WHITE SPRUCE: ARTIFICIAL REGENERATION IN CANADA

by

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ABSTRACT

Artificial regeneration programs and practices in Canada for white spruce (*Picea glauca* (Moench) Voss) are described in detail. Topics include seed production, cone collection, seed processing, nursery work, site preparation, seeding, planting, stand tending, protection and growth and yield.

RESUME

Les programmes et pratiques de régénération artificielle de l'épinette blanche (*Picea glauca* [Moench] Voss) au Canada sont décrits en détail. Les sujets comportent la production des semences, la cueillette des cônes, le traitement des semences, le travail à la pépinière, la préparation du terrain, l'ensemencement direct, le plantage, l'entretien des peuplements, la protection, la croissance et le rendement.

PREFACE

The purpose of this publication is to assemble in one document information on the general subject of white spruce plantation establishment and management in Canada. Current silvicultural practices are described for the various phases of the regeneration process, from cone collection through seeding and planting to intermediate stand treatment, together with relevant biological and mensurational information. Where possible, what appear to be the best practices are so indicated, but in most cases the report deals more with how operations are carried out in Canada than how they ought to be. In order to present a rounded view, some details of procedures not peculiar to white spruce have been included, e.g. in nursery work; and conversely some operations, as yet little practised in white spruce plantations but which seem likely to be developed therein, have been described from experimental results and from experience reported for other species.

While this report is intended to be entirely practical, the speed of technological development will soom make some material out of date, e.g. that on container planting. Likewise, cost data soon lose relevance in these inflationary times, but it is hoped that where costs are stated the accompanying dates will help keep them in perspective.

Numerical data in the text are usually cited in the units as published, whether yard/pound or metric, and are followed by the appropriate equivalents in brackets. In making the conversion, both the rules for rounding and the inferred accuracy of the original values were taken into account.

Sources of information include the literature, personal research, visits to all provinces with white spruce artificial regeneration programs and interviews or correspondence with individuals concerned with them.

ACKNOWLEDGEMENTS

Much of the material presented here was obtained directly from members of the Canadian forestry community, and thanks are due those individuals listed below for their assistance in this regard. Information used is not further acknowledged unless it was obtained through correspondence, in which case the source is footnoted. Affiliations given here are those applying when contact was made by the author. Reviewers of individual chapters of the manuscript are marked with an asterisk.

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WHITE SPRUCE: ARTIFICIAL REGENERATION IN CANADA

by

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I. INTRODUCTION

Attributes of White Spruce as a Plantation Species

White spruce[2] is now the most widely planted tree species in Canada. A combination of circumstances accounts for this. White spruce is naturally of widespread occurrence and comprises a very large resource utilized both for pulpwood and for lumber. In some regions it is the only locally occurring conifer suited to the sites requiring regeneration. It can perform satisfactorily over a wide range of soils. It is shade-tolerant and able to survive and grow (if at a reduced rate) under moderate brush or hardwood canopies. Seed supplies are usually ample. Forest geneticists have encouraged the planting of white spruce by assertions that its highly variable nature indicates a capacity for considerable gains through tree improvement measures.

At the same time, there are a number of features that render white spruce less than perfect as a plantation species. The most often cited is a tendency towards post-planting check. It is subject when young to damage from spring frosts, and from the spruce budworm at later ages. It develops excessive limbiness in open stands. It is alleged to grow slower, particularly in juvenile stages, than its natural conifer associates. The importance attached to these individual drawbacks varies with region and circumstance.

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[2] Scientific names are appended.

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Extent of Planting

Despite its prominence in reforestation today, white spruce was seldom an early choice for large-scale planting. Yet the species was recommended for woodlot planting in Ontario almost a century ago (Ontario Agricultural Commission 1881), and small test plantations were set out at least as early as 1908 at Indian Head in Saskatchewan (Walker and Kerr 1954), about 1910 at the Lakehead in Ontario (Love and Williams 1968), 1912 in the Turtle Mountains in Manitoba (Bella 1968), and between 1907 and 1912 near Grand'Mère, Quebec (Wilson 1913). Experimental plantings of a later vintage were made with white spruce at Blissfield, N.B. in 1929 (Miller 1930), in the Subalpine Region of Alberta in 1947 (Blyth 1955) and in the Cormack area of western Newfoundland in 1958 (Hall 1970). The first trial plantation of white spruce[3] in British Columbia seems to have been established at Bolean Lake in 1952 (Smith 1954).

The earliest example of extensive white spruce planting came from the forest industries with the Laurentide Company establishing 15 mi^2 (39 km^2) of plantations, mostly of this species, near Grand'Mère, during the period 1919-32 (Cunningham 1953). Various pulp company plantings established about 1.5 million white spruce in the 1920's in Ontario, and industrial reforestation was sporadically active in the 1930's and 1940's when the largest single endeavour with this species was the planting of 900 ac (360 ha) at Drummondville, P.Q. (Stiell 1958, Popovich and Houle 1970).

The first forest tree planting by provincial authorities seems to have been in Ontario, in 1908 (Zavitz 1947), and in Quebec in 1912 (Leavitt 1913). Once of minor importance in these programs, the white spruce component has reached a leading position in both provinces. In Manitoba, the passage of the Canada Forestry Act in 1949 provided the impetus for accelerated white spruce reforestation. New

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[3]Now so identified (personal communication from J.H.G. Smith), although originally reported as Engelmann spruce.

or increased regional activity by the pulp and paper industry seems to have been responsible for the inception of large-scale planting of the species in British Columbia, Alberta, New Brunswick and northern Ontario during the 1950's, and in Saskatchewan in the 1960's. By 1965 an estimated total of 300,000 ac (120,000 ha) had been seeded or planted to white spruce in Canada (Cayford and Bickerstaff 1968).

Currently it is part of the reforestation program of every province except Newfoundland. In 1971 an estimated 51.6 million white spruce were planted in Canada, distributed approximately as shown in Table 1. In addition, 1,400 ac (570 ha) were direct-seeded in Alberta, and 300 ac (120 ha) in Manitoba.

Table 1. Geographical distribution of white spruce planting in 1971

Province	% total trees
*British Columbia	10.9
*Alberta	3.0
*Saskatchewan	2.3
Manitoba	4.8
*Ontario	60.2
Quebec	14.5
*New Brunswick	3.6
Nova Scotia	0.5
Prince Edward Island	0.2
	100.0

(*Company involvement, as independent program or in collaboration with provincial authorities, included)

Although there seems to be some disenchantment with white spruce in the Maritimes, owing to the existing or expected difficulties cited, elsewhere some large increases in planting are taking place. This is so in British Columbia, where about 25 million white spruce were sown in nurseries in 1972, and also in Ontario. Saskatchewan has set a target of 5 million trees for 1977, and Quebec is expanding production to 17.5 million trees. The net result for Canada suggests an accelerated white spruce program for some years to come, possibly levelling off at about double the 1971 rate.

Natural Distribution of White Spruce

White spruce occurs in all the forested regions of Canada except the Pacific coast and the hardwood zone of extreme southern Ontario (Hosie 1969). With the possible exception of white birch it is the most widely distributed tree species (Figure 1), and is found on a great diversity of sites. White spruce may grow in pure stands, e.g.,

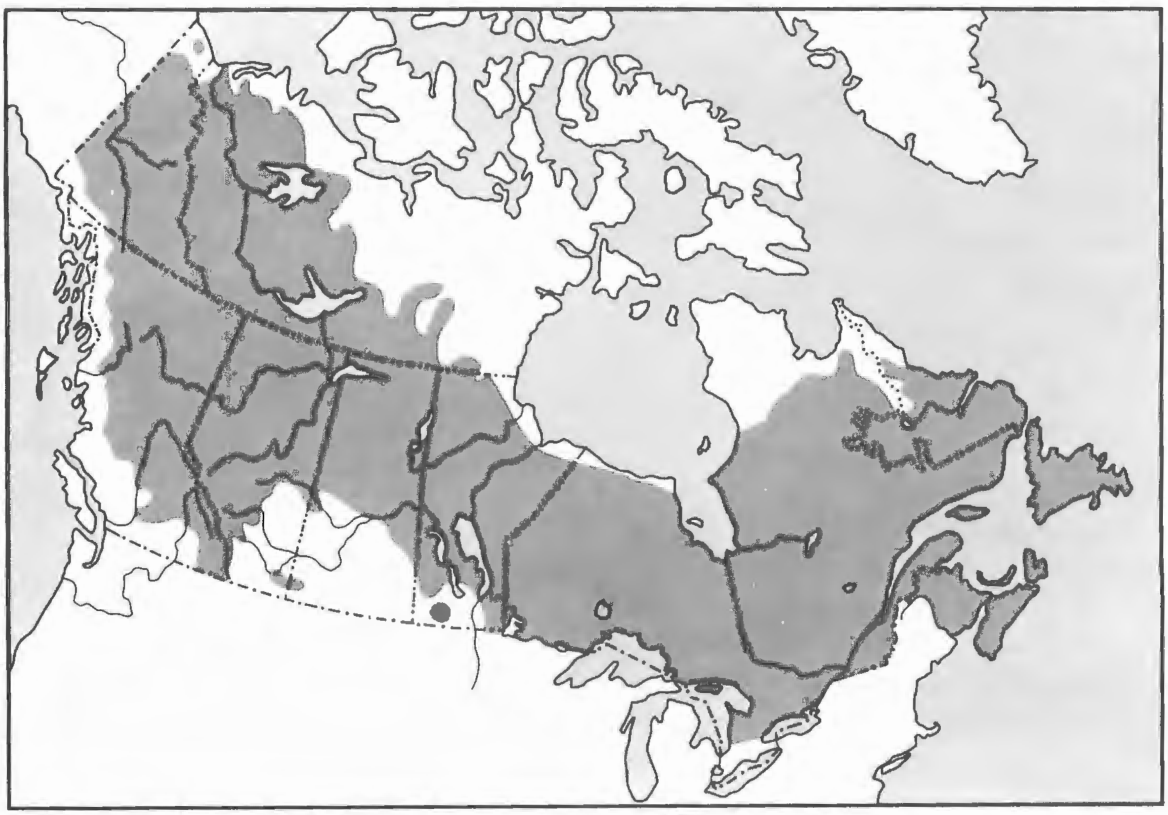


Figure 1. Range of white spruce in Canada. After Hosie 1969.

on alluvial soils along rivers in the Yukon and Northwest Territories (Robinson 1960), on a variety of sites in central Saskatchewan (Kabzems 1971) and western Manitoba (Rowe 1955), and on abandoned farmland in Nova Scotia (Drinkwater 1957), but most characteristically is found in mixtures, and numerous hardwoods and other conifers are included among its natural associates. Thus for many parts of Canada the establishment of pure white spruce plantations introduces a new forest type.

"Western white spruce" and "Porsild's spruce" are two named varieties (Hosie 1969). They are found in western and northwestern Canada. A similar species, Engelmann spruce, occurs east of the Cascades in south and central British Columbia, extending to the east slopes of the Rockies in Alberta (Garman 1953). It is mainly a high elevation tree, and in Canada its range, except at higher altitudes, is largely overlapped by that of white spruce (Figure 2). The two species interbreed freely where they coincide, chiefly at medium elevations, and produce many intermediate forms (Ogilvie 1972, Daubenmire 1974). The variety "western white spruce" is thought by some authorities to be one of these hybrids (Roche 1969*a*). Identification from morphological features can be extremely difficult. The apparently complicated taxonomy of these closely related forms does not in fact cause practical problems in the operation of reforestation programs. In British Columbia all forms are regarded as "interior spruce" for planting purposes and adherence to the seed zone concept described later avoids the necessity of subspecies identification during cone collection. A similar approach is followed in Alberta, the only other province where these questions of nomenclature arise for white spruce.

Two other species crosses have been described for very localized areas. Sitka spruce, a coastal species, hybridizes with white spruce where the ranges of the two species overlap in the Nass, Skeena and Bulkley River valleys of northwestern British Columbia; the area concerened is small, and the hybrids do not appear to have any particular silvicultural significance (Garman 1957, Roche 1970). Putative black spruce-white spruce hybrids are reported from north of

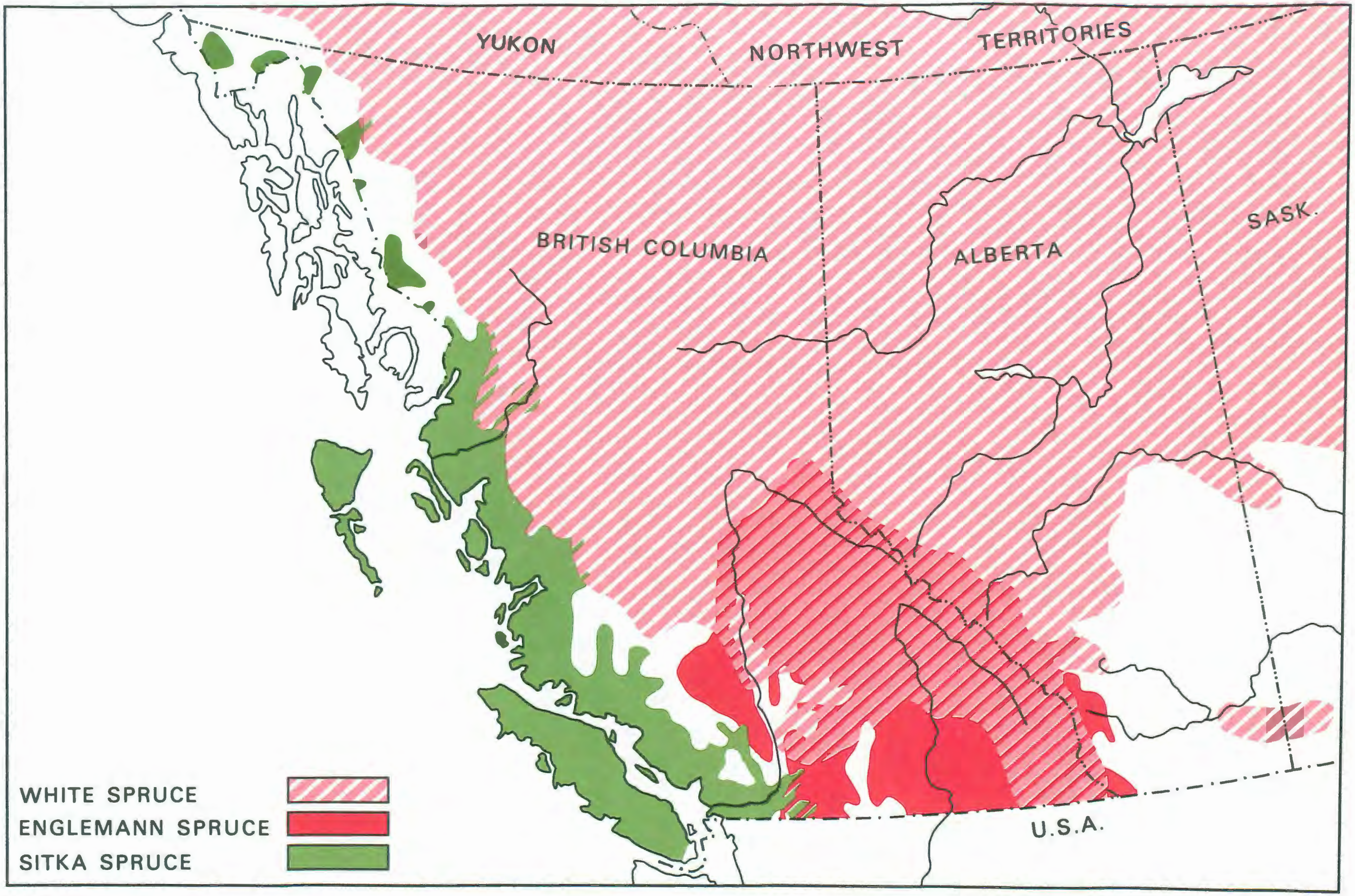


Figure 2. Range of white, Engelmann and Sitka spruce in western Canada. After Hosie 1969.

latitude 57° in British Columbia, where the two species are associated in muskeg stands (Roche 1969*b*).

References to Introduction

Bella, I.E. 1968. Growth of white spruce planted in the Turtle Mountains. For. Chron. 44(3):45-46.

Blyth, A.W. 1955. Seeding and planting of spruce on cut-over lands of the subalpine region of Alberta. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 2.

Cayford, J.H. and A. Bickerstaff. 1968. Man-made forests in Canada. Can. Dep. Fish. For., For. Branch Publ. 1240.

Cunningham, G.C. 1953. Growth and development of coniferous plantations at Grand'Mère, P.Q. Can. Dep. Resour. Dev., For. Branch, For. Res. Div. Silvic. Res. Note 103.

Daubenmire, R. 1974. Toxonomic and ecologic relationships between *Picea glauca* and *Picea engelmanni*. Can. J. Bot. 52(7):1545-1560.

Drinkwater, M.H. 1957. Field spruce in Nova Scotia. Can. Dep. North Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 65.

Garman, E.H. 1953. Pocket guide to the trees and shrubs of British Columbia. 2nd (revised) ed. Dep. Lands For., B.C. For. Serv. Publ. B.28.

Garman, E.H. 1957. The occurrence of spruce in the interior of British Columbia. Dep. Lands For., B.C. For. Serv. Tech. Publ. T.49.

Hall, J. Peter. 1970. Ten-year development of planted conifers in western Newfoundland. Dep. Fish. For., Can. For. Serv. Publ. 1273.

Hosie, R.C. 1969. Native trees of Canada. 7th ed. Dep. Fish. For., Can. For. Serv.

Kabzems, A. 1971. The growth and yield of well stocked white spruce in the Mixedwood Section in Saskatchewan. Sask. Dep. Nat. Resour., For. Branch Tech. Bull. 5.

Leavitt, Clyde. 1913. Forest planting in Quebec. I. By the Provincial Government. *In* Forest Protection in Canada, 1912. Comm. Conserv. Can., Comm. For., Bryant Press, Toronto, Ont. p. 134-136.

Love, D.V. and J.R.M. Williams. 1968. The economics of plantation forestry in southern Ontario. Can. Dep. Reg. Econ. Expans., Can. Land Inventory Rep. 5.

Miller, G.L. 1930. The provincial forest nursery in New Brunswick. *In* 69th Annu. Rep. Dep. Lands and Mines, Prov. N.B. for the Year Ended 31st Oct., 1929. p. 81.

Ogilvie, R.T. 1972. Speciation in the North American spruces and its relation to white spruce. *In* R.G. McMinn (ed.) White Spruce: The Ecology of a Northern Resource. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-40:1-7.

Ontario Agricultural Commission. 1881. Report of the Commissioners and Appendices A to S. C. Blackett Robinson, Toronto, Ont. p. 144, 149.

Popovich, Stevo et Normand Houle. 1970. Etude préliminaire de trois plantations du Québec (croissance, rendement et productivité). Ministère des Pêches et des Forêts, Service canadien des Forêts Rapport d'Information Q-F-X-3.

Robinson, J.M. 1960. Forest resources of the Northwest Territories portion of the Mackenzie River basin. Polar Rec. 10(66):230-236.

Roche, L. 1969*a*. A genecological study of the genus *Picea* in British Columbia. New Phytol. 68(2):505-554.

Roche, L. 1969*b*. Introgressive hybridization in the spruce species of British Columbia. *In* C.W. Yeatman (ed.) Proceedings of the Eleventh Meeting of the Committee on Forest Tree Breeding in Canada. Part 2. Can. Dep. Fish. For., For. Branch. p. 249-270.

Roche, L. 1970. The silvicultural significance of geographic variation in the white Engelmann spruce complex in British Columbia. For. Chron. 46(2):116-125.

Rowe, J.S. 1955. Factors influencing white spruce reproduction in Manitoba and Saskatchewan. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 3.

Smith, J. Harry G. 1954. A cooperative study of Engelmann spruce - alpine fir silviculture and management. Northwest Sci. 28(4): 157-165.

Stiell, W.M. 1958. Pulpwood plantations in Ontario and Quebec. Can. Pulp Pap. Assoc., Woodlands Sect. Index 1770 (F-2).

Walker, John and W.L. Kerr. 1954. Dominion forest nursery stations progress report 1947-1952. Can. Dep. Agric., Exp. Farms Serv.

Wilson, Ellwood. 1913. Forest planting in Quebec. II. Planting by The Laurentide Company. *In* Clyde Leavitt, Forest Protection in Canada, 1912. Comm. Conserv. Can., Comm. For., Bryant Press, Toronto, Ont. p. 136-137.

Zavitz, E.J. 1947. Reforestation in Ontario. Can. Geogr. J. 34(4): 156-180.

White spruce plus tree, ca. 120 ft (37 m) tall, 150+ years old. Fort Babine Road, B.C. Canadian Forestry Service photo.

II. SEED CHARACTERISTICS AND HANDLING

Choosing seed with a potential for producing high-performance stock should be the first step in a reforestation program. Since this potential is genetically determined, it can only be ensured by selection of seed from parents of known attributes and origin. In practical terms this involves collecting seed from trees (1) demonstrated to be adapted to local conditions, and (2) with good form, growth rate or other desirable qualities. Results can be extremely poor if the first of these principles is ignored, and optimum performance can never be attained without applying the second. Research into some aspects of tree improvement is active for white spruce in every province in Canada, and these programs are expected, by selection and breeding, to identify and propagate superior types from which seed will eventually be available (Nienstaedt and Teich 1971).

Collection, transport, extraction and storage are the next stages in seed procurement, and each must be performed to a high standard if the full ptential of the chosen seed is to be realized.

Seed Source

A local population of a tree species has, over the ages, become adapted to its particular environment through processes of natural selection, and the manner in which it reacts to that environment is passed on from one generation to the next. Such a population may not perform well if introduced to another area, even within the overall range of the species, where soil and/or climatic conditions are different. It is considered safest, therefore, only to use planting stock derived from seed collected near the planting site, or at least within the area where similar ecological conditions prevail. Such areas of uniform environment ("seed zones") have been delimited, often quite broadly, for many forested portions of Canada. Tests with young trees of several spruce species suggest that zones should not exceed 2^{o} latitude in width or 200 m (660 ft) in altitude

(Morgenstern and Roche 1969).

Most authorities responsible for reforestation programs in Canada now recognize the seed-zone principle. In the mapping of zones, criteria have differed somewhat from one province to another, but the general aim has been to define zones in which ecological conditions are uniform; compromise is sometimes made with political or administrative boundaries to simplify application of the system. In defining nine seed zones in the Maritimes (Figure 3), Fowler and MacGillivray (1967) took into consideration climate, latitude, spring phenology and Loucks' (1962) forest classification. Thirteen provisional *zones de récolte* (Figure 4) have been recognized in Quebec (Campagna and Fortin 1971), based largely on Rowe's (1959) forest sections (areas characterized by distinctive patterning of vegetation and physiography), but with prevailing temperature and precipitation taken into account (Boissinot 1973). Ontario's 13 "seed collection zones" (Figure 5) are modifications of site regions (climatic regions within which the relation between plant succession and landform is reasonably uniform) as described by Hills (1961) and Hills and Pierpoint (1960). Boundaries of the 12 "seed control zones" proposed for Manitoba (Figure 6), were based on the existing knowledge of the genetic variation within species, and local climatic, physiographic and vegetation data (Calvert undated). No formal seed zones have been established in Saskatchewan, although 12 zones on an east-west basis have been chosen for practical testing. In Alberta, delineation of seed zones is under consideration and at present the use of seed is restricted to within 50 mi (80 km) of, and 500 ft (150 m) above or below, the collection site (Kennedy 1969, 1970). British Columbia has 67 seed zones (Figure 7), based primarily on climatic characteristics but also restricting seed movement to 100 mi (160 km) north or south, or 500 ft (150 m) vertically, from the point of origin. The large number of zones in British Columbia is occasioned by the often steep terrain and large elevational differences within short lateral distances.

