated the plant within three weeks but the plants were not killed and produced new foliage afterwards. Glyphosate application did not produce any lethal effects on *Kalmia* even at the rate of 7 L/ha. Mulching treatments killed the plant and stopped its vegetative regrowth most effectively whereas cutting and burning stimulated the vegetative sprouting of *Kalmia*.

Discussion: Like other ericaceous heath forming species *Kalmia* is an opportunistic plant equipped with very efficient reproductive organs. The plant produces an extensive underground rhizome system with a large number of vegetative buds which help in quick recovery of the plant following disturbance. Higher specific leaf area in plants under forest canopy enables the plant to maximize absorption and utilization of incident light. Also, by reproducing mostly by vegetative means under forest cover, the plant conserves energy and whatever energy is allocated for sexual reproduction is also done effectively since most of the seeds produced are fertile. On the burnt-over site *Kalmia* seems to be very wasteful in that it produces a large number of empty seeds. On sites where *Kalmia* is sparsely but fairly evenly distributed under forest canopy, removal of forest cover by clear cutting or burning will enhance *Kalmia* regrowth and within eight years it may occupy the ground completely. Management intervention must be introduced before that time to stop *Kalmia* regrowth on the site. What environmental or genetic factor(s) trigger the rhizome spread and vegetative sprouting of *Kalmia* is not precisely known. It is now clear that *Kalmia* humus is inhibitory to the growth and development of roots of black spruce which affect natural regeneration of the forest. The compounds responsible for this kind of root growth inhibition are not yet identified. More research is needed to extract and identify those compounds from *Kalmia* humus. Of all the treatments applied to control *Kalmia*, mulching is the most promising method which is also environmentally sound. Field trials should be established to determine its effectiveness in controlling *Kalmia* on cutover and burnt-over sites in central Newfoundland.

BIOCHEMICAL RESPONSE OF PLANTED BLACK SPRUCE AND JACK PINE SEEDLING TO SILVICULTURAL TREATMENT

by

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Introduction: Spruces and pines are the two major coniferous components of the boreal forest and account for over 80% of the 1.26 million hectares planted in Canada between 1980 and 1985 (61% spruce, 25% pine). In eastern Canada, the predominant planted spruce is black spruce (*Picea mariana* (Mill.) B.S.P.) and the predominant pine, jack pine (*Pinus banksiana* Lamb.).

A large study was undertaken in 1986 with the objective of understanding how planted seedlings of these two conifer species would respond to changes in environmental conditions produced by some common silvicultural treatments. We report here some of the differences found in the biochemical response of these two species to environmental manipulations.

Methods: Bareroot jack pine and black spruce seedlings were planted in the spring of 1986 in a split plot design. Scarification of the organic layer down to mineral soil was the main plot treatment and resulted in increased soil temperature (Treatment T). Fertilization and/or brush control were the two subplot treatments and resulted in significant increases in light and nutrients, respectively (Treatments B and F, respectively). Seedlings were harvested just at budbreak in May; after the completion of shoot extension in July; and again towards the end of the growing season in mid-September. Samples were frozen and then analyzed for various biochemical compounds.

Results: For each biochemical compound there was generally one two-way interaction between treatments (i.e. TxF, TxB, or BxF) which dominated. Thus, BxF means are discussed for the non-structural carbohydrates and TxF means discussed for the free amino acids and total nitrogen.

Non-Structural Carbohydrates (NSC): Pine tended to maintain lower concentrations of readily available carbon (i.e. NSC = sugars + starch) than spruce in needles but maintained higher NSC concentrations in roots. NSC differences between pine and spruce were more apparent earlier in the growing season for needles but were more apparent later in the growing season for roots. Similarly, for both pine and spruce, changes in environmental conditions most affected NSC levels in the early and mid growing season for needles whereas differences in root NSC concentrations were more apparent later in the growing season.

Free Amino Acids (FAA) and total nitrogen: FAA represent the readily available pool of N. Under some circumstances, FAA can be more sensitive to treatment efects than total %N. For example, in September there were no significant differences in the TxF interaction for total nitrogen while there were indeed differences for FAA.

Conclusions: Jack pine and black spruce differ in their biochemical response to changes in environmental conditions. The growth responses of these seedlings were also quite significant (see Brand and Penner, this volume). Knowing which biochemical compounds to sample at which time of year for a given species is essential if we are going to effectively use these measures to assess the physiological status of planted seedlings.

STABILITY IN THE BOREAL FOREST/ERICACEOUS DWARF-SHRUB HEATH ECOTONE OF EASTERN NEWFOUNDLAND

by

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The Kalmia Heaths (dominated by *Kalmia angustifolia* L.) of eastern Newfoundland cover extensive areas previously occupied by boreal coniferous forest. At present, trees in the heath occur only as sporadic individuals or small residual islands that escaped destruction by burning and cutting. The age of these heaths is variable but at least 15-20 years is required for ericaceous shrubs to achieve dominance of the site. Therefore, it is unlikely that slash or buried seeds will act as an *in situ* seed source for future tree establishment. If long-term succession of Kalmia heath back to forest is to occur, it must be from remote seed sources located in forests along the heath perimeter or sporadic residual trees in the heath landscape. Thus, succession must be by a mechanism of Relay Floristics rather than Initial Floristic Composition *sensu* Egler. The objective of this study was to test the hypothesis that boreal coniferous forest could re-establish in ericaceous dwarf shrub heath by a process of relay floristics.

To test the stability of existing forest-heath ecotones, two experimental areas were investigated. The first area was used to test the hypothesis that tree islands in the heath landscapes could be undergoing active expansion. The second experimental area was used to test the hypothesis that a relatively small island of heath in a forest landscape could be invaded by trees relatively rapidly. In the former experimental area (forest island) seed supply and dispersal might be limiting but in the latter (heath island) this would be very unlikely. The insular configuration offered the additional advantage of testing the effect of wind on seed dispersal and subsequent succession.

On each site the stability of the ecotone was assessed by monitoring the following parameters:

(*i*) The presence, viability of the seed source and effective dispersal of tree seed supply;

(*ii*) The levels of tree establishment with direction and distance from the stand edge;

(*iii*) The quality of seedbeds for successful germination;

(*iv*) The population age structure of invading trees to assess the nature of establishment over time, i.e. progressive or retrogressive;

(*v*) The growth rates of invading tree populations to determine the time required for the new treeline to mature to produce a cone crop and initiate secondary relays.

An empirical model incorporating seed production, viability and dispersal distance of surrounding forest suggested that levels of viable tree seed would be adequate throughout the heath island but only up to distances of 30-50 m from the forest island. However, tree establishment in the ecotone was only adequate at maximum distances up to 10 m from the forest edge.

Adequate regeneration was recorded up to 20 m in the heath island but the vast proportion of this regeneration was attributed to advance (pre-disturbance) regeneration not applicable to the relay floristics model.

Analysis of the seedbeds surrounding the forest island and within the heath island showed loose litter and fructicose lichens to be the dominant seedbed types. These seedbeds are considered antagonistic to future establishment of regeneration.

The age structure of invading tree populations demonstrated that rates of seedling establishment had generally decreased with time since disturbance. Vegetative layering by *Picea mariana* (Mill.) B.S.P. in the southeast and southwest quadrants of the forest island provided an important exception to this general trend.

Analysis of the height age growth relationships of *Picea mariana* showed considerable reduction in tree height growth in the heath ecotone compared to seral hardwood thickets growing on the same site type.

In conclusion, all of the variables considered essential to the process of succession by relay floristics show a negative trend. Thus, the hypothesis that forest might re-establish in these dwarf shrub heaths naturally through a process of relay floristics is rejected. The ecotone between ericaceous heath and boreal forest is considered stable at least to the extent that climate can be considered stable.

INITIAL RESPONSES OF BLACK SPRUCE TO OPERATIONAL PRECOMMERCIAL THINNING PRACTICES[1]

by

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From 1975 to 1980 approximately 8000 ha of productive coniferous forests were precommercially thinned within insular Newfoundland. Coincidentally a regional spruce budworm (*Choristoneura fumiferana* (Chem.)) outbreak peaked during this same period. This case study was initiated in order to evaluate the response of black spruce (*Picea mariana* (Mill.) B.S.P.) trees to precommercial thinning conducted during this period. The study areas consisted of two black spruce stands situated on medium sites within central insular Newfoundland. Both areas were partially thinned in 1977 at an age of 25 years. Results indicated that absolute and relative diameter, basal area and volume and specific volume increments were greater in the thinned than in the unthinned portions at each area within seven years of treatment. Live crown ratios were greater in the treated portions than in the untreated portions however there were no consistent differences in cylindrical form factor or specific gravity eight years after thinning. Only a limited number of these increases could be statistically attributed to thinning due partially to the inversely related effects of thinning and spruce budworm defoliation. These results suggest that unless protection programs are implemented during spruce budworm outbreaks only minimal gains will be realized from thinning black spruce stands.

[1] For complete details, see Newton, P.F. 1988. Initial response of partially defoliated black spruce trees to precommercial thinning. Can. For. Serv., Nfld. For. Centre, St. John's, Nfld., Inf. Rep. N-X-264.

DEVELOPMENT OF A STAND DENSITY MANAGEMENT MODEL FOR PURE BLACK SPRUCE FOREST TYPES WITHIN CENTRAL NEWFOUNDLAND: APPLICABILITY OF THE SELF-THINNING RULE[1]

by

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The self-thinning rule describes the asymptotic total stem volume (V)-number of trees per unit area (N) relationship as inversely proportional with a power exponent of -0.5 within stands undergoing density-dependent mortality. The applicability of this relationship within black spruce (*Picea mariana* (Mill.) B.S.P.) stands during self-thinning was the subject of this study. Principal component analysis was used to estimate the parameters of the rule. Tests of hypotheses were employed to determine if V and N were significantly correlated and whether the slope for the observed V-N relationship was significantly different from the expected value. The data consisted of 37 growth periods derived from twenty-seven 0.081 ha semi-permanent sample plots situated on sites of medium quality throughout central insular Newfoundland. From these data 15 asymptotic growth periods were selected during which density-dependent mortality occurred. Results indicated that V and N were significantly correlated ($r = -0.8697$) and the slope of the observed V-N relationship (-0.5830) did not significantly differ from the expected value (-0.5) at the 95% confidence level.

