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WHITE SPRUCE

THE ECOLOGY OF A NORTHERN RESOURCE

The proceedings of a symposium
Edited by R.G. McMinn
Canadian Forestry Service

WHITE SPRUCE: THE ECOLOGY OF A NORTHERN RESOURCE

Proceedings of a Symposium held June 21, 1971;
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Edited by

R. G. McMINN

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5320 - 122 STREET
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FOREWORD

Forests are potentially a renewable resource. Anticipated needs will not, however, be met by the leisurely pace and variable quantity and quality of the products provided by fortuitous regeneration following logging or wildfire. Purposeful procedures must be followed to ensure regeneration of the most appropriate species in the required time and place.

Regeneration of the northern forest resource can be especially constrained. Soils may be cold, wet or infertile, growing seasons short and increments insufficiently high to attract appreciable financial outlay to obtain regeneration. Consideration of all the constraints -- biological, economic and political, on the management of white spruce in northern forests was not possible during a single afternoon. The papers presented at a symposium arranged by the Ecology Section of the Canadian Botanical Association for the 1971 Annual Meeting in Edmonton, Alberta, represent a conspectus of current interests. The first one introduces white spruce by way of its evolutionary background. Two others deal with conditions for regeneration in contrasting white spruce types in Alberta. The prospects for circumventing losses from seed-eating mammals, the imputed nemesis of many direct seeding attempts, are given in another paper concerning Alberta's forest resource. An experiment in Ontario is used as the basis for a discussion of the part played by soil moisture, nutrition and weed competition as constraints on the growth of young white spruce. Finally, work being done in British Columbia to improve the quality of outplanting stock through the establishment of seed orchards is reviewed.

These papers provide insight into efforts to overcome the difficulties inherent in managing white spruce, an important northern resource. They are published in the expectation that an appreciation of the problems and approaches being taken to husband this resource will be of interest to a wider audience than that able to attend the symposium.

R. G. McMinn
Symposium Chairman

SPECIATION IN THE NORTH AMERICAN SPRUCES AND ITS RELATION TO WHITE SPRUCE

R. T. Ogilvie

Department of Biology, University of Calgary

ABSTRACT: The broad evolutionary relationship of northern spruces is reviewed. Current knowledge of species evolution in western North American spruces is summarized from investigations in introgression, morphometric analyses, chemosystematics, paleobotany, genecology and crossability studies. An ecological interpretation is given concerning the dominant role of spruce on the east slopes of the Rocky Mountains in Canada.

As background to this symposium on white spruce, I shall give a general review of what is known concerning the evolutionary history of white spruce: how white spruce is related to other species of the genus, the pathway by which it has evolved, the post-Pleistocene history of the western spruces, and its role of introgressive hybridization in the recent speciation of the spruces.

There are approximately 30 species of spruce, distributed through the Northern Hemisphere from the polar regions of North America, Europe and Asia as far south as Mexico, the Caucasus, the Himalayas and southern China. Eastern China and Japan have the greatest number of spruce species (approximately 16), and it is inferred that this region is the centre of origin of the genus. There are nine species in North America, two of which occur as restricted endemics in Mexico, four in Europe and western Asia, one in central Asia, and two in the northern India subcontinent.

The genus is isolated from other conifers; there is no difficulty in separating spruce from other genera such as pine or hemlock. But within the genus spruce, only minor morphological characters have developed to differentiate the species, despite very long periods of evolutionary time. As Wright (1955) has discussed, the genus spruce is evolutionarily conservative.

There is no interspecific variation in chromosome number in the spruces, 2n = 24 being constant, as in most of the Pinaceae. Thus, conventional cytotaxonomic studies do not provide useful information on the systematics or evolution of the spruces.

Comparative morphological analyses, using such characters as cones, cone scales, cone bracts, seedwings, twig pubescence and sterigmata, are highly informative for interpreting relationships among the various spruces.

The results of studies of interspecific crossability are also valuable for suggesting relationships. Many of the species are not well isolated genetically; they readily hybridize under artificial or natural conditions. Approximately 37 interspecific hybrids have been documented between North American, European and Asian species. They originate from introgressive hybridization, natural hybridization and artificially produced crosses. Figure 1 shows crossing between 18 spruce species. *Picea glauca* and *P. abies* have the most hybrids (10 each). Interspecific hybridization in North American spruces has attracted numerous studies because of its significance to systematics, evolutionary science, forest genetics and silviculture (Wright 1955, Garman 1957, Taylor 1959, Horton 1959, Morgenstern and Farrar 1964, LaRoi and Dugle 1968, Daubenmire 1968, Ogilvie and von Rudloff 1968, Habeck 1969, Roche 1969, Hanover and Wilkinson 1969).

Figure 2 shows the distribution of North American spruces. Hybridization occurs between *P. glauca*, *P. sitchensis*, *P. engelmannii* and *P. pungens*, but only in a small proportion of their ranges. This pattern also holds for the introgressive hybridization between *P. mariana* *P. rubens*. The three isolated endemics, *P. breweriana* in the Siskiyu Mountains on the Oregon-California border, *P. chihuahuana* in the Sierra Madre Occidentale and *P. mexicana* in the Sierra Madre Orientale, are morphologically and genetically isolated from all other North American spruces. They are believed to be ancient evolutionary migrants from Asia (Gordon 1968).

Several groups of species closely related evolutionarily may be recognized. In North America they are the *glauca* - *engelmannii* - *sitchensis* - *pungens* Complex and the *mariana* - *rubens* complex; in Europe, the *abies* -

obovata Complex, and in Asia, the *retroflexa - montigena - asperata - likiangensis* Complex. There are, moreover, close evolutionary ties between the Species Complexes of the different continents.

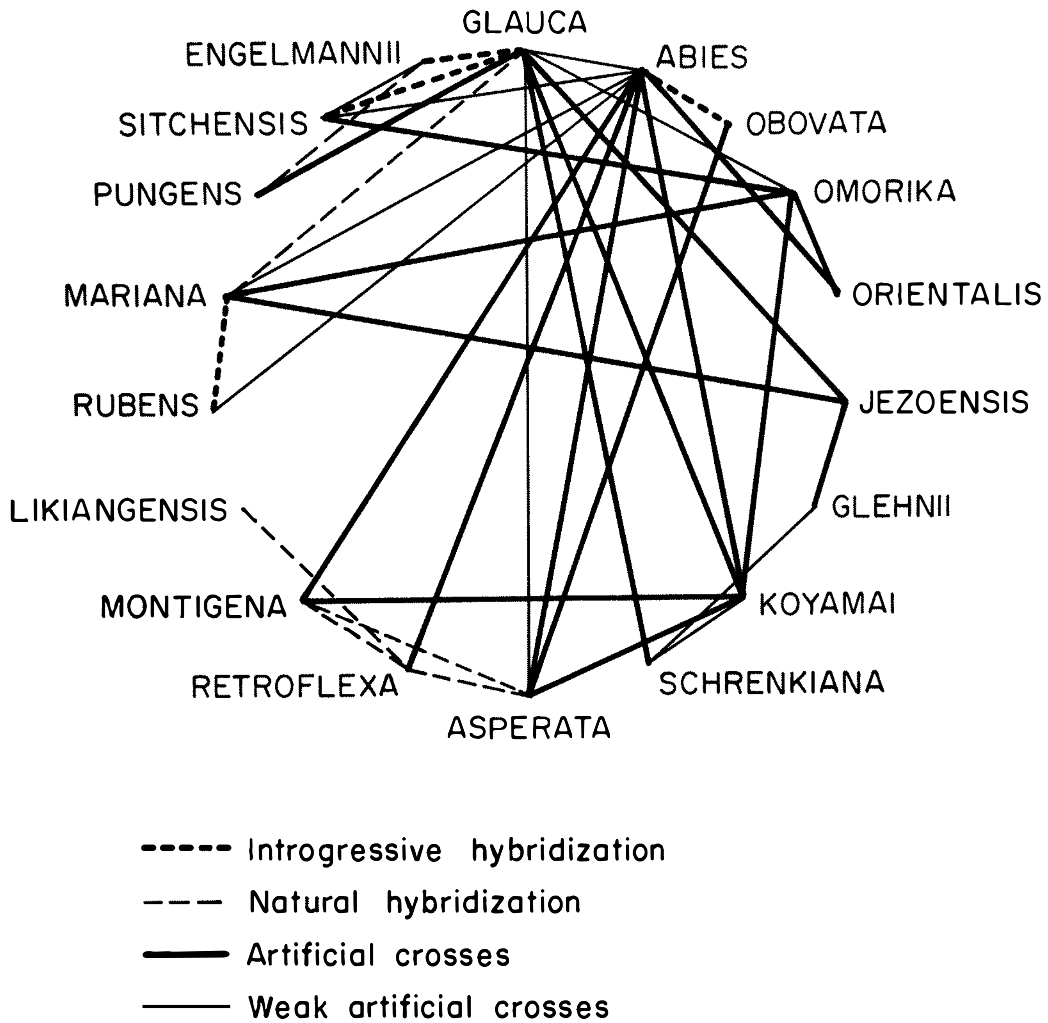

FIG. 1. Crossability in Picea species. Based on Wright (1955), Roche (1969), Fowler (1966), Klaehn and Wheeler (1961), Hannover and Wilkinson (1969).

The new fossil spruce from arctic western North America, *P. banksii*, is one such evolutionary tie between the North American and Eurasian species (Hills and Ogilvie 1970). The fossils, which are from Late Miocene to Early Pliocene sediments (approximately 12 million years B.P.), are most closely related to *P. glauca*, but morphologically form a link with the Eurasian *P. abies* Complex migrated to North America via the Bering land-bridge. By late Miocene, *P. banksii* was present in arctic western North America. From it

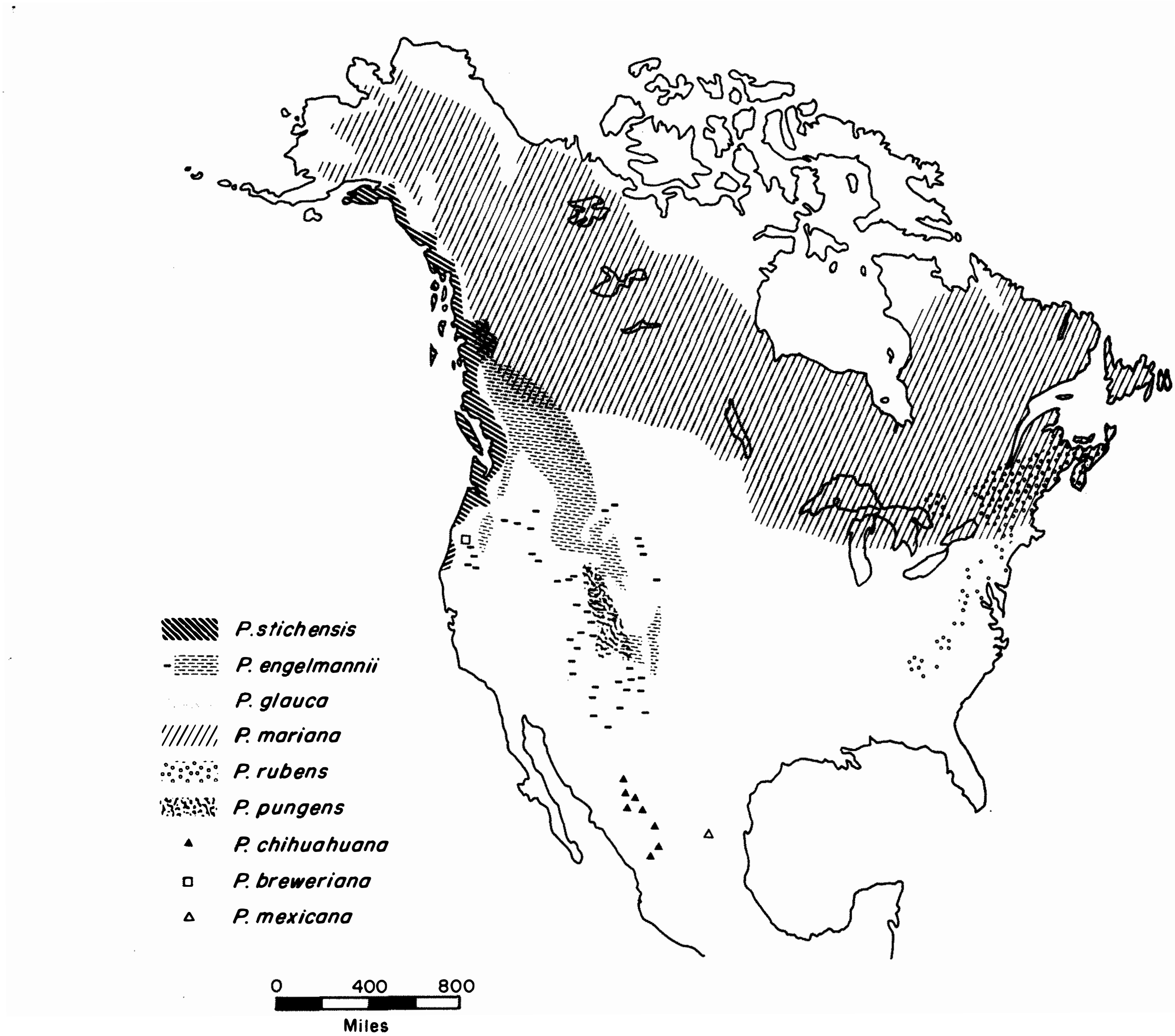

FIG. 2. Distribution of North American spruces.

were derived, first the *P. mariana* Complex and subsequently the *P. glauca* Complex.