The foregoing nothwithstanding, provenances (geographic seed sources) are sometimes discovered which will produce seedlings capable

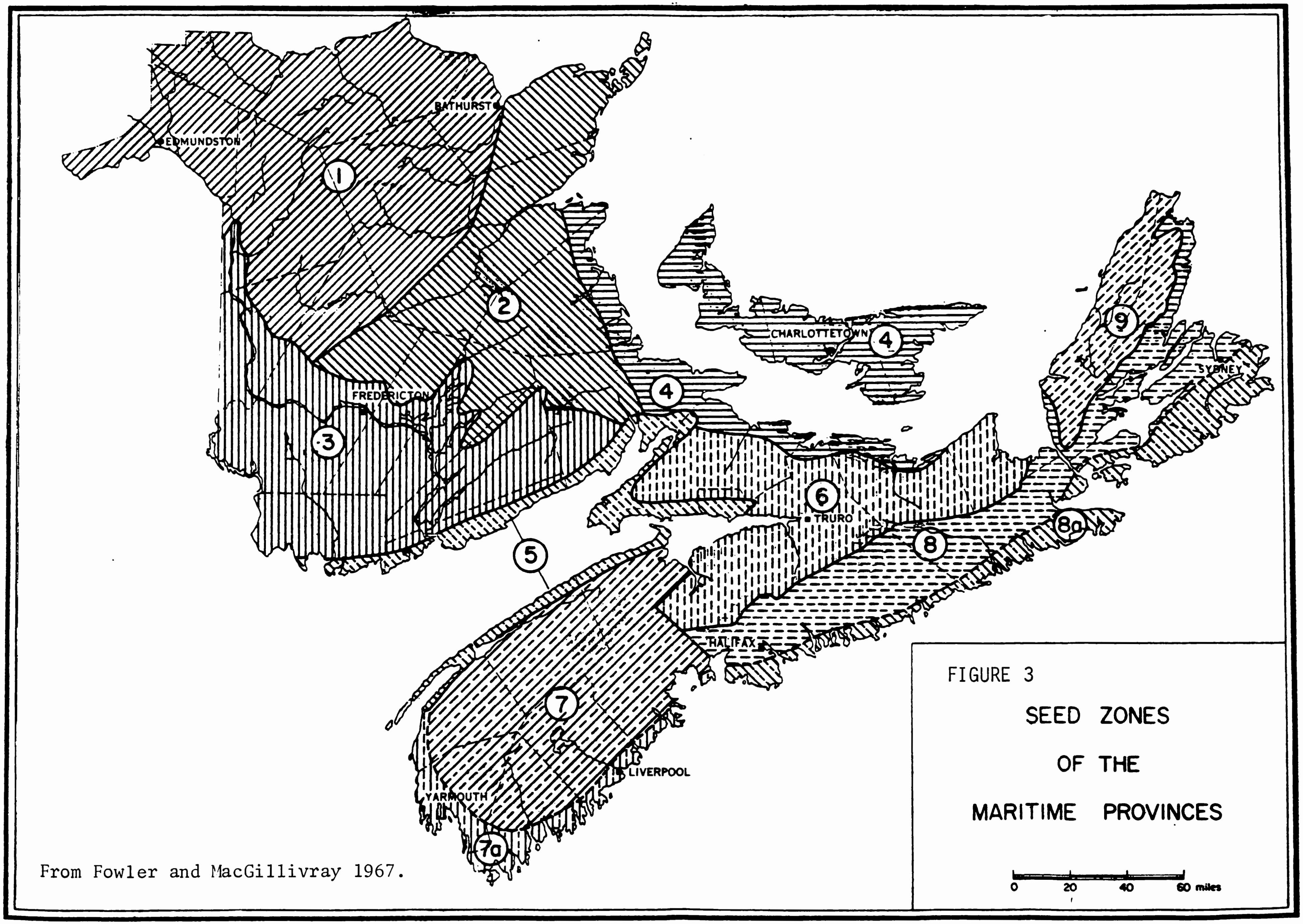
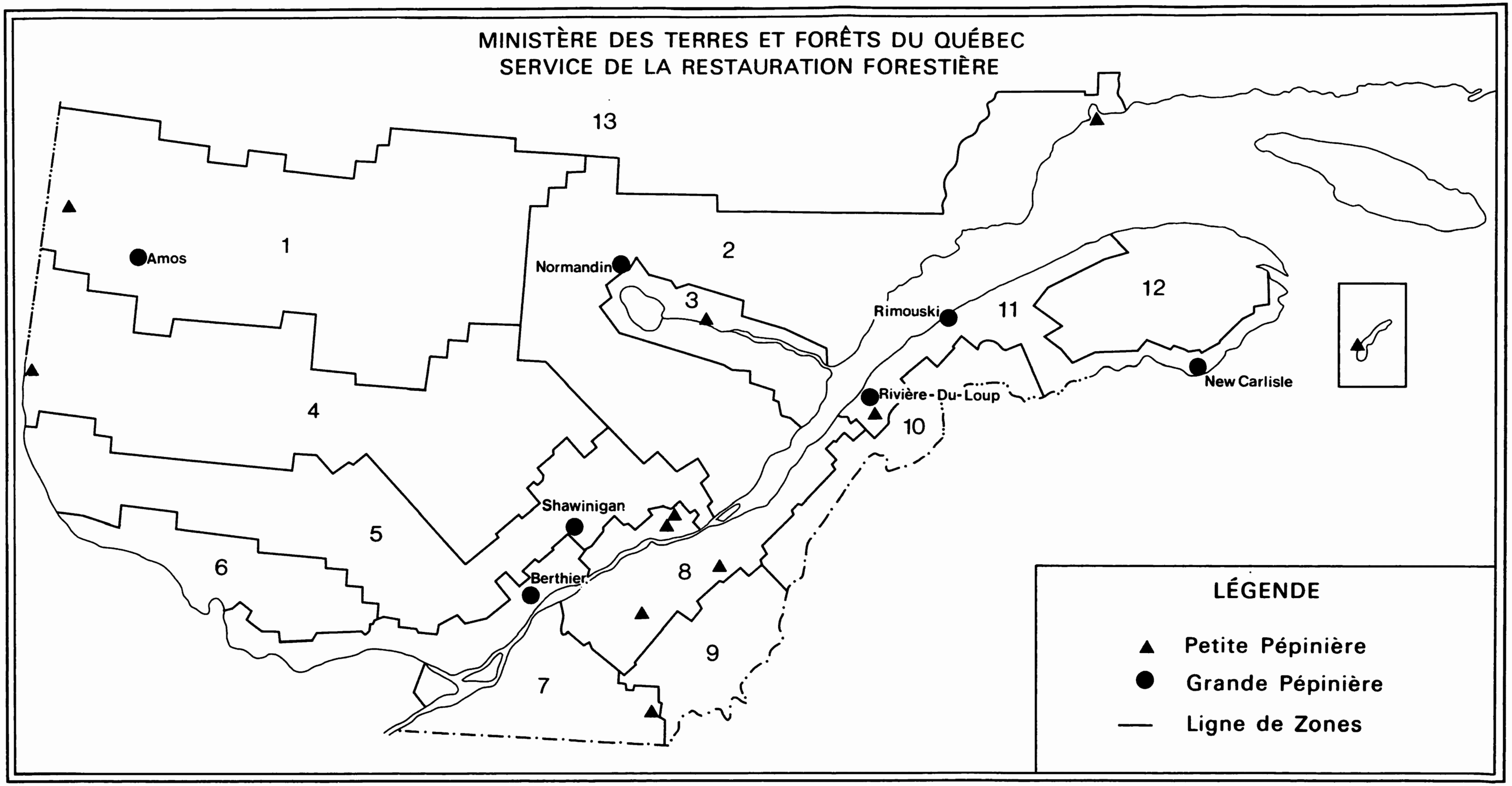


FIGURE 3

SEED ZONES OF THE MARITIME PROVINCES

From Fowler and MacGillivray 1967.



Carte montrant la délimitation des zones de récolte de semences forestières et la localisation des pépinières forestières du ministère des Terres et Forêts.

Figure 4. Collection zones for forest tree seed in Quebec.

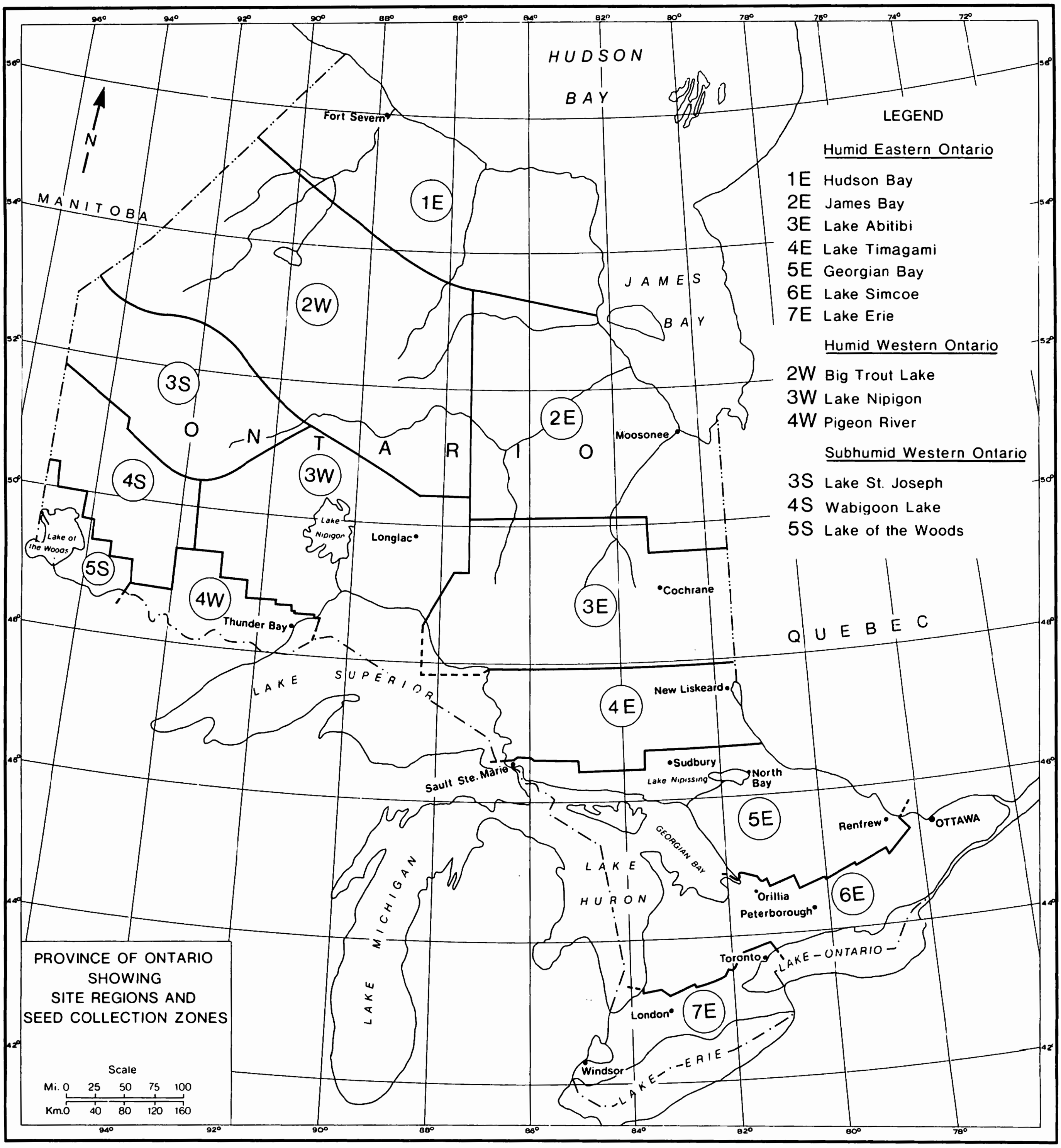


Figure 5. Ontario seed collection zones. After Hills 1961.

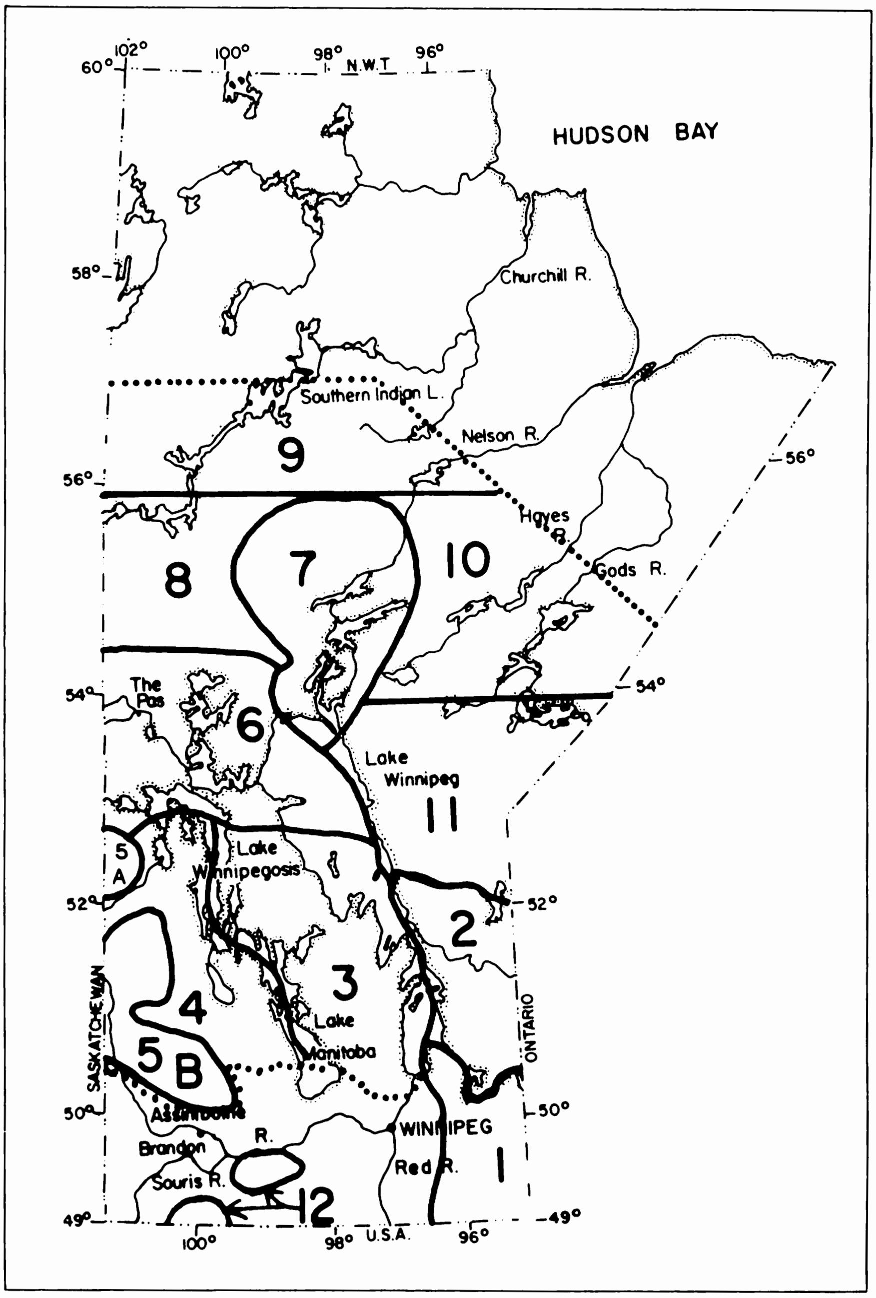


Figure 6. Proposed seed zones for Manitoba. From Calvert undated.

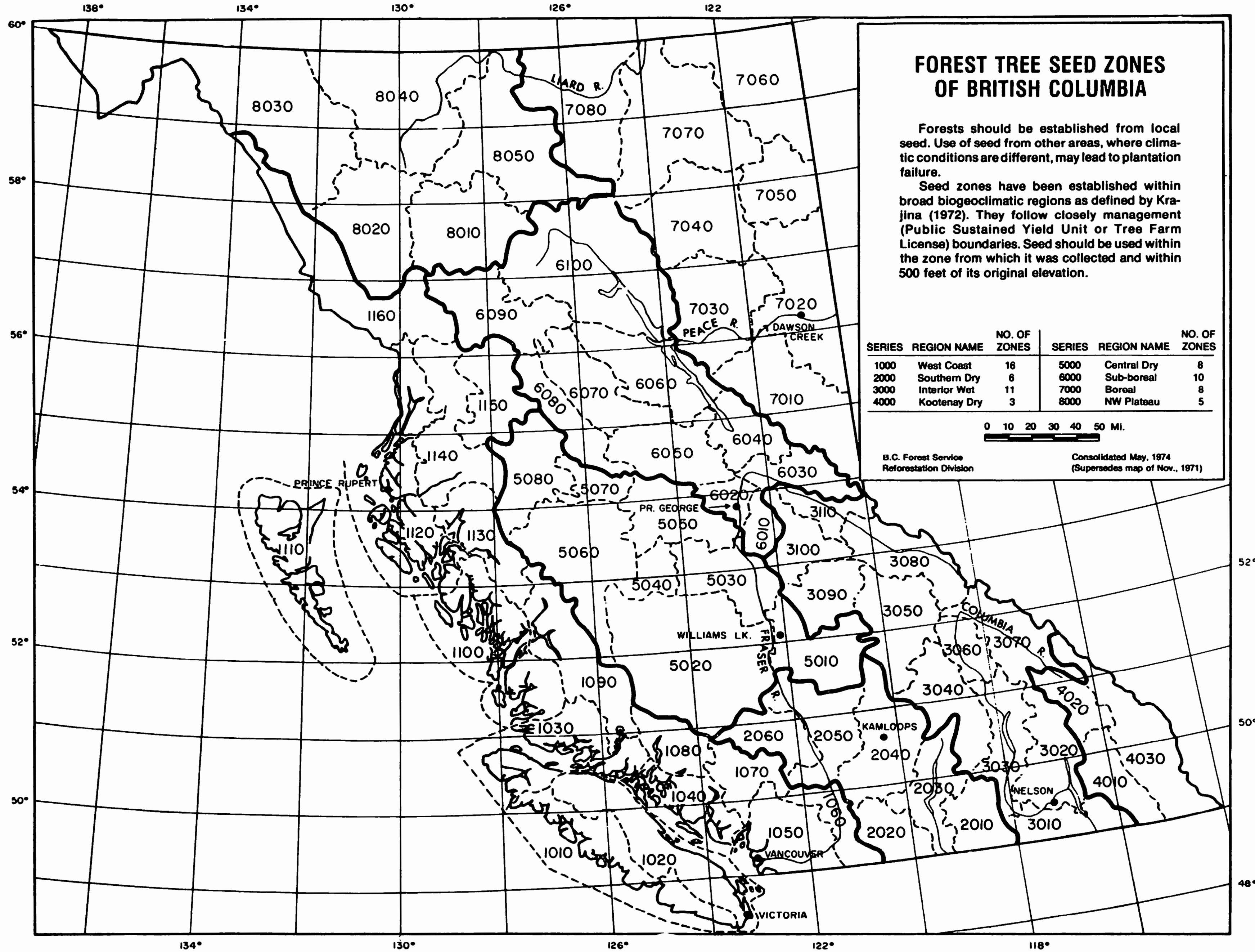


Figure 7. Forest tree seed zones of British Columbia.

of outperforming the local stock. Tree improvement research has turned up some specific seed sources for white spruce in which juvenile growth and hardiness were superior to that of the local provenances against which they were tested (Nienstaedt 1969). Stock derived from some sources in Ontario has shown exceptional early growth elsewhere in Ontario (Teich, Morgenstern and Skeates 1975) and in Quebec and the Maritimes as well (Teich 1973). However, until performance of a particular provenance has been worked out for local conditions, the seed-zone approach appears safest. It is to be expected that some currently accepted zone boundaries will be subject to modification as provenance trials test their validity (Calvert undated). A major source of material for provenance research comprises about 1,000 white spruce seedlots, collected from many areas across Canada and the northern United States, identified as to geographic source and stored in the seed bank at the Petawawa Forest Experiment Station, Chalk River, Ontario (Pickett 1974).

Seed Production

Seed-bearing Age

White spruce is an early and prolific seed bearer. Cones have even been observed on a four-year-old transplant the summer after spring planting (Sutton 1969). In New York State, white spruce have been reported bearing cones in "collectable quantities" at 12 to 15 years (Kennedy 1952). In white spruce plantations, growing at spacings of 5 x 5 ft (1.5 x 1.5 m) at the Petawawa Forest Experiment Station, Chalk River, Ontario, 8% of trees were cone-bearing at age 20, 22% at age 25, and 55% at age 30 years (Stiell 1955). A plantation established as a seed production area at Orono, Ontario, produced a collectable crop 12 years after planting[4]. In mixedwood stands in Manitoba and Saskatchewan seed production by white spruce begins at

[4]Personal communication from Douglas A. Skeates.

ages of 45 to 60 years (Rowe 1955). The *Woody Plant Seed Manual* gives 30 years as the minimum commercial seed-bearing age, with 60 years as the optimum (U.S. Department Agriculture 1948), figures which are confirmed for Ontario (Ontario Department Lands and Forests 1966). Since it is desirable to collect from stand-grown trees, which for their age have smaller crowns and smaller cone-bearing potential than open-grown individuals, crops of commercially worthwhile size can be expected from trees of middle age or older.

Phenology

White spruce characteristically flowers for a short period in May or June (Canada Department Forestry 1961), with dates progressing from south to north. For example, an observation of pollination as late as July 27 was made on the northeast shore of James Bay near latitude 55^{o} (Hustich 1950). Male strobili occur most abundantly in the middle portion of the crown, and female strobili in the upper crown (Eis 1967*b*). The heavier the crop, the further down the crown the cone-bearing zone extends (Waldron 1965). The cones mature during the same year, with seedfall occurring, on the average, 98 days after pollen-shed according to a study at Indian Head, Saskatchewan (Cram and Worden 1957).

Cones ripen in all parts of Canada in August-September, the exact time depending on locality and prevailing weather, and sometimes a few days later in more northern regions. Earliest and latest dates reported for Ontario are August 15 and September 29 respectively (Ontario Department Lands and Forests 1966).

Collection should not be delayed once cones are considered ripe, since they then open within a few days and begin shedding seed (Ontario Department Lands and Forests 1966). The majority of white spruce seeds are dispersed within a few weeks, but a small proportion may remain in the cones for the better part of a year (Rowe 1953). In Saskatchewan, Cram and Worden (1957) found that seed yield increased 40%, and germination of stratified seed increased 14%, in the last four weeks of maturity; maximum yield of seedlings per cone was obtained when harvesting was delayed until three to six days before natural seedfall. On the other hand, after-ripening will proceed in cones picked a short time before maturity, allowing some leeway in collection time (Levy 1970). From a study at Kananaskis, Alberta, Crossley (1953) concluded that cone picking as much as two weeks early would be effectual, although some reduction in viability would have to be accepted. However, success with this approach apparently depends on storing the cones under relatively cool conditions, i.e., less than 24°C (75°F) (Zasada 1973).

Determination of Seed Ripeness

Many indications of ripeness are employed. The real criterion is the condition of the embryo -- it is mature when it fills the seed cavity, and little anatomical change occurs after it reaches maximum size (Rauter and Farrar 1969). This can be determined with X-rays, a method used at seed plants, but cutting is the practical field test and seed is usually considered ripe when 75% of the cavity is filled. Other direct indications of ripeness are a darkening of the seed coat to deep brown or black; firmness or brittleness of the seed (Crossley 1953, Ontario Department Lands and Forests 1966); and lack of exuded moisture when the seed is crushed.

Cone condition is commonly used to judge seed maturity. Ripeness is usually presumed when the cone colour turns from green to brownish, although Crossley (1953) found this unworkable at elevations of about 5,000 ft (1,520 m) near Kananaskis, Alberta where red-coned as well as green-coned spruce types occur; he found flexibility of the cone when pressed between finger and thumb a reliable indicator of ripeness. Cram and Worden (1957) reported that cones are ready to collect when their moisture content falls to 48%. They recommended that commercial collectors test ten fresh cones in a container of turpentine or kerosene, and delay collecting until nine cones float in the turpentine or eight in the kerosene. In another specific gravity test, cones are said to be mature when they begin to float in water, and collection should be completed within the following eight days. Yet again, if white spruce cones stand upright on the bottom of a container of linseed oil, or rise slowly, they are ready to collect (Carman 1953). Another approach is based on accumulated temperature above 5°C (41°F) experienced by the cones. In a test in Alaska of white spruce seed collected at latitude 64°51', and stored under relatively cool conditions, maximum germination was found with a summation of ca. 625 to 681 degree-days after June 1st, or somewhat before some of the usually accepted external signs of cone or seed ripeness appeared (Zasada 1973).

Most authorities agree on the importance of observing cones closely during the last stages of maturity so that the optimum period for collection is not missed. Periodic cutting tests should be made to judge the extent of insect damage and proportion of hollow seed.

Seed Crop Frequency

Reports on white spruce seed crop periodicity are extremely variable. According to *Woody Plant Seed Manual* good seed crops occur every two to six years, with light crops in intervening years (U. S. Department Agriculture 1948). One 8-year period in Wisconsin produced one bunper, one good, three medium and one poor crop, and two failures (Stoeckeler and Jones 1957). One stand in Riding Mountain Forest, Manitoba, which was observed for ten years, produced one heavy crop (65% of trees bearing cones) in that period, with four moderate and two light crops, and three failures (10% of trees bearing cones); dominant and codominant trees produced heavier crops and produced them more frequently than did lower crown classes (Waldron 1965). Elsewhere in Manitoba, records indicate heavy cone crops occurring in 12 out of 40 years (Rowe 1955). There may be regional patterns in Canada, where reports of crop frequency range between "every two or three years" and "every five to seven years". The interval may be even greater in far northern regions, according to observations on white spruce in Alaska (Zasada and Viereck 1970). The only real consensus seems to be that good crops are borne irregularly, but on the average about every four years. Local experience may eventually lead to more precise forecasts for specific, limited areas.