[1] For complete details see Newton, P.F. 1988. *In:* A.R. Ek, S.R. Shifley and T.E. Burk, eds. Forest Growth Modelling and Prediction: Proceedings of the IUFRO Conference, Aug. 23-27, 1987, Minneapolis, Minnesota. USDA For. Serv., Northcent. For. Exp. Stn., Gen. Tech. Rep. NC-120, pp. 604-610.

FACTORS AFFECTING THE LIMITATION TO NATURAL REGENERATION OF WHITE SPRUCE SEEDLINGS BY ALUMINUM

by

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A series of experiments were conducted to observe the effect of aluminum on seed germination and the establishment, growth, respiration and nutrient relations of seedlings of white spruce. Factors influencing the degree to which aluminum is toxic, such as aluminum concentration, the timing of exposure to seedlings to aluminum, pH, and cation amelioration of aluminum toxicity, were also examined. Aluminum concentrations of up to 500 µM (pH 4.5) did not inhibit seed germination. Aluminum damaged root meristematic tissue and reduced root elongation. A reduction in root length was induced by 10 µM, a concentration three orders of magnitude lower than extractable aluminum levels of organic horizons of typical podzolic soils. Aluminum toxicity could be eliminated by the addition of P to nutrient solutions. For example, toxicity symptoms induced by 100 µM aluminum could be eliminated if 10 µM P was added to the nutrient solution. X-ray microanalysis of tissues of aluminum-treated seedlings indicated that aluminum was concentrated in the root epidermis. Aluminum concentration did not affect P concentration in the epidermis, cortex or stele. However, K concentration decreased in the root epidermis and cortex as the external aluminum concentration increased. Aluminum did not reach the stele region of the root and was not taken up into the shoot. The findings of these studies suggest that aluminum could inhibit the natural regeneration of white spruce by preventing root penetration of the rooting medium thereby preventing seedling establishment.

Growth variables for 15-day-old white spruce seedlings germinated and grown in water from days 0 to 8 and exposed to Al from days 8 to 15.

	Aluminum Concentration (µM)			
Variable	0	50	100	500
Length (mm)				
Root	15.1a[a]	10.7b	8.7c	9.3bc
Shoot	53.2a	53.9ab	56.0b	56.0b
Total Seedling	68.3	64.6	64.7	65.3
Fresh Weight (mg)	336	318	329	338
Dry Weight (mg)				
Root	4.2a	3.5b	3.2b	3.0b
Stem	12.5a	12.4a	12.9ab	13.9b
Cotyledon	10.8	10.1	10.4	10.3
Seed Coat	18.1	17.0	18.3	17.4
Total Seedlings	45.6	43.0	44.8	44.6
Root:Shoot	0.18a	0.15b	0.14c	0.12c
Respiration ($mg\ CO_2$ / g dry wt / h)	2.5	2.0	2.3	2.1

[a] Values followed by the same letter are not significantly different at the 5% level.

Growth variables for 15-day-old white spruce seedlings grown for 1 week with (+) or without (-) 100 µM Al or 10 µM P.

	Treatment			
Variable Al	+	-	+	-
P	-	-	+	+
Length (mm)				
Root	7.2a[a]	11.3b	10.0b	10.8b
Shoot	50.5a	53.9b	54.7b	52.8b
Total Seedling	57.7a	65.2b	64.7b	63.5b
Fresh Weight (mg)	279a	315b	312b	300b
Dry Weight (mg)				
Root	2.2a	3.1b	3.2b	3.2b
Stem	14.1	13.6	13.8	13.4
Cotyledon	11.2	9.8	10.9	10.3
Shoot	25.3	23.4	24.7	23.7
Total Seedling	27.5	26.5	27.9	26.8
Root:Shoot	0.09a	0.13b	0.13b	0.13b
Respiration ($mg\ CO_2$ / g dry wt / h)	1.5	1.6	1.3	1.3

[a] Values followed by the same letter are not significantly different at the 5% level.

THE GROWTH AND DEVELOPMENT OF WHITE SPRUCE (*PICEA GLAUCA*) IN NEWFOUNDLAND

by

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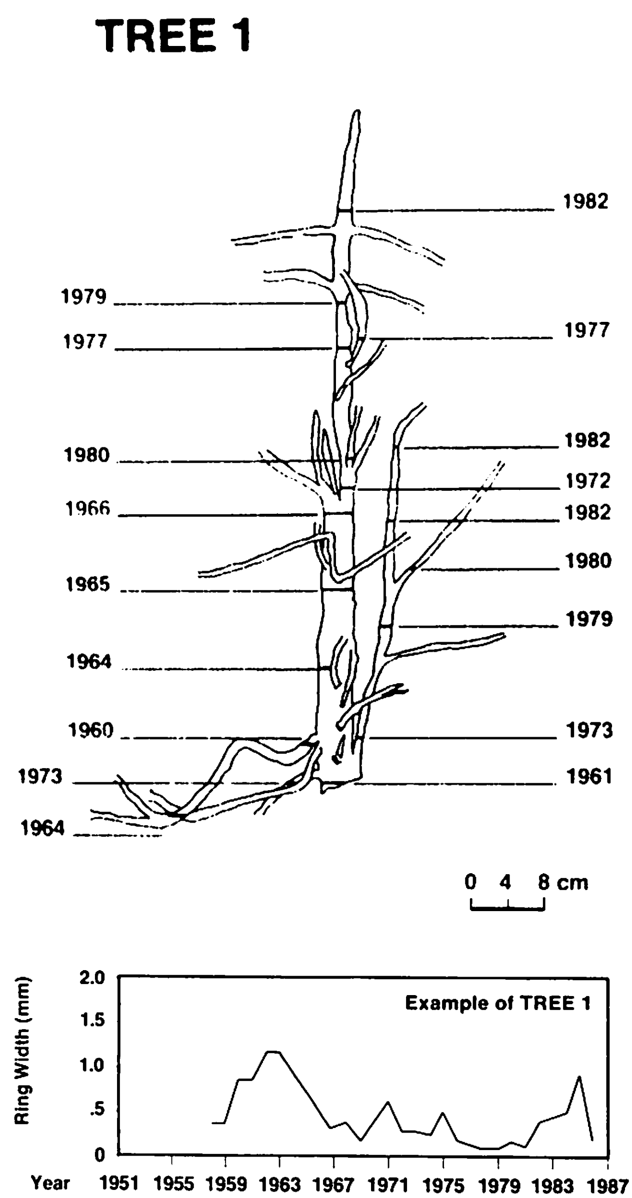
White spruce (*Picea glauca* (Moench) Voss) is widespread throughout insular Newfoundland but forms only about 2% of the volume of the major tree species. Because of its good sawlog properties as well as its value as a pulping species there has been recent interest in including white spruce in intensive silvicultural programs.

The principal white spruce vegetation types are (*i*) exposed coastal and alpine white spruce on rapidly to well drained orthic humo-ferric podzols on thin till, or typic folisols over bedrock, (*ii*) old field white spruce on moderate flats and slopes with well to moderately well drained orthic podzols on deep glacial fill formerly cultivated for pasture or root crop production, (*iii*) white spruce on rich soils - a) natural, b) ungulate induced. The natural and ungulate induced white spruce types are the most valuable for forestry as they occupy the richest sites with the highest capability classes, 3-4. The volume increment is often in access of 4 m^3/ha/yr on the rich slope seepage soils or alluvial areas.

The origin of most stands of white spruce in central Newfoundland can be traced back to severe overbrowsing by moose of rich balsam fir regenerating forests. Stand conversion from balsam fir to white spruce following overbrowsing often creates a two-age, semi-open stand similar in structure to the old field white spruce succession type. In these stands today many of the stubby continuously browsed balsam fir are still alive (up to 80 per 0.04 ha) but are less than 1 m in height compared to greater than 10 m seed producing white spruce of the same age which are forming an uneven age greater than 80% white spruce stand. Six dwarfed balsam fir trees, stem analyzed reveal the main years of intensive browsing and show a good correlation between the ages of white spruce, dwarfed balsam fir and the age of the cutover.



IMPACT OF CLEARCUTTING WITH DIFFERENT HARVESTING SYSTEMS IN BLACK SPRUCE STANDS (*PICEA MARIANA* (MILL.) B.S.P.)

by

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A province-wide study was initiated in 1982 to examine the effects of different harvesting systems on the regeneration of conifer and mixed stands. This study includes 143 black spruce stands, one of the most important stand types in Quebec. Plots established in those stands were measured before and after cutting and five years later. Four different harvesting systems were studied:

System 1: Full tree harvesting with a feller-forwarder

System 2: Full tree harvesting with a feller-buncher and a wheeled skidder

System 3: Full tree harvesting with chainsaw felling followed by skidding

System 4: Tree-length harvesting with chainsaw followed by skidding

Coniferous advance growth was generally abundant and comprised mostly black spruce layers. An important destruction of this advance growth occurred with all systems, System 1 being less destructive. This system is the only one where clearcut areas still had an average stocking over 60% immediately after cutting. Stocking and density improved in the following years so that, on the average, all systems provided stockings higher than 60% after five years. With System 1, stockings over 80% were obtained and dominant coniferous stems accounted for 60% stocking, which is 15 to 20% higher than with other systems.

Recently, efforts have been put into the preservation of advance growth. Although promising, improvements for System 2, which is the one generally used in black spruce stands, are limited by the boom reach of the available feller-bunchers. Harvesting machinery manufacturers are currently working on new feller-delimbers that could do a lot to improve the amount of advance growth protected during clearcutting operations.