By the beginning of the Pleistocene, the various members of the *P. glauca* Complex had become differentiated. Glacial advances and retreats during the Pleistocene brought about a sequence of migrations, isolations and coalescences of the populations comprising this Complex. Thus, *P. sitchensis* survived in several isolated localities along the Pacific Coast from British Columbia to California; *P. pungens* survived in ice-free areas of the southern Cordillera, and *P. engelmannii* in ice-free areas of the northern Cordillera. *P. glauca* survived south of the Continental ice sheet, in the Yukon Valley and in ice-free localities along the corridor between the Cordilleran and Continental ice sheets. *P. glauca* became isolated in several areas of western North America during interglacial stages. Examples are such outposts as the Cypress Hills of southeastern Alberta - southwestern Saskatchewan and the Black Hills of South Dakota.

Information on the immigration of spruce following deglaciation comes from palynological studies (e.g. Ritchie and co-workers). Thus, a spruce-dominant forest was present in Manitoba by 11,800 years B.P., and in southern Saskatchewan by 11,600 years B.P. In east central Alberta, spruce was present in very low frequencies ($\pm$ 1%) in the poplar-dominated forest at 11,400 years B.P., but by 9,800 years B.P., spruce was the dominant. The picture for the Rocky Mountains of Alberta is still highly confused (Heusser 1956, 1960). There are extremely high frequencies of pine and correspondingly very minor amounts of spruce; there is no dating available for the pollen strata, and it is not possible to determine the differential roles of *Picea engelmannii* and *P. glauca*.

An ecological interpretation may be given to the ultimate composition of the forests on the east slopes of the Rocky Mountains. The vacuum created by the absence of two major forest zones (the *Pinus ponderosa* Zone and the *Thuja - Tsuga* Zone, which are present west of the Rocky Mountains) and a drastic restriction of a third zone (the *Pseudotsuga* Forest Zone) was filled by the products of extensive introgressive hybridization between *P. glauca* and *P. engelmannia*. These hybrid spruces now occupy a wide altitudinal zone right from valley bottom to timberline. Intense selection at the environmental extremes of these spruces (e.g. at upper timberline and in certain valley bottom habitats) has resulted in populations with very high genetic diversity and morphological heterogeneity.

I should like to suggest the important future avenues of research in spruce systematics and evolution:

1) detailed comparative morphological analyses of populations;
2) intensive paleobotanical investigations (including macrofossils and pollen) in "critical biogeographic areas" - e.g. in unglaciated corridors, unglaciated ranges of hills and valley systems and in land bridges;
3) chemosystematic analyses of populations;
4) genecological and provenance studies; investigations of species crossability and population genetics.

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SITE FACTORS CONTRIBUTING TO THE SPRUCE REGENERATION PROBLEM IN ALBERTA'S MIXEDWOOD

J. C. Lees

Canadian Forestry Service, Northern Forest Research Centre
Edmonton, Alberta

ABSTRACT: Soils in the Mixedwood Section are clayey and wet. White spruce regenerated under natural conditions when two major limiting conditions were met: a receptive seedbed of rotten wood or mineral soil from wind-thrown stumps, and freedom from severe competition from ground vegetation. Wildfire, hot enough to burn off organic surface horizons, was an important factor under natural conditions. In recent years, fire has been effectively controlled and the forest manager is unwilling to wait for gradual seeding-in on preferred seedbeds. Silvicultural treatments and results of experimental studies are reviewed and the course of future investigations if indicated.

INTRODUCTION

The spruce-aspen Mixedwood Section (B18a) of the Boreal Forest (Rowe 1959) extends from northeastern British Columbia in a decreasing strip to the southeast corner of Manitoba. It reaches its optimum development in the Province of Alberta, extending from south of Lesser Slave Lake, close to the geographical centre of the Province, to the North West Territories around Wood Buffalo Park. The spruce-aspen Mixedwood is typified by gently rolling topography, with abundant lakes joined by short, well-filled river channels. Typical of these are Lesser Slave Lake, the largest in Alberta; the Wabasca Lakes; Fawcett Lake; Calling Lake; Lac la Biche and Cold Lake in Alberta, and Meadow Lake in Saskatchewan; and the interlocking system of river channels which take these waters on to the Great Lakes, and via Lake Athabaska to the Arctic Ocean. Since the town of Slave Lake, for example, is roughly 1800 feet above sea level and the Arctic Circle is about 1800 miles away as the rivers flow, the drop-off is only about one foot per mile.

Climate in the region is typified by long, severe winters and short, hot summers with total annual precipitation around 18 to 20 inches, of which 15 inches falls as rain in the summertime. There are approximately 3-4 feet of winter snowfall.

Soils in the area are derived from tills dumped by two great ice sheets: the Cordilleran ice sheet moving from the Rocky Mountains southeastward, and the Keewatin ice sheet moving southwestward from the Arctic regions and joining in a tension zone around Barrhead, Obed and Edson, and are mainly fine textured silts and clays. They are generally poorly structured and have impeded vertical water drainage. Horizontal water movement within the profile is common at the interface of the various soil horizons, particularly at the interface of the organic and mineral soil horizons. Organic matter accumulates on the surface of heavy textured soils to a depth of 3 to 36 inches in the forested areas. Soils are typified by the Grey Wooded group, which occurs on more than 50 million acres in Alberta and is associated with approximately 40 million acres of organic soils (peat more than 12 inches deep). Series names assigned to the type are usually local names, and it is the Braeburn Orthic Grey Wooded soil (Odynsky, Wynnyk, and Newton: 1952) from which the moisture regime variations to be discussed are derived. Although these soils are often very moist to wet during the growing season, they support productive stands of white spruce (*Picea glauca* (Moench) Voss). Windblow is a hazard to the shallow rooted spruce trees characteristic of the Mixedwood.

Productive logging is not a problem since operations take place over frozen ground in wintertime. Logging, however, removes a very useful water pump, loss of which is manifest by an abrupt rise in the water table and a proliferation of vegetation, particularly grasses. Timber operations in the area are currently managed under a "Quota" system whereby established operators are entitled to a continuous supply equal to their best productivity over the previous six years, provided they assume responsibility for regeneration. However, they have the option of regenerating the cutover areas or paying a levy of $2.00 per thousand board feet logged to the Provincial Government. The Alberta Forest Service then assumes responsibility for regeneration.

CONDITIONS FOR REGENERATION

The distribution of white spruce as a component of the spruce-aspen Mixedwood complex is dependent on several major constraints: (1) an adequate seed supply, (2) a receptive seedbed, (3) a favourable microclimate, and (4) freedom from severe ground vegetation competition. In natural successional stages, the requirements for spruce regeneration are met largely on two distinct seedbed types: exposed mineral soil, and rotten wood - mineral soil from the upturned root plates of windblown stems and rotten wood from the shorter-lived hardwoods of the species mix. Mineral soil seedbeds occur only sporadically but, with the intimate mixture of spruce and aspen (*Populus tremuloides* Michx.), rotten hardwood seedbeds are fairly evenly distributed. A rotten wood seedbed is usually moisture-conserving on drier sites. On wet sites, the old logform is raised above the surrounding surface water, yet remains in good contact with it during short summer droughty periods. For several growing seasons a fallen log or broken stump resists colonization by lesser vegetation since such microsites are colonized by seedlings rather than perennating root-stocks that can quickly invade freshly exposed patches of mineral soil. The rotten log, receptive to conifer seed, moist, and resisting vegetation colonization, is the preferred spruce seedbed. When forests are undisturbed, the regeneration period is essentially continuous. Seedlings slowly filter in as gaps develop in the overwood and as receptive seedbeds are created.

Fire interrupts the progression to this climax state. In the past, wildfire was often hot enough to burn off the organic soil horizon, which otherwise effectively sealed off the site for spruce regeneration. Wildfires exposed mineral soil and promoted aspen suckering since the increased insolation raised soil surface temperatures and created the necessary environment to induce aspen roots to sprout. Spruce then seeded in from the unburned stand margin, although rotten wood remained the preferred seedbed. The aspen shelterwood was a favourable environment for survival and growth of spruce seedlings.

SILVICULTURAL PRACTICES TO PROMOTE REGENERATION

Wildfire is now intolerable in the Mixedwood and the forest manager is unwilling to wait 30 years or more to see productive spruce forests reestablished. Silvicultural treatments, if carefully applied, may restock cutover and burned over areas. A two-cut uniform shelterwood system with seedbed scarification after the first cut, has produced satisfactory stocking of natural seedlings and vigorous growth of planted stock (Lees 1970). Time of overstory removal must be adjusted to seedling development, especially height growth. Seedbed scarification with planting under immature aspen successfully utilizes the shelterwood concept.

Problems remain on wet sites on the poorly drained fine-textured soils. Machine scarification techniques are unsuccessful, and mineral soil seedbeds exposed with a bulldozer blade are subject to severe flooding at snow-melt and after heavy growing-season rains. Seedbed flooding can occur several times each growing season. Laboratory and controlled field testing, using trays of healthy seedlings, showed that 14 days' immersion are lethal for 2-year-old spruce seedlings (Table 1). Repeated shorter periods are also lethal. Analysis of individual tray data confirmed the significance of date of immersion during the growing season (Lees 1964, 1971).

TABLE 1. White spruce seedling survival by date and duration of immersion under field and laboratory conditions.