Collection is generally considered worthwhile only in a good seed year. Since bud information in white spruce commences in July of the year before flowering (Fraser 1962), a direct estimate of the potential cone crops can be made one year before it matures by counting ovulate (female) buds on one branch of each of several trees in September (Eis and Inkster 1972). This method is accurate when applied, but unfavourable weather during and after flowering, insect attacks, cone rusts etc. can effectively reduce the actual cone crop well below the previous year's estimate; on the other hand, a potentially poor crop can be identified with certainty (Eis 1967).

Crop Size

Cone yields vary widely, as indicated in Table 2. The maximum value of 2 bu (0.73 hl) of cones per tree cited for Ontario is also reported from Alberta. From the table, this should mean at least 13,200 cones per tree. However, in 1950 what was described as a very heavy crop in southern Ontario averaged 8,000 cones per tree, and in 1954 a "fairly good" crop at Indian Head, Saskatchewan yielded 2,112 cones per tree (Tripp and Hedlin 1956). Variable stand density and individual tree size no doubt contribute to some of these disparities. For example, in the Riding Mountain stand cited earlier, dominant trees produced more cones than codominants, and intermediate and suppressed trees progressively fewer still (Waldron 1965). In practice, small trees are disregarded in cone collection.

Yields per acre will naturally depend on numbers of cone-bearing trees. About 50 seed trees per ac (125/ha) have been reported for one district in Alberta. The Riding Mountain stand had 102 dominants and codominants per ac (252/ha), which produced the bulk of the crop (Waldron 1965). In 1960 a "very heavy" crop from mixedwood stands in northwestern Ontario, containing probably less than 20 cone-bearing white spruce per ac (50/ha), produced an estimated 31,500 cones per ac (77,800/ha) (Hughes 1967).

Table 2. Some expressions of white spruce cone and seed yield

Measure	Value			Source
lb cones/bu (kg/hl)	23.0		(28.7)	Levy 1970
closed cones/bu (cones/hl)	6,600-8,500		(18,100-23,400)	Ontario Dep. Lands & Forests 1966
	*6,500-8,000		(18,400-22,700)	U.S. Dep. Agriculture 1948
bu cones/tree (hl/tree)	2		(0.7)	Ontario Dep. Lands & Forests 1966
	*1.0-2.5		(0.35-0.88)	U.S. Dep. Agriculture 1948
oz clean seed/bu cones (g/ℓ)	12		(9.4)	Ontario Dep. Lands & Forests 1966
	*6-20		(4.8-16.1)	U.S. Dep. Agriculture 1948
	*24		(19.3)	Eliason 1952
	11.8-14.0		(9.2-10.9)	Wang 1973
clean seed/lb (seed/kg)	Low	Average	High	
	184,000 (405,600)	267,000 (588,600)	350,000 (771,600)	Ontario Dep. Lands & Forests 1966
	135,000 (297,600)	226,000 (498,200)	401,000 (884,000)	Cited by Safford 1974

*These values and their metric equivalents refer to U.S. bushels:
1 U.S. bu = 0.968,938 imperial bu = 35.238,08 ℓ

The quantity of sound seed finally realized is very much less than the number of seed actually produced. One study showed that only 66% of all seed formed were from the central portion of the cone capable of producing fertile seed; in addition, many potentially fertile seed are hollow, owing to insect feeding -- at least 47% each year in Ontario and Saskatchewan according to one estimate (Tripp and Hedlin 1956). Empty seed also result from lack of pollination. In the Riding Mountain investigation it was found that the proportion of sound seed was lower in years of light seedfall, and lower in small than in large cones. In the heavy crop year, seedfall was estimated at 5.6 million seed per ac (13.8 million/ha), but only 59%, or 3.3 million (8.2 million/ha), were sound (Waldron 1965). At 267,000 seeds per pound (Table 2) this would be equivalent to 12.4 lb of seed per ac (13.9 kg/ha). In a year of "moderate" seed production it was estimated that 1.0 million sound seeds were shed (Waldron 1965) or, at the above rate, 3.7 lb per ac (4.1 kg/ha), and the 10-year average was, likewise, equivalent to 2.5 lb of sound seed per ac (2.8 kg/ha) per year. This last value may be compared with the 2.4 lb seed per ac (2.7 kg/ha) cited as the expected yield from white spruce seed production areas in the North Central Region of the United States -- presumably a yearly average (Pitcher 1966).

Seed Procurement

Parent Tree Characteristics

Cones should be picked from trees showing desirable characteristics, although there is no guarantee that these will be exhibited by all of their offspring, owing to open pollination and uncertainty as to the other parent's attributes. It is likely, however, that average quality of the progeny will be better than if only random selections were made; and if quality is generally high throughout the stand where cones are collected, chances are also better for good quality seedlings. Healthy trees exhibiting good form and growth rates and evidence of good cone yields are obvious candidates for collection. As far as form and stature are concerned, it is performance in the stand that counts, and this may be hard to judge if collecting from open-grown trees, which should therefore be avoided unless specific information about them is available. Other desirable characteristics cited for white spruce are wind firmness; short branches, neither thick nor drooping; high degree of self pruning; freedom from heart rot under old-field conditions; good expression of dominance in the stand; late flushing to avoid spring frosts; early attainment of rapid height growth; freedom from spruce galls; resistance to snow fungus; ability to escape serious sawfly injury (Rudolf 1956). This is a formidable list and the attributes are scarcely of equal importance, nor are they inherited to the same degree. Two of them considered very desirable in Canada are evasion of late frosts and early assumption of rapid growth. Teich and Pollard (1973) reported two provenances from Ontario which, by combining fast growth with early flowering, would be of particular value to breeding programs if they maintain the rapid growth in later years.

Seed Production Areas

A means of putting seed supply on a systematic basis is the development of seed production areas (SPA's). These are stands chosen for their above average quality and managed exclusively for optimum production of seed. Benefits are assured, protected, and concentrated sources of supply, and maintenance of consistent seed quality. In addition, geographic origin is positively identified, parental type is selected, and the SPA has a residual timber value when no longer required for its original purpose (Pitcher 1966). In the North Central Region of the United States, seed produced in white spruce SPA's cost much more than purchased seed, but the increase in cost of nursery transplants raised from SPA seed was less than 1%; this seed gave more seedlings per pound and the seedlings seemed more vigorous (Pitcher 1966). Similarly, in Ontario, costs of collecting white spruce seed from SPA's are 100% greater than general collection but minimal in relation to the genetic gains expected to be obtained in a relatively short time (Rauter 1974).

Seed production areas should be located in all seed zones where collecting (and planting) are to be carried out. Recommendations for white spruce SPA establishment in the Lake States called for selecting superior stands, not less than 30 years old and preferably 45 to 60 years (Rudolf 1959). In Nova Scotia it was recommended that priority be given to stands: with a high proportion of fast growing trees; large enough to yield about 500 dominants or codominants of superior form and performance; located on sites similar to those expected to be reforested; aged 40 to 50 years at stump height; containing 60% or more of the volume in white spruce; with at least 50% of the spruce having a height/age ratio greater than 1.16 (Sidhu 1972). In Ontario, younger stands are preferred so that full-length crowns can be retained, and some plantations of good quality have been chosen for SPA's, partly owing to scarcity of pure white spruce natural stands (Lane 1976).

Stands should be cleaned of small and inferior spruce, other tree species and brush as well. Thinnings should be made in two or more stages to encourage good crown development of the best trees, ca. 30 to 170 per ac (75 to 420/ha), leaving them at an average spacing of about half stand dominant height. To prevent contamination from unwanted sources of pollen a 400-ft (120-m) wide surround should be treated in the same way as the SPA proper, or else cleared of all white spruce. The SPA should be afforded normal protection, and measures should also be taken to control squirrels. A road system to allow future access by trucks and cone-picking equipment should be installed at the time of thinning (Rudolf 1959, Sidhu 1972). Fertilizing has been recommended to promote seed production, but effective treatments have not been reported for white spruce, and the need is probably not very great for a species which is such a prolific seed bearer, in comparison with some others. Some success in promoting early flowering in 10-year-old white spruce, through a combination of fertilizing with 200 g (7 oz) ammonium nitrate per tree at the end of May and root pruning a week later, was reported by Holst (1961).

Nearly all provincial governments appear to acknowledge the merits of SPA's, and either have active programs or are seeking suitable white spruce stands for seed production management. Ontario has the most advanced system, with a total of 13 areas, comprising 215 ac (87 ha), located in seed zones where planting is most active. Forest services in Prince Edward Island, Saskatchewan, Alberta and British Columbia all have selected, thinned and cleaned white spruce plantations or natural stands for seed production. No provincial program is yet considered complete. At least one industrial white spruce SPA has been established -- by Kimberly-Clark Pulp and Paper Company in northern Ontario (Humphreys 1967).

Seed Orchards

Forest tree breeders regard SPA's as temporary measures to be superseded in time by seed orchards. A seed orchard is a plantation "of genetically superior trees, isolated to reduce pollination from genetically inferior outside sources, and intensively managed to produce frequent, abundant, easily harvested seed crops. It is established by setting out clones (as grafts or cuttings), or seedling progeny, of trees selected for desired characteristics" (Zobel *et al.* 1958). A seed orchard is based on the results of tree improvement research, and thus is a long-term endeavour, at least to the point where seed will be available in quantity. To save time, orchards may be established before evaluation of the quality of the material is complete, and gradually upgraded by removal of less promising individuals as they are recognized as such. The planting stock for seed orchards is provided through "plus tree" programs which entail the selection of superior parent trees and the collection of cones and/or scions from them. The rigours and rationale involved in setting standards for white spruce plus trees, as well as the practicalities and test procedures needed for such programs, have been described by Kiss (1976) and Teich (1975).

Fairly high seed yields may be realized at young ages in seed orchards. Rudolf *et al.* (1974) cited an average annual production estimate of 25 lb per ac (28 kg/ha). White spruce grafts planted at 15 x 15 ft (4.6 x 4.6 m) would be expected to produce 15,672 cones per ac (38,725/ha) at nine years, or enough seed from a 7-ac (2.8-ha) orchard to produce 4 million plantable seedlings, according to one experiment in Wisconsin (Nienstaedt and Jeffers 1970). The value of a seed orchard as a continuing source of high quality material for planting stock justifies quite intensive cultural methods, including fertilizing, spraying, mowing, discing and drainage, as may be indicated to protect the trees and encourage cone production (Rudolf *et al.* 1974).

While authorities in several provinces anticipate developing white spruce seed orchards eventually, a start has only been made in two. The Ontario Ministry of Natural Resources has three grafted orchards, totalling 25 ac (10 ha) and involving a large number of clones; none are old enough to produce worthwhile quantities of seed. Kimberly-Clark Pulp and Paper Company has seed orchards of both grafted and seedling white spruce (McPherson 1971). In British Columbia, scions have been collected from plus trees, and grafted preparatory to setting out in seed orchards (Kiss 1972).

Cone Collection

Buying cones in bulk without knowledge of their geographic origin, or the type of trees from which they were picked, is to be avoided and has to a large extent been discontinued. Most authorities now prefer to designate the stands, or even the trees, from which cones will be collected, and to rule on the state of cone maturity before picking begins. Exercising at least this degree of supervision, organizations may employ their own crews for the job, or purchase cones by contract. Prices quoted in 1972 varied between provinces and localities from $2.75 to $9.80 per bu ($7.55 to $27.00 per hl). The 1975 rates on white spruce SPA's in Ontario were $35.00 per hl ($12.70 per bu) (Lane 1976).

The standard unit of cone measurement has been the bushel (0.36 hl), with 1- or 2-bu burlap bags the standard containers. A precisely calibrated metal, plastic or wooden measure is used for checking actual quantities. The bushel will soon give way to a metric unit, as has already occurred in Ontario and Quebec where the hectolitre has been adopted, with 0.4 hl (1.1 bu) the standard measure.

It is difficult to collect from white spruce in closed stands, where cones are confined to the top quarter or third of the crown. General cone collections are therefore most often made from trees which have been felled for the purpose, or in the course of summer logging. In the latter case, supervisory personnel may mark selected trees with flagging in advance of cutting.

Felling is of course out of the question when collecting cones from plus trees or SPA's, except for the final harvest. These seed trees may be climbed inside the crown, and hooks used to pull cone-bearing branches in towards the climber, who picks directly into a shoulder bag or sack hooked to the tree (Dobbs *et al.* 1974). Crew safety and efficiency can be greatly improved through practical instruction in climbing techniques. Extension ladders are also used for cone collection, and where the trees are adequately spaced portable towers are efficient. The Ontario Ministry of Natural Resources has developed a trailer-mounted, hydraulically elevated, telescoping tower with a maximum platform height of 54 ft (16.5 m), lateral platform reach of 9 ft (2.7 m), and rotation of 360°; the trailer is 16 ft 4 in. (5.0 m), long by 7 ft (2.1 m) wide[5]. Another piece of equipment which has been operated in Ontario SPA's (although its use with white spruce was not reported) is a portable utility platform, 2.5 x 3 ft (0.8 x 0.9 m) resting on a hydraulic cylinder and powered by a portable generator; maximum height of the elevated platform is 24 ft (7.3 m), and the unit is mounted on a two-wheeled trailer, towed by a tractor (Eng 1971). Similarly, a bucket mounted on an articulated hydraulic arm, as employed by utility companies, is useful for picking along roadsides, or from very open-grown trees where the terrain is suitable; this

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[5]Cone-picking tower. Ontario Dep. Lands and Forests. Mimeo, 3 p.

method is used at the Indian Head Nursery, Saskatchewan, where large, full-crowned, planted white spruce make up the seed source.

On one white spruce SPA in Michigan, some trees were topped, by climbing and sawing, at a point where stem diameter was 2 to 4 in. (5 to 10 cm); falling cones were collected on a plastic sheet on the ground, and the remainder stripped from the severed top at the nursery; collection costs were reduced by about 68%. By only topping 10% of trees at one time, several collections would be possible, and topped trees appeared to be developing new cone-bearing crowns (Slayton 1969). This author also suggested shooting off spruce tops with a 30.06 rifle. The amount of crown removed seems critical with these techniques if satisfactory regrowth is to take place.

A promising device for harvesting cones is a hydraulic tree shaker. This machine is clamped to the stem, and vibrates rapidly, shaking off the ripe cones (FAO 1968). Trials by the Alberta Forest Service indicate that design modifications of existing equipment will be needed for satisfactory performance with white spruce. Shakers, manufactured in Canada and the United States, can be mounted on wheels or tracks. If perfected, these machines would be well adapted to use in SPA's where good access and large, concentrated production would offer the most economical possibilities.

An entirely different approach, and one widely used in Canada, is the exploitation of squirrel caches which can be found easily in the duff, under roots, in hollow logs etc. within the stand. Viability of seed from squirrel-cut cones has been found to be at least as good as that from cones collected directly from the tree (Wagg 1964). The ability of a squirrel to distinguish between cone-bearing trees with good growth characteristics and those with bad is immaterial provided the general quality of the stand is sufficiently high to warrant cone collection in the first place.

A novel collection method which has been suggested in Alberta, and elsewhere (U.S. Department of Agriculture 1948), although perhaps not attempted with white spruce, would involve recovering shed seed from the surface of ponds or backwaters, where very large numbers sometimes accumulate. The seed would have to be collected and dried out promptly to prevent germination.

Field Storage and Transport

After cones have been collected there may be a delay before they can be shipped to the extraction plant (usually by a less than two-day truck haul). Fresh cones have a moisture content of nearly 50% (Cram and Worden 1957), and during the waiting period it is necessary to prevent them from overheating and moulding, which can seriously diminish germination per cent. The surest procedure is to spread the cones under cover, on trays, plastic sheeting or a floor, to dry out. This may take two days to a week, during which cones should be turned or stirred at least once a day (Ontario Department Lands and Forests 1966). Permanent cone-drying sheds near collection points would be advantageous. In one district in Alberta cones are dried in local sports arenas, packed into sacks with scoop shovels, and loaded onto trucks by portable conveyor. Some authorities feel that cones can be bagged as soon as they are picked, and it is sufficient simply to spread out the full sacks and keep them shaded and ventilated until shipped. In fact, sacks should only be partially filled, to allow for expansion of cones as they dry (Dobbs *et al.* 1974). Burlap is suitable for bags because it is not airtight; plastic, on the other hand, prevents aeration and promotes heating and moulding (Wang 1973).

It is necessary to identify each seed lot (seed from one cone collection), from harvesting right through intervening processes to sowing in the nursery bed, and thereafter the seedlings derived from that lot to ensure their ultimate planting in the appropriate seed zone. As a first step in record keeping, the species, collector, harvest date, exact geographic location, stand description and other relevant data should be listed in the field for every seed lot (Wang 1973). The mechanics of subsequent paper work vary, but a simple method is to assign each seed lot a number and attach a label with this number on it to every sack of cones from that seed lot. The list of descriptive data, bearing the same number, is mailed to the seed-extraction plant where it becomes part of the seed lot's official record. If the seed is to be exported, arrangements may be made for inspection and certification as to origin by a designated authority, under a scheme of the Organization for Economic Cooperation and Development (Piesch and Phelps 1971).

Seed Processing

Seed processing consists essentially of (a) extracting the seed from the cones, (b) detaching the wings from the seed, and (c) separating sound seed from unsound, and from all extraneous matter. The operations, with varying degrees of elaboration, are carried out in that sequence. A sample of the refined seed is then tested for germination rate and other properties and the seed lot is placed in storage until required for sowing in the nursery or for direct seeding in the field.

Extraction

On receipt at the seed plant, cones are spread out on trays, usually under cover in a well-ventilated but unheated building[6]. They should be protected from rain, snow, birds and squirrels. They may be left for weeks or months, until it is convenient to handle them. During this period after-ripening takes place if cones were collected somewhat green. Considerable drying occurs also, and cones should be turned over frequently to accelerate this and prevent heating. Occasionally, cone scales open sufficiently in the drying shed to allow most of the seed to fall out onto the trays, in which case no further treatment is necessary. But as a rule, artificial heat must be applied to fully open the scales. (Sometimes partially open cones are first placed in a mechanical shaker to remove loose seed). Heat treatments in their simplest form consist of placing the cones over hot air

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[6]At Duncan, B.C. the sacks of cones are placed on racks in a shed pending extraction in the kiln.

registers at room temperatures. For large-scale production, efficient extraction requires dry kilns or "hot rooms" with controlled temperature, relative humidity and air circulation. At most plants the cones are loaded onto shallow, mesh-bottomed trays arranged in tiers on dollies which are wheeled into the kiln, and out again at the end of the schedule. Circulation is achieved either by fans blowing over hot water coils, or by forced air systems. Temperature-humidity-time combinations in the extraction process are critical in that excessive values can impair viability of the seed. Tests by Carmichael (1958) at Angus, Ontario showed that high temperatures are more damaging when combined with high humidities and sustained for a long period. He considered safe limits for white spruce to be 120°F (49°C) at 10, 20 or 30% relative humidity applied for up to 70 hours. Temperatures of 150°F (66°C) and over were damaging, with 180°F (82°C) lethal to white spruce seed under all circumstances. Kiln practice is not uniform in Canada, and it seems that satisfactory results can be obtained with a variety of schedules, some of which are shown in Table 3.

Some extraction is effected in the kiln by seed dropping out of cones as the scales open, but most takes place in mechanical shakers to which the fully opened cones and loose seed are next transferred. Shakers have a reciprocating or a revolving action. The most common pattern is a horizontal or slightly inclined cylinder enclosed in wire mesh. The cylinder is rotated, tumbling the cones with the aid of wooden baffles, and the seed falls through the mesh into tubs or onto a conveyor belt. The empty cones work their way to a chute at the end of the shaker.

A different approach is employed by the Ontario Ministry of Natural Resources in its tree seed plant at Angus where the kiln contains two revolving drums which are loaded with cones. The drums rotate fully every 90 seconds, and the air flow is reversed automatically every hour. The seeds fall out of drums into a hopper as they are released from the cones -- i.e. are removed from the kiln as soon as extracted.

Table 3. Selected kiln schedules for white spruce seed extraction

Temperature		Relative humidity	Time	
°F	°C	%	hrs	Remarks
100-120 (dry bulb) 81- 84 (wet bulb)	38-49 27-29	17-23	6	Chalk River, Ont. Moore cross-circulation kiln (Wang 1973).
105-110	41-43	46	16	Duncan, B.C. Moore kiln, hot water coils, internal fans.
120	49	20 (start) 10 (finish)	8-12	Angus, Ont. Steam-heated coils, reversing fan.
120	49	35	8-24	Berthierville, Que. Forced air kiln.
130	54	38	4-6	Convection kiln (U.S. Dep. Agriculture 1948).
130	54	37	10	Forced air kiln (Stoeckeler & Jones 1957).
135	57	20	10	Maximum allowable values (Carmichael 1958).

Cone-picking tower. Ontario Ministry of Natural Resources. Canadian Forestry Service photo.

Cone-drying shed. Duncan, B.C. B.C. Forest Service photo.

White spruce cones in drying shed. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

Specific gravity table for final seed cleaning. Duncan, B.C. B.C. Forest Service photo.

Determining moisture content of extracted seed. Duncan, B.C. B.C. Forest Service photo.

Germination cabinet for seed testing. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

Dewinging

The seed may than be passed over vibrating screens or through a fanning mill to remove the coarser foreign material in a preliminary cleaning process, but are characteristically next treated to remove the seed wings.

In small extraction plants, dealing with limited quantities of seed, the wings are rubbed off by hand or by kneading in a damp sack, methods reputed to cause minimal damage to the seed. Otherwise, one of several mechanical systems is employed.

By the commonest method, up to 1 1/2 bu (0.5 hl) of seed are rotated in a small cement mixer for 15 to 20 minutes. The seed is moistened with about one-half pine of water per bu (1.5 ℓ/hl), sometimes added as a spray. Dewinging by this method is said to damage relatively few seed, but the resulting mass of seed and wings must be dried before they can be separated. Drying may be accomplished on racks at ca. 80°F (27°C) for 12 to 16 hours, with heat applied by electric cables or hot air.

Another frequently used machine is a brush dewinger. Nylon brushes mounted on a central spindle revolve inside a cylinder, rubbing the seed against the mesh wall. Fine debris falls through the mesh, the mixture of seed remains inside.

At Duncan, British Columbia, wings are detached by vacuuming the seed through about 10 ft (3 m) of corrugated rubber hose. This technique causes some damage to the seed coat, and other methods are being examined[7].

At Indian Head, Saskatchewan, a stone-fruit depulper is used for dewinging white spruce. The seed are placed in a vertical steel cylinder 12 x 20 in. (30 x 51 cm), with vanes at the bottom mounted on a disc with a diameter slightly less than that of the cylinder. The seed and wings work under the disc and are discharged by a chute; some debris passes out of a side chute above the disc. The depulper

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[7]Personal communication from A.H. Bamford.

operation is said to be rapid, and less damaging to the seed than are brush dewingers.

Cleaning

The seed must now be segregated from the detached wings and other debris with which it is mixed. Cleaning procedures first separate seed from objects of a **different size**, by passing the mixture over vibrating screens of two gauges, one of which will admit finer material than the seed and one nothing larger than seed-sized objects.

Sound seed is separated from objects of a **different weight**, including empty seed, by fans or air currents which winnow away the lighter objects. A sloping fabric-covered table through which air is passed divides the heavier from the lighter seed with the aid of gravity (Switzer 1959), a method used at Duncan, British Columbia.

Finally, material of **different shape**, such as needle fragments, can be separated on an inclined moving belt to which they adhere but down which the seed will roll. The design of a recently developed belt cleaner for small samples of seed was described in detail by Hergert, Wang and Yeatman (1971).

The foregoing are the main procedures used in cleaning, and are accomplished with a variety of equipment arranged in different combinations. A simplified approach is embodied in an all-purpose air aspirator, used at Chalk River, Ontario for cleaning small lots of seed. This consists of a plexiglass cylinder 40 in. (1 m) tall, with a mesh-bottomed cup at the base, into which is placed a charge of 200 g (7 oz) of seed. A fan beneath the cup blows everything but the sound seed up the cylinder into a trap (Wang 1973). Another laboratory seed cleaner, a two-stage aspirator powered by vacuum, which first rough cleans in a batch process and then separates filled and empty seed as a continuous process, will clean a U.S. quart-size lot (ca. 1.1 ℓ) in 1 to 3 minutes (Woollard and Silen 1973).