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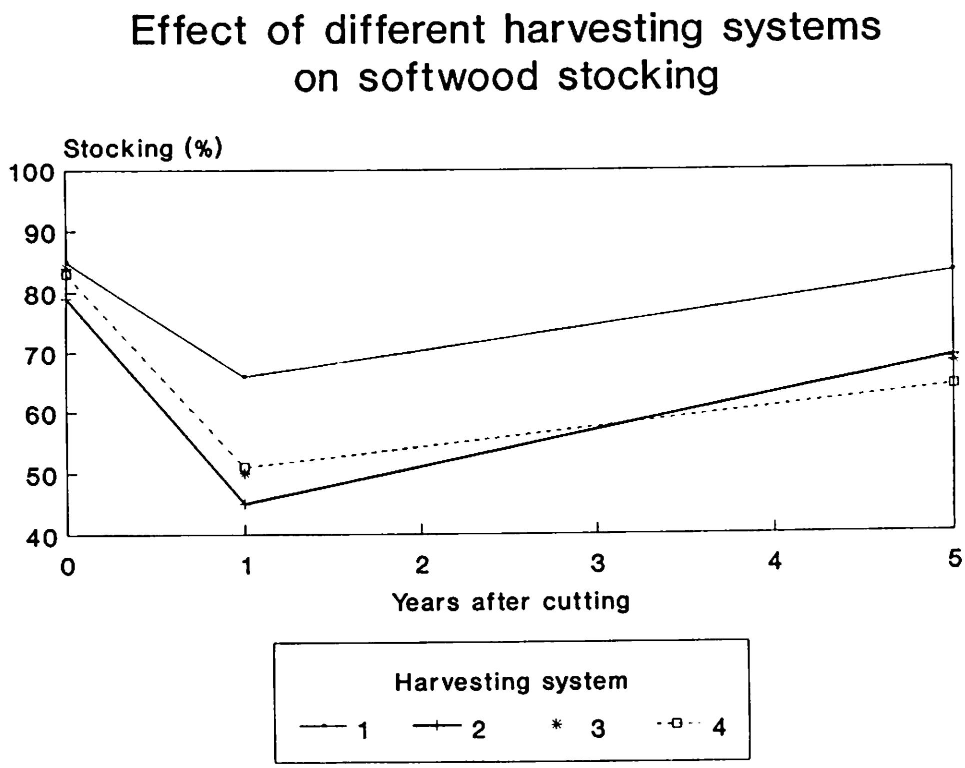
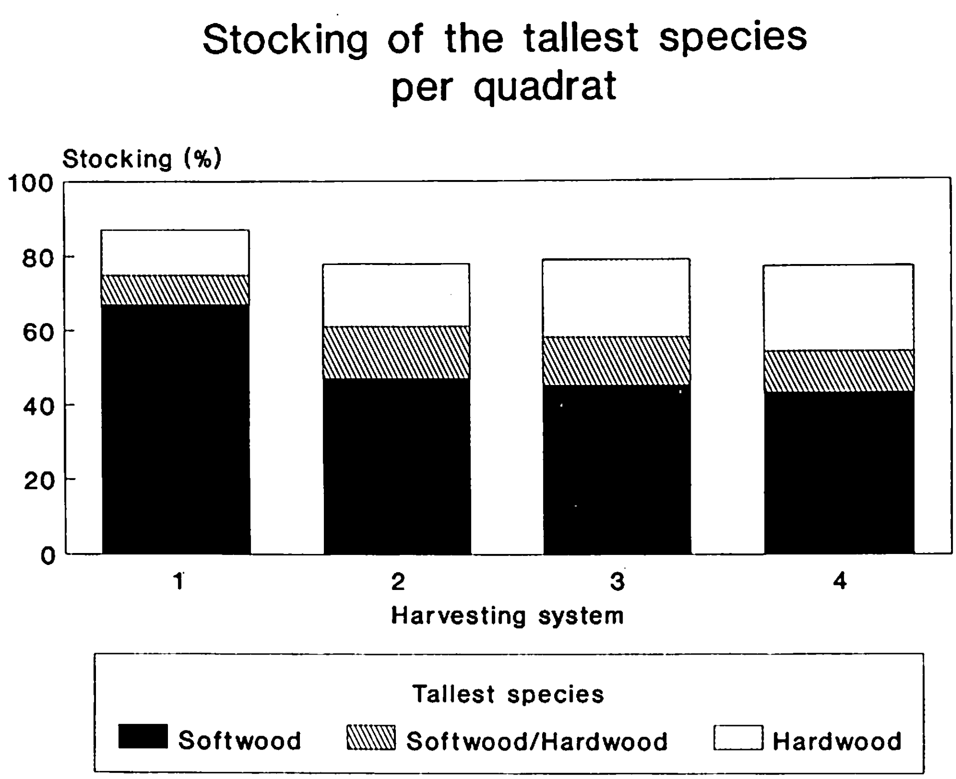

Effect of different harvesting systems
on softwood stocking
Stocking (%)
100
90
80
70
60
50
40
0
1
2
3
4
5
Years after cutting
Harvesting system
1
2
3
4


Stocking of the tallest species
per quadrat
Stocking (%)
100
80
60
40
20
0
1
2
3
4
Harvesting system
Tallest species
Softwood
Softwood/Hardwood
Hardwood

BACKGROUND TO FORESTRY IN NEWFOUNDLAND

THE ROLES AND RESPONSIBILITIES OF THE FORESTRY AGENCIES IN NEWFOUNDLAND

by

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INTRODUCTION

The roles and responsibilities of the forestry agencies in Newfoundland have developed as a result of the system of Federal and Provincial governments in Canada, and of a land tenure arrangement that is somewhat unique to the Province of Newfoundland. This paper briefly outlines the responsibilities of the three major forestry agencies, particularly in the areas of management and funding responsibilities.

LAND TENURE

The area of the Province of Newfoundland and Labrador is approximately 15,000,000 ha. Productive forest land is the largest single land class followed by non-productive forest land, bogs, barrens and residential land (Table 1).

Forest Land Tenure in the Province can be divided into four basic types:

(*i*) *Fee-simple granted*: generally provides the holder with all rights to the property in question including timber, mineral and certain water rights.

(*ii*) *Leased*: generally 99 years in duration with renewal clauses that in most cases only provides a right to harvest the timber, although mineral rights may occassionally be included. These leases were issued around the turn of the century and are no longer available.

(*iii*) *Licenced*: generally for a shorter period of time than leases. Licences usually do not contain automatic renewal clauses and only provide for timber harvesting activities. Some old 99 year licences will expire soon and will be replaced by shorter term licences.

(*iv*) *Unalienated Crown*: all rights retained by the Crown.

Peters, R.D. 1990. The Roles and Responsibilities of the Forestry Agencies in Newfoundland. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 171-174.*

On the Island of Newfoundland approximately 42% of the land is unalienated Crown land, and 2% is made up of national parks, reserves or small private holdings. The remaining 56% is controlled by the two pulp and paper companies operating in the Province as either private (10%) or leased/licensed (46%) land. The land base of the paper companies is maintained through a mixture of all types of tenure.

The fiber requirements of the industry largely come from this land base and in 1988/89 1,726,556 m^3 (solid) came from company limits, and another 164,135 m^3 from Crown land. Other timber harvested from Crown land included approximately 49 million fbm of sawlogs and 433,200 m^3 for a variety of other uses, such as fuelwood. In general, the lands held by the Crown are of a lower capability than those held by the paper companies and are located primarily in the coastal regions (Table 2).

In Labrador virtually all of the land is held by the Crown and the harvest in 1988/89 consisted of 515,000 fbm of sawlogs (primarily for domestic use) and 42,736 m^3 (solid) of pulpwood for export.

Labrador represents one of the few remaining blocks of quality black spruce in eastern Canada, and the Province is actively trying to develop the forest potential in the area.

In Newfoundland and Labrador the holder of the land generally has responsibility for conducting silviculture, but the Province establishes the requirements.

GOVERNMENT OF CANADA

The Federal Government's land holdings in the Province are largely contained in the two National Parks, military reserves and lands around airports and other Federal Government buildings. These holdings represent less than 1% of the total land base of the Province. As with any other land holder, this ownership brings certain forest management responsibilities. However, in Newfoundland and Labrador, as in the other provinces of Canada, the Federal Government does not have a responsibility for

Table 1. Land class areas for the inventorized portion of Newfoundland and Labrador (in thousands of hectares).

LAND CLASS	NEWFOUNDLAND Area	NEWFOUNDLAND Percent	LABRADOR Area	LABRADOR Percent
Forest Land				
Productive	2,825.5	39.5	3,611.8	44.5
Non-Productive	1,941.5	27.1	2,855.4	35.2
Sub-total	4,767.0	66.6	6,467.2	79.6
Water	575.6	8.0	701.5	8.6
Sub-total	575.6	8.0	701.5	8.6
Non-Forested				
Soil Barren	383.4	5.4	164.3	2.0
Rock Barren	298.5	4.2	256.1	3.2
Bog	1,075.7	15.0	526.9	6.5
Cleared Land	20.3	0.3	6.1	0.1
Agricultural Land	11.9	0.2		
Residential	23.8	0.3		
Rights-Of-Way	5.5	0.1		
Sub-total	1,819.1	25.4	953.4	11.7
TOTAL	7,161.7	8 122.1		

Table 2. Breakdown, by tenure and occupancy of the productive forest area of the Island of Newfoundland.

	Area ('000 ha)	Percent of Total Productive Area
By Tenure		
Leased/Licenced	1,299.7	46
Crown	1,186.7	42
Private	282.6	10
Reserved	56.5	2
TOTAL	2,825.5	100
By Occupancy		
Corner Brook Pulp and Paper	1,007.9	35
Abitibi-Price (Grand Falls)	639.7	23
Abitibi-Price (Stephenville)	76.3	3
Crown	1,049.1	37
Other	52.5	2
TOTAL	2,825.5	100

forest management outside its own holdings. This is not to say that the Federal Government does not influence forest management. Through its research activities and funding mechanisms the participation by the Federal Government in forest management is essential. The Federal Government through Forestry Canada focuses on national and international issues and generally assumes a co-ordinating role when management issues involve one or more provinces.

The Canadian Council of Forestry Ministers (CCFM) provides a forum whereby the Provincial Ministers and their federal counterpart meet on a regular basis to discuss areas of mutual concern. Major items dealt with by this group over the last three or four years have included the Canada/United States Softwood Lumber Countervail investigation and the National Forest Sector Strategy.