Duration of immersion	Field test: Date of immersion: June 30	July 30	August 13	Mean	Laboratory test
3½ days	84	92	96	90.7	64
7 days	74	88	90	84.0	34
10½ days	60	72	64	65.3	18
14 days	54	70	52	58.7	0
Mean	68	80	76		

Wetter areas have the most severe vegetation competition. Any treatment that improves these sites for spruce regeneration will also improve them for grasses, sedges, herbs and shrubs. Results from shelterwood study blocks have shown that spruce overstory removal (the second cut), which allowed more light to reach the seedbed and raise soil temperatures, resulted in severe vegetation competition. On cut blocks, stocking to spruce seedlings fell from 40 to 16 percent 10 years after cutting. Competition was most severe on the wetter areas. On uncut blocks, stocking remained at 33 percent but the shading and low temperatures, which controlled ground vegetation growth also held back height growth of spruce seedlings. Seedlings tallied 10 years earlier were still present, but their height growth was unsatisfactory and their vigor was poor. Ground vegetation cover, estimated by sighting on a checkerboard of 100 squares from a distance of 33 ft (Fig. 1) averages 74 per cent for cut blocks

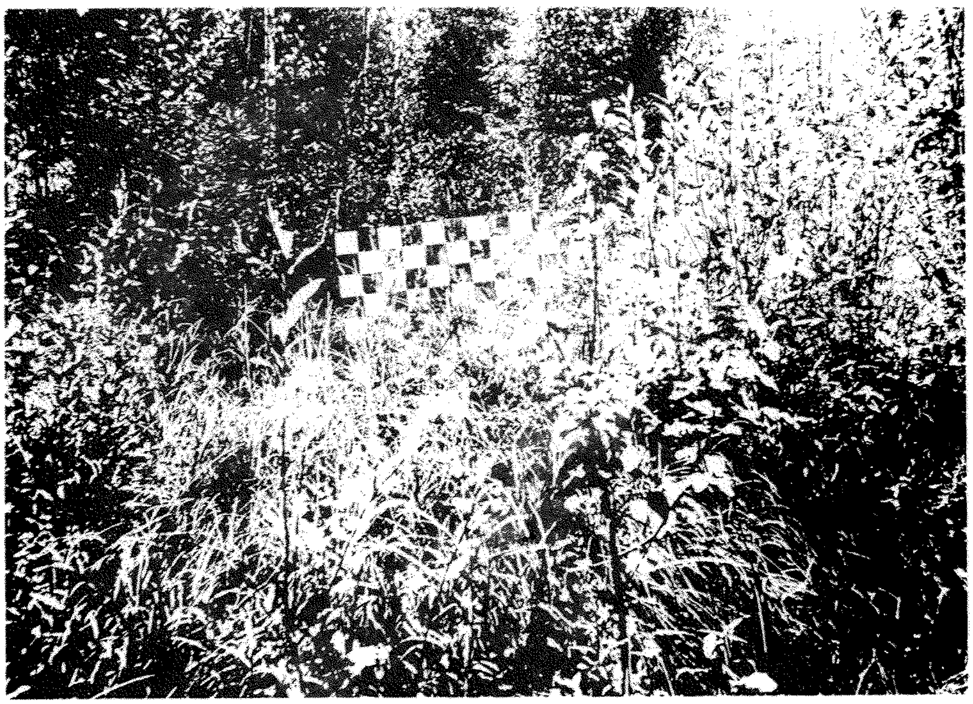

FIG. 1. Vegetation competition in cut-over Mixedwood stand, showing checkerboard used to estimate cover, in this case rated as 95 percent.

10 years after cutting and 48 per cent for uncut blocks (Table 2). Seedling height growth was reduced from 2 inches per year to only 1 inch per year.

TABLE 2. Vegetation competition, regeneration stocking and height growth of spruce seedlings in uncut and cut blocks after 10 years.

Parameter assessed	Site	Cut	Uncut
Vegetation Competition (percent cover)	Dry	70	51
	Moist	77	51
	Wet	76	44
	Mean	74	48
Regeneration Stocking (percent milliacre)	Dry	17	32
	Moist	17	43
	Wet	15	25
	Mean	16	33
Mean height of tallest seedling each quadrat (in)	Dry	15.5	9.4
	Moist	14.4	10.5
	Wet	14.2	7.4
	Mean	14.7	9.4
Mean leader length of tallest seedling each quadrat (in)	Dry	1.9	1.0
	Moist	2.2	1.4
	Wet	2.6	1.0
	Mean	2.2	1.2

FUTURE DEVELOPMENT

Before the forest manager invests in regeneration of the cutover areas, he must know how to assess the site for regeneration and potential productivity. To make this decision, he should be provided, by the ecologist with tools for a "regeneration chance" assessment, including a forest cover-type classification, a physiographic site assessment, a soil-series identification kit, a soil-moisture status measure, a vegatation-competition hazard rating, and a probing of depth to mineral soil. The combination of these assessments in many areas of the Mixedwood will result in "little chance" or "too expensive" rating.

The Stand Establishment Group at the Northern Forest Research Centre plans to investigate two main problems in the Mixedwood:

1. Regeneration of spruce on potentially productive forested wetlands.
2. Vegetation competition for spruce seedling and transplant growth.

The first study will establish the characteristics of preferred microsites for spruce on wetlands. A range of promising site preparation techniques designed to create a uniform distribution of 'safe' sites will be tested. Seedling responses to site improvement treatments will be measured, together with changes in soil physical characteristics, including soil moisture content, available pore space, aeration and water levels.

The second study will examine the interaction of severity of vegetation competition and seedling growth over a soil-moisture regime range, and will isolate some key competition components above and below ground surface level. In the greenhouse, competing species will be raised from seed collected in the field. Once competition treatments are established, conifer seedlings at different stages of development will be introduced.

A major objective is to develop a hazard rating for the forest manager to use in the assessment of regeneration chance. The site factors that will have the greatest influence on the forest manager's decision to regenerate white spruce in Alberta's Mixedwood are: landform; physiographic site; forest cover type and regeneration status; soil series; depth to mineral soil; moisture regime in the rooting zone, and vegetation competition. From a consideration of these, silvicultural prescriptions for regeneration may be written.

Further ecological research is required into the potential of spruce advance growth, the usefulness of existing balsam fir regeneration and the environment under immature aspen stands where white spruce grows satisfactorily.

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SOIL TEMPERATURE, SEEDLING GROWTH AND WHITE SPRUCE REGENERATION

F. Endean

Canadian Forestry Service, Northern Forest Research Centre
Edmonton, Alberta

ABSTRACT: The development of deep organic layers in the overmature spruce stands of the east slope Foothills Section is viewed as site degradation and a serious impediment to the establishment of regeneration following clear-cutting. Low soil temperature beneath this organic layer is thought to be a major factor limiting regeneration success. Soil temperatures are elevated for a few years following reduction of organic layers by prescribed burning.

INTRODUCTION

The main white spruce (*Picea glauca* (Moench) Voss) associations in Alberta occur in two very different site and climatic situations, the Mixedwood Section (B18a: Rowe 1959) and the east slope Foothills Section (B19: Rowe 1959). While the greater part lies in the Mixedwood Section, approximately 2.75 billion cu ft of the province's white spruce are in the east slope Foothills Section. Some 15 percent of this volume is in mature to overmature stands.

This paper concerns some biological aspects of the regeneration of spruce stands in the east slope Foothills Section. These stands are an important source of material for pulp production and a small but vigorous lumber industry. Equally important, they occur in some of Canada's finest recreational lands and are essential to watershed protection. The problems inherent in regenerating these stands well illustrate the complexity of managing spruce cover types in an extreme environment.

EAST SLOPE SPRUCE STANDS

A distinctive feature of the upper foothills of the east slopes of the Rocky Mountains is that they are forested with conifers to their summits, which rise to as much as 6000 ft a.s.l. Extensive overmature spruce stands are typical of the area. Alpine fir (*Abies lasiocarpa* Hook) is a subsidiary species and black spruce (*Picea mariana* (Mill.) BSP) occurs in wet hollows. Hardwoods are rare. High quality overmature stands average 3,000 cu ft of spruce and 800 cu ft of alpine fir per acre. The average height of the dominant spruce is 89 ft; the alpine fir is only 64 ft. The total number of stems averages 490 per acre. Ground vegetation and advanced growth of conifers are sparse and there is a deep carpet of moss, mainly *Hylocomium splendens* and *Pleurozium schereberi*. These stands have been untouched by fire or other disturbance for at least 300 years.

Their soils, which have developed on deep glacial tills, range from relatively freely drained, well-developed Orthic Grey Wooded to imperfectly drained, compacted sandy clay Gleysols with 47 percent silt and clay. This material inhibits downward movement of water, which remains perched and moves laterally. Drainage is also impeded by ice, which occurs as an intermittent layer at a depth of 6 inches until the end of June. A significant feature of these sites is the depth of unincorporated organic material, which on freely drained sites is 6 inches deep and on imperfectly drained sites is up to 24 inches deep. F layers are 1 to 6 inches deep, with a thin melanized H layer on freely drained sites and 6 to 18 inches of sticky black muck resting on the till on imperfectly drained sites. There are approximately 15,000 acres of this much type in the Edson Forest District alone.

A number of factors have probably contributed to the formation of these organic layers:

- continuous spruce fir cover for at least 300 years, without interruption by wildfire;
- high elevation (stands are usually above 4000 ft) and cool climate;
- very cold soils resulting from climate, elevation and the self insulating effects of the organic layers as stands mature;
- high moisture levels due to poor drainage in the plateau topography.

There is no indication that these stands are now able to regenerate satisfactorily in their natural state and after clear-cutting, natural regeneration is inadequate. Attempts at artificial regeneration by scarification and planting or seeding have been unsuccessful because normal equipment cannot expose mineral soil and the wet, excessively deep organic layers are a poor rooting medium for seedling establishment.

INVESTIGATION OF THE REGENERATION PROBLEM

Since 1967, the Canadian Forestry Service has been investigating whether site degradation is occurring and whether disturbance by prescribed burning can ameliorate sites sufficiently for the successful establishment of regeneration. Two typical cutover areas were chosen in west central

Alberta, 15 miles north of Hinton (53°45'N, 117°25'W), on till capped plateaux at an altitude of 4,800 ft a.s.l.

Soil Temperature

Data gathered so far indicates that the soil temperature factor is probably the most significant. Temperatures were measured by potentiometer and copper/constantan thermocouples placed at three depths; i) beneath the F layer, ii) at the base of the H layer, and iii) one inch into mineral soil. Forty-eight separate locations were sampled. Temperature was recorded at weekly intervals between 1300-1400 hours when values were near maximum for the upper layers and 1-2°F less than maximum for the lower layers. Separate studies were also made of diurnal variation.

Average soil temperatures in cutover plots are given in Table 1. Diurnal variation between 1000 and 1600 hours during August 1967 was 3°F under an organic layer 3-6 inches deep and 2°F in the mineral soil beneath

TABLE 1. Average soil temperature at three depths in cutover plots during the growing season for the period 1967-70.

	Temperature (°F)			
	June	July	August	September
At base of F layer	42	47	48	41
At base of H layer	36	41	44	42
1 inch into mineral soil	36	39	42	42

Standard error of means vary from 6 to 15 percent

this layer. Under 9 inches of organic layer, variation in the mineral soil was less than 1°F. Daily and average monthly temperatures showed a marked delay in soil warming below the organic layer. Detailed measurements by Lesko (1971) are in agreement with the monthly averages for cutover areas found in this study.

The present study has shown that immediately after burning, soil temperatures increased by 25 percent beneath the litter and 10 percent in mineral soil beneath. Burning removed 1 to 2 inches of moss and F layer. This increase in temperature was maintained into September when soil temperatures normally decline. The warming effect appears to be of limited duration since, three years after burning, temperatures on the cutover were only 1 to 2°F higher than those on the unburned areas.

Seedling Performance

Three-year-old white spruce seedlings were planted on burned and unburned plots in autumn 1969 and sampled in 1970 after one year's growth. The increase in dry weight of seedlings planted in the burned cutover area was 112 percent for roots and 62 percent for shoots, compared with 36 percent and 2 percent, respectively, in unburned areas. How much of this difference is attributable to soil temperature is not known. Lesko (1971) shows that only exchangeable potassium and calcium is significantly increased as a result of burning. It seems probable therefore that temperature change had a pronounced effect.

DISCUSSION

The principles involved in these findings are more important than the details. The soil temperatures observed are lower than those quoted by Fransilla (1962) for June to August at 61°N in Finland, and are slightly lower than those quoted by Jeffrey (1963) for cutovers in the Peace River flood plains at 59°N.

There appears to be no published information on the temperature tolerance of white spruce roots. Helmers (1961) sets 64°F as the optimum for root growth of redwood. Nightingale (1935) found the greatest growth in apple roots at 65°F, with a lower limit of 44°F. The generally accepted minimum for normal biological activity is 40°F. Recent work by Ackerman (1971) shows that both root and shoot growth of seedlings of three Alberta provenances of white spruce are minimal at a soil temperature of 40°F, even when air temperatures are 60 to 80°F. The total weight of seedlings grown in soil temperatures of 40°F averaged 0.5 mg in 12 weeks. Ackerman showed that root and shoot growth increased with increasing soil temperature up to 60°F. Shoot/root ratio was at a minimum of 1.2 at a soil temperature of 50°F, with a total plant weight of 36 to 40 gm.