Some extraction plants run the seed through a second time to increase the yield; at Berthierville, Quebec, for example, the smaller #2 seed is augmented by about 5% with a second run.

Storage

Owing to fluctuating seed production, most organizations try to build up stocks from collections in good years to even out the supply to nurseries. Processed seed is therefore stored, in the short run, until the next (spring or fall) sowing season, and, for the long term, to offset poor crop years. Storage requirements are simple but must be rigorously maintained if viability is not to suffer.

The seed must be dry, and while some extraction plants are satisfied with a subjective estimate, most ensure that the moisture is reduced to known values in the range of 5% to 10% of fresh weight, with 7% about average. At Angus, Ontario, drying is carried out on racks with forced air circulation. When dry, the seed is place in airtight containers -- glass jars, metal drums or cannisters of varying capacity, e.g. 15 to 45 lb (6.8 to 20.4 kg), or 4 or 5 gal (18 or 23 ℓ) of seed. Plastic and polyethylene containers are unsuitable, especially for long storage (Wang 1974).

Cold storage is essential, but opinion in Canada is divided over whether the appropriate temperature is 0^{o}F (-18^{o}C) or in the range 32^{o}F to 38^{o}F (0^{o} to 3^{o}C). A multi-species study by Allen (1957) showed insignificant losses in germination capacity for white spruce seed stored for 7 years at 0^{o}F (-18^{o}C) or 32^{o}F (0^{o}C), but seed at fluctuating room temperatures lost viability completely over the test period. More recent evidence suggests the superiority of subfreezing storage temperatures, and Wang (1974) recommended -10^{o}C to 2^{o}C (14^{o}F to 36^{o}F).

Quite lengthy cold storage of white spruce is feasible -- up to 20 years, according to experience at the Petawawa Forest Experiment Station. Some other seed plants report viability holding up well for ten years. A slight drop may occur after the first or second year; but a slight increase, sometimes reported after six months or a year, is most likely due to sampling variation, and hence more apparent than real.

Testing

The quality of processed seed must be known if a realistic estimate is to be made of sowing rates in the nursery or on forest sites, and scientific, controlled tests are carried out systematically to this end at the larger and better equipped seed establishments. A confusing variety of procedures and specifications are currently in use, but although some give satisfactory results, most will not be described here. Rather, the rules of the International Seed Testing Association approved for white spruce (ISTA 1975) are stressed. These rules are backed by considerable experience, and their general adoption would offer users the additional benefits of standard testing procedures.

Viability is considered the most important attribute and is the only one consistently evaluated at all seed plants. A good deal of work has been done to determine optimum conditions for germination tests, and specific aspects, relating to white spruce, have been reported by Crossley and Skov 1951, Fraser 1971, Heit 1968, Phipps 1969, Santon 1970 and Vaartaja 1963. The following specifications conform to ISTA (1975), however. Preconditioning of the seed so that uniform, prompt reaction to test procedures can be expected, is the first step. Cold stratification (to simulate fall and winter storage on the forest floor, which in nature precedes spring germination) involves storage for 21 days at low temperatures, $3^{o}C$ to $5^{o}C$ ($37^{o}F$ to $41^{o}F$), on a moist, sterile, absorbent medium.

The next step is to place the prechilled seed in four lots of 100 each on filter or blotting paper, with pH in the range 6.0 to 7.5, in a controlled environment cabinet for 21 days. Daytime temperatures of $30^{o}C$ ($86^{o}F$) for eight hours are alternated with $20^{o}C$ ($68^{o}F$) for 16 hours. Light, 750 to 1250 lux (70 to 116 foot candles), is supplied during the daytime period.

Germination may start as early as the fifth day. The first count should be made on the seventh day, the last on the twenty-first. Germinability expresses the cumulative percentage of the 400 seeds which had germinated in 21 days. Test data are recorded for each seed lot. At laboratories following rigorous procedures, germination of white spruce seed tested immediately after extraction averages 80% or better, although individual lots may vary from 50% to 95%.

A completely different approach, allowing indirect but reliable estimates of germinative potential by means of a chemical test, has been described by Hocking and Etter (1969). This procedure could easily be automated and one technician should be able to test up to 100 seed lots in two or three days.

An auxiliary test, suitable for small lots or research work, is made by the Forest Tree Seed Unit at the Petawawa Forest Experiment Station, by which X-rays are used to examine the endosperm, and abnormalities so revealed help to explain poor germination.

Retesting for viability is commonly carried out at yearly or biyearly intervals and whenever any part of the seed lot is withdrawn from storage for sowing. The new germination values are entered on the records after every test.

Purity, or proportion of clean seed in the gross weight of the seed lot (including foreign material), should be determined by weighing not less than a 5-g (0.18-oz) sample of processed seed, then removing the impurities and reweighing.

The weight of clean seed may then be determined and expressed as the weight per 1,000. Eight 100-seed samples of dry, clean seed are weighed and the mean and variance determined. If the coefficient of variation does not exceed 4.0%, the weight of 1,000 seeds is then calculated. A higher coefficient of variation necessitates taking additional samples.

At one seed establishment the 100-seed samples are selected by a device consisting of a revolving spiral ramp, which lines up the seed in single file, and an electronic counter. Care in the use of such equipment is indicated, since bias caused by the presence of empty seed has been demonstrated for white spruce (Rudolph and Bauer 1974). Apart from its importance for calculating sowing rates, seed weight is significant in that larger seed tend to produce larger seedlings, if not better germination or survival (Burgar 1964, Ackerman and Gorman

1969).

Extraction and test data should be recorded in detail for each seed lot (Wang 1973).

References to Seed Characteristics and Handling

Ackerman, R.F. and J.R. Gorman. 1969. Effect of seed weight on the size of lodgepole pine and white spruce container-planting stock. Pulp Pap. Mag. Can. 70(C):167-169.

Allen, G.S. 1957. Storage behaviour of conifer seeds in sealed containers held at 0°F., 32°F., and room temperature. J. For. 55(4):278-281.

Boissinot, Guy. 1973. Le reboisement et ses techniques au Québec. Pulp Pap. Mag. Can. 74(1):110-112, 114-116.

Burgar, R.J. 1964. The effect of seed size on germination, survival and initial growth in white spruce. For. Chron. 40(1):93-97.

Calvert, R.F. Undated. Tree improvement in Manitoba. Man. Dep. Mines, Resour. Environ. Manage., Res. Branch Inf. Ser. 2.

Campagna, Jean P. et Jean M. Fortin. 1971. Le reboisement au Québec - Réalisations et objectifs. *In* E.K. Morgenstern (ed.). Proc. 12th Meet. Comm. For. Tree Breed. Can. Part 2. Dep. Fish. For., Can. For. Serv. p. 191-199.

Canada Department of Forestry. 1961. Native trees of Canada. 6th ed. Bull. 61.

Carman, R.S. 1953. How tree seed is procured. Pulp Pap. Mag. Can., Woodlands Rev. Sec., Jan.

Carmichael, Alan J. 1958. Determination of the maximum air temperature tolerated by red pine, jack pine, white spruce and black spruce seeds at low relative humidities. For. Chron. 34(4):387-392.

Cram, W.H. and H.A. Worden. 1957. Maturity of white spruce cones and seed. For. Sci. 3(3):263-269.

Crossley, D.I. 1953. Seed maturity in white spruce. Can. Dep. Resour. Dev., For. Res. Div. Silvic. Res. Note 104.

Crossley, D.I. and L. Skov. 1951. Cold soaking as a pre-germination treatment for white spruce seed. Can. Dep. Resour. Dev., For. Branch, Div. For. Res. Silvic. Leafl. 59.

Dobbs, R.C., D.G.W. Edwards, J. Konishi and D.P. Wallinger. 1974. Cone pickers manual. B.C. For. Serv./Can. For. Serv. Joint Rep. 1.

Eis, S. 1967. Cone crops of white and black spruce are predictable. For. Chron. 43(3):247-252.

Eis, S. and J. Inkster. 1972. White spruce cone production and prediction of cone crops. Can. J. For. Res. 2(4):460-466.

Eliason, E.J. 1952. Seed source and propagation of spruce in New York. N.Y. For. IX(2):16-18.

Eng, K.C. 1971. Tree improvement at the Ontario Tree Seed Plant. *In* E.K. Morgenstern (ed.). Proc. 12th Meet. Comm. For. Tree Breed. Can. Part 2. Dep. Fish. For., Can. For. Serv. p. 37-43.

Food and Agriculture Organization. 1968. Vehicle-mounted trunk shaker for tree seed harvesting. For. Equip. Notes A.55.68.

Fowler, D.P. and H.G. MacGillivray. 1967. Seed zones for the Maritime Provinces. Can. Dep. For. Rural Dev., For. Branch Inf. Rep. M-X-12.

Fraser, D.A. 1962. Apical and radial growth of white spruce (*Picea glauca* (Moench) Voss) at Chalk River, Ontario, Canada. Can. J. Bot. 40:659-668.

Fraser, J.W. 1971. Cardinal temperatures for germination of six provenances of white spruce seed. Dep. Fish. For., Can. For. Serv. Publ. 1290.

Heit, C.E. 1968. Thirty-five years' testing of tree and shrub seed. J. For. 66(8):632-634.

Hergert, G.B., B.S.P. Wang and C.W. Yeatman. 1971. A belt cleaner for small samples of tree seed. For. Chron. 47(1):40-41.

Hills, G.A. 1961. The ecological basis for land-use planning. Ont. Dep. Lands For., Res. Branch, Res. Rep. 46.

Hills, G.A. and G. Pierpoint. 1960. Forest site evaluation in Ontario. Ont. Dep. Lands For., Res. Branch, Res. Rep. 42.

Hocking, D. and H.M. Etter. 1969. Rapid germinability test for white spruce. Can. J. Plant Sci. 49(4):527-528.

Holst, M.J. 1961. Experiments with flower promotion in *Picea glauca* Moench) Voss and *Pinus resinosa* Ait. *In* Recent Advances in Botany, Univ. Toronto Press, Toronto, Ont. p. 1654-1658.

Hughes, E.L. 1967. Studies in stand and seedbed treatment to obtain spruce and fir reproduction on the mixedwood slope type of northwestern Ontario. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1180.

Humphreys, E.R. 1967. An industrial tree-improvement program in northern Ontario. *In* Proc. 10th Meet. Comm. For. Tree Breed. Can. Part II:85-86.

Hustich, Ilmari. 1950. Notes on the forests on the east coast of Hudson Bay and James Bay. Acta Geog. 11(1):3-83.

International Seed Testing Association. 1975. International rules for seed testing approved at the 17th ISTA Congress, Warsaw, Poland 1974. Prelim. Issue.

Kennedy, J.D. 1952. Spruce plantations - installation and care. N.Y. For. IX(2):6-8.

Kennedy, Larry L. 1969. Seed - from collection to established tree. For. Chron. 45(6):421-427.

Kennedy, L.L. 1971. Tree breeding and silviculture in Alberta - needs and objectives. *In* E.K. Morgenstern (ed.). Proc. 12th Meet. Comm.

For. Tree Breed. Can. Part 2. Dep. Fish. For., Can. For. Serv. p.175-180.

Kiss, G. 1972. Selecting spruce for seed orchards. *In* R.G. McMinn (ed.) White Spruce: The Ecology of a Northern Resource. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-40:40-44.

Kiss, Gyula K. 1976. Plus tree selection in British Columbia. *In* E.K. Morgenstern (ed.) Proc. 15th Meet. Comm. For. Tree Breed. Can. Part 2. (In press).

Lane, C.H. 1976. Tree seed program in Ontario. *In* E.K. Morgenstern (ed.) Proc. 15th Meet. Comm. For. Tree Breed. Can. Part 2. (In press).

Levy, Donald M. 1970. A guide to tree selection and cone collection in Nova Scotia. N.S. Dep. Lands For., Ext. Div., Ext. Note 62.

Loucks, O.L. 1962. A forest classification for the Maritime Provinces. Proc. N.S. Inst. Sci. 25(2):85-167.

McPherson, J.A. 1971. An industrial tree improvement program in northern Ontario. *In* E.K. Morgenstern (ed.). Proc. 12th Meet. Comm. For. Tree Breed. Can. Part 2. Dep. Fish. For., Can. For. Serv. p.77.

Morgenstern, E.K. and L. Roche. 1969. Using concepts of selection to delimit seed zones. Proc. 2nd World Consult. For. Tree Breed. FAO, FO-FTB-69-2/16. 8 p.

Nienstaedt, Hans. 1969. White spruce seed source variation and adaptation to 14 planting sites in northeastern United States and Canada. *In* C.W. Yeatman (ed.). Proc. 11th Meet. Comm. For. Tree Breed. Can. Part 2. Can. Dep. Fish. For., For. Branch p. 183-194.

Nienstaedt, Hans and Richard M. Jeffers. 1970. Potential seed production from a white spruce clonal seed orchard. Tree Plant. Notes 21(3):15-17.

Nienstaedt, Hans and Abraham Teich. 1971. The genetics of white spruce. U.S. Dep. Agric., For. Serv. Res. Pap. WO-15.

Ontario Department Lands & Forests. 1966. Manual of seed collection. Timber Branch, Reforestation Sec. TM-513 (Revised).

Phipps, Howard M. 1969. Artificial light - a possible pretreatment method for dormant white spruce seed. Tree Plant. Notes 20(2): 9-10.

Pickett, T.L. 1974. Seed source search and white spruce seed source inventory. Dep. Environ., Can. For. Serv. Inf. Rep. PS-X-50.

Piesch, R.F. and V.H. Phelps. 1971. Certification of source-identified British Columbia tree seed under the O.E.C.D. scheme. Dep. Environ., Can. For. Serv. Inf. Rep. BC-X-60.

Pitcher, John A. 1966. Cone and seed yields in white spruce seed production areas. *In* U.S. Dep. Agric., For. Serv., North Cent. For. Exp. Stn. Res. Pap. NC-6:76-77.

Rauter, R. Marie. 1974. The genetic considerations of direct seeding. *In* J.H. Cayford (ed.). Direct Seeding Symp. Timmins, Ont. Sept. 11, 12, 13, 1973. p. 49-54.

Rauter, R.M. and J.L. Farrar. 1969. Embryology of *Picea glauca* (Moench) Voss. *In* Ernst J. Schreiner (ed.). Proc. 16th Northeast. For. Tree Improv. Conf., U.S. For. Serv. p. 13-24.

Rowe, J.S. 1953. Viable seed on white spruce trees in midsummer. Dep. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Silvic. Leafl. 99.

Rowe, J.S. 1955. Factors influencing white spruce reproduction in Manitoba and Saskatchewan. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 3.

Rowe, J.S. 1959. Forest regions of Canada. Can. Dep. North. Aff. Natl. Resour., For. Branch Bull. 123.

Rudolf, P.O. 1956. Guide for selecting superior forest trees and stands in the Lake States. U.S. Dep. Agric., For. Serv., Lake States For. Exp. Stn., Stn. Pap. 40.

Rudolf, P.O. 1959. Seed production areas in the Lake States: guidelines for their establishment and management. U.S. Dep. Agric., For. Serv., Lake States For. Exp. Stn., Stn. Pap. 73.

Rudolf, Paul O., Keith W. Dorman, Robert G. Hitt, and A. Perry Plummer. 1974. Production of genetically improved seeds. *In* Seeds of Woody Plants in the United States. U.S. Dep. Agric., For. Serv., Agric. Handb. 450:53-74.

Rudolph, Thomas D. and Edmund O. Bauer. 1974. Bias in subsampling forest tree seed with a vibratory electronic seed counter. For. Sci. 20(3):221-223.

Safford, L.O. 1974. *Picea* A. Dietr. Spruce. *In* Seeds of Woody Plants in the United States. U.S. Dep. Agric., For. Serv., Agric. Handb. 450:587-597.

Santon, John. 1970. Effect of stratification on germination of freshly harvested seed of several spruce and pine species in eastern Canada. Dep. Fish. For., Can. For. Serv. Inf. Rep. PS-X-17.

Sidhu, S.S. 1972. Selection of superior stands of white spruce in Nova Scotia. Dep. Environ., Can. For. Serv. Inf. Rep. M-X-27.

Slayton, Stuart H. 1969. A new technique for cone collection. Tree Plant. Notes 20(3):13.

Stiell, W.M. 1955. The Petawawa plantations. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 21.

Stoeckeler, J.H. and G.W. Jones. 1957. Forest nursery practice in the Lake States. U.S. Dep. Agric., For. Serv., Agric. Handb. 110.

Sutton, R.F. 1969. Silvics of white spruce (*Picea glauca* (Moench) Voss). Can. Dep. Fish. For., For. Branch Publ. 1250.

Switzer, George L. 1959. Elimination of empty or blind coniferous seed by specific gravity separation. Tree Plant. Notes 35:15-16.

Teich, A.H. 1973. White spruce provenances in Canada. Dep. Environ., Can. For. Serv. Inf. Rep. PS-X-40.

Teich, A.H. 1975. Outlook for selected spruces and pines in Canada. White Spruce. *In* E.K. Morgenstern, M.J. Holst, A.H. Teich and C.W. Yeatman. Plus-tree Selection: Review and Outlook. Dep. Environ., Can. For. Serv. Publ. 1347:28-33.

Teich, A.H., E.K. Morgenstern and D.A. Skeates. 1975. Performance of white spruce provenances in Ontario. Dep. Environ., Can. For. Serv. and Ont. Minist. Nat. Resour., Div. For., Spec. Joint Rep. 1.

Teich, A.H. and D.F.W. Pollard. 1973. Rapid-growing precocious white spruce provenances. Bi-mon. Res. Notes 29(2):13-14.

Tripp, Howard A. and Alan F. Hedlin. 1956. An ecological study and damage appraisal of white spruce cone insects. For. Chron. 32(4): 400-410.

United States Department of Agriculture. 1948. Woody-plant seed manual For. Serv., Misc. Publ. 654.

Vaartaja, O. 1963. Germination of white spruce seed not affected by extreme pH. Can. Dep. For., For. Entomol. Pathol. Branch Bi-mon. Prog. Rep. 19(3):2-3.

Wagg, J.W.B. 1964. Viability of white spruce seed from squirrel-cut cones. For. Chron. 40(1):98-110.

Waldron, R.M. 1965. Cone production and seedfall in a mature white spruce stand. For. Chron. 41(3):314-329.

Wang, Ben S.P. 1973. Collecting, processing and storing tree seed for research use. IUFRO Work. Party S2.01.06, Int. Symp. Seed Process., Bergen, Norway. I-Pap. 17.

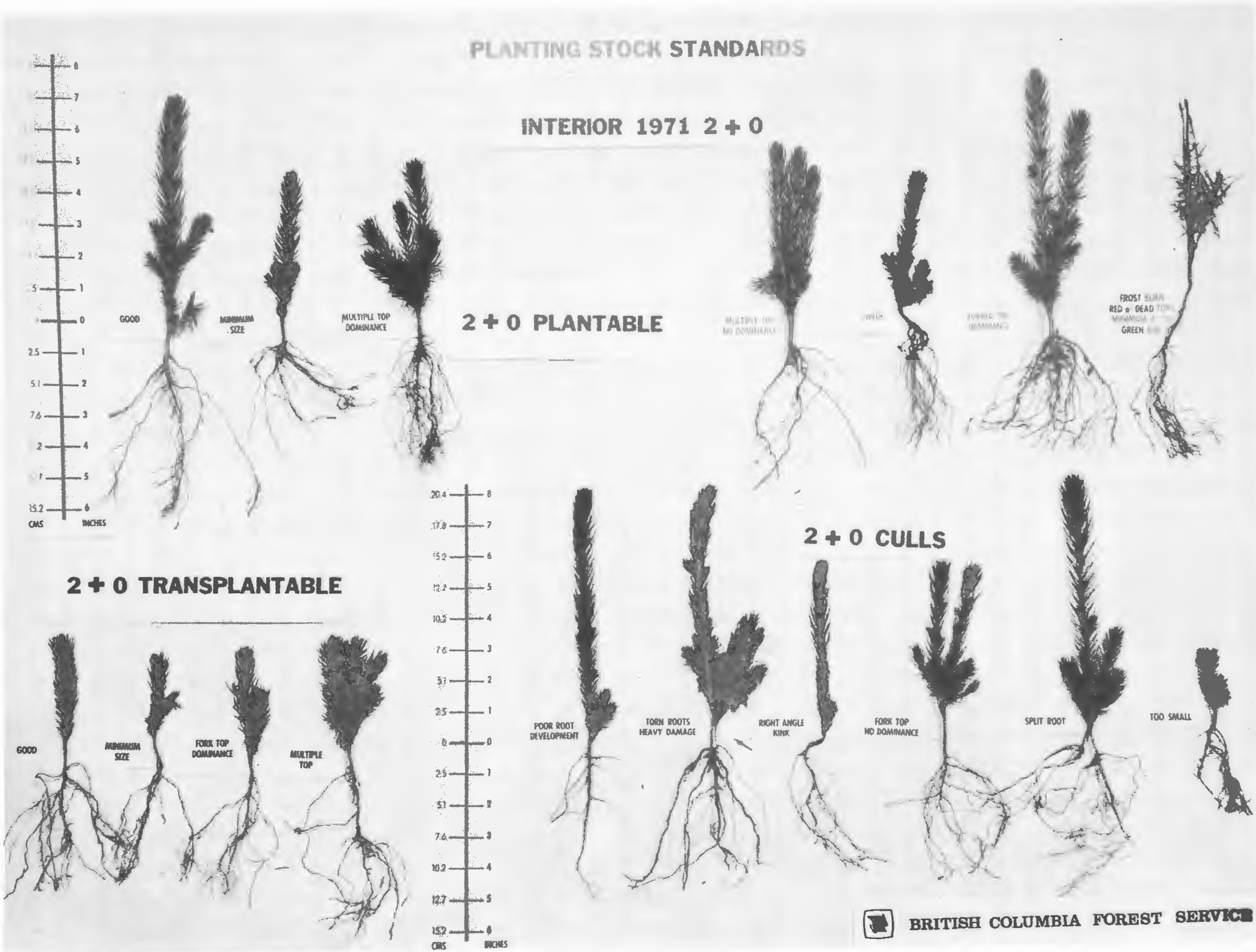
Wang, B.S.P. 1974. Tree-seed storage. Dep. Environ., Can. For. Serv. Publ. 1335.

Woollard, Robert F. and Roy R. Silen. 1973. All-pneumatic laboratory seed cleaner successful. Tree Plant. Notes 24(4):15-17.

Zasada, John C. 1973. Effect of cone storage method and collection date on Alaskan white spruce *(Picea glauca)* seed quality. IUFRO Work. Party S2.01.06, Int. Symp. Seed Process., Bergen, Norway. I-Pap. 19.

Zasada, John C. and L.A. Viereck. 1970. White spruce cone and seed production in interior Alaska, 1957-68. U.S. Dep. Agric., For. Serv. Res. Note PNW-129.

Zobel, Bruce J., John Barber, Claud L. Brown, and Thomas O. Perry. 1958. Seed orchards - their concept and management. J. For. 56(11):815-825.


PLANTING STOCK STANDARDS
INTERIOR 1971 2 + 0
2 + 0 PLANTABLE
GOOD
MINIMUM SIZE
MULTIPLE TOP DOMINANCE
FROST BURN
RED & DEAD
GREEN
2 + 0 TRANSPLANTABLE
GOOD
MINIMUM SIZE
FORK TOP DOMINANCE
MULTIPLE TOP
2 + 0 CULLS
POOR ROOT DEVELOPMENT
TORN ROOTS HEAVY DAMAGE
RIGHT ANGLE KINK
FORK TOP NO DOMINANCE
SPLIT ROOT
TOO SMALL
CMS
INCHES
BRITISH COLUMBIA FOREST SERVICE

III. NURSERY PRACTICE

White spruce planting stock is raised either in nursery beds to produce bare-root seedlings and transplants, or in greenhouses as individually containerized seedlings. Both types of production are increasing, the latter more rapidly in some provinces. Current trends in nursery practice show the sometimes conflicting objectives of improved planting stock and lowered production costs.

Bare-root Stock

Bare-root plants, which still account for the bulk of white spruce planting stock, are raised at one or more nurseries in most provinces. The length of time plants are retained in the nursery varies from two to five growing seasons after germination, and there are numerous options for seedling and transplant production (Figure 8). In the simplest cases the plants are grown as seedlings for two years (as in British Columbia), or three years, and then field-planted. Alternatively they may be transplanted after two years into the seedbed, and grown at lower plant densities for an additional one or two years in the nursery before planting in the field. Some variations of these regimes are transplanting the smaller seedlings for a year when the sturdier individuals are lifted for field planting; leaving small transplants for an additional year; lifting halfway through a growing season; or holding over plantable seedlings because of problems with the field program.