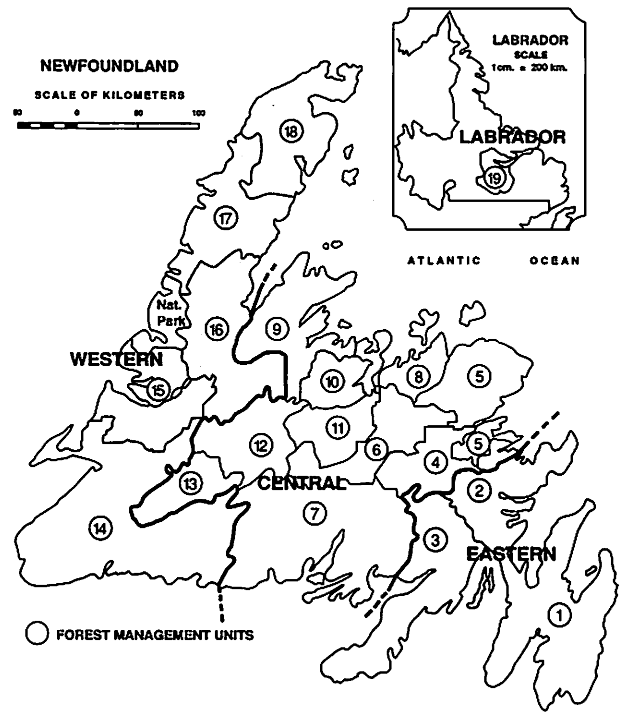
GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

As previously stated, the Province has responsibility for establishing forest management guidelines in the Province.

In order to facilitate the administration of the resource and these guidelines for management, the Province has been divided into 19 Forest Management Units (see Figure), each of which has an assigned professional and technical staff. Each of these Units is managed on a sustained yield basis. In addition to regulating the activities of other land holders, the Province carries out all forest management activities on Crown land. Operators on Crown land obtain a permit to cut timber and pay a stumpage fee for the volume harvested. Their only responsibility is to utilize acceptable harvesting practices.

PULP & PAPER COMPANIES

The various types of tenure held by the Province's pulp and paper companies do not contain a provision that requires them to carry out forest management practices, as these documents were issued between 50 and 85 years ago. In order to facilitate and encourage good forest management, the Province established the Forest Management Taxation Act in 1974. This Act provides for a two tier tax structure, with a low tax for forest lands that are managed within the guidelines developed by the Province, and a significantly higher tax for lands that are not properly managed. The tax applies to all land owners with holdings over 120 hectares.



FUNDING

A major source of funding for forestry activities in the Province has been a series of Federal-Provincial Agreements. These Agreements commenced in 1974 with the Forest Subsidiary Agreement I and, including the current Forest Resource Development Agreement, over $180 million has been spent on a variety of activities that have included resource road construction, silviculture and technology transfer (Table 3).

In addition to the Federal Provincial Agreements, there are direct provincial expenditures by the Department in the order of $20 million/year, plus further expenditures by the pulp and paper companies.

FUTURE DIRECTIONS

Significant changes in the roles and responsibilities of the forestry agencies in Newfoundland do not appear likely in the near future. However, while the Federal Government will continue to be a major funding source, there are indications that the focus of this funding, particularly in the area of silviculture, will gradually shift from current silviculture requirements and focus on backlog sites and other aspects such as public information and R&D (research and development).

Table 3. Canada-Newfoundland Forest Resource Development Agreement (1986-90) .

	Funds allocated to program ($)
FOREST RESOURCE MANAGEMENT	
Silviculture	26,600,000
Forest Access Roads	5,300,000
Forest Management, Inventory and Planning	5,000,000
Forest Protection	1,750,000
RESEARCH AND DEVELOPMENT, OPPORTUNITY IDENTIFICATION AND TECHNOLOGY TRANSFER	
Research and Development	2,500,000
Opportunity Identification	750,000
Technology Transfer	3,050,000
ADMINISTRATION, COMMUNICATIONS AND EVALUATION	
Administration and Communications	1,600,000
Human Resource Development	450,000
Economics, Evaluation and Program Management	1,000,000
TOTAL AGREEMENT	$48,000,000

THE CONTRIBUTION OF THE FORESTRY SECTOR TO THE ECONOMY OF NEWFOUNDLAND

by

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INTRODUCTION

Newfoundland is part of the boreal forest region of Canada. In eastern Canada this region extends quite far south, due to the climatic influence of the Labrador current. This cool ocean current originates from Baffin Island and Greenland and meets the gulf stream south of Newfoundland.

Productive forest is defined in Newfoundland as land capable of producing at least 35 m^3 per hectare at rotation. On the Island of Newfoundland, productive forest accounts for approximately 2.9 million hectares or 35 percent of the total inventoried land area. In Labrador, productive forest comprises 3.6 million hectares or 44 percent of the total inventoried land area. The total area of productive inventoried forest land in Newfoundland (including Labrador) represents 4.6 percent of the national total.

The main commercial species on the Island by volume are balsam fir (*Abies balsamea* (L.) Mill.) 49 percent, black spruce (*Picea mariana* (Mill.) B.S.P.) 34 percent, and white birch (*Betula papyrifera* Marsh.) 11 percent. In Labrador, the main species are black spruce and balsam fir. Coniferous species account for 93 percent of the total forest growing stock in the province.

The gross merchantable volume of timber in the province is an estimated 525 million m^3, of which 487 million m^3 is softwood species (Table 1). This volume represents 38 percent of the total timber volume in the Atlantic provinces (Nova Scotia, New Brunswick, P.E.I. and Newfoundland), and 2.4 percent of Canada's total wood volume.

Munro, J.A. 1990. The Contribution of the Forestry Sector to the Economy of Newfoundland. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 175-177.*

THE HISTORICAL DEVELOPMENT OF THE RESOURCE

For thousands of years prior to European discovery, indigenous native peoples used the forest resources of Newfoundland and Labrador for fuel, shelter and boats. These people made little impact on the resource, however, because of their small population and simple culture. The first recorded European discovery of North America occurred around the year 1,000 AD when Vikings settled briefly in northern Newfoundland at L'Anse au Meadow. The next recorded landing in Newfoundland was by John Cabot during his voyage of discovery in 1497. For almost 400 years following Cabot's discovery, the major economic activity in Newfoundland was fishing. Forest areas bordering the coast were utilized in support of the fishery for tools, building supplies, fuelwood, fresh water and game. Most natural resources were generally treated as common property goods.

Interior forest resources were left largely untouched during the early period. However, in the late 1800s efforts were made to diversify the economy. A major step in this process was the completion of a railway across the Island from St. John's to Port aux Basques to provide access to interior resources. Although good agricultural land was limited, expansive mineral and forest resources provided a basis for economic development. With forestry, initially a sawmilling and later a newsprint industry developed in the interior region of the Island.

During this period of early development some elements of forest policy evolved which are still important today. Two of these were:

(*i*) coastal forests were used in support of the fishery and treated as a common property resource;

(*ii*) interior forests were made available for large scale industrial development and allocated through fee simple grants, leases and licenses which carried private property status.

The resulting tenure pattern on the Island was a coastal band reserved as a common property area for domestic and small scale commercial harvesting operations in support of the fishery, while the resources of the interior were held as private property by large scale forest industries. This situation greatly influenced the subsequent development and structure of the Island's forest industry. In Labrador, extensive timber licenses were issued, but no large scale sustained development occurred.

The newsprint industry that developed on the Island during the 1900s culminated in the construction of three mills in Grand Falls, Corner Brook and Stephenville by the 1980s. The sawmill industry, while important at the turn of the century, has been gradually displaced from the interior forest areas. In the coastal forest areas, however, the sawmill industry has survived. At present there are about 1,400 licensed operating sawmills in the province consisting mainly of small "push-bench" mills.

Another major use of the forest resource is for domestic and commercial fuelwood. Each year about 20,000 domestic cutting permits are issued. An estimated 530,000 m^3 of softwoods are harvested annually for fuelwood.

The forest land base also produces a wide variety of non-timber benefits. For example, in 1987 nearly 70,000 big and small game licenses, and 24,000 inland fishing licenses were issued. Also, national and provincial parks received about 3 million visitors.

THE ECONOMIC IMPORTANCE OF FORESTRY

Newfoundland's population of about 568,000 represents 2.2 percent of the Canadian total (Table 2). In 1987 the provincial economy accounted for about 1.3 percent of the national gross domestic product (GDP). The Newfoundland unemployment rate is generally twice the national average and per capita incomes are also relatively lower.

In 1987, Newfoundland's forest industry generated about 5,160 person years of directly employment (Table 3). However, an additional 3,612 person years of indirect employment is also created from forest industry activity. In 1987 the industry shipped goods worth an estimated $600 million. While forestry is one of the key sectors of the Newfoundland economy, other sectors make an equal if not greater contribution. For example, the GDP generated by fishing and mining in 1987 was $535 million and $455 million respectively, compared to $205 million for forestry. In terms of employment, fishing created nearly four times as much direct employment than forestry, and more than six times that for mining.

THE MAIN FORESTRY ISSUES

A number of forestry issues exist in Newfoundland. Perhaps the two most critical issues relate to forestry and the environment, and wood supply. The former issue reflects a growing global awareness of the importance of the forest environment in the context of sustainable development. The second issue of wood supply stems largely from massive forest damage due to several insect outbreaks over the past two decades. Recent estimates from the Provincial Department of Forestry and Agriculture indicate current and future softwood deficits on the Island during the next twenty to thirty years, based on the harvesting of roundwood using conventional technology. The challenge facing forest managers in Newfoundland is to increase fibre utilization and stand volumes while maintaining the quality of the forest environment.

All of these points should, I hope, make for an interesting setting for you as you discuss the management of the boreal forest in Newfoundland and elsewhere.

Table 1. Wood volume, Newfoundland and Labrador[a].

Forest Type	Newfoundland and Labrador (million m³)	Newfoundland and Labrador as percent of	
		Atlantic Provinces	Canada
Softwood	487	48	2.7
Hardwood	38	1	0.7
Total	525	38	2.4

[a] Gross merchantable volume on productive, non-reserved forest land.

Table 2. General structure of the Newfoundland forest industry, 1987.