It seems clear that in the decadent, overmature spruce stands of the east slope Foothills Section, soils are very cold, forming an inhospitable rooting medium for both mature trees and seedlings. Site degradation is probably occurring. Lyon, Buckman and Brady (1952) state that nitrification stops at 40°F. Although obviously capable of existing at these temperatures, spruce on these sites enjoy far from optimum conditions for root growth. Such conditions are probably typical of many spruce/fir stands above 4000 ft. a.s.l. in Alberta, including the subalpine stands of southern Alberta and the National Parks.

In the natural state, it is likely that the trend of soil cooling and reduced growth potential was corrected by periodic wildfire and frequent low intensity ground fires. Our present system of increasingly efficient fire protection largely prevents such an amelioration.

This leaves us with an ecological problem. It has been argued that these stands should not be utilized, since regeneration can be expensive and difficult. This argument merely avoids the problem and is likely to result in significant areas of derelict forest which are wasted material, a source of insect and fungal scourges, and aesthetically ugly.

A promising and reasonably economical method of regeneration has been developed (Ferdinand 1970). The organic material is bulldozed into windrows and spruce seed is sown on the mineral soil. This method, however, has been criticized as ugly and a long-term fire hazard.

Their topographic situation on the catchments of major streams gives east slope Foothills stands hydrological importance. The ecology and courses of lower streams have presumably adjusted over the last three centuries to a slow rate of water release, due to the thick organic layers and slow rate of thawing of their soils. Rapid amelioration of such sites on a large scale might well produce undesirable reactions at lower elevations.

It is certain that in the east slope Foothills Section we have an ecological repair job on our hands; a job created largely by nature but aided by our practices. This job should not be thrown back at the utilizer. Similar problems will undoubtedly crop up in other spruce cover types as we make more and more use of our forests. Such problems must be faced and decisions made largely on the basis of what we know now.

I wonder whether ecologists are prepared to move from the world of quiet research to decisions with a deadline like this one.

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SMALL MAMMALS AND REGENERATION OF WHITE SPRUCE IN WESTERN ALBERTA

A. Radvanyi

Canadian Wildlife Service, Edmonton, Alberta

ABSTRACT: Trapping studies indicated that small mammal populations are never likely to be low enough to permit successful direct seeding for white spruce regeneration in western Alberta without adequate seed treatment. Recovery of radio-tagged seed showed that nearly 50 percent of spring sown seed can be destroyed by small mammals within three months despite current methods of seed treatment. Effective protection from small mammal depredation has been provided by a new graphite/R-55 repellant/latex coating in laboratory tests and limited field trials.

For almost seven decades, foresters in North America have turned repeatedly to direct seeding hoping to find in it an economical and rapid means of regenerating cutover forest lands. These attempts have resulted in repeated failures and frequently the hitherto unproven destruction of seed by small mammals has been blamed. Scientific journals abound with references to the destructive capabilities of small mammal species. For example, Hooven (1958) calculated that a small mammal population of only two animals per acre, each consuming 300 Douglas-fir seeds per night, could, within a matter of 35 nights, consume all the seeds broadcast to start the new crop.

In 1960, the Canadian Wildlife Service was requested to undertake a study to determine the influence of small mammal populations on white spruce regeneration. Repeated broadcast seeding at the rate of one pound per acre, that is approximately 220,000 seed, had not yielded the 300 to 400 trees per acre being sought by Northwest Pulp and Power Ltd. to regenerate its cutover forest lands near Hinton. The initial objective of the study was to determine what happened to this seed. An extensive program of live trapping and seed tagging was started to find out which species of small mammals were present on cutover lands, how populations varied throughout the year and from year to year, the home range of individual animals, and whether coniferous seeds were being eaten.

Beginning in 1962, the fate of radio-tagged spruce seeds, 3 to 12 months after being set out, was ascertained by relocating them or what was left of them, using a sensitive portable scintillometer (Fig. 1). Finding seeds measuring only 2.5 to 3 mm in length was a time-consuming and arduous task but, of the 17,000 white spruce seeds set out over an 8-year period, 91 percent were recovered.

FIG. 1. Portable scintillation counter used to locate white spruce seeds which have moved to 15 inches below the soil surface since they were set out some months previously. Some seeds were moved as much as 200 ft from the nearest point of placement.

This trapping and seed recovery study showed that in some years, small mammals, principally white footed mice, redback moles, meadow moles, chipmunks and shrews can destroy, within 3 months, 50 percent of the white spruce seeds sown in late spring. Following winter seeding, only one third as many were destroyed and 5 to 7 times as many germinated. Although the number of seeds destroyed did not appear to be directly related to the number of small mammals present, populations are unlikely ever to be low enough under natural conditions to permit successful regeneration by direct seeding using previous seed treatments.

Losses occurred during this study despite seed treatment with the aluminum powder-endrin-arasan-latex coating which had been standard practice for the past two decades. Beginning in the fall of 1968, a critical search was made for a more effective protective coating. Following some 50 experiments over the next two years, the aluminum powder, endrin and arasan were dropped and the latex was modified. Dull, black graphite powder replaced the shiny aluminum, and an effective rodent repellent R-55 (tertiary-butysulfenyldimethyldithiocarbamate) replaced both the endrin and arasan. Seed germination was improved by changing the pH of the latex from the highly alkaline 9.6 commonly used to a slightly acidic microenvironment of 4.6.

Publication of the development of the R-55/graphite coating (Radvanyi 1970) brought an immediate response throughout the North American continent, particularly because there was no suitable replacement for endrin, which had been banned from further use in the United States and Canada. While considerable laboratory and limited field testing of the new coating formulation has shown its superiority to the old treatment, it is not considered to be the final answer and must be subjected to further laboratory and large-scale field testing. Current studies suggest that a different R-55/graphite/latex formulation will be required for each tree species to achieve the high degree of protection (more than 95% effectiveness) which has been achieved for white spruce in the laboratory. At least two more years of laboratory and five more years of field testing are anticipated before operational aerial broadcast seeding using the new coating treatment can be used to reduce the many thousands of acres of backlog and new cutover areas requiring artificial regeneration each year.

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CONSTRAINTS ON THE GROWTH OF YOUNG WHITE SPRUCE

R. F. Sutton

Canadian Forestry Service, Great Lakes Forest Research Centre,
Sault Ste. Marie, Ontario

ABSTRACT: Constraints on the growth of young white spruce are meteorologic, biologic and edaphic. The components of constraints vary in time and space, both qualitatively and quantitatively. Results from experimental plantings with two stocks on three soils contrasting in texture and fertility, using treatments which included fertilization with nitrogen, weed control and irrigation, are used to illustrate some of the constraints.

INTRODUCTION

Some of the more important constraints on growth of planted white spruce (*Picea glauca* (Moench) Voss) in eastern Ontario may be seen from the effects of various experimental treatments (Sutton 1968). Treatments included fertilization with nitrogen, in some cases with supplementary additions of phosphorus and potassium, weed control and irrigation. Effects were studied in three soil types, contrasting in texture and fertility.

STUDY AREAS

Experimental plantings were made on abandoned farmland in the National Capital Commission's Green Belt around Ottawa, at a latitude of 45°20' N, between 75° and 76° W longitude. All plantings were on level ground consisting of unconsolidated Quaternary sediments underlain by more or less horizontally-bedded sandstones and dolomitic limestones. Differences in texture and fertility among the three soil types are shown in Table 1. The "Clay" soil was a moderately well-drained regosolic Rideau Clay (Hills et al. 1944); the "Loam" was a colluvially modified Rideau Clay; and the "Sand", a gleyed podzol of imperfectly drained Rubicon Sand, was formed from non-calcareous outwash or deltaic sand overlying lacustrine-marine clays in which ground water moves slowly.

The species native to the area include white elm, red maple, eastern cedar, balsam fir, and possibly black and white spruces on the

TABLE 1. Soil characteristics of experimental plots (Ap horizon)

	Experimental Area		
	Clay	Loam	Sand
Percent Sand	28	53	80
Percent Clay	61	23	11
Textural class	clay	sandy clay loam	sandy loam
pH*	6.5	6.3	4.8
Total Nitrogen (me/100g)	0.25	0.21	0.15
Cation Exchange Capacity (me/100g)	22	15	8
Exchangeable Potassium (me/100g)	0.28	0.13	0.08
Exchangeable Calcium (me/100g)	14	10	3

* in $0.01M CaCl_2$

Rubicon sand; and white elm, white ash, red maple, sugar maple, beech, basswood, white oak, white pine and perhaps red pine, eastern hemlock and white spruce on the Rideau clay and loam.

The Ottawa Valley was opened up to lumbering early in the 19th century and settlement began almost immediately. The study areas were settled before 1881 and were farmed until about 1960. The crops grown were chiefly small grains, hay and potatoes. Fertilizer amendments were probably applied with reluctance, if at all.

Mean annual temperature in the study area averages 5.5°C (42°F). Mean potential evapotranspiration exceeds mean precipitation by about 40 mm (1.5 in) each month, May through August (Table 2). Precipitation, moreover, had been below normal during the 8 years prior to the initiation of the experiment and this trend continued unabated throughout. A particularly severe drought in May and June 1965 generated such headlines as "Farmers leaving land as drought turns Ottawa Valley into a wasteland" (Toronto Globe and Mail, June 23, 1965). The whole period of accumulating deficits was one of record duration and intensity. This, therefore, was a favourable time for evaluating the effects of irrigation.

TABLE 2. Mean precipitation and potential evapotranspiration in the Ottawa Greenbelt.

	Month			
	May	June	July	August
Precipitation (mm)	70	80	90	80
Potential Evapotranspiration (mm)	110	120	130	110

EXPERIMENTAL DESIGN

Experiment P62, begun in 1962, was a fully randomized design with 6 replications of 3 nitrogen, 2 weed control and 2 irrigation treatments in all combinations. The nitrogen treatments (200 lb./ac, 100 lb./ac and 0 lb./ac as ammonium nitrate) were applied in 1962 and repeated in 1963. Weed control was maintained for the first five years after planting. Trees were irrigated during their first 2 growing seasons in the field, the aim being to apply through the growing season one gallon of water to each treated plant each week in which rainfall was less than one inch. Applications averaged four gallons of water in each of the first two growing seasons, although the droughtiest area (P62 Loam) received more than twice the amount of water that was applied to the wettest area (P62 Sand). Greatest apparent need was a basis for choosing the area first to receive irrigation after each interruption. Foliage samples for nutrient analysis were collected at intervals throughout the following 8 growing seasons.

Experiment P63, begun in 1963, was a repetition on adjacent plots of the 1962 treatments, together with an additional replication. Supplementary P and K (both at 100 lb. per acre per annum) was applied in 1963 and 1964 to one replicate in each of the P62 and P63 studies. All planting stock was raised in northern Ontario at the Kapuskasing nursery of the Spruce Falls Power and Paper Company. The P62 stock was from seedlots 53-255 and 53-256, and the P63 stock was from seedlot 56-296. All seed was collected from good stands of white spruce.