Transplants, long considered the ideal for white spruce, are giving way in many Canadian nurseries to seedlings for field-planting stock, mainly on grounds of production economy. For example, comparative costs per thousand in 1968-69 for Ontario nurseries averaged $27.00 for 2-2 transplants versus $16.50 for 3-0 seedlings (Robinson 1973), and in Quebec corresponding costs were $25.00 and $15.00 (Campagna and Fortin 1971). Nevertheless, the superior survival and growth of transplants observed in comprehensive experimental work

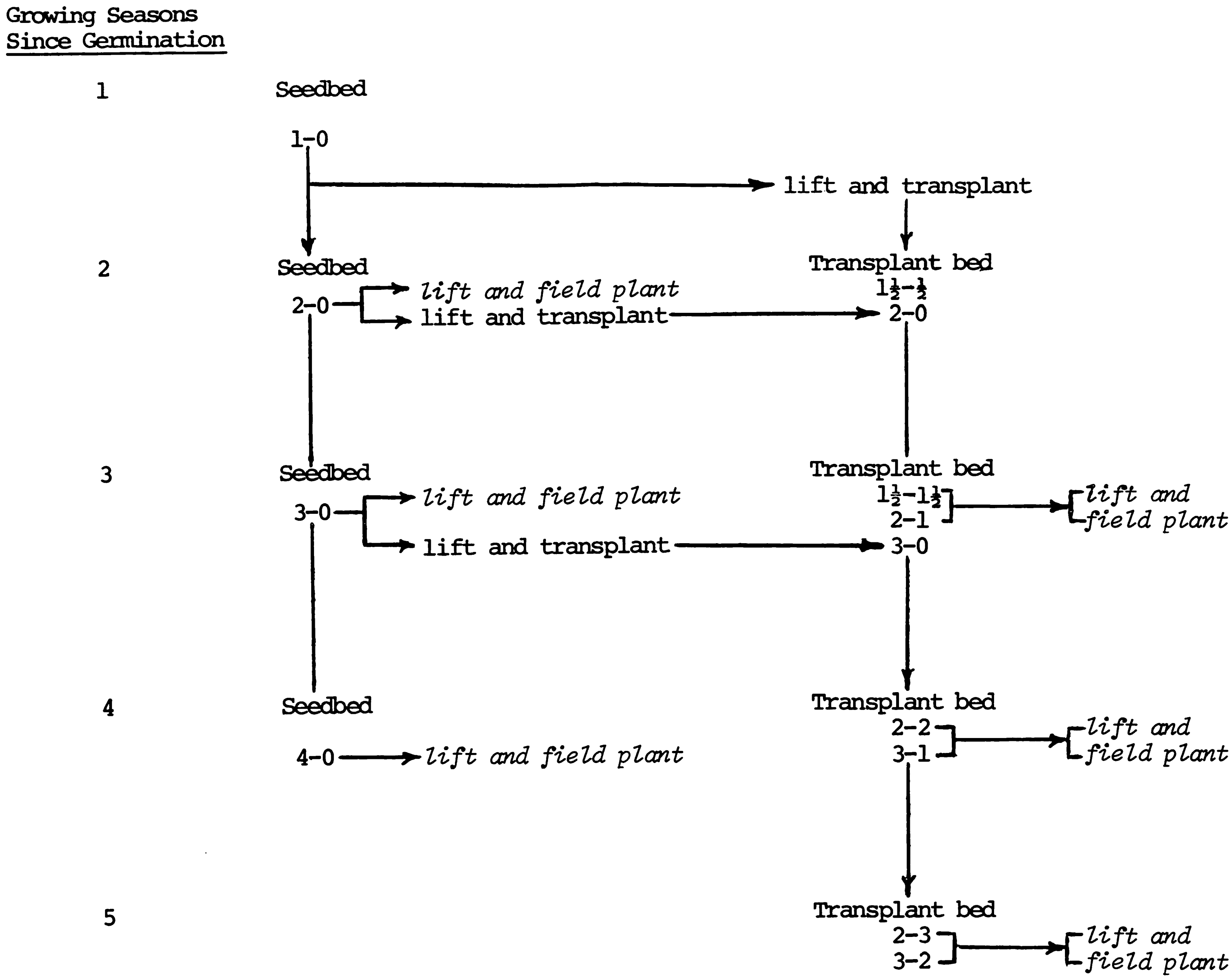


Figure 8. Some options for seedling and transplant production.

led Mullin and Howard (1973) to conclude that the use of 2-2 rather than 3-0 stock would result in a saving of about 24% in attaining the same aggregate stand height ten years after planting.

The changeover to seedlings is not complete and is unlikely ever to be so, owing to their inadequate performance under adverse field conditions. Thus in southern Ontario about 15% of white spruce stock is still produced as transplants for fall planting in certain areas, and in northern nurseries the proportion is considerably higher. In Prince Edward Island 2-1 transplants are preferred for cutover sites. In British Columbia about two-thirds of the stock are planted as 2-0, with the smaller "unplantable" seedlings being transplanted for one year. Similarly in Alberta, small 3-0 seedlings are transplanted for a year. In Saskatchewan the provincial nurseries have made a partial conversion from production of 2-2 transplants to 3-0 seedlings. On the other hand, authorities at the Prairie Farm Rehabilitation Administration nursery at Indian Head feel that large 2-2 transplants are necessary for the successful establishment of shelter belts.

The following sections emphasize procedures for white spruce, and are not intended as comprehensive statements on nursery practice in general. Several such treatises exist (three of which deal specifically with Canadian conditions) and the following material has drawn heavily from them (Armson and Carman 1961*b*, Armson and Sadreika 1974, Stoeckeler and Jones 1957, van den Driessche 1969, Wilde 1958).

Soil Management

Nursery soil requirements for white spruce are similar to those for conifers in general: light textures (loamy sands or sandy loams) with less than 20% silt plus clay content; organic content of at least 2%; stonefree; reasonably level; well-drained; reaction in the range pH 5 to 6. The intrinsic nutrient supply is not critical since artificial means are essential in any case to restore fertility levels in soils which would otherwise become depleted by removal every few years of entire seedling crops, both roots and tops. Satisfactory standards for white spruce nursery beds, maintained with chemical fertilizers, have been stated (Wilde 1958) as follows:

Reaction range (pH)	5.0-6.0
Exchange capacity (m.e./100 g)	7.0
Total N (%)	0.12
Available P_2O_5 (lb/ac)	70
Available K_2O (lb/ac)	200
Exchangeable Ca (m.e./100 g)	2.5
Exchangeable Mg (m.e./100 g)	1.0

An adequate, balanced nutrient regime produces plants which make the best field performance, but those provided with an oversupply tend to be succulent and less able to withstand adverse site conditions.

Of the major elements essential to plant growth, nitrogen, phosphorus and potassium are regularly applied as fertilizers, calcium and magnesium less commonly. White spruce is reported to have a "low" ability to absorb all except phosphorus where it is rated "medium" (Armson and Carman 1961*b*). It is not considered possible to supply in advance sufficient nutrients to last a whole seedbed rotation of two or three years (Krause 1971), and amounts to be added each year will vary with the age of the seedlings. Nitrogen should only be applied during the growing season (Armson and Sadreika 1974). Not only is growth increased by appropriate fertilization (e.g. Armson 1968) but the growing season of white spruce seedlings in the nursery beds can be extended (Armson 1966). Timing and placement of fertilizers in relation to soil surface also influence the degree of white spruce response (Armson 1963, Meagher and Armson 1963).

Determination of the nutrient status of the soil is a necessary and highly specialized proceeding. Neither soil tests nor plant tissue analysis alone seems to be wholly satisfactory, and both are often considered desirable before the quantity of specific fertilizer to be applied can be recommended. Effectiveness of treatment is judged by the size and appearance of seedlings, and experience with a particular nursery soil and species leads in time to the best interpretation of test results, and the corrective steps to be taken. Armson and Sadreika (1974) presented, for various classes of stock, ranges of nutrient concentration which have been found in foliage of white spruce in Ontario nurseries, values which may be helpful in interpreting tissue analyses (Table 4). Many nurseries find it advantageous to maintain contact with university laboratories where advice and analytical services are available, and to participate in continuing programs of applied soils research.

The cycle of soil management and seedbed preparation can be taken as starting after a crop of seedlings has been lifted. The practice then is either to fallow the seedbeds for up to a year, or to cultivate them and sow (and later plough down while green) a cereal or herbaceous crop for which buckwheat, oats, rye, millet and lupines are variously favoured in individual nurseries. The supposed intention is to increase the soil's organic and nitrogenous content, although only leguminous plants such as alfalfa or lupines can supply the latter. Armson and Sadreika (1974) feel the objectives are better met by the direct addition of peat and chemical fertilizers respectively. They acknowledge the value of a standing crop to limit wind erosion of sandy soils, however.

A good many nurseries are preoccupied with lowering the soil reaction, mainly, it seems, to control the damping-off associated with high pH, but also because alkaline soils present nutritional problems for conifers[8]. Heavy applications of acid peat is one approach, and has proved successful in the forest nursery at Charlottetown, Prince Edward Island, where, over a number of years, pH was reduced to between 4.5 and 5.6. At some other locations this method has been less successful in lowering pH, although it may maintain the status quo and will improve the organic content of the soil. Treatment with sulphuric acid, ammonium phosphate, aluminum sulphate or flowers of sulphur is a more direct and positive means of acidifying soils (van den Driessche

[8]At Indian Head, Saskatchewan, however, soil pH is 7.5 yet no ill effects on seedlings have been observed, and damping-off is satisfactorily controlled with Mylone. (Common and chemical names of pesticides are appended).

Table 4. Ranges of nutrient concentrations in white spruce foliage as per cent of dry weight*

	Northern Ontario					Southern Ontario						
Nutrient	1-0	2-0	3-0	1-1	2-1	1-0	2-0	3-0	1-1	2-1	1-2	2-2
N	1.25 to 3.08	1.81 to 2.27	1.62 to 2.07	1.40 to 1.48	2.11 to 2.42	2.32 to 2.77	1.76 to 2.78	1.51 to 2.12	2.22 to 2.58	1.98 to 2.50	1.39 to 2.22	1.56 to 2.75
P	0.23 to 0.37	0.11 to 0.22	0.15 to 0.25	0.11 to 0.14	0.18 to 0.25	0.26 to 0.34	0.21 to 0.31	0.10 to 0.23	0.15 to 0.24	0.12 to 0.19	0.18 to 0.19	0.12 to 0.16
K	0.28 to 2.63	0.54 to 1.92	0.50 to 1.25	1.41 to 1.69	0.58 to 0.82	0.67 to 2.10	0.42 to 0.63	0.59 to 1.20	0.55 to 0.64	0.53 to 1.14	0.45 to 0.67	0.18 to 1.15
Ca	0.47 to 0.92	0.57 to 0.83	0.07 to 0.99	0.31 to 0.50	1.04 to 1.18	0.30 to 1.07	0.70 to 1.63	0.63 to 0.81	0.31 to 0.81	0.29 to 2.04	0.20 to 0.83	0.81 to 1.70
Mg	0.10 to 0.13	0.08 to 0.10	0.07 to 0.11	0.08 to 0.09	0.10 to 0.11	0.08 to 0.14	0.09 to 0.13	0.09 to 0.11	0.06 to 0.10	0.06 to 0.12	0.07 to 0.10	0.06 to 0.21

*From Armson and Sadreika 1974

1969, Armson and Sadreika 1974, Stoeckeler and Jones 1957).

One of the last operations prior to sowing is sterilization of the soil to exterminate disease organisms, insects, and weed roots and seeds which may persist. Granular dazomet applied three to four weeks before sowing at 300 to 600 lb/ac (335 to 672 kg/ha), and watered in, is a common treatment. Other substances used are Vorlex; and allyl alcohol, methyl bromide, or metam, all of which require air temperatures above 50°F (10°C). Application may be as a vapour, under plastic sheeting left in place for a few days. At Berthierville, Quebec, it has been observed that metam, by killing the essential soil microorganisms as well, can cause a phosphorus deficiency which can be counteracted by fertilizing with 672 kg/ha (600 lb/ac) triple superphosphate (Campagna and White 1973). At Fredericton, New Brunswick, blood and bone meal are added to counteract loss of nitrifying bacteria.

The presowing application of chemical fertilizer (phosphorus and potassium, but not nitrogen) may be made before or after soil sterilization.

Seedbed Preparation

Seedbeds are 3 to 5 ft (0.9 to 1.5 m) wide, up to 800 ft (245 m) long, and are separated by paths 18 to 24 in. (46 to 61 cm) wide. Although sideboards have generally been abandoned, most nursery beds are still raised a few inches above the paths, sometimes with the aid of a tractor-drawn shaper, and may be either rolled to give a flat top, or "crowned". Beds are not raised at the Provincial Tree Nursery at Oliver, Alberta.

Sowing

Most nurseries sow white spruce seed sometime in the fall -- from late September to early November. The main advantages are natural stratification and a longer first growing season which produces a larger seedling, to say nothing of more conveniently apportioning the workload. Spring sowing, (always practised in British Columbia) is carried out as soon as soil conditions permit (usually in April or May) to give as long a growing season as possible.

Presowing treatment of seed frequently involves the application of various chemicals. Commonly used are fungicides, e.g. Arasan, and captan -- the most widely used chemical, and one considered effective against damping-off by some nurserymen, but not by others (Bamford 1970). Cayford and Waldron (1967) noted toxic effects from captan to surface-sown white spruce seed, and tests in British Columbia indicated that it reduced germination and survival (Lock, Sutherland and Sluggett 1975). Arasan is also used as a bird repellant.

These substances are applied to the seed with an inert sticker such as Methocel or latex, and aluminum flakes may be added as a lubricant. Storage is feasible for at least a year after the seeds have been coated (Cayford and Waldron 1966).

Spring-sown seed must, in addition, have been stratified or soaked in water (both treatments in Ontario) (Armson and Sadreika 1974)) to ensure prompt and complete germination. Santon (1970) recommended moist stratification at $34^{o}F$ to $38^{o}F$ ($1^{o}C$ to $3^{o}C$) for two to four weeks for white spruce seed. An exception may be seed of the Alberta variety, whose irregular response to stratification (Hellum 1968) suggests that treatments should only be used for seed lots where the need has been demonstrated by prior testing (Hocking 1972).

Density of sowing depends on viability as found from germination tests, expected survival as based on experience with the species and nursery, and whether or not the resulting seedlings will be transplanted before field-planting. If they are to be transplanted, then Canadian nurseries aim at producing a white spruce seedbed density at age 2-0 of 45 to 150 (average 90) seedlings per ft^2 (485 to 1615, average 970, per m^2). This is somewhat higher than the 75 per ft^2 (805 per m^2) recommended for potential transplants in Lake States nurseries (Stoeckeler and Jones 1957). If seedling stock is to be field-planted without transplanting, densities must be lower to provide sturdier plants. The range for these in Canadian nurseries is 25 to 50, and the average 35, seedlings per ft^2 (270 to 540, average 375, per m^2).

Stoeckeler and Jones (1957) recommend a density of 40 to 50 per ft^2 (430 to 540 per m^2).

Both drill and broadcast sowing are practised. By the former method seed is sown in rows, commonly 6 in. (15.2 cm) apart, with 6- or 7-drill machines. Seedlings in rows simplify both mechanical and chemical weeding. Machines are also used for broadcast seeding, except in the smaller nurseries. After sowing, the seed is immediately covered with 1/8 to 5/16 in. (3 to 8 mm) of sand, either by a mechanical sander or a roller attachment on the seeder. In some nurseries the soil surface is then covered with burlap, nylon netting, straw, marsh hay (because weed-free), sawdust, snow fencing, brush or a sprayed-on mixture of water and wood fibre, variously said to prevent blowing of the sand, protect against birds, conserve moisture or, by retarding a rapid rise of soil temperatures in the spring, prevent too early germination. A pre-emergent application of chlorthal or diphenamid weedkiller is made in some nurseries, but prometryne applied the day after sowing at 0.56 kg active ingredient (a.i) per ha (0.50 lb/ac) has been recommended in British Columbia (van den Driessche and Balderston 1974).

Fall-sown seed may germinate from early May (Indian Head, Saskatchewan) to July (Hadashville, Manitoba). Spring-sown seed takes 10 to 28 days to germinate, cold weather prolonging the period. Burlap covering must be taken off as soon as seedlings emerge but some mulches are not removed. If the mulch is sawdust, its decomposition results in an additional drain on the soil nitrogen which must be compensated for by additional fertilizer. Mineral spirits (petroleum derivatives containing 6 to 24% aromatics) may be applied as weedkillers just after germination while the seedcaps are still in place, and at Surrey, British Columbia diazinon is used at this point to counter springtails which feed on the germinants.

Seedbed Care

The principal treatments of nursery seedlings are shading, watering, weeding, fertilizing, root pruning and winter protection.

Shade is agreed to be beneficial to young white spruce and is provided at a majority of nurseries for all or part of the first year, and at a few for the second year as well. Snow fencing or lath screens, supported above the seedbeds on stakes or sideboards, and admitting about 50% light, are the usual shades. At Fredericton, New Brunswick, nylon mesh is used. The costs of the shades themselves, as well as of removing them for watering and replacing them afterwards (not considered necessary in Ontario), are appreciable in large nurseries. There is, therefore, a trend away from the use of shades, with some losses in seedling growth and numbers seen as acceptable trade-offs for cost reduction. Some nurserymen feel that the cooling effects of irrigation can partially compensate for the loss of shade, and at the Red Rock Nursery, Prince George, British Columbia, trials have been made with flax sown between the seedling rows to provide a "waving" shade. On the other hand, local conditions can be overriding, as at Big River, Saskatchewan, where shades are considered essential for protection against hail, other benefits apart.

Nursery stock is highly dependent on soil moisture for survival and growth, and rainfall must be supplemented for much, if not all, of the seedling rotation. Secondary uses of irrigation are cooling unshaded first-year seedlings in hot weather, and protection against unseasonable frosts. The water supply, besides being sufficient, should be free of toxic materials, and should have an acid reaction. Some Canadian nurseries are handicapped with an alkaline water supply, but the conditions can be remedied by an appropriate acid injection system (Armson and Carman 1961*a*). At Red Rock, British Columbia the water is pumped from a deep well after which storage in a pond is thought advisable, to allow it to warm up before application to nursery beds. Underground mains and portable aluminum pipes with sprinkler heads, or solid set equipment, make up the distribution system.

Control of the quantity of water supplied is necessary, on the one hand to provide enough to sustain healthily growing plants, and on the other to avoid an excess which might waterlog the soil, drown the roots, leach out nutrients, and favour disease-causing fungi (Wilde 1958, Lees 1964). A sufficient quantity of water has been added when the soil is at field capacity to an appreciable depth below the roots. This condition is present when free water has drained away from well-soaked soil. The moisture content is then between 12 to 15% in loamy soils (Stoeckeler and Jones 1957), for example. Soil moisture can be measured by two methods, both of which employ devices buried in the nursery beds, and require calibration for the particular soil to allow direct readings in the desired units. British Columbia nurseries use soil moisture blocks. These measure electrical resistance, which increases as the soil becomes drier, and van den Driessche (1969) indicated the relation for a silt loam nursery soil. Tensiometers (used at Indian Head, Saskatchewan) express the moisture tension in the soil in terms of atmospheric pressure -- higher pressures reflecting increasing dryness; a portable model has been used in Ontario.

The amount of water to be added by irrigation is governed primarily by climate[9] and soil drainage properties, and more immediately by the stage of plant development, prevailing weather and current soil moisture conditions. Judgement in determining when and how much to irrigate should be based on a knowledge of measured soil moisture and seedling growth response to particular moisture levels. Armson and Sadreika (1974) showed dry weight yields for 2-0 white spruce in relation to three moisture regimes; they cited evidence that white spruce suffered less growth reduction under moisture stress than did other conifers grown in Ontario. Nevertheless, choice of irrigation schedules is subjective in most Canadian nurseries, depending rather on experience and the appearance of the seedlings than on a precise knowledge of soil moisture status. Some nurseries apply water in definite quantities, e.g. one-inch units. (An "inch" of water added to one acre is equivalent to 22,611 gallons, i.e. 254,000 ℓ/ha). Shortage of labour to move shading and sprinkling equipment sometimes

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[9]The forest nursery at Charlottetown, P.E.I. appears to be unique in never requiring irrigation.

prevents as much watering as the nurserymen would like to accomplish.

Moisture requirements at germination are critical. The germinants are confined to the uppermost soil layers, which can dry out very quickly, and must be kept continuously moist. Irrigation is continued throughout the first summer and is particularly important where shades are not used. Some nurseries add up to 8 in. (20 cm) of water during the first year. An equal, or slightly less, amount of water is applied in the second seedbed year, less in the third year. Heavy watering is the rule immediately after transplating to assist root adaptation and counteract transpiration losses; or before summer transplanting, to cool the soil. Otherwise irrigation of transplants seems to be less than for seedlings, and at some nurseries none is applied in the second transplant year. Watering at night has been recommended as the most efficient application for older seedlings and transplants (Bamford 1970).

For protection from unseasonable frosts, spraying with water should be commenced as soon as temperatures fall to 32^{o}F (0^{o}C) and maintained until all ice has melted from the seedlings (van den Driessche 1969).

Weeds, as unwanted consumers of the water and nutrients supplied for the benefit of tree seedlings, and as competitors for light and growing space, must be eradicated from nursery beds before they get large enough to create problems and before they produce seed to propagate themselves. Weeding is particularly intensive during the early part of the rotation. Chemical weedkillers allow large savings in labour costs and are used whenever it is judged safe to do so without harming the seedlings. Opinion on this point varies amongst nurserymen, and as some weeds are very resistant to chemicals in doses non-toxic to seedlings, a certain amount of hand weeding and mechanical cultivation is conducted in all nureries. Kozlowski (1963) described the results of treatment with a number of herbicides on white spruce seedlings and transplant beds, and Sutton (1970) outlined the selective action of various herbicides for weed control in forestation.

During the first seedbed growing season hand weeding only is used at a majority of nurseries. At others, mineral spirits are applied six to ten weeks after germination at 15 to 60 gal per ac (170 to 675 ℓ/ha). Paraquat can be applied during the summer between the rows of drill-sown seedlings (if they are shielded from the chemical -- a difficult undertaking) at 60 oz in 60 gal of water per ac (4.2 kg in 675 ℓ/ha). Simazine may be applied at 1 to 3 lb a.i. per ac (1.1 to 3.4 kg/ha) in the fall.

In the second year hand weeding is still the rule, but mineral spirits, simazine or atrazine are used also. Little weeding is required in the third seedbed year. After transplanting, weeding may be needed in the new beds, and chemical treatments are continued with up to 10 lb per ac (11.2 kg/ha) of effective simazine being applied in some nurseries. However van den Driessche (1975) considered that even 4 lb a.i. per ac (4.5 kg/ha) might be high "for repeated application of this relatively persistent herbicide". Weeding by cultivator is easier in transplant beds, and is used for larger and more resistant weed species.

Fertilizing can be accomplished with seedbed-straddling spreaders, or by metered injection into the watering system. As noted earlier, guidance for rates of application comes from soil and plant tissue analyses which should be carried out annually. Schedules will vary with seedling age, seedbed density and the nature of the soil, and although Armson and Sadreika (1974) have made specific recommendations for nitrogen application to white spruce in Ontario nurseries (Table 5), no universal prescriptions can be laid down.

During the first seedbed year nitrogen fertilizers are applied in nearly all Canadian nurseries. Ammonium sulphate (21-0-0) is the most popular form, and up to 200 lb/ac (220 kg/ha) may be added: the higher rates in several applications over the growing season. Urea (46% N) at 436 lb/ac (489 kg/ha) is sometimes used instead, but is an expensive source of nitrogen. Ammonium phosphate (11-48-0) may be added as well, usually later in the summer.

In the second year, nitrogen applications tend to be heavier. If seedling appearance or tissue analysis made the previous fall so

Table 5. Rates and frequency of nitrogen applications to white spruce in Ontario nurseries*

Season	No. of applications	Amount N per application		Total N per year	
		lb/ac	kg/ha	lb/ac	kg/ha
1-0	4-7	10-30	11.2-33.6	50-200	56.0-224.2
2-0	4-9	20-25	22.4-28.0	80-225	89.7-252.2
3-0	4-8	20-30	22.4-33.6	80-200	89.7-224.2
1-1	2-3	20	22.4	40- 60	44.8- 67.2
1-2	3-4	20-25	22.4-28.0	50-100	56.0-112.1
2-1	2-5	25-30	28.0-33.6	60-120	67.2-134.5
2-2	3-5	15-25	16.8-28.0	40-130	44.8-145.7

*From Armson and Sadreika 1974.

warrant, potassium as sulphate (0-0-53) or chloride (0-0-62) at 90 to 100 lb/ac (100 to 110 kg/ha), or phosphorus in mixed fertilizers (e.g. 11-48-0), may be added.