Industry Sector	Employment (person-years)	Value of Shipments (million $)	Value Added (million $)
PRIMARY			
Logging	1,400	100.5	52.0
Biomass	165	5.5	3.0
SECONDARY			
Sawmilling	747	28.0	14.9
Converted Wood Products	448	20.1	10.7
Pulp and Paper	2,400	445.7	124.6
TOTAL	5,160	599.8	205.2

Table 3. Economic indicators of Newfoundland and Canada, 1987.

Indicator	Newfoundland	Canada	Nfld. as % of Canada
Population ('000)	568	25,493	2.2
GDP (million $)	6,382	491,651	1.3
GDP/Capita ($)	11,235	19,286	58.3
Unemployment (%)	17.9	8.8	-

SILVICULTURE IN NEWFOUNDLAND: AN OVERVIEW

by

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INTRODUCTION

Although forestry has represented an important part of the Newfoundland economy through most of the twentieth century, the intensive use of silviculture has only occurred during the past 15 years. A number of events have contributed to this recent development. These include: the completion of a province-wide forest inventory in 1967; catastrophic fire and insect losses over the past thirty years; an increase in mill production; and an ever increasing loss of productive land base to other resource users. These events placed limits on the forest resource base and indicated the need for investment in protection, silviculture and utilization technology if timber supply was to be sustained into the future. In fact, a recent analysis of wood supply and demand has projected supply deficits in the medium term (20-40 years).

Through a series of cost-sharing agreements between the Federal Government, Provincial Government, and Industry dating back to 1975, some 85,000 hectares of forest land has been treated through reforestation and stand improvement techniques. A major forest nursery at Wooddale capable of producing 12-15 million seedlings annually has been established, along with two smaller satellite facilities, one near St. John's and one in Labrador which produce seedlings to meet the needs of their respective areas. A research program with emphasis on forest genetics and more recently, work study, has been initiated to compliment the established research activity of Forestry Canada (previously the Canadian Forestry Service). Significantly, a large part of the present silviculture program is now being conducted by the forest industry.

Masters, A. 1990. Silviculture in Newfoundland: An Overview. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 179-184.*

SILVICULTURE TECHNIQUES

At present several silvicultural techniques are being utilized in the Provincial program. In the forest improvement program the main technique is thinning of over-dense juvenile stands of balsam fir. Stands from 2-5 meters in height with densities from 15-100,000 stems per hectare are spaced to 2000-3000 stems per hectare. This is usually done manually with clearing saws or chainsaws. At present there is some movement towards thinning in the older age classes, 20-40 years. To date only limited work has been done with thinning in spruce stands.

Unlike the thinning program, the reforestation program is targeted primarily towards the spruce forests. At present, it is estimated that 65% of black spruce and 90% of the balsam fir areas cut regenerate naturally after harvesting. Most sites require some type of preparation prior to planting. At present the province utilizes various types of mechanical site preparation machinery. The most popular machines are the drag, row, and patch scarifiers from Scandinavia. In addition, blade scarifiers such as Young's Teeth and the C & H Plough are utilized on a much smaller scale. To remove slash various rakes have been used and at present the Department is attempting to develop an operational prescribed burning program. In addition to these techniques some site preparation has been done with aerially applied herbicides.

Once prepared, sites are planted with either container or bareroot seedlings. Presently, 90% of the seedlings are normally grown in poly houses for 21-24 weeks, while the bareroot are planted as 2+1 or 2+2 seedlings. The present program size is 10-12 million seedlings per year, planted primarily in the black spruce forests of Central Newfoundland.

STATISTICAL INFORMATION

The area treated silviculturally has increased exponentially over the past decade (Figure 1). However, treatment levels are expected to start to level out over the next decade with a slight increase to the 18,000 - 20,000 hectares per year range.

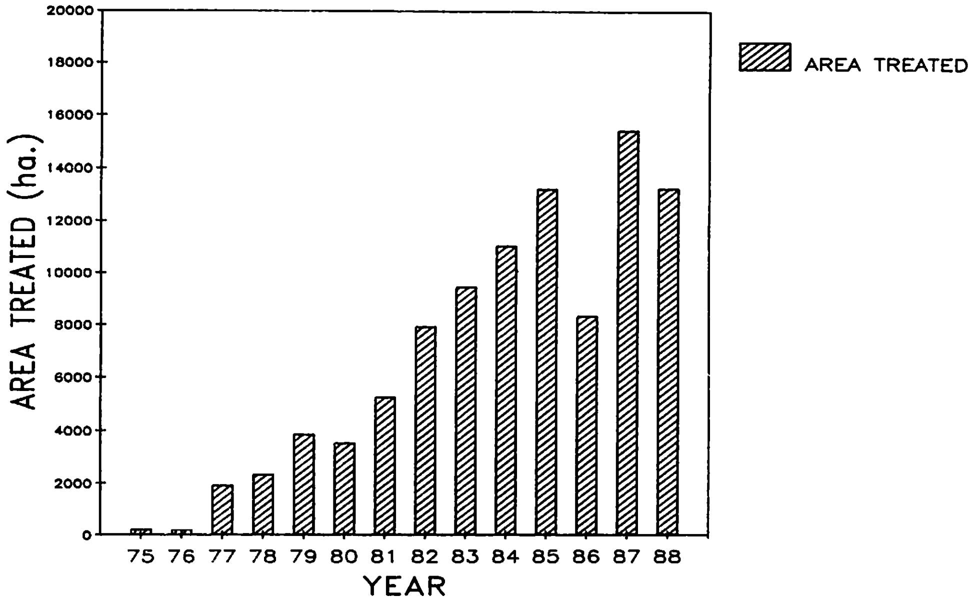

Figure 1. Silviculture treatment, Newfoundland and Labrador, 1975-1988.

In 1975 the total area treated in the province comprised of 156 hectares of pre-commercial thinning (Figure 2). By 1982, the program had increased dramatically in size and techniques have diversified with the addition of reforestation. The 1988 program shows further growth in overall size, with the introduction of vegetation management as a silvicultural technique for both plantation release and site preparation.

Abitibi-Price, who harvests primarily from the black spruce forests of Central Newfoundland, treats significant areas through reforestation (Figure 3). Corner Brook Pulp and Paper, who harvest primarily in the balsam fir stands on the West Coast of the Island, carries out almost exclusively pre-commercial thinning. The Crown program is presently weighed more towards reforestation than pre-commercial thinning. However, the next decade should see a shift in emphasis towards forest improvement.

The silvicultural program for Newfoundland is compared with national programs in Figures 4-7. Figures 4, 5 and 6 show respectively, the productive land base, the gross merchantable volume, and the total area silviculturally treated for each province in Canada. Figure 7 breaks the silvicultural treated area into planting and thinning. It can be seen that Newfoundland represents a relatively minor component of the national forestry scene, both in basis of total volume of its forest and the magnitude of the areas silviculturally treated. One significant factor silviculturally, however, is that the province has the fourth largest thinning program in the country.

Canada's silvicultural efforts are compared with those of other countries in Figure 8.

FUTURE DIRECTION

Although silviculture is relatively new to forestry in Newfoundland, it has expanded quickly and evolved into a multi-dimensional program. The evolution of techniques are expected to continue at a rapid pace for the foreseeable future. The following represents this author's opinion on the probable direction the program will take over the next decade.

Reforestation

1. Planting program will continue at the present levels of 10 - 12 million seedling per year. Present levels will ensure that areas of failed regeneration will be reforested. There will, however, be movement towards more species diversification.

2. Direct seeding program utilizing primarily black spruce for wildfire areas will be expanded. It is estimated that up to 20 per cent of wildfire areas can be successfully regenerated through aerial seeding.

3. The use of prescribed fire for site preparation will expand. Initially this will be undertaken in the fir forests of Western Newfoundland, where many forest stands are unmerchantable due to insect infestations. These areas will be converted to other, more insect resistant species.

4. There will be a movement away from bareroot nursery stock, and towards greenhouse grown container stock.

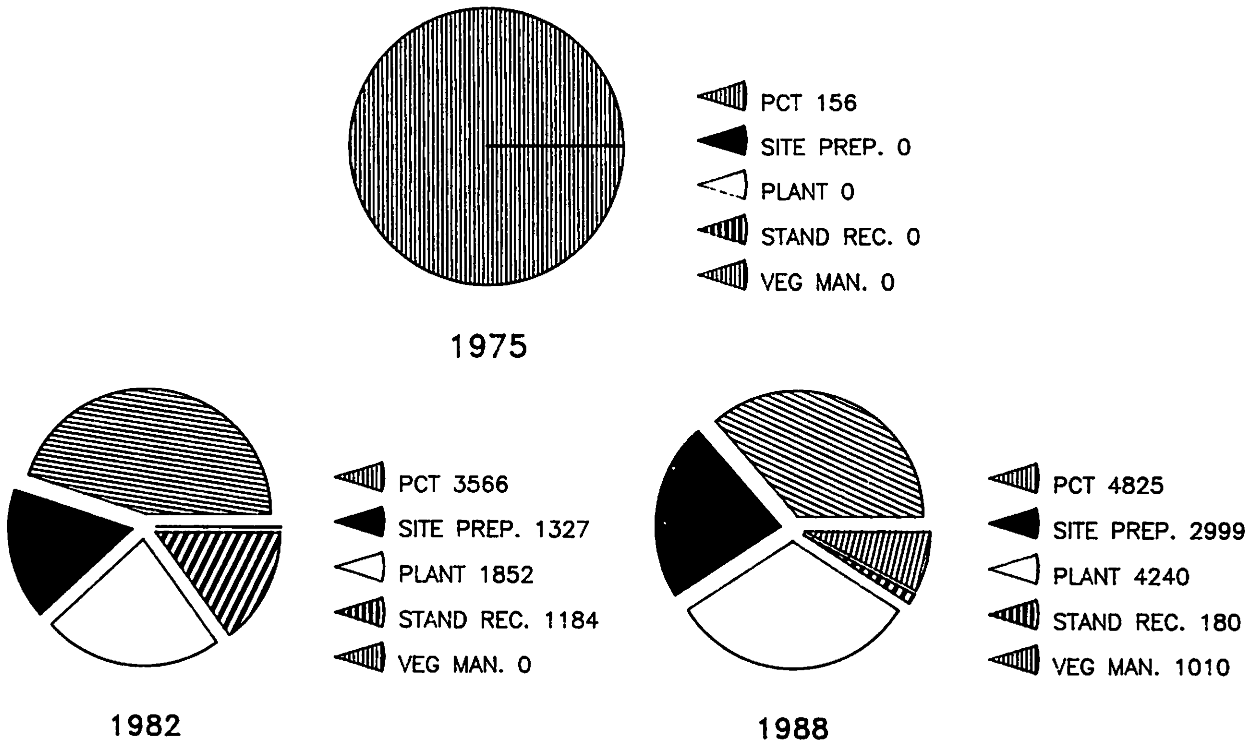

Figure 2. Area by treatment (ha) for Newfoundland and Labrador.