RESULTS AND DISCUSSION

Relative Performance of P62 and P63 Stocks

The overall performance of the P63 plants was considerably better than that of the P62 stock (Fig. 1). This was not predictable

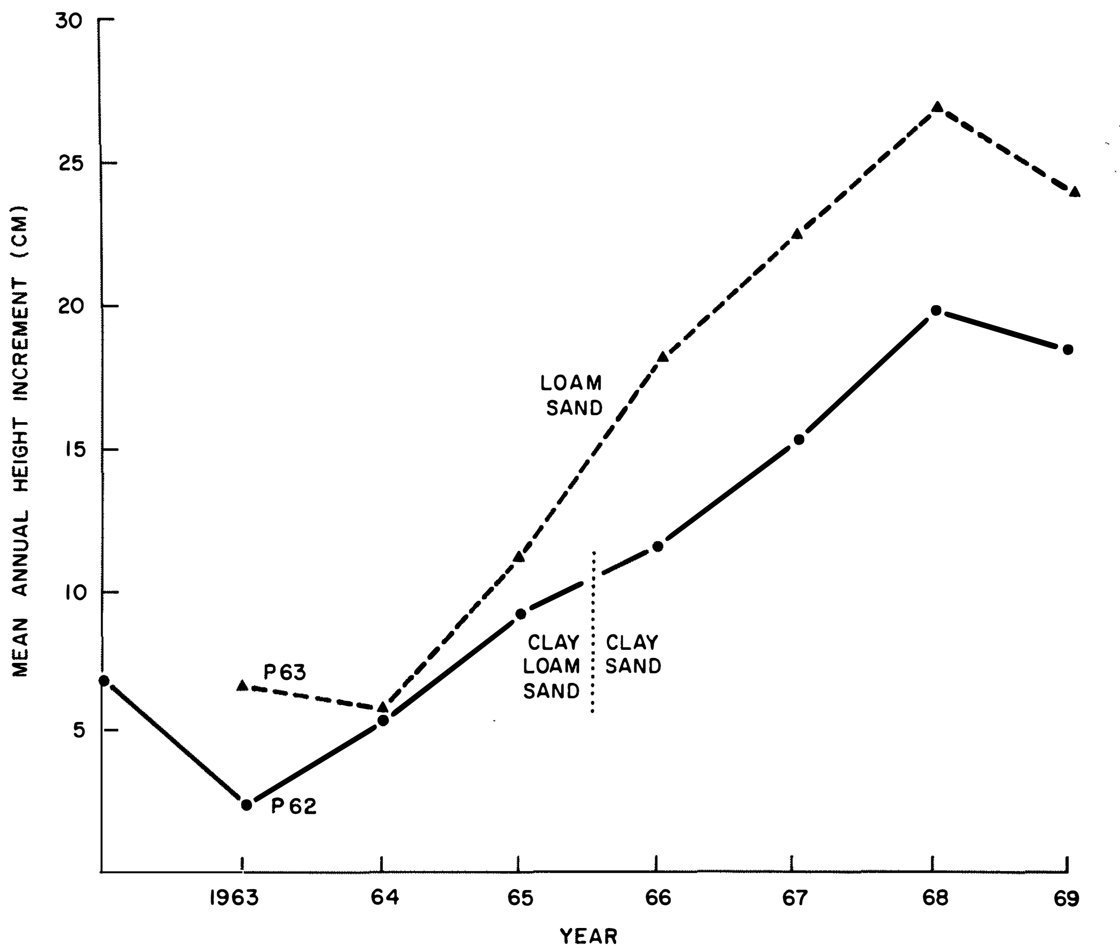

FIG. 1. Annual height increment for P62 and P63 white spruce, overall. The P62 Loam replicates burned in the spring of 1966 and are excluded thereafter. The P63 Clay suffered such high mortality that it has been excluded from the analysis.

from the appearance of the stocks. The P63 plants averaged 5 cm shorter at planting and looked poor; other stock would have been used had it been available. Yet, the second-year reduction in height increment was much less in the P63 than in the P62 stock, and the P63 stock by 1969 (after one fewer growing season in the field), averaged 25 cm taller than the P62 stock. This differential is two-thirds of that recorded from the most successful treatment. It is therefore a matter of consequence to learn how to estimate the growth potential of planting stock. The present system of morphological grading used in Ontario, even when rigidly applied, seems to give little indication of future performance. Furthermore, response to differences in climate and soils following outplanting may vary according to stock.

Both the P62 and P63 stock showed reduced height increment in 1969, breaking the well-established trend that obtained during the previous 5 years (Fig. 2). This reduction, attributed to the onset of

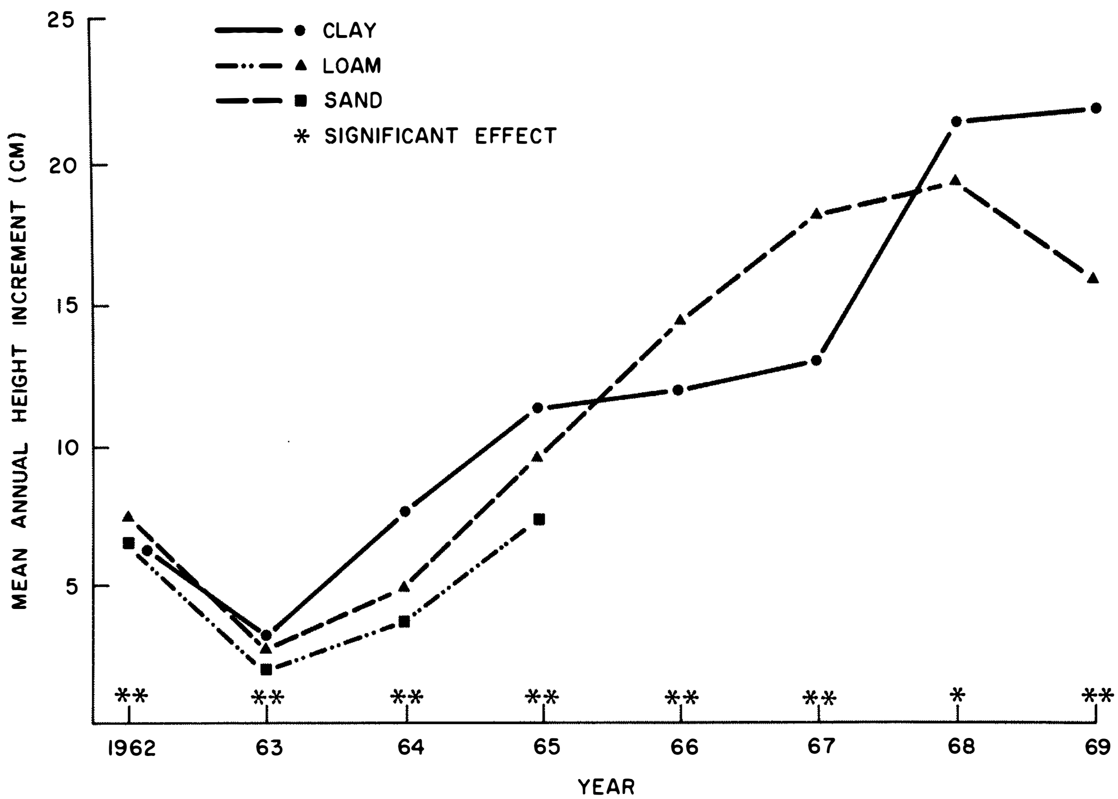

FIG. 2. Annual height increment for P62 white spruce by soils. Single and double asterisks denote significance at the P.05 and P.01 levels, respectively.

specific competition, was pronounced in 3 of the 4 plantations remaining in 1969.

The effect of the 1965 drought on the P62 stock was most clearly expressed on the Clay site even though, as might be expected (Motley, 1949), height increment was not reduced until 1966 (Fig. 2). Mean increments on the P63 stock in the Loam and Sand areas were similar to one another (Fig. 3), as were mean heights after 7 growing seasons.

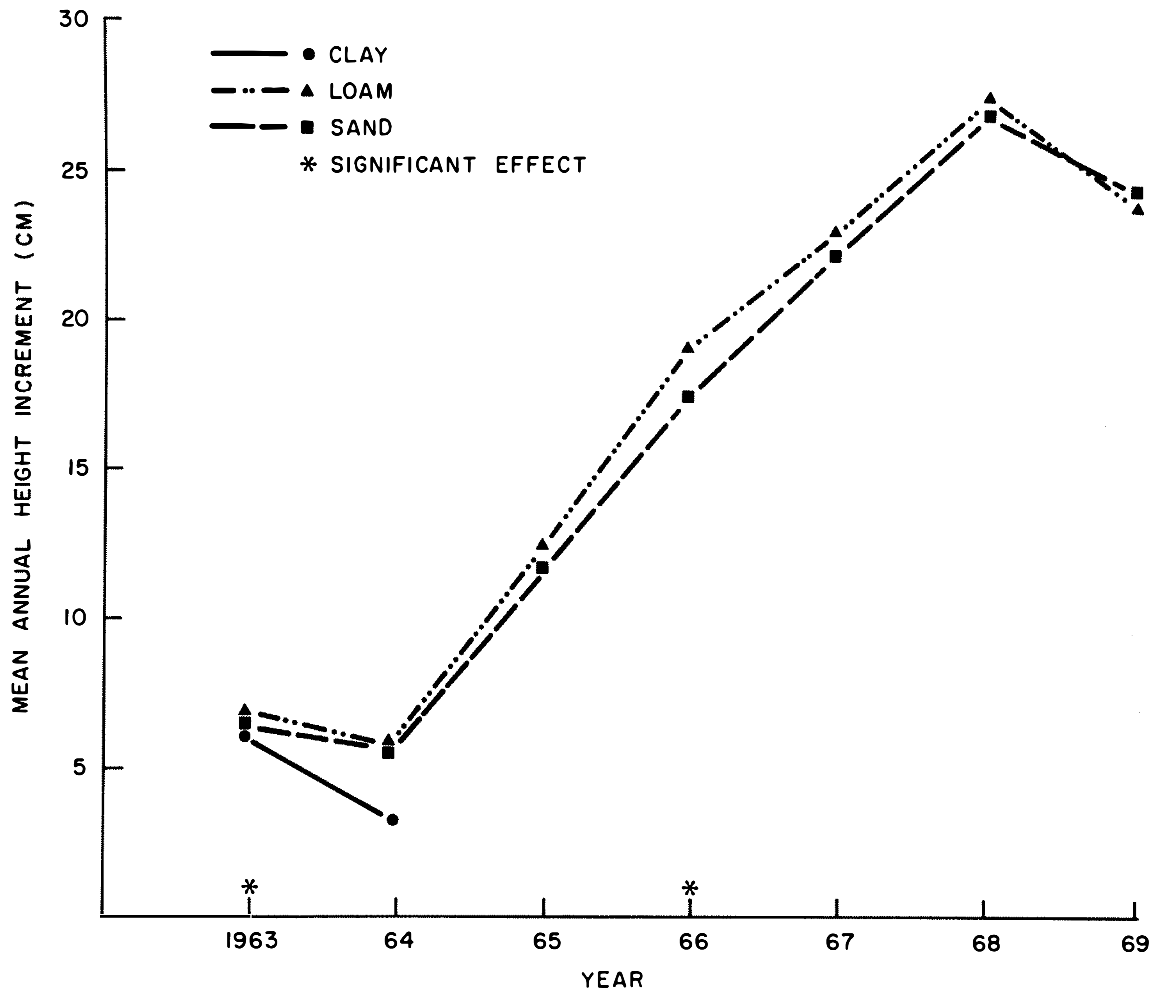

FIG. 3. Annual height increment for P63 white spruce by soils. Asterisk denotes significant at the P.05 level.

Effect of Irrigation

The only significant (P.05) effect of irrigation on annual increments of the P62 stock occurred during the third growing season (1964) when a positive response was evident on the Clay site (Fig. 4). After 8 growing seasons, however, even on the Clay site, trees that had been irrigated during their first two years after outplanting averaged only 5 cm taller than non-irrigated trees. On the sand, the irrigated trees were 5 cm shorter than the non-irrigated trees.