Third-year seedbeds receive similar or heavier dosages (lighter at Hadashville, Manitoba). Transplants may receive complete (NPK) fertilizers, but applications depend greatly on prior soil treatment to the transplant beds.

In most nurseries roots of growing seedlings are cut back or some stage to encourage a compact fibrous system; to manipulate top/root ratios; to prevent development of long roots which would be subject to damage in lifting and handling and would make the seedlings difficult to plant; and to reduce tangling with neighbouring root systems. Incidental soil aeration is seen as a side benefit by some nurserymen.

If properly conducted, root pruning should not have adverse effects. Farrar and Huntley (1969) found that root systems of 1-0 and

2-0 white spruce, pruned in late September at the time of transplanting into the greenhouse, quickly functioned and developed new root tips. Sutton (1967) reported that lateral root pruning of 3-0 white spruce was followed by good field survival (except where laterals were pruned flush with the tap root), height growth was not affected, and root systems regenerated rapidly. In another experiment, undercutting white spruce seedbeds at 2-in. and 4-in. (5.1- and 10.2-cm) depths reduced height growth in the nursery, but if carried out after the cessation of shoot growth (June 25) subsequent field survival and growth of 3-0 seedlings were improved over that of unpruned stock (Mullin 1966).

Undercutting is carried out with a tractor-mounted blade, fixed or reciprocating, drawn beneath the soil surface at 4 to 8 in. (10.2 to 20.3 cm). This operation is generally performed in the second seedbed year, and early in the growing season; it may be deferred to the third year, or repeated in that year (as at Kemptville, Ontario). Lateral root pruning (less common) is accomplished with rolling coulters or vertically mounted knives.

Top pruning of white spruce nursery stock is not a standard treatment, but is occasionally practised if the plants have grown too tall and unwieldy. A power-driven chain flail was found effective for this at Hadashville, Manitoba in 4-0 white spruce which, for non-technical reasons, could not be lifted after the usual three years. In an experiment at Midhurst, Ontario, in which 2-1 white spruce were pruned back with a tractor-mower to a height of 5 in. (12.7 cm) in June neither nursery nor field survival were affected (Mullin 1957).

The main object of **winter protection** is the prevention of frost heaving which tears the roots and exposes them to drying. Heaving is most prevalent in heavy soils, where there is early frost and little snow cover, and 1-0 seedlings are the most vulnerable. The simplest approach is to leave on the shades, which moderate the heat of the sun and prevent accumulated snow from blowing. As well, or instead, the beds may be covered with conifer brush, straw, peat moss, or a layer of sawdust which appears to be the most effective (Mullin 1965). However, if there is much sawdust decomposition, an additional drain on the soil nitrogen will result, which may be made up by extra fertilizer the following year.

Transplanting

Transplanting aims at producing sturdier stock for field-planting, by providing the individual plants more growing space for the latter part of their nursery development than would be available if left in the seedbeds. The superiority of transplants in many field situations is acknowledged, but high costs have considerably reduced production of this class of stock, as previously remarked.

In all but the smallest nurseries seedlings are lifted with the aid of machines. These usually consist of horizontal blades with trailing fixed or vibrating metal fingers, drawn beneath the seedbed surface, loosening the soil and uprooting the seedlings without undue damage. The seedlings are then picked up by hand, placed with their roots in tubs of water and trucked to the transplant beds.

The seedlings are set out in the new beds with 5- to 11-unit Holland transplanters. The operator of each unit places the seedlings under short pieces of strap fixed at one end to the rim of the planting wheel. As the wheel turns the seedlings are inserted successively into a narrow furrow which is immediately closed by packing wheels, leaving the seedlings upright. Care must be taken to keep the roots moist and the machines usually have canopies to minimize drying. Transplanting rates of 90,000 seedlings a day with a 6-row machine were reported by one nursery, but production will vary with planting density. Seedlings are generally spaced at 2- to 3-in. (5.1- to 7.6-cm) intervals in rows 6 to 12 in. (15.2 to 30.5 cm) apart (maximum 1 1/2 in. by 24 in. (3.8 by 61.0 cm). Potential 2-1 transplants are usually grown at the closer spacings, 2-2 at the wider.

Most lifting and transplanting is done together in the spring. In a few nurseries, e.g. Indian Head, Saskatchewan, seedlings are lifted in the fall and held overwinter in sealed polyethylene-lined crates at ca. 34°F (1°C) for spring transplanting. At some nurseries, notably in Ontario, seedlings may be transplanted in July of the second seedbed year, at age $1\frac{1}{2}$-0 rather than 2-0. The object is to take advantage of the July peak of the white spruce cycle of root growth (Bunting 1966), as well as the smaller, more easily handled size of seedling.

Harvesting

Spring harvesting is preferred in most nurseries, although exigencies of other nursery work or of the reforestation program being supported may dictate some fall lifting. Only at Surrey, British Columbia are harvesting and packing regularly conducted from late fall through the winter.

Lifting is performed much as at transplanting. A tractor-drawn seedling harvester[10], developed in Ontario, and used in a number of Canadian nurseries, automates lifting by digging up the seedlings and carrying them up a vibrating chain conveyor which shakes off the soil and deposits them in bins; capacity is 400,000 to 500,000 seedlings per day. A harvester developed at Indian Head, Saskatchewan comprises two U-blades, two belts inclined upwards at 30° to carry the seedlings up from the bed, and a rear conveyor which drops them into 3,000-seedling bins on an adjacent tractor-drawn trailer; the machine harvests two rows at a time at a rate of ca. 12,000 seedlings per hour where density is 4 to 5 per linear ft (13 to 16 per m). An 8-row harvester utilizing an undercutter blade, counter-runing belts for seedling transportation, and activated tines with rod extensions for soil removal has been developed in Virginia (Heltzel 1970); preliminary plans were to operate it at 15 to 20 bed-feet (4.6 to 6.1 m) per minute, permitting harvesting of 126,000 to 168,000 loblolly pine seedlings per hour. At Kemptville, Ontario work is proceeding on a 6-row belt harvester to lift individual drills and hold the seedlings upright for orderly placement in bins, and perhaps tie them in bales.

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[10] Grayco tree seedling harvester. Ontario Dep. Lands & Forests. Mimeo. 3 p.

After lifting, plants should be taken immediately into a packing shed where root drying is minimized during culling, bundling etc; (hand-lifted stock should be dipped in water as soon as taken from the soil). Some sort of grading procedure is usually followed, although few definite standards are reported for white spruce. Armson and Sadreika (1974) describe a seedling index, based on top height, stem diameter and root area as an approach to judging seedling quality. British Columbia nurseries require a minimum top length of 4 in. (10.2 cm) and a basal stem diameter of 1/10 in. (2.5 mm) for 2-0 white spruce seedlings. Studies in Ontario on 10-year growth of white spruce after field-planting indicated that minimum planting stock top length of 6 in. (15.2 cm) and diameter of 12/64 in. (4.8 mm) are desirable for 2-2 transplants (Brace 1964, Mullin and Svaton 1972). In that province minimum dimensions required for 3-0 seedlings are now 15 cm (5.9 in.) for top length, 3.6 mm (0.14 in.) for stem diameter and 30 cm (11.8 in.) for root length. Unacceptable characteristics other than small size that may be considered in grading are damaged roots, stem injuries, brown foliage or multiple leaders with none dominant. In face, "grading" does not usually go beyond separating "plantables" from "culls", but in some nurseries seedlings which are undersized but otherwise well proportioned and sound are transplanted for a year[11]. Culls may reach 40% where this procedure is not followed.

Packing and Storage

Acceptable plants are tied in bundles of 10 to 50 (at some nurseries the roots are trimmed to ca. 8 to 12 in. (20 to 30 cm) long), and packed for shipment or storage. The most common practice is to place the bundles root to root, pack the roots in wet sphagnum moss,

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[11] Grading at Indian Head, Sask. is exceptional in two ways: (1) minimum top length for 2-2 transplants is 9 in. (22.9 cm), deemed necessary for the rigours of shelter belt planting, but not considered reasonable for forest stand establishment (2) plants are graded **before** lifting, by pulling substandards; if the bed averages too short, it is held over to age 2-3.

and wrap the bales in plastic, waterproof paper, or burlap (or combinations of these), leaving the foliage exposed. Double- or triple-layered paper bags, or polyethylene-lined bags or cartons may be used instead of bales.

Storage may be brief or as long as over winter. For all but the briefest periods, cold storage facilities are necessary to meet the objectives of keeping the stock moist, preventing heating and moulding, and maintaining dormancy. Where early shipment is anticipated, temperatures just above freezing are the rule. Over-winter storage conditions of below freezing, ca. -3°C to -4°C (27°F to 25°F), and relative humidities in the range 86 to 100%, have been shown to give good results with 3-0 white spruce in closed (but not sealed) polyethylene bags (Mullin and Bunting 1972, Mullin and Parker 1974) and in bales (Slayton 1970). For winter storage at Surrey, British Columbia white spruce is held bare-root in sealed polyethylene bags inside cartons, at ca. 34°F (1°C). Moulding of the foliage can be a problem in cold storage, and was attributed by Hocking (1971*a*) to the presence of free water on the needles. He recommended maintaining a low (0°C (32°F) or less) and constant storage temperature and cooling the plants to that temperature before closing their containers.

It is evident that large amounts of sphagnum moss may be required for this phase of the nursery operation. An alternative, adopted at Lawrencetown, Nova Scotia, is to dip the roots after lifting, and again when packing, into a solution of sodium alginate -- 1 lb of powder to 10 gal water (10 g/ℓ)[12]. This keeps the roots wet, right up until planting. Advantages of this approach seem to be avoidance of moss procurement and handling, simplification of packing and reduction of weight and bulk of packaged stock. Another technique, adopted in Ontario for spring-lifted dormant stock, which allows cool storage at 33°F to 35°F (0.5°C to 1.0°C) of white spruce for up to six

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[12] Burgess, R.H. 1971. Out of the doldrums: reforestation in Nova Scotia. Paper Presented at 53rd Annual Meeting, Woodlands Section, Canadian Pulp and Paper Association.

weeks, is storage in "plant-fresh" bags[13]. These are made of two layers of polyethylene resin, the inner black and the outer gray, which reduce heating and prevent loss of water vapour, but allow the passage of oxygen and carbon dioxide; no wet moss is used (Bunting 1975).

Shipping

Planting stock is mostly transported to the planting area by truck, occasionally by railway express. The great majority of shipments in Canada reach the planting site within 24 hours. In Ontario, recommended maximum truck hauls are eight hours by day or 12 hours overnight[13]. Shipment is generally in bales or bags as described, infrequently in bulk with the roots in moss but the plants otherwise unpackaged. The stock must remain cool and moist, and a minimum requirement is covering the load with a tarpaulin. Refrigerated trucks are sometimes used for long trips in hot weather. Hauling by night may be feasible for certain distances. Stock in burlap bales with wooden stiffeners has been air-dropped in Ontario without apparent damage; free dropping was found more accurate and less troublesome than parachute drops (Grinnell 1955).

Greenhouse Prouction

Raising bare-root planting stock in greenhouses has not been practised widely, but offers possibilities of greatly reducing the production period by artificially extending the growing season and improving the seedling environment. Trials in Michigan with plastic greenhouses (some heated to 45°F (7°C), starting in March) produced 2-0 white spruce with heights of 6.6 in. (16.8 cm) compared to 3.0 in. (7.6 cm) for seedlings grown outside (Phipps 1973). A more intensive

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[13]Ontario Ministry of Natural Resources. 1975. Guidelines for the general handling of nursery stock. Unpublished, internal material dealing with lifting, storage and transportation of bare-root stock in a variety of nursery and field situations.

[13]Ibid.

approach at the Petawawa Forest Experiment Station in Ontario, which involved sowing in a special medium in pots, supplemental light, controlled (fluctuating day and night) temperatures, and feeding with a nutrient solution through the automatic watering system, produced white spruce over 26 cm (10.2 in.) tall in 25 weeks (Pollard and Teich 1972). Enriching the carbon dioxide content of the air is another possible treatment, and in a trial at Petawawa a 3- to 5-fold enrichment increased the weight of 3-week-old white spruce by 61% (Yeatman 1970).

Later work with white spruce at Petawawa was reported by Pollard and Logan (1975) as follows. Enrichment of CO_2 up to 1,000 ppm was beneficial, but the treatment can only be applied in a closed system and is therefore impractical in ventilated greenhouses. Addition of high-intensity illumination, 22,000 lux (2,040 ft candles), for long photo-periods yielded heavier seedlings. The use of low-intensity incandescent lamps, ca. 400 lux (40 ft candles), before mid-April and after mid-August to extend the day length to 16 hours would satisfactorily maintain growth and be relatively inexpensive. The most suitable temperature was a 25°C/20°C (77°F/68°F) day/night regime.

These experiments demonstrate the potential of intensive methods, and their adaptation to rearing limited quantities of stock is evident. Large-scale production is a matter of scaling up facilities, essentially an engineering problem, and will be dictated by the economics of intensive greenhouse systems.

One example of industrial application is the greenhouse facility at the forest nursery of J.D. Irving Co. at Juniper, New Brunswick. There, seedlings are grown for six months (March to August, and August to March) in the greenhouse, then transferred to nursery beds, and finally harvested as $\frac{1}{2}$-$1\frac{1}{2}$ transplants. The greenhouse is a Nissen-hut-shaped structure with a polyethylene covering; seed are sown on peat moss in two 12- by 96-ft (3.7- by 29.3-m) beds; hot water heating keeps the air at 60°F (16°C) and, by underground pipes, the beds at 65°F (18°C); the air is circulated by fans via elevated ducts. Four two-bed greenhouses share a common header house.

Seedbed shaper. Prince George, B.C. Canadian Forestry Service photo.

Drill seeding. Prince George, B.C. B.C. Forest Service photo.

Chemical weed control in spruce nursery beds. B.C. Forest Service photo.

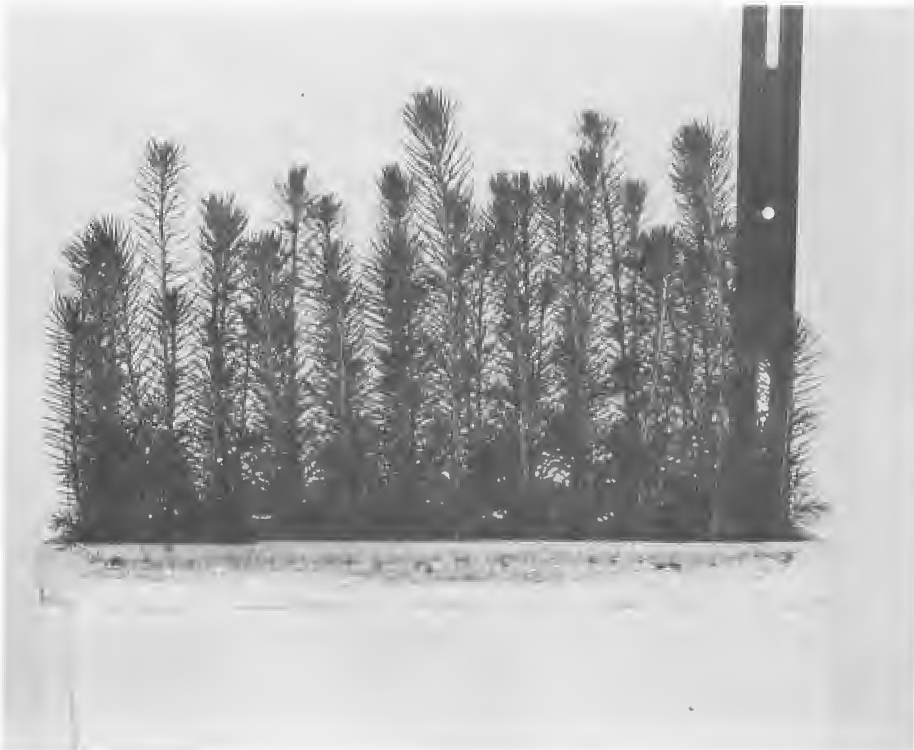
Lateral root pruner. Prince George, B.C. Canadian Forestry Service photo.

2-0 white spruce in transplant beds. Juniper, N.B. Canadian Forestry Service photo.

Love machine for lifting seedlings. Surrey Nursery, B.C. B.C. Forest Service photo.

Sorting seedlings. B.C. Forest Service photo.

Packing seedlings. Prince George, B.C. B.C. Forest Service photo.



Spruce seedlings in BC/CFS Styroblock. B.C. Forest Service photo.

10-week old white spruce in American Can BR-8 blocks. Hinton, Alta.
Canadian Forestry Service photo.

Container Stock

Rationale for Development

Many observers have concluded that the expanding scale of reforestation, needed to cope with increased cutting rates and accumulating backlogs of inadequately stocked burns and cutovers, can only be met by mechanizing the processes of seedling production and planting. Walters (1967) considered that this would require the plants to be individually encapsulated (i) to allow the rigorous handling to which a mechanized system would subject them and which bare-root plants could not withstand, and (ii) to provide uniformly sized and shaped units amenable to manipulation by machinery during nursery care, transportation and planting. To this end he designed, in 1950, his bullet (a pointed plastic container) in which the seedling would be grown and field-planted, and a gun for inserting the bullet into the ground; this was the beginning of container planting in Canada (Walters 1961).

Definition

A "containerized" seedling is essentially one which is grown individually rather than in a shared nursery bed, and is planted with the unit of soil in which its roots are embedded still intact. The technical implications of container systems are intensive greenhouse production to provide seedlings sufficiently well developed for field-planting within weeks rather than years, and which are easily transported and planted. The short rearing period is due both to optimim growing conditions in the greenhouse, and to the fact that a much smaller seedling is plantable (because its roots will not be disturbed) than would be possible with bare-root plants at a similar stage of development.

Characteristics

Many potential advantages have been claimed for container-planting systems, some of which have been realized (Ackerman *et al.* 1965, Bingham 1974, Carman 1967, Grinnell 1971, Kinghorn 1970 and 1974, Low 1971, Reese 1972, Sirén 1968, Walters 1967):

(i) In the greenhouse, growth can be maximized by environmental control, root systems shaped as required, and optimum root-shoot ratios attained; disease and insect problems are virtually eliminated; the plantable seedling ratio is high; a reliable system for raising valuable seed lots in short supply is provided; much increased production leads to lower overhead and supervisory costs; nursery (greenhouse) site requirements are simple.

(ii) In the field, root systems are better protected in all operational procedures; planting rates are high, and hence costs are lower, and the system is suitable for piecework; planting is possible throughout the growing season, giving operational flexibility, spreading the silvicultural work load, and thus avoiding peak labour requirements, allowing development of trained crews for the longer season, and more efficient use of supervisory staff.

Disadvantages anticipated are due mainly to the small size of container seedlings so far planted, e.g. they are less able to compete with other vegetation, and are more vulnerable to animal damage (Low 1971, Reese 1974, Scarratt 1974). One problem directly attributable to the container itself is proneness to serious frost heaving, particularly on bare mineral soils (Arnott 1974, Ferdinand, Kay and Hellum 1974, Fraser and Wahl 1969); another is the attraction of the protruding containers to crows which often pull them up.

The requirements of an efficient container system have been described as (i) reducing manual labour input to a minimum (ii) permitting production of consistently uniform and high quality crops (iii) utilizing a container which will be present only as long as needed and effectively ceasing to exist on planting with respect to root egress (Kinghorn 1970). It is emphasized that automation is the eventual objective, and the whole production-planting operation must be regarded as a system.

Container Types

A number of container types have been developed in Canada since 1950, and many more tested (Figure 9). Recent stages of container development have been documented in detail (Waldron 1972, Cayford 1972, Tinus, Stein and Balmer 1974). There are essentially three categories of container:

(i) Separate containers, e.g. Walters' "Bullet", Ontario split plastic tube, Research Council of Alberta (RCA) peat "Sausage", Japanese "Paperpot", in which single seedlings are grown and field-planted. They are designed with slits or open ends so that the roots can grow into the soil, and most types are either split apart or "biodegraded" (disintegrated by the action of soil organisms).

(ii) Multiple moulds, e.g. BC/CFS "Styroblocks", Swedish "Multipots", Spencer-Lemaire "Books", from each cavity of which the seedling is extracted together with the plug of soil enclosing its roots and then planted (i.e., the container is dispensed with prior to planting).

(iii) Rigid columns of compressed rooting medium, e.g. American Can Co. "BR-8" (Schneider, White and Heiligmann 1970), in which the seedling is rooted and later planted (i.e., no container is involved, although the root-plus-soil planting unit is employed).

Few final decisions on container types seem to have been taken in Canada so far, although Paperpots have been chosen by the Manitoba Government (Meseman 1974) and by a company in Nova Scotia (Routledge 1974). Generally there is a tendency for provinces to give first consideration to their own home-grown products, where these exist -- e.g. Bullets and Styroblocks in British Columbia, Sausages and Books in Alberta, plastic tubes in Ontario; and in Quebec an extruded paper skin container is to be developed in preference to existing types (Bonin 1974).

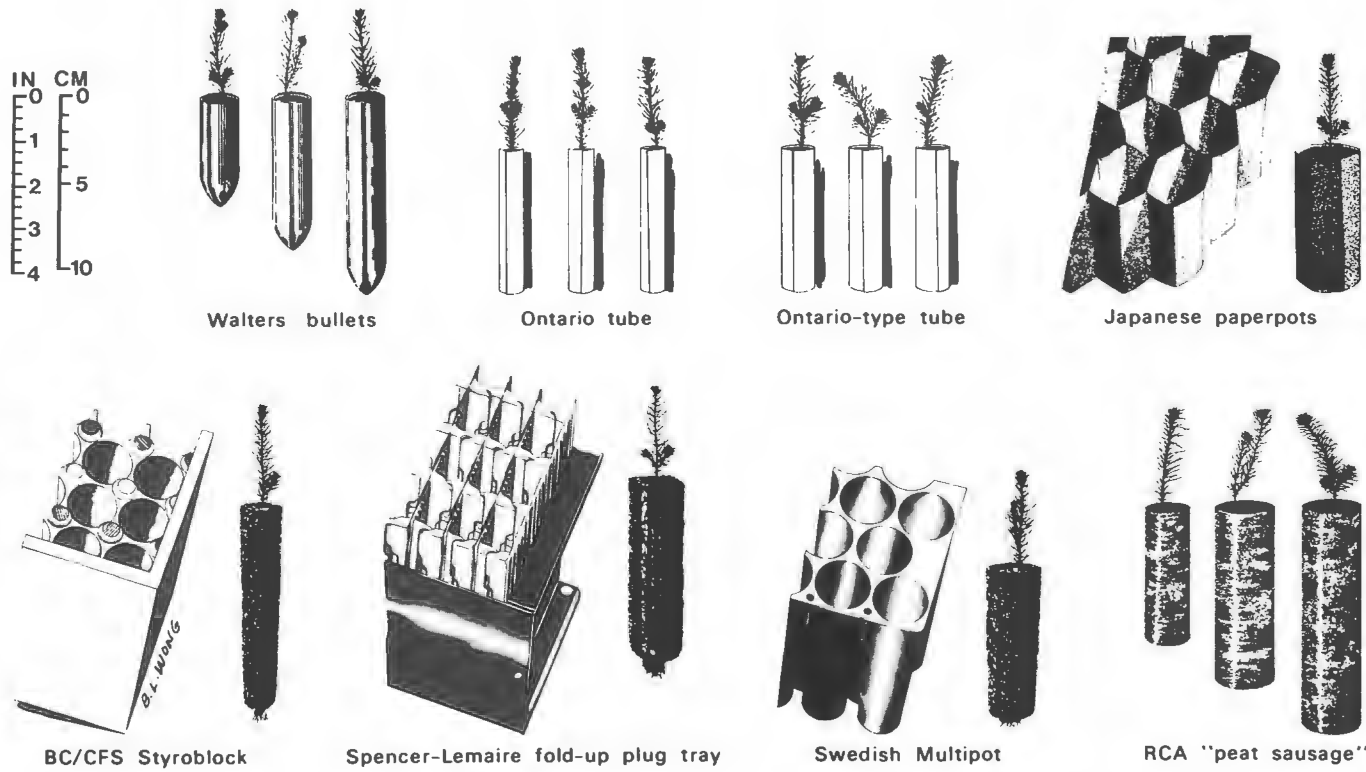


Figure 9. Some seedling container types. From Cayford 1972.

Compatibility with Seedling Requirements

The basic design of a container must at least allow development of a seedling of the desired specification and permit free growth of the roots after planting. The "desired specification" for white spruce seedlings, while an obvious starting point, is by no means settled. It is agreed, though, that most early work with containers produced seedlings which were too small, both because the greenhouse period was too short and because container size was inadequate, confining root growth even before the seedlings were field-planted (Endean 1972, Johnson 1974, Scarratt 1972*a*, 1972*b*, 1972*c*, Van Eerden 1972).