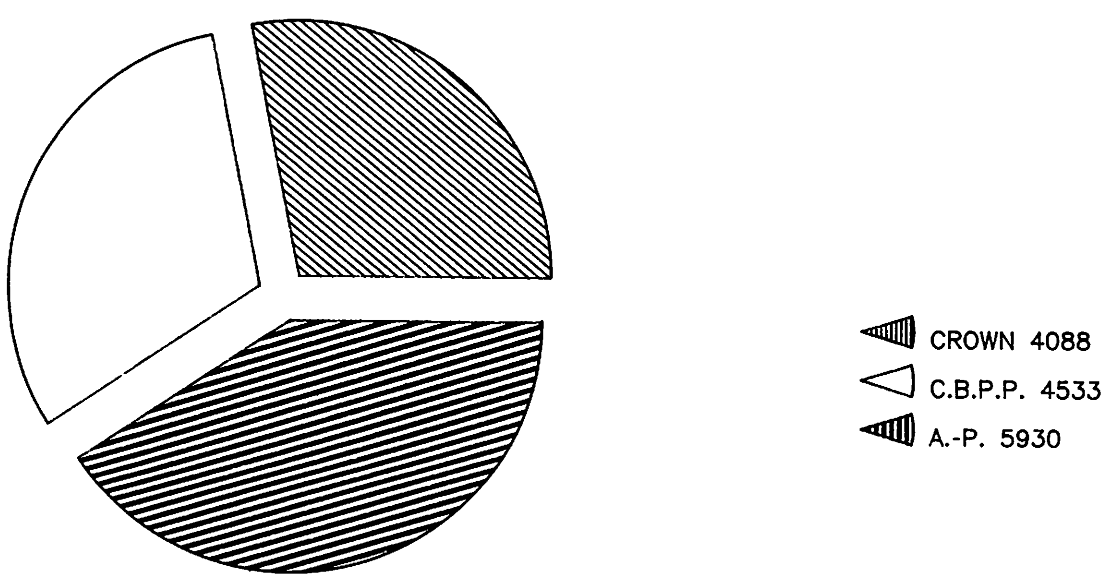

Figure 3. Silviculture treatment (ha) by tenure for Newfoundland and Labrador 1988.

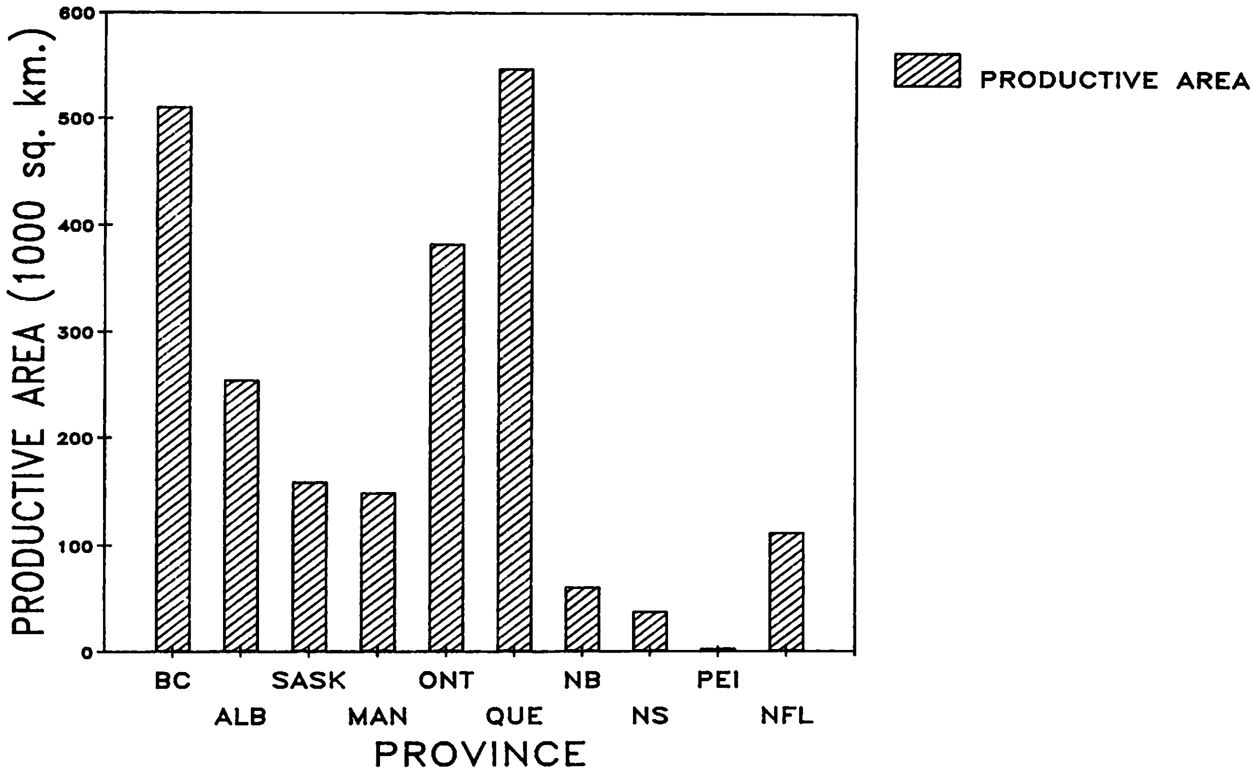

Figure 4. Productive land base of Canada, 1986.

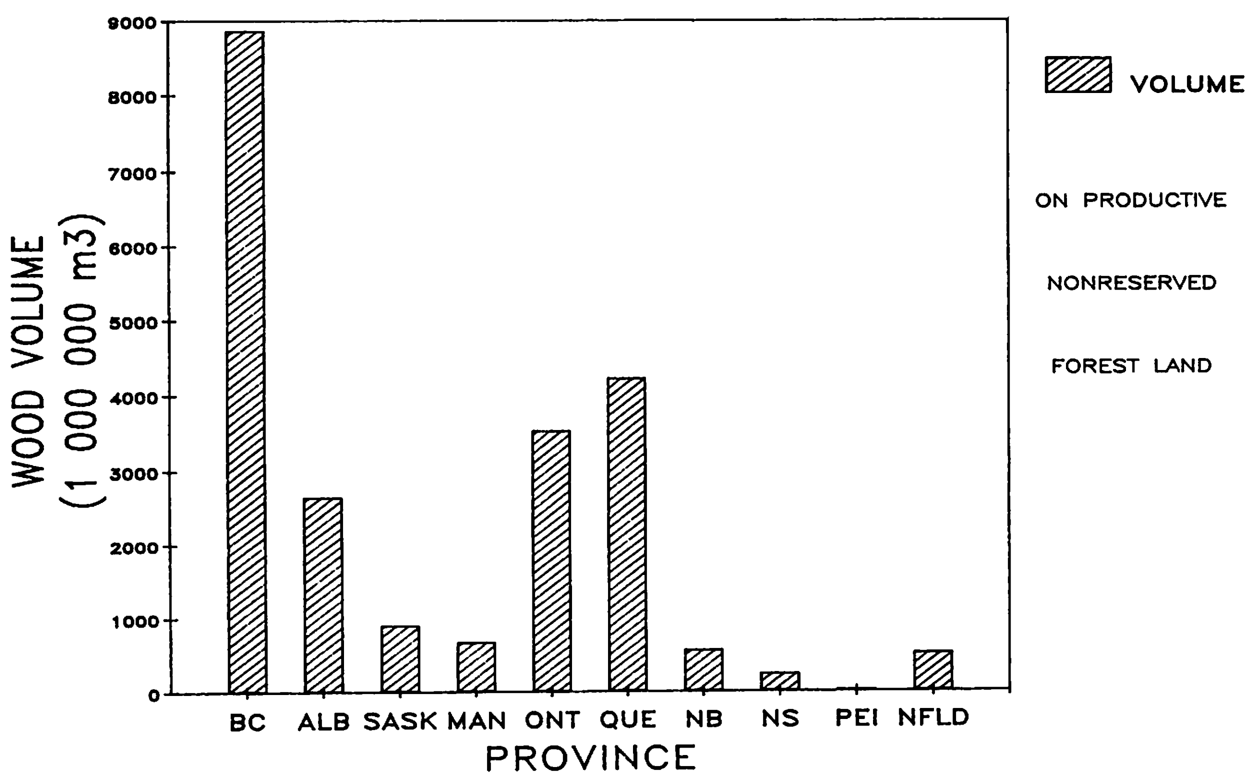

Figure 5. Gross merchantable volume for Canada, 1986.