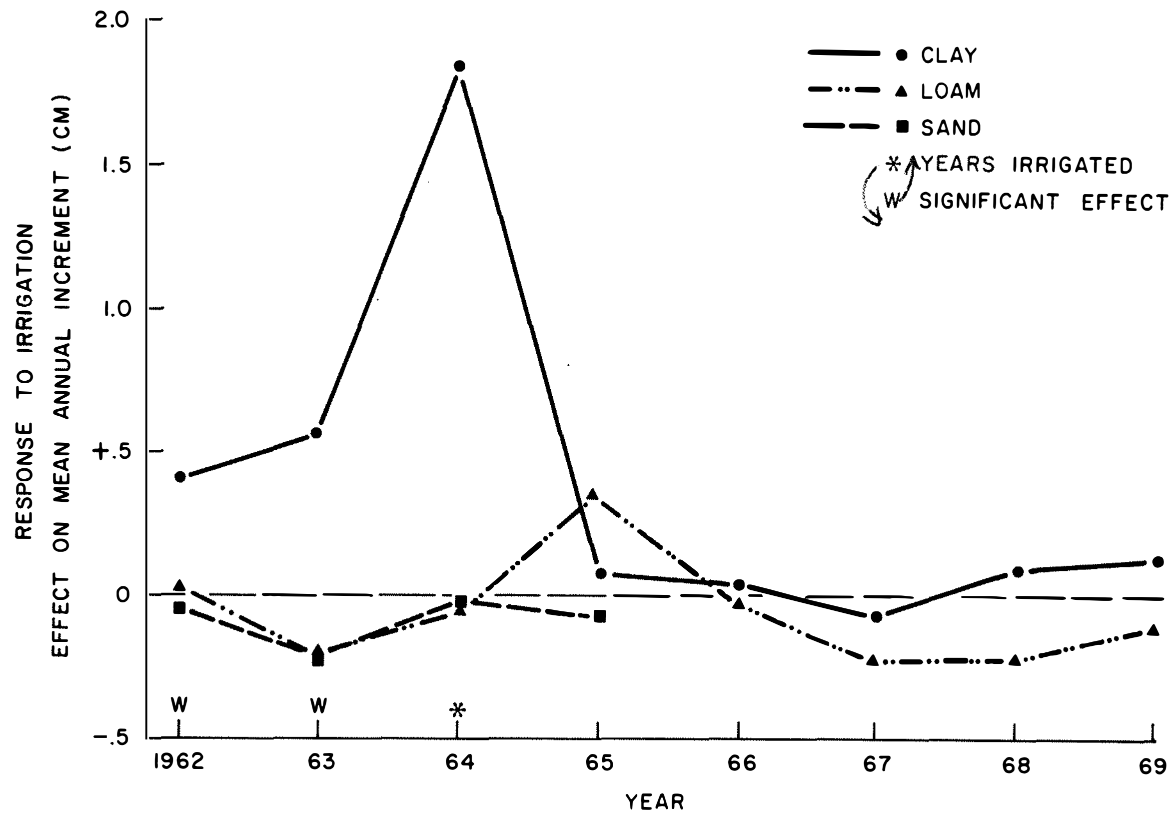

FIG. 4. Influence of soil type on effect of irrigation on P62 white spruce height increment. Asterisk denotes significance at the P.05 level.

Unlike the P62 stock, irrigated P63 trees on the Sand site were taller than the non-irrigated trees, although the difference was only 8 cm after 7 growing seasons. Irrigated trees on the Loam site showed a similar increase. Whether any increase would have occurred on the Clay site could not be determined because so many trees died that no analysis could be made. Significant (P.01) positive responses were obtained in each of the first two growing seasons (the period when irrigation was applied) and in 1965, the third season (Fig. 5). The significance in the 7th growing season is regarded as fortuitous.

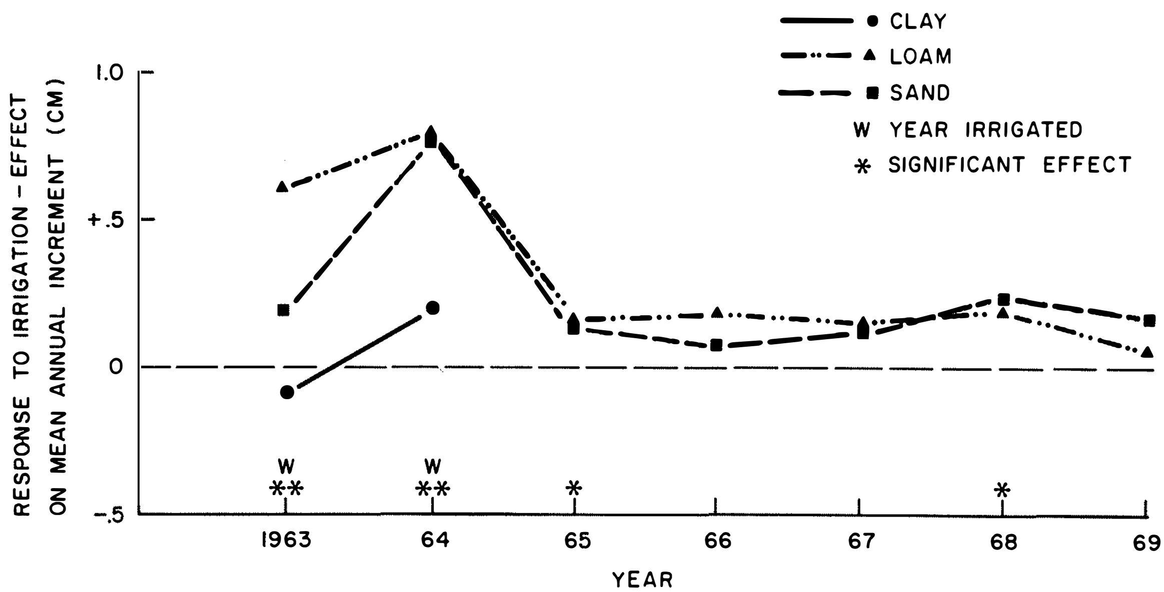

FIG. 5. Influence of soil type on effect of irrigation on P63 white spruce height increment. Single and double asterisks denote significance at the P.05 and P.01 levels, respectively.

In general, response to irrigation during the first two years following outplanting was meagre, notwithstanding the experimental period being one of drought.

Effect of Fertilization

The effect of fertilization on both the P62 and P63 stocks in all soil types was generally depressive, though usually non-significant and of small amounts (Fig. 6). After 8 growing seasons, mean height of the P62 stock without fertilization was 118 cm, with 100 lb./ac it was 114 cm and with 200 lb./ac it was 113 cm. There was a slight positive response in the second growing season (1964), but competing vegetation responded more vigorously than the trees and tree growth subsequently was depressed. This depressive effect illustrates the pitfall of imprudent fertilization. In addition to the effect of enhanced competition, growth reduction may also result from an accentuated or created nutrient imbalance. Ions of nutrients already in short supply may be flushed out of the root zone by mass action, further impoverishing the "fertilized" trees.

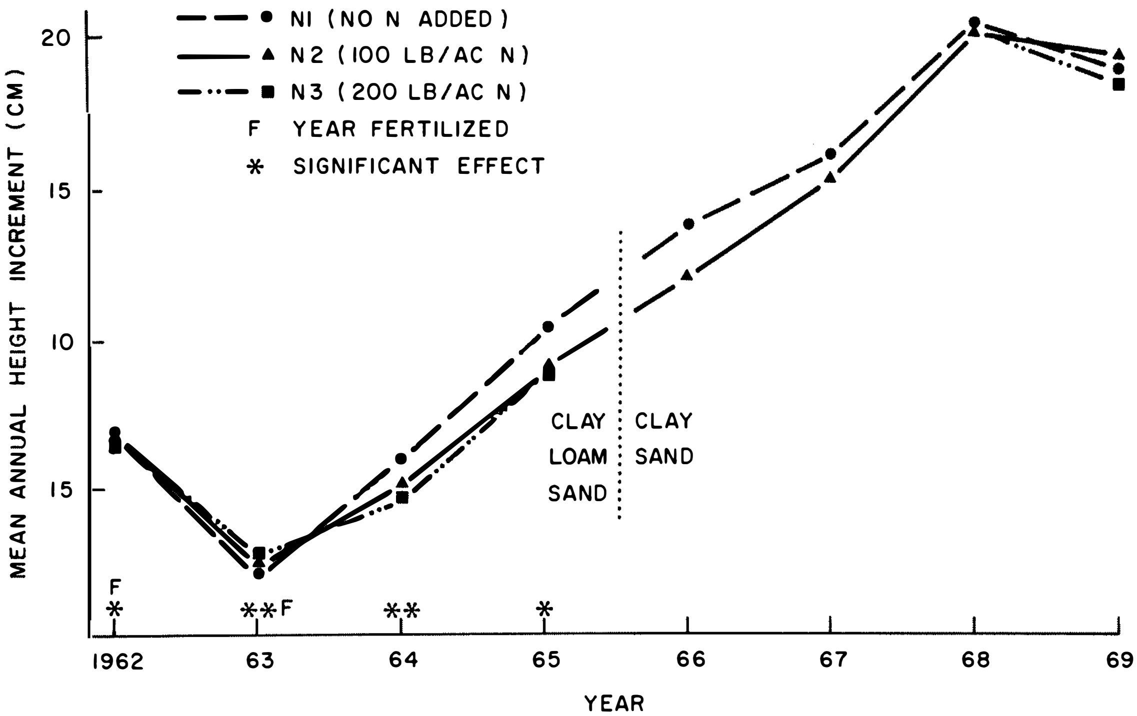

FIG. 6. Overall effect of N fertilization on P62 white spruce height increment. Single and double asterisks denote significance at the P.05 and P.01 levels, respectively.

Effect of Weed Control

The strength of the positive response to weed control is well illustrated by the P63 trees in the Loam and Sand areas (Fig. 7). After 7 growing seasons, trees in the weed controlled plots averaged 155 cm, 36 percent taller than the 114 cm of trees in the uncontrolled plots.

Weed control had a very strong influence on the nutrient status of the trees freed from competition. The strong initial "flush" of fertility initiated by the weed control treatment possibly results from the slow release of balanced nutrient ions derived from the breakdown of root and other organic matter in the soil. The cessation of nutrient uptake by competing roots has, in the first instance, less effect. This initial "flush", lasting 2 or 3 years only, is followed by a more modest enhancement of nutrient levels. The effect on height increment parallels nutritional effects.