Several size criteria have been offered for white spruce. Seedling height of at least 3 in. (7.6 cm) by Robinson (1973), 4 in. (10.2 cm) by Van Eerden (1972), and 4 to 5 in. (10.2 to 12.7 cm) by Scarratt (1973) have been proposed tentatively. Recommendations for the age at which seedlings will be sufficiently well developed for planting are mostly in the range 12 to 18 weeks (20 to 30 weeks in British Columbia), exclusive of overwintering in outside cold frames, now often the case with white spruce. Age is not always a good guide, as size reached in a given time will vary with greenhouse regime and time seedlings are placed outside. In Alberta, Ferdinand, Kay and Hellum (1974) included the following composite seedling requirements: (i) top height 3 to 5 in. (7.6 to 12.7 cm) (ii) total dry weight 300 to 500 mg (0.011 to 0.018 oz), (iii) shoot/root ratio less than 3 and (iv) sturdy, woody stems and fibrous roots. "Attainable target sizes" for white spruce in British Columbia with Styro 2 containers were reported as: (i) height 14 cm (5.5 in.), (ii) root collar diameter 3.0 mm (0.12 in.), (iii) dry weight 1.5 g (0.05 oz) and (iv) shoot/root ratio 1.5 to 2.0 (Van Eerden 1974). In Ontario, an arbitrary performance standard calls for a container seedling which, three years after planting, will have the same "impact" (height plus survival) as 3-0 seedlings at that time; for white spruce this would probably be a 14- to 16-week seedling 6 in. (15 cm) tall at summer planting, and 20 in. (51 cm) tall three years after planting (Reese 1974, Scarratt

1974).

Increasing diameter rather than length of the container improves root density (Boudoux 1970), and overall seedling growth (Hocking and Mitchell 1975), and Scarratt (1972*d*) concluded that 3 in. (7.6 cm) may be sufficient length, especially to facilitate planting in shallower soils and to give rapid root egress from solid-walled containers such as the Ontario tube. However, longer tubes might be advantageous where upper soil layers are droughty in summer, for which condition a 5-in. (12.7-cm) length has been recommended in Manitoba. In terms of container size which will allow unrestricted root development compatible with adequate top growth, it appears that volumes of not less than 2.3 cubic in. (37.7 cc) (equivalent to a cylinder ca. 1 in. (2.5 cm) in diameter and 3 in. (7.6 cm) long) are required (Endean 1972, Ferdinand 1972). However, the Ontario white spruce standard already described would entail a container volume of 3.7 cu in. (60.6 cc), i.e. a tube 1.25 in. (3.2 cm) by 3 in. (7.6 cm) long, according to Scarratt (1973). The practical upper size limit does not seem to have been demonstrated. Even larger containers are now available, and the proposed Quebec paper tube will be 1.5 in. (3.8 cm) by 4 in. (10.2 cm), giving a volume of 7.1 cu in. (116.3 cc) (Bonin 1974). As with container size, shape and cavity design of some types also undergo continual modification (e.g. Sjoberg 1974, Spencer 1974, Walters 1974).

Cost and Automation

Many container designs are probably capable of producing an acceptable seedling, but the choice will be governed by cost and adaptability to automation which will be the most important consideration in the long run. Mechanization is still incomplete for most phases of container production and planting in Canada, although development is underway. In Scandinavia it appears that at least one of the systems on trial in Canada (Japanese Paperpots) will shortly be fully mechanized in the field as well as in the nursery (Haig 1972).

According to Sirén (1968) the cost of the final product is determined mainly by operating costs, yield per unit area, production time and material costs. In this respect increasing container size to meet biological constraints will increase not only container costs, but production costs (because fewer containers can be accommodated in the nursery per unit area), and transportation costs as well (Glade 1972, Kinghorn 1972). Few cost data are available in Canada, and comparisons may be difficult unless the items included are specified. A "standard" nursery cost of $22 per thousand seedlings for large-scale container operations in 1975 was proposed by Vyse and Ketcheson (1974) "as a target or goal for reforestation workers in Canada".

Comparisons of three containers types at Oliver, Alberta, in 1971 for 520,336 Styroblock 2 plugs, 486,690 Spencer-Lemaire Book plugs, and 188,416 RCA Sausages showed production costs in the ratio of 1.3:1.0:1.3 (Smyth and Karaim 1972). Production costs of containers at Oliver appeared to be of the order 70 to 80% of those for 3-0 seedlings (McDougall and Kennedy 1972, Smyth and Karaim 1972). More recently, production of container seedlings in Alberta was said to cost almost as much as 3-0 stock (Ferdinand, Kay and Hellum 1974). Figures given for 9/16-in. (1.4-cm) tubed seedlings in Ontario are very similar to those for 3-0 seedlings (MacKinnon 1970, Robinson 1973), and one study showed costs of producing 1-0 spruce container seedlings to be 40% higher than those for 3-0 bare root (Reese 1974*a*). Vyse and Ketcheson (1974) have concluded that cost savings with container systems lie in the planting, not the production phase.

Greenhouse Procedures

Only a few systems have been tried on an operational or even a pilot scale with white spruce (or any other species) in Canada. Detailed descriptions of all or part of the rearing process have been published for seedling production with Bullets (Walters 1967 and 1974); Styroblocks in British Columbia (Matthews 1971, Sjoberg 1972 and 1974, Van Eerden 1974); Books and Sausages in Alberta (Ferdinand, Kay and Hellum 1974, Grainger 1974); Ontario-type tubes in Alberta (Carman 1967) and in Ontario (Williamson 1964, Ontario Department Lands and

Forests 1967, MacKinnon 1970, Reese 1974); and Paperpots in Manitoba (Meseman 1974) and in Nova Scotia (Routledge 1974). Mineral nutrition of seedlings was reviewed in detail by Brix and van den Driessche (1974). The following is based mainly on these descriptions, but it should be understood that technology in this field is evolving rapidly and some procedures are soon outdated.

Rooting media for containers are usually some type of peat, which offers advantages of lightness, cohesiveness and good water-holding properties. Shredded peat, acid peat moss, "peat paste", fibrous peat, peat slurry, 3:1 peat:vermiculite and 2:1 peat: "Terralite" mixtures and ground bark are variously used. The pH should be adjusted to some specific value in the range of ca. 4.5 to 5. For example, dolomite lime may be added at from $1\frac{1}{2}$ to 5 lb/yd^3 (0.9 to 3 kg/m^3) of growing medium to raise pH. Styroblocks may be filled mechanically in a frame by shaking down with an eccentric cam, at rates of 100,000 cavities per man day; Bullets may be loaded similarly, or with a compressor-operated turntable and soil-metering grids. Ontario tubes are filled by a hand-operated loader. Soil is usually tamped down after filling by these processes. At Oliver, Alberta, Books are filled by brushing on peat at 80% moisture content, and vibrating it down. Peat sausages are filled by continuous extrusion of the medium into a 10-ft (3-m) tube which is later chopped into individual containers with a gang cutter. Some container-filling operations attempt to control the density of the medium in the cavities.

Sowing in the containers is accomplished in British Columbia with a precision drum seeder with vacuum seed selection and air brush for removing excess seed; Styroblocks, passing beneath on a conveyor, are sown at a rate of 40,000 per hour; if viability is low, two or three runs are made. Bullets are seeded with vacuum-operated nozzles, part of the soil-loading machine, as a continuation of the same operation; extra, smaller bullets may be seeded concurrently and later gun-planted into normal-sized Bullets where germination has failed. Ontario-type tubes also are sown with vacuum equipment. Some container types have not yet had automatic seeders developed for them. At

Oliver, Books are deliberately overseeded, with later thinning considered cheaper than refilling blanks. After sowing, the seed may be covered with grit or coarse sand. In most instances stratified or water-soaked seed is used, but at Oliver the seed is stratified in the containers -- for 6 weeks at 34° to $36^{\circ}F$ (1° to $2^{\circ}C$).

The soil is thoroughly moistened and the trays of containers then placed in a warm, 70° to $80^{\circ}F$ (21° to $27^{\circ}C$), humid (85% RH) atmosphere. Germination takes 2 1/2 to 14 days. The trays or flats are then placed in greenhouses with controlled temperature and ventilation. Temperatures are usually kept constant at ca. $70^{\circ}F$ ($21^{\circ}C$), but at some nurseries is alternated with $50^{\circ}F$ ($10^{\circ}C$) at night. In hot weather cooling is accomplished by fans, screens, watering or evaporation. Supplementary light may be provided to increase day length to 16 or 18 hours. The discussion of controllable greenhouse parameters under "Bare-root Stock" is equally applicable to container seedling production. However, attaining optimum growing conditions through manipulation of all environmental factors is not the objective of many operational greenhouses. Nova Scotia Forest Industries' Paperpot seedlings are raised in unheated plastic-covered greenhouses, from which the plastic is removed after about 60 days and the plants left uncovered until planting the following spring. At Surrey, British Columbia the mild coastal climate permits rearing seedlings out of doors and the containers are taken outside as soon as germination is complete, and placed on pallets under saran shadecloth which admits 46% full light.

Watering is generally applied as appears necessary, although at Surrey soil moisture blocks are weighed to help determine actual conditions. Weighing batches of containers to ascertain moisture content is another approach, used, for example, with Sausages. Heavy watering may be necessary periodically to leach out accumulated salts from fertilizers. Overhead watering is the usual method, and travelling overhead irrigation booms have been developed in British Columbia. Subirrigation of tubes and bullets has been practised by flooding pans in which the perforated flats are contained. Very cold water should be allowed to warm up before irrigation. Sprinklers, some thermostatically controlled, are used for frost protection.

Nutrients are usually added via the watering system, rather than by mixing with the soil in advance. "Balanced" fertilizers are provided, of which the nutrient solution developed by Ingestad (1967), and a commercial product "RX-15" are two widely used; Routledge (1974) described another. In Alberta, seedlings are fertilized with a solution containing NPKMg in the ratio 3.6:1:5:1.5, plus micro-nutrients, devised especially for white spruce (Hocking 1971*b*). In Ontario, nutrient concentrations required for the peat medium are based on plant analysis, and soil analyses made both before seeding and at time of seedling sampling, as follows: N 1.00%, P 0.05%, K 0.06%, Ca 1.50%, and Mg 0.35%.

The fertilization regime early in the production period should be such as to promote rapid growth, and later to improve seedling quality with respect to post-planting survival and winter hardiness (Brix and van den Driessche 1974). Heavy nitrogen applications are stressed in most nurseries, and high phosphate at early or early and later growth stages; e.g., in one schedule at Surrey 10 oz 10-52-10 and 2 1/2 oz 28-14-14 per 100 gal (625 g and 155 g per 1000 ℓ) of water per week were applied, followed by 6 1/2 oz 28-14-14 per 100 gal (405 g per 1000 ℓ) per week after the second flush of needles.

Weeding is done by hand. In Ontario captan 50 W is applied to 10 g per gal (2.2 g/ℓ) to control damping-off, and at Hinton, Alberta thiram fungicide is sprayed on in aqueous solution. In British Columbia hydrated ferrous ammonium sulphate at 25 g/ℓ (4 oz/gal) may be used to control moss.

There is a tendency in the latter stages of seedling development for roots to grow out of the ends of containers and become entangled, making container separation difficult as well as damaging to the seedlings. Root egress can be prevented by coating the surface of the trays with copper paint or, more effectively, by "air pruning" which involves leaving at least 1 in. (2.5 cm) of well-ventilated air space beneath the perforated trays (Scarratt 1972*e*).

At some nurseries extra seedlings in a container are pulled out or clipped off to leave only one, but at others it is assumed that one seedling will become dominant. Towards the end of the greenhouse regime, blanks should be replaced so that each tray will have a full complement of seedlings.

Seedlings are not kept in the greenhouse for the full growing period, but are moved outside to cold frames at age 4 to 12 weeks, depending on the climate and the season when the seed was germinated, to become accustomed to normal temperatures and their fluctuations, and eventually **hardened off** prior to planting. Shade may be provided for the first part of the process, and reduction of water and nutrients for the latter part. Anti-frost measures should be available in this period, in the form of heating cables or adequate watering facilities. Overwintering white spruce seedlings outside is becoming common practice. An anti-desiccant may be applied before dormancy. However, at Surrey, British Columbia, the stock is bundled in plugs and stored at 2°C (36°F) to prevent low temperature damage to the roots.

As noted earlier, age when planted (exclusive of the overwinter period) varies with greenhouse regime and climate. Fourteen weeks is now virtually the minimum age, and some schedules allow a full year. Trays of well-watered containers are transported in tiers or racks by truck, with tarpaulin covers to minimize drying. Jarring is to be avoided as much as possible in loading and hauling. Storage and watering at the planting site are easier if the containers are left in the trays until needed. Styroblocks, however, are particularly bulky and difficult to pack for transport and the practice of extracting the plugs at the nursery and wrapping them with plastic in cylindrical bundles of 25 (tops protruding), which are packed upright in cartons of 500 plugs each, is more economical of space in transit; it also avoids the necessity of shipping the empty containers back from the planting site for reuse (Bamford 1974, Kinghorn 1972).

References to Nursery Practice

Ackerman, R.F., D.I. Crossley, L.L. Kennedy and J. Chedzoy. 1965. Preliminary results of a field test of bullet planting in Alberta. Can. Dep. For., For. Res. Branch Publ. 1098.

Armson, K.A. 1963. The effects of levels and times of fertilizer application on the growth of white spruce seedlings. Soil Sci. Soc. Am. Proc. 27(5):596-597.

Armson, K.A. 1966. The growth and absorption of nutrients by fertilized and unfertilized white spruce seedlings. For. Chron. 42(2):127-136.

Armson, K.A. 1968. The effects of fertilization and seedbed density on the growth and nutrient content of white spruce and red pine seedlings. Univ. Toronto, Fac. For. Tech. Rep. 10.

Armson, K.A. and R.D. Carman. 1961*a*. An acid injection system for nursery irrigation water. Tree Plant. Notes 46:11-13.

Armson, K.A. and R.D. Carman. 1961*b*. A manual for forest tree nursery soil management. Ont. Dep. Lands For., Timber Branch.

Armson, K.A. and V. Sadreika. 1974. Forest tree nursery soil management and related practices. Ont. Minist. Nat. Resour., Div. For., For. Manage. Branch.

Arnott, J.T. 1974. Performance in British Columbia. *In* Richard W. Tinus, William I. Stein, and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:283-290.

Bamford, A.H. 1970. Innovations in present nursery production of conventional planting stock. For. Chron. 46(6):481-486.

Bamford, A.H. 1974. Development of the British Columbia container program. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo, Great Plains Agric. Counc. Publ. 68:53-58.

Bingham, Charles W. 1974. Achieving forestation goals. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:3-7.

Bonin, Pierre. 1974. Quebec's container-grown seedling program. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:339-344.

Boudoux, Michel E. 1970. Effect of tube dimension on root density of seedlings. Bi-mon. Res. Notes 26(3):29-30.

Brace, L.G. 1964. Early development of white spruce as related to planting method and planting stock height. Can. Dep. For., For. Branch, Dep. Publ. 1049.

Brix, H. and R. van den Driessche. 1974. Mineral nutrition of container-grown tree seedlings. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68: 77-84.

Bunting, W.R. 1966. Extension of the planting season. *In* Proc. Conf. Artif. Regeneration Ont. Feb. 15-16, Richmond Hill, Ont. Dep. Lands For., mimeo. p. 13-16.

Bunting, W.R. 1975. Modern tree packaging. Your Forests 8(1):32-33.

Campagna, Jean P. et Jean M. Fortin. 1971. Le reboisement au Québec-Réalizations et objectifs. *In* E.K. Morgenstern (ed.) Proc. 12th Meet. Comm. For. Tree Breed. Can. Part 2. Dep. Fish. For., Can. For. Serv. p. 191-199.

Campagna, Jean Paul and Donald P. White. 1973. Nursery soil fumigation affects growth and phosphorus nutrition of pine and spruce seedlings. For. Chron. 49(5):219-223.

Carman, R.D. 1967. An indistrial application of the container-planting technique. Pulp Pap. Mag. Can. 68(4):WR181-188.

Cayford, J.H. 1972. Container planting systems in Canada. For. Chron. 48(5):235-239.

Cayford, J.H. and R.M. Waldron. 1966. Storage of white spruce, jack pine and red pine seed treated with Arasan, Endrin, and aluminum flakes. Tree Plant. Notes 77:12-16.

Cayford, J.H. and R.M. Waldron. 1967. Effects of captan on the germination of white spruce, jack and red pine seed. For. Chron. 43(4):381-384.

Endean, F. 1972. Assessment of different types of containers for growing seedlings in Alberta. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:119-128.

Farrar, J.L. and G.D. Huntley. 1969. The effect of root pruning on root extension growth of *Pinus banksiana* and *Picea glauca* seedlings. Extr. from Rep. For. Res. Glendon Hall Fac. For. Univ. Toronto 1968/1969, 1969(5-6). Cited in For. Abstr. 31:752, abstr. 6287.

Ferdinand, S.I. 1972. Container planting program at North Western Pulp and Power Ltd. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2: 21-25.

Ferdinand, S.I., W.C. Kay and A.K. Hellum. 1974. Container program in Alberta. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:44-52.

Fraser, J.W. and W.W. Wahl. 1969. Frost and tubed seedlings. Can. Dep. Fish. For., For. Branch Inf. Rep. PS-X-12.

Glade, L. 1972. Container planting program in Alberta. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:10-14.

Grainger, George D. 1974. Container-growing mechanization and costs. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.)

Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:158-162.

Grinnell, W. Ross. 1955. Planting stock dropped by air. Tree Plant. Notes 20:26-27.

Grinnell, W. Ross. 1971. Forestry horizons. Pap. Presented 1971 Annu. Meet., Am. Soc. Agric. Eng., Wash. State Univ., Pullman, Wash.

Haig, R.A. 1972. Container planting in Finland, Sweden and Scotland. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:160-165.

Hellum, A.K. 1968. A case against cold stratification of white spruce seed prior to nursery seeding. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1243.

Heltzel, John B. 1970. The Virginia forest tree seedling harvester. Tree Plant. Notes 21(1):27-28.

Hocking, D. 1971*a*. Effect and characteristics of pathogens on foliage and buds of cold-stored white spruce and lodgepole pine seedlings. Can. J. For. Res. 1(4):208-215.

Hocking, D. 1971*b*. Preparation and use of a nutrient solution for culturing seedlings of lodgepole pine and white spruce, with selected bibliography. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-1.

Hocking, Drake. 1972. Effects of stratification of Alberta white spruce and lodgepole pine seeds on emergence in operational seed-beds. Bi-mon. Res. Notes 28(4):26-27.

Hocking, D. and D.L. Mitchell. 1975. The influences of rooting volume-seedling espacement and substratum density on greenhouse growth of lodgepole pine, white spruce, and Douglas fir grown in extruded peat cylinders. Can. J. For. Res. 5(3):440-451.

Ingestad, Torsten. 1967. Methods for uniform optimum fertilization of forest tree plants. *In* Pap. XIV IURFO Kongress. München. III:265-269.

Johnson, H.J. 1974. Canadian Forestry Service container planting trials in Alberta, Saskatchewan and Manitoba. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:298-305.

Kinghorn, J.M. 1970. The status of container planting in western Canada. For. Chron. 46(6):466-469.

Kinghorn, J.M. 1972. Seedlings on the move. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:152-153.

Kinghorn, James M. 1974. Principles and concepts in container planting. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:8-18.

Kozlowski, T.T. 1963. Nursery weed control in white spruce seedlings and transplants. Univ. Wisconsin For. Res. Note 103.

Krause, H.H. 1971. Potassium budget for forest nursery soil. J. For. 69(4):226-228.

Lees, J.C. 1964. Tolerance of white spruce seedlings to flooding. For. Chron. 40(2):221-225.

Lock, W., J.R. Sutherland and L.J. Sluggett. 1975. Fungicide treatment of seeds for damping-off control in British Columbia forest nurseries. Tree Plant. Notes 26(3):16-18,28.

Low, Alan J. 1971. Tubed seedling research and development in Britain. Forestry 44(1):27-41.

MacKinnon, George E. 1970. Container planting in Ontario. For. Chron. 46(6):470-472.

Matthews, R.G. 1971. Container seedling production: a provisional manual. Dep. Environ., Can. For. Serv. Inf. Rep. BC-X-58.

McDougall, F.W. and L.L. Kennedy. 1972. The status and future of reforestation in Alberta. Can. Pulp Pap. Assoc. WS 2611(F-2)10.

Meagher, M.D. and K.A. Armson. 1963. The effect of phosphorus placement on the growth of white spruce seedlings. J. For. 61(12): 918-920.

Meseman, W.T. 1974. Paperpot containerization in Manitoba. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:366-367.

Mullin, R.E. 1957. Experiments with root and top pruning of white spruce nursery stock. Ont. Dep. Lands For., Div. Res., Res. Rep. 36.

Mullin, R.E. 1965. Effects of mulches on nursery seedbeds of white spruce. For. Chron. 41(4):454-465.

Mullin, R.E. 1966. Root pruning of nursery stock. For. Chron. 42(3): 256-264.

Mullin, R.E. and W.R. Bunting. 1972. Refrigerated overwinter storage of nursery stock. J. For. 70(6):354-358.

Mullin, R.E. and C.P. Howard. 1973. Transplants do better than seedlings, and ... For. Chron. 49(5):213-218.

Mullin, R.E. and J.D. Parker. 1974. Bales *versus* polybags in cold and frozen overwinter storage of nursery stock. Can. J. For. Res. 4(2): 254-258.

Mullin, R.E. and J. Svaton. 1972. A grading study with white spruce nursery stock. Commonw. For. Rev. 51(1):62-69.

Ontario Department Lands & Forests. 1967. Provisional instructions for growing and planting seedlings in tubes. Revised 1967.

Phipps, Howard M. 1973. Growth response of some tree species to plastic greenhouse culture. J. For. 71(1):28-30.

Pollard, D.F.W. and A.H. Teich. 1972. A progeny test of rapidly grown white spruce seedlings. Bi-mon. Res. Notes 28(3):19-20.

Pollard, D.F.W. and K.T. Logan. 1975. Prescription of the aerial environment for a plastic greenhouse nursery. *In* Proc. 12th Lake States For. Tree Improv. Conf. (in press).

Reese, K.H. 1972. Container planting program in Ontario. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:29-32.

Reese, Kenneth H. 1974. Container production in Ontario. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:29-37.

Robinson, Fred C. 1973. Forest regeneration in Ontario. Pulp Pap. Mag. Can. 74(2):29-32, 35.

Routledge, Hollis T. 1974. Boreal species on short rotation. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:119-123.

Santon, John. 1970. Effect of stratification on germination of freshly harvested seed of several spruce and pine species in eastern Canada. Dep. Fish. For., Can. For. Serv. Inf. Rep. PS-X-17.

Scarratt, J.B. 1972*a*. Tubed seedling research in northern Ontario. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:129-141.

Scarratt, J.B. 1972*b*. Relationship between size at planting and growth of white spruce tubed seedlings. Dep. Environ., Can. For. Serv. Inf. Rep. 0-X-168.

Scarratt, J.B. 1972*c*. Effect of tube diameter and spacing on the size of tubed seedling planting stock. Dep. Environ., Can. For. Serv. Inf. Rep. 0-X-170.

Scarratt, J.B. 1972*d*. Container size affects dimensions of white spruce, jack pine planting stock. Tree Plant. Notes 23(4):21-25.

Scarratt, J.B. 1972*e*. Air space controls root extension from open-ended containers during seedling production. For. Chron. 48(5): 242-245.

Scarratt, J.B. 1973. Containerized seedlings: relation between container size and production period. Bi-mon. Res. Notes 29(1): 4-6.

Scarratt, John B. 1974. Performance of tubed seedlings in Ontario. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:310-320.

Schneider, G., Donald P. White and Randall Heiligmann. 1970. Growing coniferous seedlings in soilless containers for field planting. Tree Plant. Notes 21(3):3-7.

Sirén, Gustaf. 1968. Views on the mechanization of forest regeneration. Institutionen för Skogsföryngring, Skogshögskolan. No. 14:271-289. Can. Dep. Fish. For. Libr. Transl. 213.

Sjoberg, N.E. 1972. Container planting program in British Columbia. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:2-6.

Sjoberg, N.E. 1974. The styroblock container system. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:217-228.

Slayton, Stuart H. 1970. Storing baled red pine, black spruce, and white spruce over winter feasible in Upper Michigan. Tree Plant. Notes 21(4):15-17.

Smyth, J.H. and B.W. Karaim. 1972. An economic analysis of reforestation costs in Alberta. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-41.

Spencer, Henry A. 1974. To "engineer" the container. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:229-232.