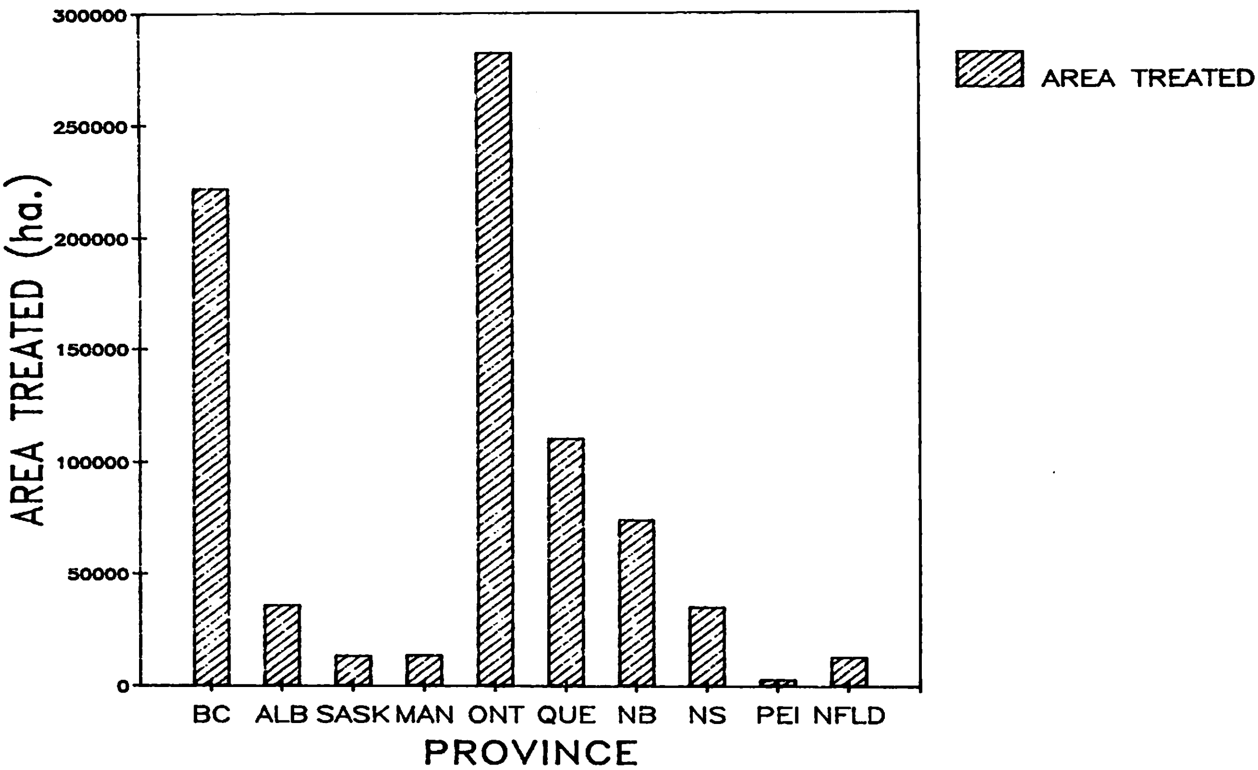

Figure 6. Total area treated silviculturally in Canada, 1985-86.

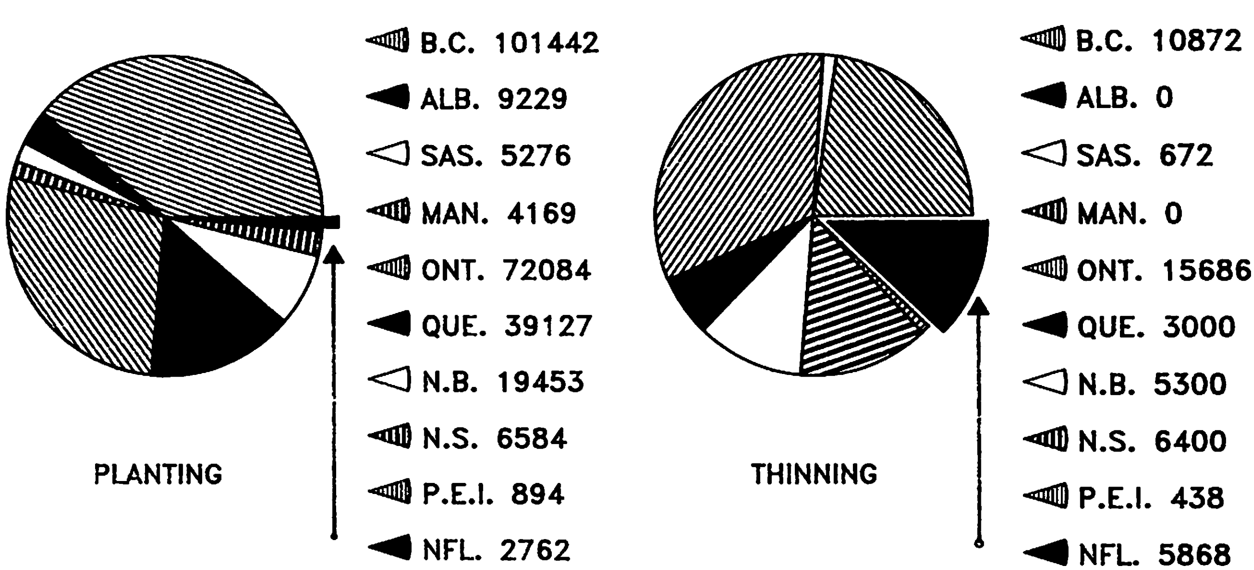

Figure 7. Planting and thinning in Canada, 1985-86.

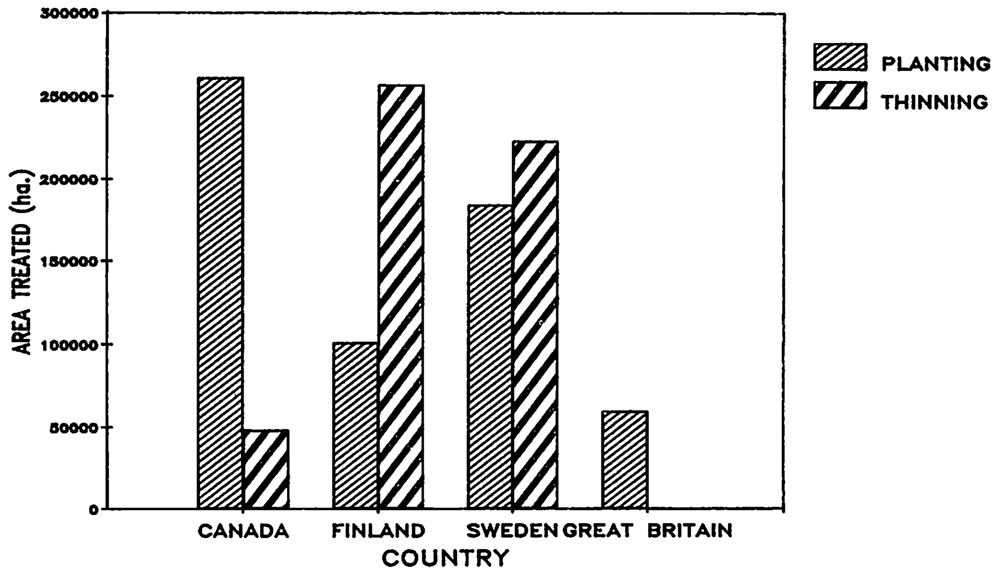

Figure 8. Comparison of Silviculture treatments in Canada, Finland, Sweden and Great Britain (planting and thinning).

Forest Improvement

1. The thinning program will increase, particularly in balsam fir in the 20-40 year age class. The objective will be to attempt to minimize the impact of the wood supply deficit projected for between the years 2010 and 2040.

2. Will there be development of a program of fertilization? This technique will be further investigated to determine its economic feasability if used in conjunction with thinning.

3. A program of vegetation management utilizing both herbicides and manual brushing will expand. This program will evolve parallel to the plantation established program. In the short-term, the majority of vegetation management will be comprised of aerially applied herbicide.

Research

1. There will be a continued effort in the area of forest genetics. The next decade will see continued development of clonal seed orchads with the first genetically improved seed available in the late 1990s.

2. Work study techniques, will play a more important role particularly in the area of methods study. This program will continue to develop with training and technology transfer from the British Forestry Commission. Significant gains in worker productivity can still be achieved, and this should ensure that treatment costs remain relatively constant over the next decade in spite of inflation.

3. Growth and yield curves will be developed for silviculturally treated stands. Present growth and yield curves will be refined as further information becomes available through the Department's permanent sample plots.

Although the above list is not all inclusive, it should be representative of the more significant initiatives that will be undertaken during the 1990s.

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A SUMMARY OF THE SILVICULTURAL ACTIVITIES OF CORNER BROOK PULP AND PAPER LTD., CORNER BROOK, NEWFOUNDLAND

by

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The Pulp and Paper Mill at Corner Brook, Newfoundland has been producing newsprint since its construction in 1925, and at one point during the 1960s it was the largest pulp and paper mill in the world. While it has been operated by several organizations over the years, the longest period of ownership has been by Bowaters (1938-1984). In 1984 the mill was purchased by Kruger Inc., a privately owned organization based in Montreal, Canada. A general fact sheet describing the mill and its woodlands operations is provided in Table 1.

Table 2 illustrates the development of the Company's silviculture program since its start in 1976. As can be seen, precommercial thinning has been the major thrust of the program so far, and this will likely continue into the future. While there are several reasons for this, the most important one is that there is a projected wood shortage 20-40 years from now, due to an imbalance in age class structure. There is a major shortage in the middle (30-50 year) age class. Pre-commercial thinning or spacing will reduce the normal rotation age of 70 years down to 45-50 years, allowing a bridging of the age classes. As a related point of interest, some 90% of all cutovers on Company limits regenerate naturally, with densities in excess of 50,000 stems/ha at time of spacing (10-12 years; 2-3 metre in height).

While the high level of natural regeneration obviously reduces the need for planting, the Company does plant between 1 million and 2 million seedlings annually. In recent years, more emphasis has been placed on matching species to site. The Company currently plants white spruce, black spruce, jack pine and red pine.

Brown, W.A. 1990. A Summary of the Silvicultural Activities of Corner Brook Pulp and Paper Ltd., Corner Brook, Newfoundland. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc. Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 185-188.*

As can also be seen in Table 2, the Company has been involved in several other different silvicultural treatments over the years, including direct seeding, scarification, raking, road reclamation, stand reclamation, herbicide application and prescribed burning. While several of these past treatment types have held on over the years, several others have fallen by the wayside. The Company's silviculture program is specifically designed to provide a continuity of economic fibre to the mill. Silviculture treatments that contribute the least towards this specific objective, or those that are uneconomical from a cost/benefit perspective, are dropped from the program.