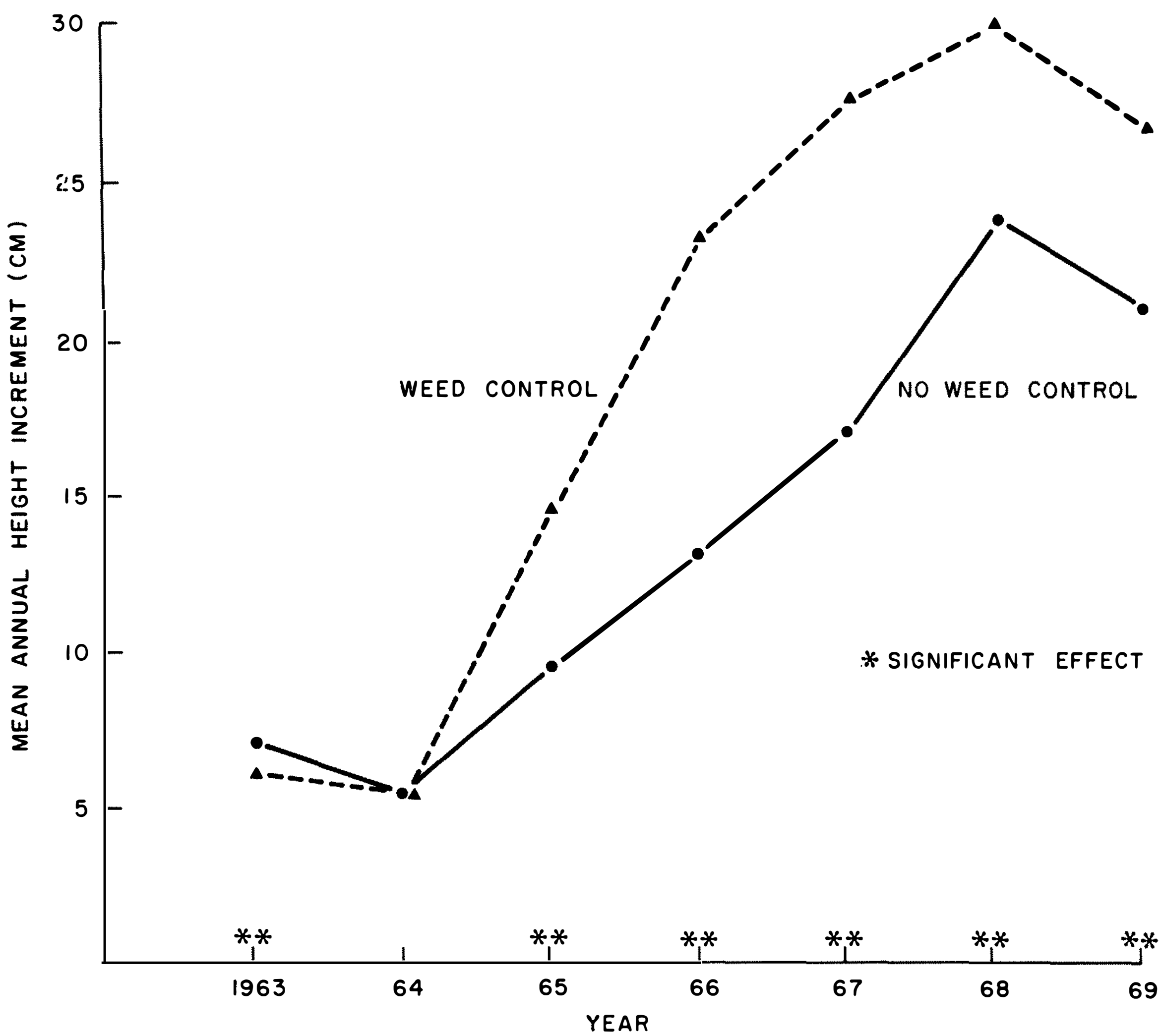

FIG. 7. Effect of weed control on P63 white spruce height increment. Double asterisk denotes significance at the P.01 level.

Weed Control/Fertilizer Interaction

The reduction in increment on the P62 fertilizer treatment areas following termination of weed control (Fig. 8) is illustrative of the interaction between fertilization and weed control. Without weed control, fertilization may only enhance the competitiveness of weeds. The relative strength of response of the low nitrogen treatment (100 lb./ac) is, however, anomalous.

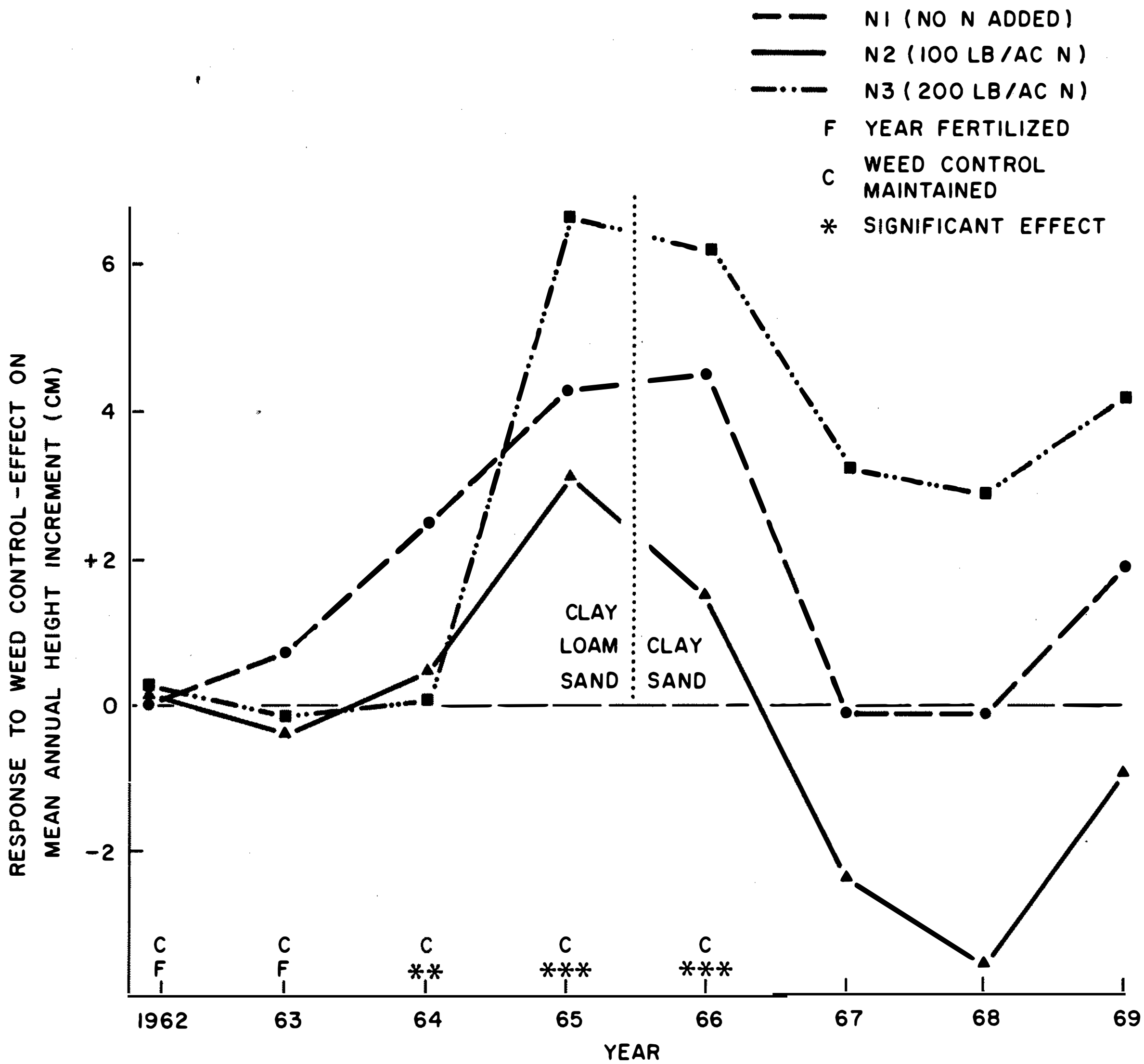

FIG. 8. Effect of N fertilization as influenced by weed control on P62 white spruce height increment. Weed control was maintained 1962 through 1966. Double and triple asterisks denote significance at the P.01 and P.001 levels, respectively.

Weed Control/Soil Interaction

Weed control was particularly beneficial on the Sand area (Fig. 9), a site with low fertility. Initially weed control was also beneficial on the Clay area. Trees in the weed control plots on Clay soils, however, received a severe set back in the exceptionally dry summer of 1965 because severe cracking in the bare clay soil as it dried out inflicted severe root pruning. In 1966, height increments were little better than that of trees in the non-weed control plots, and for the following two growing seasons the non-weed control trees made substantially greater height growth than the weed control trees. After 8 growing seasons, the mean height growth of trees in the weed controlled Clay plots was only 4 cm greater than that of trees that had not been relieved of competition.

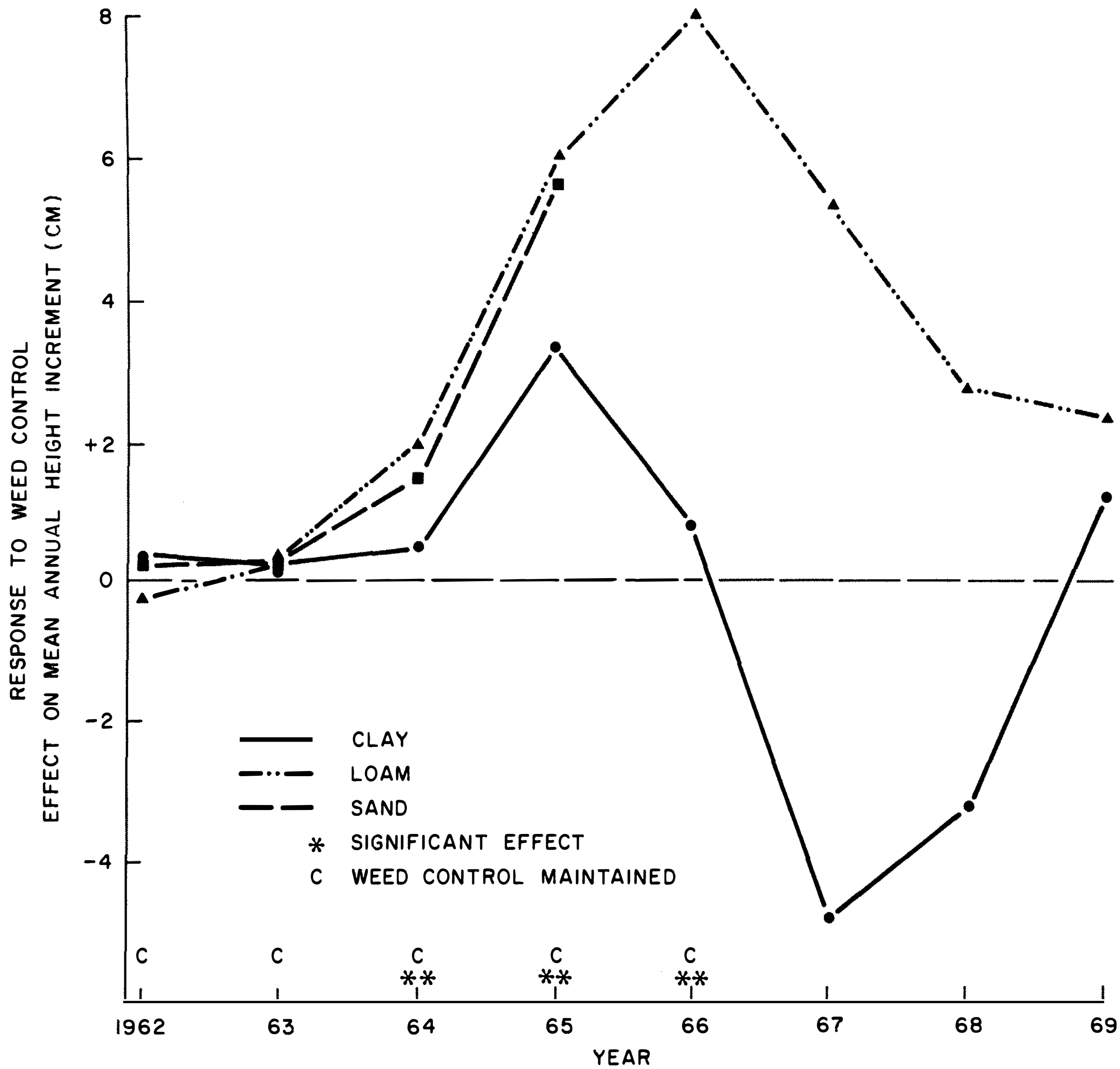

FIG. 9. Effect of weed control as influenced by soil type on P62 white spruce height increment. Double asterisks denote significance at the P.01 level.

Foliar Nutrient Levels

The question of nutrition is one of enormous complexity, although in recent years considerable progress had been made in establishing normal ranges of nutrients and in determining the effect of controlling factors. For 3-year-old white spruce in Ontario grown under the relatively favorable conditions of a well-run nursery, that is, where the necessary irrigation, weed control and fertilizers are provided, foliage nutrient percentages may approximate 1.8-2.4 N, 0.18-0.25 P, 0.50-1.00 K, 1.4 Ca and .35 Mg (Armson and Carman 1961).

On lifting from the nursery bed, a seedling suffers some degree of mutiliation, desiccation and loss of carbohydrates even before introduction into the relatively hostile environment of the planting site. With elongation and growth following flushing, nutrients, notably nitrogen and potassium, move into the new tissue. If root growth is slow (which it will be if the rooting medium is not suitably moist, fertile and warm) uptake will be insufficient to maintain initial levels of nutrients. The shedding of old needles or even all but the current year's needles, noted in many outplants, is thought to be primarily a consequence of these needles becoming deficient in one or more nutrients, that is, a *nutrient stress* rather than a *moisture stress*, although the latter effect may be complementary.