Table 3 provides a brief summary of future silviculture program direction for this Company. Precommercial thinning will maintain its dominance in the program and planting, seeding and herbicides will continue at about the same or at a slightly increased level. It is anticipated that prescribed burning will take on a sharp increase in the near future as it is an excellent and cost-effective treatment. Scarification, stand reclamation and road reclamation will remain low keyed.

Table 1. Corner Brook Pulp and Paper Limited.

MILL

History:

1925 - Mill built by Newfoundland Power & Paper Company a group of British Investors)

1928 - Bought by International Paper - New York

1938 - Bought by Bowaters

1984 - Bought by Kruger Inc.

Product: Newsprint

Pulping System: 85% TMP; 15% Sulphite

Species Mix: 60% bF; 40% bS

Capacity: 330,000 metric tons - 4 machines

No. of Employed: 1,000 (mill only)

Markets: 65% U.S.; most of balance shipped to Britian and South America; 98% sold outside of Canada.

Ownership: Kruger Inc. of Montreal, Canada. One of the largest privately owned organizations in the North America pulp and paper industry. Three pulp and paper mills producing more than 1,000,000 tons per year. Also, produces paperboard and packaging.

WOODLANDS

Total Land Base: 2,450,000 ha

Productive Forest: 1,124,000 ha

Avg. vol/ha: 125 m^3/ha

Tenure: 25% Freehold; 75% licensed

Species Composition: 62% bF; 38% bS

No. Employed: Logging - 700; Silviculture - 150

Logging Method: Manual felling - 75% shortwood; 25% tree-length

Contract Cutting: 80%

Table 2. Silviculture Progress Summary 1976 - 1988 (area treated, in hectares).

Year	PCT	Planting	Direct Seeding	Scarification and Raking	Road Reclamation	Stand Reclamation	Herbiciding	Prescribed Burning	Total
1976	17.6	-	-	-	-	-	-	-	17.6
1977	323.9	-	-	-	-	-	-	-	323.9
1978	524.4	-	-	-	-	-	-	-	524.4
1979	564.9	-	-	-	-	-	-	-	564.9
1980	340.5	-	-	-	70.8	-	-	-	411.3
1981	2,074.1	100.8	-	202.4	35.9	-	-	-	2,413.2
1982	2,464.9	523.4	-	297.2	-	231.1	-	-	3,516.6
1983	1,765.4	521.5	231.9	-	-	188.2	-	-	2,707.0
1984	2,199.8	457.7	-	-	-	210.0	125.0	378.8	3,371.4
1985	3,562.5	278.5	-	176.7	-	-	180.0	-	4,197.7
1986	2,824.1	242.5	-	-	-	-	252.0	-	3,318.6
1987	2,639.3	306.6	258.0	-	-	-	1,216.0	-	4,419.9
1988	2,472.9	547.7	-	-	-	-	531.0	-	3,551.6
Total	**21,774.3**	**2,978.7**	**489.9**	**676.3**	**106.7**	**629.3**	**2,304.0**	**378.8**	**29,338.0**
Percent	74.1	10.2	1.7	2.3	0.4	2.1	7.9	1.3	100
1989 (Plan)	3,000.0	530.0	435.0	-	-	200.0	1,750.0	800.0	

Table 3. Corner Brook Pulp and Paper Limited.

Future Silviculture Program Direction:

1. *Pre-commercial Thinning* - Clearly the most essential part of our silviculture program, and will continue on a large scale.

2. *Planting* - Will likely increase, though not significantly. Emphasis on planting wS on richer west coast sites.

3. *Aerial Seeding* - Very cost-effective. Will continue and concentrate on burns in lower priority areas more distant from the mill.

4. *Scarification* - Have not done any since 1982, as it is not required in most cases. Will continue to be low-keyed.

5. *Prescribed Burning* - An excellent, cost-effective site preparation tool. Will increase as program becomes more operational.

6. *Stand Reclamation* - Will continue to be low-keyed because of high costs and poor economics.

7. *Road Reclamation* - Discontinued because of high costs and poor economics. Many roads are currently being built with excavators -less disturbance.

8. *Herbicides* - Essential for plantation maintenance. Also, herbicides have become our main site preparation tool. Definitely a high priority treatment.

A SUMMARY OF THE SILVICULTURAL ACTIVITIES OF ABITIBI-PRICE, INC., IN NEWFOUNDLAND

by

W.P. Furey

Divisional Forester, Abitibi-Price Inc., Grand Falls Division,
P.O. Box 500, Grand Falls, Newfoundland, CANADA, A2A 2K1

On behalf of Abitibi-Price, I welcome the members of IUFRO to Grand Falls. I am very pleased to have such a high level of forestry expertise with us and I look forward to our discussions on company forest management activities over the next few days.

Abitibi-Price is the world's largest producer of newsprint, with newsprint mills in Canada and the United States. It is presently involved in the construction of two plants - one in the U.S. and the other in South America. It employs approximately 20,000 people in Canada and the U.S.

The company has two newsprint operations in Newfoundland - one in Grand Falls and the other in Stephenville in western Newfoundland. The mill in Grand Falls was built in 1909 by the Anglo-Newfoundland Development Company, owned by the Harmsworth brothers of England. It was purchased by the Price brothers of Quebec in 1965, and then sold to Abitibi-Price in 1977. Abitibi-Price is a Canadian company, with its headquarters in Toronto, Ontario.

The Stephenville mill was originally built as a linerboard mill, with construction starting in 1967. The operation was taken over by the Newfoundland Government in 1972 and subsequently sold to Abitibi-Price in 1978. Abitibi converted the operation to a newsprint operation, with production beginning in 1981.

Furey, W.P. 1990. A Summary of the Silvicultural Activities of Abitibi-Price, Inc., in Newfoundland. In: *B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, editors. The Silvics and Ecology of Boreal Spruces. 1989 IUFRO Working Party S1.05-12 Symp. Proc., Newfoundland, 12-17 Aug. 1989. For. Can. Inf. Rep. N-X-271, pp. 189-191.*

The following table provides some general information on the activities of both operations:

	Grand Falls	Stephenville
Product	Newsprint	Newsprint
Pulping System	95% T.M.P. 5% Sulphite	100% T.M.P.
Species Mix	90% Black Spruce 10%Balsam Fir	20% Black Spruce 80% Balsam Fir
Capacity	245,000 tons Annually	175,000 tons Annually
No. of Employees	900 (Mill Operation)	250 (Mill Operation)
Markets	South & Central American United Kingdom Germany U.S.A.	Japan South & Central America United Kingdom U.S.A.

With regard to woods operations, the company has 2.2 million hectares of limits in Newfoundland with which to supply fibre to both plants. Approximately 945 million hectares (45%) of this area is classed as productive forest land. The company fibre requirements amount to approximately 1.2 million cubic meters annually, and average forest land productivity is 120 cubic meters per hectare.

The land tenure consists of 6.4% private land, 24% long-term charter and 69.6% timber license. The species mix consists of 70% black spruce and 30% balsam fir, with small components of white spruce, white birch, and some other unmerchantable hardwoods.

The woodlands operation, which employs approximately 900 people, uses three harvesting systems:

1. *Manual Tree Length* - skidded to roadside;

2. *Manual Short Wood* - forwarded to roadside;

3. *Harvester Processed Short Wood* - forwarded to roadside.

The company has a fairly large silviculture program which employs up to 200 people during the operating season. The major treatments utilized consist of spacing in young stands and planting, with lesser amounts of work in the areas of seeding, site preparation, herbicides, and stand reclamation. Table 1 shows the breakdown of the work performed to date and gives an indication of the present level of the program. Post-treatment densities are approximately 2,100 stems per hectare. Survival and growth rates following treatments are good.

Some of the problem areas which will be discussed further during the next few days include the two following main subjects:

Growth check in plantations: Planted black spruce seedlings go into a period of check following outplanting which lasts two to three years. If the site is dominated by Kalmia there are concerns that this check could be long-term or even permanent.

Matching species to site: More research is needed to determine which tree species will grow best on the various sites.

Table 1. Abitibi-Price Silviculture Projects, 1976-1989.

Treatment	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	TOTAL
Planting ('000 trees)	-	-	-	132.0	353.0	980.0	2,012.8	1,398.6	2,156.0	3,455.0	340.0	5,063.0	4,201.9	4,182.4	24,274.7
Site Preparation (ha)	-	-	-	87.0	98.0	650.0	726.0	1,333.0	1,473.0	1,096.0	503.0	1,013.8	1,629.9	1,070.0	9,679.7
Site Reclaimation (ha)	-	-	-	-	-	-	60.0	-	226.0	119.6	63.0	-	-	-	468.6
Pre Commercial Thinning (ha)	14.6	739.0	377.0	-	114.0	353.0	207.0	1,096.0	949.0	1,375.0	2,243.0	1,432.1	1,668.8	2,203.0	12,756.9
Fertilization (ha)	-	-	-	-	-	82.0	-	-	-	-	-	-	-	-	82.0
Seedling Production ('000 Trees)	-	-	-	70.0	70.0	50.0	-	-	-	-	-	-	-	-	190.0
Surveys (ha)	-	-	-	-	-	7,052.0	5,312.0	28,317.0	23,935.0	3,014.0	2,911.0	4,762.0	5,400.0	5,186.0	85,889.0
Cone Collection (litres)	-	-	-	5,240.0	630.0	-	4,000.0	-	-	-	-	-	-	-	9,870.0
Herbicides (ha)	-	-	-	-	-	-	-	-	125.0	210.0	794.0	397.0	479.0	1112.0	3,117.0
Prescribed Burning (ha)	-	-	-	-	-	-	-	-	-	230.0	-	-	-	-	230.0

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Country	**Number**
Canada	
B.C.	5
Alta.	1
Ont.	12
Que.	4
N.B.	1
Nfld.	35
	58
Finland	4
Norway	1
Sweden	5
U.S.A.	5
TOTAL	**73**

Employer	
government	56
university/college	11
private consultant	3
private forestry	3
TOTAL	**73**

Type of Employment	
research	30
research management	7
forest management: government	23
private	5
teaching	8
TOTAL	**73**