In the new foliage, the basic pattern of change is one of concentration of N, P and K to initial maxima, followed by a rapid decrease during the first part of the growing season, and thereafter by a diminished rate of decrease. The amount and rate of initial decline were related to site, being least in the Clay area. Nutrient levels in the current year's foliage are considered to be a real reflection of the influence of site. The increased K concentration found in trees in the P63 Loam area late in the growing season is characteristic for nutrients in short supply and may be attributable to nutrient release from dead and dying vegetation (including grasses), and uptake by roots that often show a burst of late season activity. The concentration of calcium in foliage tends to increase with time (Table 3). There is often, moreover, a *negative* correlation on soils of low fertility between growth and calcium concentration, as though calcium is accumulated in a "sink" until other nutrients sufficient for growth have been taken up.

TABLE 3. Calcium concentration at 2 sampling dates, in the 1963-foliage of white spruce planted in 1962 on the relatively infertile Loam and Sand areas.

Date sampled	Calcium content (percent)	
	Loam	Sand
June 1963	.45a[1]	.51a
June 1964	1.94c	1.00b

[1] Values are means of random samples from the same 7 treatments in each instance.
Values that do not have a following letter in common are significantly (P.01) different.

Concentrations of P in current-year foliage of the P63 white spruce decreased by 26 percent, 55 percent and 63 percent on the Clay, Loam and Sand sites, respectively, between early summer (June 26, 1963) and late summer (August 9, 1963). This illustrates both the strength of the nutrient stress that may develop after outplanting and the fact that it is highly dependent on soil fertility. Such a decline is thought to result from "planting disturbance", that is, the loss of mobile nutrients from roots and aerial parts which the outplant's impaired root system cannot replenish and maintain at initial levels. The depression of K levels during the years of planting in current foliage below levels that occurred the following years is taken as a manifestation of the "planting disturbance" effect rather than a reduction to levels characteristic of the site. The levels obtained in the second and subsequent years following outplanting are thought to exemplify values equilibrated with site.

Decreases from the initial values of N, P and K are rapid, the amount and rate depending on site. Decreases were least in the Clay areas. Since height increment in the year of outplanting is little dependent on site, nutrient levels in the current year's foliage are considered to be a real reflection of the influence of site.

Fertilization with N had an immediate effect on the concentration of N in current year foliage, but only as long as fertilization was continued. The effect was strongest on the Sands, intermediate on the

Loams, and least on the Clays. The effect could not be discerned in the third growing season.

Weed control also had a very strong influence on the N concentration of current year foliage, and though it tended to persist longer, it was still a relatively short-term nature. The "flush" of fertility is not continued indefinitely.

Irrigation definitely depressed the concentration of N in current year foliage, especially on the less fertile soils.

Supplementary fertilization with P and K had little effect on the concentrations of these nutrients in current year 1964 foliage of trees on the P62 Clay, but increases in these nutrients (and especially of P) on the Loam and Sand areas were pronounced (Table 4). It may be significant that levels of foliar P and K in the P62 Loam and Sand areas were increased by the supplementary fertilization to approximately the levels found in the P62 Clay. These data suggest that in general terms the P62 Clay area has no major deficiency in N, P or K; that the P62 Sand is low in P, and that the P62 Loam is low in both P and K. An improvement in N levels after PK fertilization was evident.

TABLE 4. Foliage nutrient levels in white spruce as affected by soil type, with and without supplementary PK fertilization.

	Foliage nutrient content (percent)					
	Without PK added			With PK added		
	N	P	K	N	P	K
P62 Clay	1.73	.21	.95	1.94	.20	1.02
Loam	1.46	.14	.69	1.77	.24	.93
Sand	1.59	.14	.95	1.74	.22	1.06

CONCLUSION

The constraints on the growth and development of white spruce (or any other species) will vary in strength and nature. In field situations, it must be supposed that the times, when each growth factor is at its optimum level, are transitory and few and far between, even if such times do occur. We can be sure that conditions are less than optimum virtually all the time. We do not know what optimum growth is and, in any event, once conditions have been sub- or supraoptimal, conditions for optimal growth for the stressed plant may be considerably different from those that would have given optimum growth in the unstressed condition. In spite of this, it is useful to consider the growth made by trees as being an expression of optimum growth depressed by the effect of constraints. By comparing performances in terms of the criteria in which we are interested, on different sites and under different weather conditions and treatments, a picture of the nature and strength of the constraining factors can be built up, together with an idea of what, if anything, can be done about them to improve growth.

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SELECTING SPRUCE FOR SEED ORCHARDS

G. Kiss

British Columbia Forest Service
Prince George, British Columbia

ABSTRACT: A tree improvement program developed by the British Columbia Forest Service for white and Engelmann spruce in the Interior of British Columbia is described. Above average (in size and form) trees are selected in wild stands. Grafted clones are established in seed orchards. Each tree is progeny tested. Based on results of the progeny tests, undesirable lines are eliminated. Progress to date is described.

INTRODUCTION

Increased demand on our forest resources has necessitated artificial regeneration of cutover forest lands by planting nursery raised seedlings. While this practice is costly, it provides an opportunity for selecting seedlings that will probably be of better quality than the average natural stock.

To obtain high quality white and Engelmann spruce (*Picea glauca* (Moench) Voss and *P. engelmannii* Parry) seedlings, the British Columbia Forest Service has initiated a tree improvement program based on genetic principles. The immediate aim of the program is to:

1. Select "plus" trees based on phenotypic characteristics;
2. Establish selected plus trees in clone banks;
3. Initiate open pollinated progeny trials, using seeds from these selected trees;
4. Establish clonal seed orchards of selected trees that will ultimately be thinned to the best families based on information gained from progeny trials.

Future plans include controlled crossing of selected lines and interspecific hybridization.

SELECTION OF PLUS TREES

The selection of plus trees, though often tedious, is an important phase of the program. Some of the trees selected in this way will become the nucleus of future lines to be used for reforestation. Since actual seed transfer rules have not yet been established for white and Engelmann spruce in British Columbia, the province has been divided arbitrarily into manageable "Selection Units". Selection Units are delineated so that climatic conditions within each unit do not vary too greatly.

Due to cost and time factors, trees are selected along roads where they are readily accessible. This is necessary so that cones and scion material can be collected while conditions are just right. Cones must be collected within a short time-span in the fall when seeds are ripe enough to ensure proper germination but cones are still closed so that no seeds are lost. Scion collection must be made either in the late fall after proper hardening is achieved and before snow limits access or in the spring after access is regained but before flushing takes place.

The selection technique employed is to make roadside surveys, noting potential trees in predominantly good stands. Returning later, the candidate trees are compared and evaluated and those judged to be acceptable are selected. This judgement is based on several characteristics, the most important being vigour and size. Every tree selected must have evidence of previous cone production. Other characteristic considered are straightness of stem and branching.

Trees accepted as "plus" or "candidate" trees are marked, measured for height and diameter, and mapped. Phenotypic descriptions of each tree, such as stem straightness and branching characteristics, are also recorded. Data related to the environment, including elevation, associated tree species and the most prominant shrubs and herbaceous plants in the understorey, are recorded.

In some cases, trees with defects (such as extremely heavy branching, repeated forking, excessive burliness) are also selected for use in heritability studies of these traits. These trees will not be included in the seed orchard unless the heritability studies indicate that these traits are not heritable and, moreover, their progenies prove to be of superior quality.

SEED AND SCION COLLECTION

Cones are collected from the selected trees in good seed years. Cone-laden branches are shot from trees, using a .22 calibre rifle, between the middle of August and the first half of September, depending on cone maturity. When possible, a minimum of 100 cones are collected from each tree. Cones are stored in screen bags which allow air circulation, permitting proper drying without special attention. The screen mesh is fine enough to retain any seed released during drying. Seed lots are individually cleaned and stored under refrigeration until used.

Scion collections are also made using a rifle, but later in fall or in early spring. Spruce scions are extremely perishable, their quality declining rapidly even when stored in a cooler with peat moss packing. Grafting is done as quickly as possible after collection, on well established, potted root stocks in a greenhouse. The side pocket method of grafting seems to be the most successful for white and Engelmann spruce. Both spring and fall grafting are successful, but the growth of fall grafted clones during their first winter in the greenhouse is better than the first season's growth of spring grafted clones. Spring grafted clones develop slowly, their appearance resembling "planting check" commonly seen on field planted seedlings. Fall grafted clones, however, appear to have some difficulty returning into phase with the seasonal changes.

Suitable grafting material is often difficult to obtain from mature and overmature spruce because crowns have low vigor and buds are often damaged. In good cone years this problem is accentuated since the high frequency of regenerative buds reduces the number of vegetative buds. However, axillary buds usually develop on scions lacking buds at the time of grafting.

CLONE BANKS, TEST PLANTATIONS AND SEED ORCHARDS

Successful grafts are transferred into clone banks at the Red Rock Research Centre, near Prince George. These clone banks will provide scion material for seed orchards. Successful scions usually grow much more vigorously on rootstocks than they did on the original parent tree. Future grafting from clone banks should, therefore be easier and results more consistent. All selected trees will be conserved in these clone banks regardless of the outcome of the progeny trials. A wide base of genetic variation will be available if needed in the future. In addition to the above functions, the clone banks will be readily available for future controlled crossing experiments.

Seed collected from each selected tree are sown in the research nursery at Red Rock, where they are raised to plantable size. Under our conditions this is usually 2+1 stock. Permanent test plantations will be established within each selection unit from which the parents were selected. Depending on size and diversity of selection units, 4 to 6 plantations strategically distributed on good spruce sites are planned. A minimum of 75 seedlings per selected tree will be planted at each test site. A randomized block design with a minimum of three blocks will be used. Following an establishment period of 2 to 5 years, these seedlings will be measured periodically. These measurements and phenological observations will form the basis for selecting the most desirable parents. Undesirable clones will be deleted from the seed orchard program.

Preliminary results indicate that some clones will be rejected on nursery performance alone. Filled seeds from some trees yielded low numbers of seedlings indicating the presence of lethal genes. Albino seedlings have often shown up in low yielding seed lots. A large between-tree variation observed in average seedling heights might be indicative of the relative value of the various clones.

Observation of half-sib progenies will also provide information needed to decide which line may possess traits worth combining through controlled crossings.

Continual selection among progenies, both the open pollinated progenies of the half-sib progeny trials and the full-sib progenies of the controlled crosses, should allow continued improvement of future seed orchards. The seed orchard developed for each specific area is regarded as interim until tested clones for a better orchard can be developed.

In addition to the activities outlined above, two breeding arboreta or *Piceta* are presently being established at Red Rock and at Chilliwack. A collection of about 25 species of spruces from various parts of the world are represented. When these trees reach sexual maturity, interspecific hybridization studies will be made to determine the possibility of incorporating useful traits from other spruces into white and Engelmann spruce.

PRESENT STATUS

To date, selections have been made in three selection units:

the Central Interior (Prince George area), the East Kootenay Dry Belt and in the vicinity of Smithers and Burns Lake. A total of 176, 132 and 138 trees, respectively, have been selected. Most of these trees have been successfully grafted at Red Rock. Seeds have been collected from most of the trees. Seedlings from these seeds are at various stages of development, the oldest being rising 2+1 transplants. They are slated for permanent outplanting in the spring of 1972. Preliminary observations indicate distinct variation between progenies, suggesting that our efforts will be successful. A preliminary calculation indicates that by using only the top 30 percent of the trees for seed production, we may get an improvement of between 15 to 20 percent in 2-year-old seedling height growth. This calculation was carried out for the Central Interior Selection Unit trees.

McMinn, R. G. (Ed.)

1972. White spruce: The ecology of a northern resource. (Proceedings of a Symposium held June 21 1971; Canadian Botanical Association, Edmonton, Alberta.)

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Information Officer
Northern Forest Research Centre
Canadian Forestry Service
Department of the Environment
5320 - 122 Street
Edmonton, Alberta, Canada T6H 3S5