Stoeckeler, J.H. and G.W. Jones. 1957. Forest nursery practice in the Lake States. U.S. Dep. Agric., For. Serv., Agric. Handb. 110.

Sutton, R.F. 1967. Influence of root pruning on height increment and root development of outplanted spruce. Can. J. Bot. 45(9): 1671-1682.

Sutton, R.F. 1970. Chemical herbicides and forestation. For. Chron. 46(6):458-465.

Tinus, Richard W., William I. Stein and William E. Balmer (eds.). 1974. Proceedings of the North American containerized forest tree seedling symposium. Denver, Colorado. August 26-29, 1974. Great Plains Agric. Counc. Publ. 68.

van den Driessche, R. 1969. Forest nursery handbook. B.C. For. Serv. Res. Note 48.

van den Driessche, R. 1975. Review of *Forest Tree Nursery Soil Management* by K.A. Armson and V. Sadreika, 1974. For. Chron. 51(1):36-37.

van den Driessche, R. and M.B. Balderston. 1974. Trials with selective herbicides in Forest Service nurseries. B.C. For. Serv. Res. Note 61.

Van Eerden, E. 1972. Influences affecting container seedling performance near Prince George, British Columbia. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:92-100.

Van Eerden, E. 1974. Growing season production of western conifers. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:93-103.

Vyse, A.H. and D.E. Ketcheson. 1974. The cost of raising and planting containerised trees in Canada. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:402-411.

Waldron, R.M. (ed.). 1972. Proceedings of a workshop on container planting in Canada. Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2.

Walters, J. 1961. The planting gun and bullet: a new tree-planting technique. For. Chron. 37(2):94-95, 107.

Walters, John. 1967. Container planting in forestry. Proc. Int. Plant Propagators Soc. Annu. Meet. p. 141-146.

Walters, John. 1974. Engineering for injection planting. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:241-243.

Wilde, S.A. 1958. Forest soils their properties and relation to silviculture. The Ronald Press Co., N.Y. ix + 537 p.

Williamson, V.H.H. 1964. Preparation and planting of tubed seedlings. Ont. Dep. Lands For., Res. Branch Res. Rep. 52.

Yeatman, C.W. 1970. CO_2 enriched air increased growth of conifer seedlings. For. Chron. 46(3):229-230.

Cutover and burnt site, to be planted to 2-0 white spruce. Near Fort Babine, B.C. Canadian Forestry Service photo.

IV. PLANTING

Site Selection

Site conditions for white spruce planting in Canada fall into several categories. **Cutovers** (except in Manitoba, where natural seeding is said to restock them adequately) are the commonest planting sites. If the previous stand was mixedwood, a residual of birch or aspen is often present. If an overmature stand was clear-cut (e.g., spruce-fir in the British Columbia interior) then the area is encumbered by huge amounts of debris resulting from the high proportion of cull. Depending on the time since cutting, more or less brush and grass may also be present.

Burns are often characterized by dense suckers, if aspen was a component of the previous stand, and are subject to continuing invasion by grass and hardwood brush.

Abandoned farm land still provides considerable areas for planting in Quebec and the Maritimes. It is less important in Ontario than formerly, although Staley (1970) reported 2,000,000 ac (810,000 ha) of open "forest land" in the southern part of the province. The "old fields" are usually sod-covered, and sometimes brushy, particularly if wet. Depleted soil nutrients from prolonged cropping without fertilization is a risk, often a hidden one, on these sites. While excellent white spruce plantations have been grown on some old fields (Stiell and Berry 1973), nutrient deficiencies on others have resulted in very poor growth (Cunningham 1953).

Conversion of aspen stands by planting under the canopy or in cleared strips has been practised in Alberta and Ontario. **Tolerant hardwood conversion** in eastern Canada has been achieved by planting subsequent to a commercial clear-cut followed by removal of cull residuals, and by underplanting.

In judging the suitability of such areas for planting white spruce, consideration should be given to its particular requirements and susceptibilities, as well as to factors which bear on the economics of the undertaking.

Silvics

White spruce is a shade-tolerant species, in the juvenile stage able to make optimum height growth in somewhat less than 50% of full light, although foliage production and diameter growth reach a maximum only in full light; from about age ten, height growth also is reduced by overhead shade (Logan 1969, Eis 1970), and a closed-canopy overstory will seriously retard development of white spruce beneath it (Cayford 1957, Stiell 1958).

White spruce is particularly subject to unseasonable frosts, which deform seedlings and delay their normal development by killing newly flushed, succulent shoots (Fraser 1965). Low soil temperatures, such as may prevail beneath duff of undisturbed sites, may inhibit seedling growth (McMinn 1974).

Young spruce are often adversely affected by grass, particularly sod on compact soils. White spruce may be less able to endure root competition on drier sites owing to slow downward root growth (Sims and Mueller-Dombois 1968). Physical "smothering" of planted seedlings by dense ground cover has been reported in north-central British Columbia by Armit (1970) and in the Quebec Clay Belt by MacArthur (1964). However some meadow plants, such as goldenrod, appear to offer protection to young seedlings rather than hinder their growth.

White spruce shows evidence of being one of the more nutrient-demanding conifers (Heiberg and White 1951, Lafond 1954). MacArthur (1959) concluded that it was unsuited to impoverished old-field sites in Laurentian Forest Section L.4a[14] where planted jack and red pine made adequate growth. There is little information on specific nutrient levels required by white spruce, but Wilde (1966) proferred the following minimum soil fertility factors, based on an examination of plantations on well-drained soils in Wisconsin: total

[14] "Forest Section" hereinafter refers to Rowe (1972) unless otherwise stated.

N, 0.120%; available P, 40 lb/ac (45 kg/ha); available K, 130 lb/ac (145 kg/ha); exchangeable Ca, 3.00 me/100 g; exchangeable Mg, 0.70 me/100 g.

White spruce grows on both acid and alkaline soils. Sutton (1969) considered that optimum growth is possible for pH 5.0 to 7.0 and perhaps higher. Wilde (1966) gave an approximately optimum pH range of 4.7 to 6.5 for white spruce planted on Wisconsin soils, although his sample was lacking in higher soil reaction values. Teich and Holst (1974) reported a limestone ecotype from Ontario, growing on soils with pH 6.6.

A wide range of soil moisture can be endured by white spruce, owing in part to the adaptability of its roots to varying conditions (Sutton 1969). Young seedlings can tolerate total immersion for a day or two (Lees 1964), and trees as small as one to two feet (0.3 to 0.6 m) tall have survived submerged for up to 28 days (Ahlgren and Hansen 1957). Dry sites, including loose medium and coarse sands, gravels, and shallow soils over bedrock will limit growth of white spruce plantations (Stiell 1958). "Broadly speaking", according to Sutton (1969), "white spruce will tolerate dry sites if they are fertile, and no fertile site is too moist unless the soil water is stagnant".

Soils

In general, then, site amplitude is wide, and good tolerance of shade and ability to grow on wetter soils often result in white spruce being planted on brushy and poorly drained sites where it is judged the species most likely to succeed, or least likely to fail. However, white spruce, like most species, makes best growth on well-drained loamy soils. The following are some descriptions of favourable sites as reported for different parts of Canada.

In the Montane Transition Forest Section M.4 of central British Columbia, the most productive white spruce site types are *Oplopanax* (O) (Devil's Club) -- wet to moist sandy loam or loam, over silt or clay, with drainage in the upper profile; *Disporum* (D) (Fairybells) -- moist to fresh silty or clay loam over compact till or varved clay; and *Aralia-Dryopteris* (A-D) (Sarsparilla-Oakfern) -- moist soil, from sandy loam to clay, usually gleyed at 12 to 30 inches (30 to 76 cm) (Illingworth and Arlidge 1960). In this region, white spruce is preferred for planting on the wetter sites where lodgepole pine is subject to root rot. On the drier soils the pine quickly outgrows the spruce and is considered a better choice.

In the Prairie Provinces the Mixedwood Forest Section B.18a extends from southwest Manitoba to northwest Alberta. Soils are calcareous. White spruce is widely represented in the forest cover and makes best growth on sites where intermediate moisture classes prevail, and on the lighter soils such as water-washed till, alluvium and ponded material. For best results with white spruce, Jarvis *et al.* (1966) recommended that planting be confined to the fresh and moist sites.

Sutton (1969) reported excellent growth in northern Ontario on fertile sites saturated with telluric water. In northwest Ontario (i.e. west of Sault Ste. Marie), deep and well-drained soils with fresh to very fresh moisture regimes (MR 1 to MR 3, *sensu* Hills 1952), are considered best for planting white spruce. In the middle Ottawa River-Lake Huron Site Region (i.e. Region 5E, Hills 1959), productivity for planted white spruce was rated as good or very good on fresh to wet (MR 1 to 8) light tills of the Sherborne Landtype; good on fresh to moist (MR 1 to 6) sands of the Petawawa Landtype; and very good on moist (MR 4 to 6) waterlaid light loamy and silty materials, usually stonefree, of the Rayside Landtype (Williams 1955). Also for Region 5E, very high or high potential productivity for white spruce was ascribed by Pierpoint (1962) to: fresh and moist sand and sandy loam over bedrock of the Petawawa- and Sherborne-over-Henvey and Limerick-over-Apsley Landtypes; and fresh and moist clay loam of the Denison Landtype. For deep sandy soils in the Lake Simcoe-Rideau Site Region (i.e. Region 6E, Hills 1959), potential production for white spruce plantations was rated Class I on fresh to somewhat moist sites (MR 2 to 4+) and Class II on MR's 0+ to 2- and 4+ to 6- (Love and Williams 1968).

White spruce has been recommended as a promising species for planting on clay soils in northwest Quebec (Popovich 1972). For old-field sites with loamy fine sands in Laurentian Forest Section L.4a, planted white spruce grew best on the Calliergon (Cal) (Moss) site type (Gagnon and MacArthur 1959). Plantations on old fields in Middle St. Lawrence Forest Section L.3 performed best on tills or shallow fine sand over clay, moderately drained (Popovich and Houle 1970). These authors noted a marked predilection by white spruce planted on old fields for gleyed podzols with medium drainage. Jurdant *et al.* (1969) presented the growth potential of white spruce in the Lac Saint-Jean - Saguenay region according to "*type écologique*" -- a detailed combination of vegetation cover, named soil series and moisture class.

Young experimental plantations of white spruce at Acadia Forest Experiment Station, in Eastern Lowlands Forest Section A.3 of New Brunswick, showed best growth on well-drained sites where the surface soil was permeable sandy loam (McLeod 1956).

In Nova Scotia, well-drained loamy soils are preferred for planting white spruce, but sandy loams, mainly nutrient poor, prevail.

In Newfoundland, white spruce wildlings planted on well-drained, deep, stone-free clay-loam in the Corner Brook Forest Section B.28b "performed well" over the first ten years (Hall, J. Peter 1970). In a provenance trial in Grand Falls Forest Section B.28a, a well-drained loam provided the best conditions for early growth (Nicholson 1970).

Non-soil Factors

Certain site situations are potentially limiting to the success of white spruce plantations irrespective of soil productivity.

Susceptibility of spruce to late spring frosts dictates that areas subject to these occurrences be avoided when planting. Such areas feature a topography that allows the pooling of cold air, and lacks an effective tree cover to reflect back heat radiation from the ground. Typical frost-prone areas are depressions with insufficient outlet drainage to prevent cold air accumulation, zones immediately uphill from clumps or belts of trees on otherwise cleared slopes, and shelfs or plateaus on long slopes; bracken fern is frost-sensitive, and unseasonal browning of its foliage can help to identify frosty localities (Duffy and Fraser 1963, Fraser 1965). The seriousness of frost damage to white spruce in Canada has mainly been remarked on east of Manitoba.

White spruce seedlings may be heavily browsed by snowshoe hares. Injury so caused is most prevalent in the Prairie Provinces where repeated clipping of the tops can maintain seedlings indefinitely in a stunted condition. Rowe (1955) related the degree of damage to population cycles of the hare, but in some areas browsing seems continuous. Browsing is less predominant in plantations on cutover sites, but where spruce has been planted beneath aspen stands, or in corridors bulldozed through them, it is severe enough to cast doubt on the feasibility of stand conversion by these means.

"Stand-opening disease" is caused by a serious root rot found in natural stands of white spruce from Saskatchewan to the Maritimes, and identified in spruce plantations in Ontario and Quebec. Inoculum of the pathogen has been found to persist in roots for many years after cutting the host trees, and there may be considerable risk in planting white spruce where the previous stand was heavily diseased (Whitney 1962, 1972).

Site Preparation

Sites may be treated prior to planting:

(1) to make the area accessible to men or machines and amenable to the planting operation;

(2) to remove vegetation which will compete unduly with the planted seedlings;

(3) to ameliorate the quality of the site (usually the soil drainage).

One of these pre-planting treatments will usually be necessary, or at least advantageous in speeding the planting operation or allowing unrestricted growth.

10-year old white spruce browsed by hares. Near Hodgson, Man. Canadian Forestry Service photo.

Shark-finned barrels. Ontario Ministry of Natural Resources. Canadian Forestry Service photo.

Marttiini reforestation plough. Canadian Forestry Service photo.

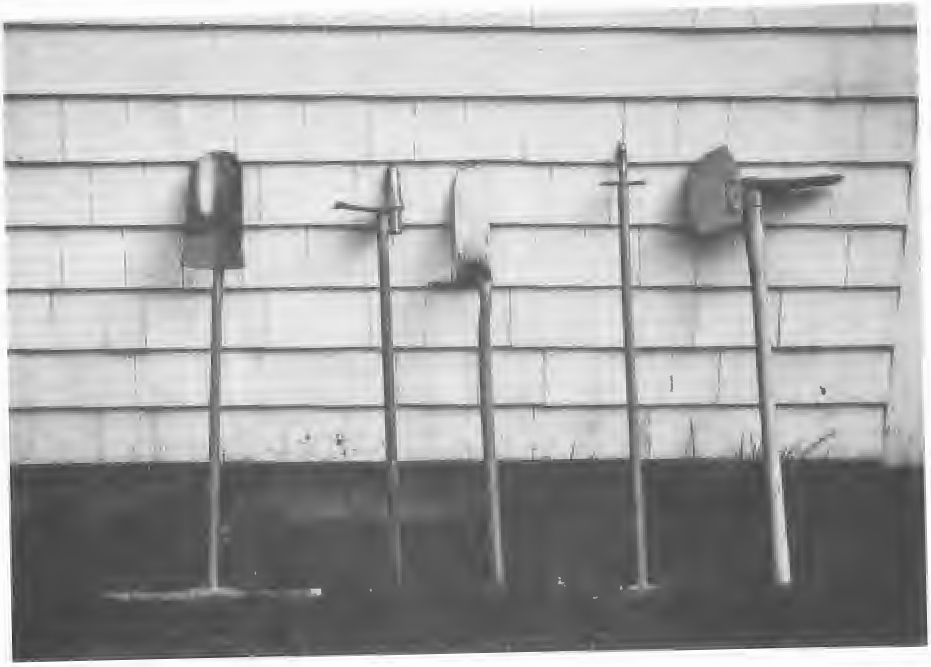
Bulldozed strip in young trembling aspen, to be planted to white spruce. Near Hodgson, Man. Canadian Forestry Service photo.

LeTourneau tree crusher. Black Brook, N.B. Canadian Forestry Service photo.

Portable refrigeration unit for planting stock. B.C. Forest Service photo.

Women's crew planting with dibbles. Prince George District, B.C.
B.C. Forest Service photo.

Crew planting cutover. Muzroll Lake, N.B. Canadian Forestry Service photo.



Planting tools, from left: concave planting bar; Multipot planting bar; Ost planting (wedge) bar; Tubeling dibble; Wiffsta planting hoe. Lawrencetown, N.S. Canadian Forestry Service photo.

Planting with mattocks. Bush Lakes, B.C. B.C. Forest Service photo.

Planting 3-0 white spruce with Wiffsta hoe. Telford Burn, N.S. Canadian Forestry Service photo.

Dibble for planting Styroblock plugs. Near Hodgson, Man. Canadian Forestry Service photo.

Finn Forester planting machine. Canadian Forestry Service photo.

Cutovers

Slash is an impediment to the planting crew. Moderate amounts, such as result from cutting stands where most material is merchantable, can be burnt. An alternative is to clear channels through the slash and one effective implement is the barrel scarifier or shark-fin drum -- a tractor-drawn steel cylinder with a spiral of welded blades and sometimes filled with cement or oil (Brown 1966). The drums, which can be drawn abreast, and in tandem as well if site conditions warrant, leave furrows to mineral soil in which the seedlings are planted. A tractor of ca. 180 dbhp (134 kW) is required. This method originated in Ontario and is also applied in Quebec, Manitoba and Saskatchewan. Cost figures cited for this type of operation include $15 per ac ($37 per ha) for 1973-74 in Quebec (Dancause 1974), and $17 per ac ($42 per ha) in northern Ontario (Heikurinen 1975). Similar operations in Alberta, carried out in 1971 with tractor-pad drags were estimated by Smyth and Karaim (1972) to cost ca. $16 per ac ($40 per ha).

The 2-unit Marttiini plough is a Finnish machine first introduced in Canada in Nova Scotia for preparation of cutover sites. A V-shaped blade, mounted in front of a medium tractor (180 dbhp - 134 kW) pushes aside slash and other surface obstacles; a large double-breaking plough, supported by two rubber-tyred wheels, is towed behind, preparing a planting surface ca. 8 feet (2.4 m) wide with deep furrow in the centre to allow drainage in wetter soils. Trials in the Maritimes indicated costs of $11 to $15 per ac ($27 to $37 per ha) (Anon. 1973*a*). A cost of $9.53 per ac ($23.55 per ha) was reported for northern Ontario (Heikurinen 1975).

Really heavy accumulations of slash such as are encountered in British Columbia after cutting old-growth spruce-fir can be windrowed by bulldozing to permit access by planters. If the stand was overmature, or the site too wet for the movement of heavy equipment, the slash can be broadcast-burned to reduce the overall quantity and provide a reasonably clean ground surface, although the large material remains. While slash burning serves also to reduce fire hazard, its use is becoming deprecated, in British Columbia at least, where solutions by mechanical methods are being sought.

Residual trees on cutovers can be felled individually. In the British Columbia interior cabling is practised: residuals are knocked down by a 150-foot (45-m) cable, supported at the centre by a "torpedo" to keep it 3 ft (0.9 m) above ground, and pulled by two tractors moving abreast.

Brush

Brush develops on almost any open site, given time, and here includes shrubs, small hardwood sprouts and suckers, as well as unwanted conifers which, if left, will grow to tree size. While both types can hinder planting and restrict early growth of seedlings, the latter, with the potential to form a high closed canopy, provides the most serious long-term competition to white spruce.

Burning, with suitable litter to provide fuel, and favourable weather, can effectively kill brush, but does not physically remove its presence, so that planting is still difficult and, in the case of species which can regenerate by root suckers (e.g. aspens, hazel) will stimulate a new and denser crop which only repeated burns will eradicate. Burning, followed by the mechanical removal of dead stems, has been practised in British Columbia to eliminate *Rubus* species, Devil's Club, elderberry and fireweed.

Chemicals also kill brush without removing it, although when dry the dead stems can be consumed by fire or uprooted. Foliage spraying of deciduous species to the point of runoff with 2,4-D at 2 or 3 lb herbicide per 100 gal (2 or 3 g per ℓ) water is effective against alder, birch, cherry, elder, Manitoba maple, sumac and willow; more than one such application is required for aspen, elm, red osier, dwarf laurel, sweet-fern, viburnum and wild plum; more than one application of 2,4,5-T at 2 to 3 lbs per 100 gal (2 or 3 g per ℓ) water (or a mixture of 2,4-D and 2,4,5-T) is needed to deal with ash, beech, blackberry, hawthorn, other maple species, oaks, rhododendron and raspberry (Canada Weed Committee 1970). Sutton (1970) recommended treatment with these chemicals in the period of full leaf expansion, using 2 to 4 lb acid equivalent per ac (2.2 to 4.5 kg/ha) applied as a high-volume spray at 50 to 150 gal per ac (5.6 to 16.8 hl/ha), or as a mist at 5 to 20 gal per ac (0.6 to 2.2 hl/ha); 4 feet (1.2 m) is about the maximum height of vegetation feasible to treat with ground equipment.

A different approach, one which will benefit the spruce at least temporarily, if not make planting easier, is to place pellets of fenuron in three one-half-oz (14-g) doses at the time of planting as close as 1 ft (0.3 m) from the seedling; dense local competition from hazel and mountain maple was effectively reduced for a few years in this manner in northern Ontario (Sutton 1965, 1974).

Mechanical methods, however, are usually employed for brush control, and aim only at partial rather than complete clearing. Ideally they would incorporate the humus with the mineral soil as well (McMinn 1974). The simplest equipment is the **bulldozer blade** effectual in clearing corridors for planting, or for digging small ditches where drainage is also a problem. But unless properly handled, a blade removes all the humus, and in heavy soils leaves a slick, compacted surface which bakes hard in summer and is prone to heaving in the fall; suckering species tend to be a problem after this treatment. More efficacious is the **V-plough**, a convex front-mounted attachment, with or without a scalping tooth to gouge a planting furrow, and pulled by a light (70 dbhp - 52 kW) or medium (100 dbhp - 75 kW) tractor (Morawski 1967). A recent development is a rolling coulter to help "float" the blade (Gemmell 1975). An advantage of front-mounted equipment is that a planting machine can be towed behind the tractor at the same time, so that site preparation and planting are carried out in one operation.

Clearing brush and other ground vegetation with **hand tools** around planting spots is expensive and may not always effectively reduce competition. Some improvement in survival and growth of subsequently planted white spruce was found in scalping experiments at Riding Mountain National Park, Manitoba (Tucker, Jarvis and Waldron

1968), but not in north-central British Columbia where Armit (1970) concluded that mechanical methods would be necessary to provide significant improvement.

Very heavy brush, and small trees up to ca. 4 in. (10 cm) dbh, can be flattened and the stems and surface roots severed and partially buried by **drum brush choppers** (Albert 1966, Morawski 1967). These are single or double cylinders ca. 7 ft long by 4 ft in diameter (2.1 by 1.2 m), with horizontal steel blades 15 to 21 in. (38 to 53 cm) apart; weighing 3 to 4 tons (2.7 to 3.6 t) when empty, or 5 to 6 tons (4.5 to 5.4 t) when full of water, drums require a heavy tractor (220 dbhp - 164 kW). Operation is limited to stone-free sites, and performance is best on firm ground. Drum choppers are used mainly in eastern Canada where one procedure is to clear 45-ft (14-m) strips with 10-ft (3-m) uncut intervals. If resulting debris is excessive, additional treatment with a V-plough may be needed before the site is plantable. **Shark-fin drums,** or heavy 30-in. (76-cm) **discs** are other towed equipment used to clear brush (Morawski 1967; Hall, John 1970).

Stand Conversion

Replacing an unwanted stand of trees with a plantation is sometimes necessary. The existing stand is often overmature, containing mainly the cull material remaining after a partial cut. In stands open enough for underplanting, **blading with light tractors** (65 dbhp - 48 kW) has been successful for tolerant hardwoods in New Brunswick, where ca. 50% of mineral soil was exposed (Post 1966), and for tolerant and intolerant hardwoods in northwest Ontario where 75% of the site was scarified (Wang and Horton 1968). In these latter stands, comparative tests showed that preparation with a **V-plough**, to scarify 35% of the area, followed by hand planting, was more efficient in tolerant hardwoods where ground cover consisted of dense maple seedlings, in terms of cost and survival of white spruce, than treatment with angle-dozers or shark-fin barrels. In intolerant hardwoods, a **V-plough** with tandem machine planting was most efficient for treating a moderately dense cover of blueberry, spiraea, sedge, bracken fern and hazel (Haig 1969). A similar approach is used in Alberta for converting aspen stands.

In northwest New Brunswick (Temiscouata-Restigouche Forest Section L.6) very large-scale conversion of tolerant hardwoods is being accomplished by J.D. Irving Company, using self-propelled LeTourneau tree crushers to prepare the site. These machines consist of three large knife-mounted drums, 6 ft (1.8 m) and greater in length and diameter, the two forward ones moving abreast, and the third behind, each independently powered by electric motors. A boom-mounted blade, fixed at a height of 10 ft (3 m) or more, precedes the drums, and the operator controls the machine from an overhead cab. Models range in size from 50 to 150 tons (45 to 135 t), and are capable of handling large trees, which are pushed over by the blade; the drums crush and chop all woody material, without seriously disturbing the soil surface but making the site completely accessible to the planters. The approach in New Brunswick has been to clear the entire site. Obviously operations of this type can be justified only on an extremely large scale.

Grass

Dense or tall grass provides serious competition to spruce seedlings. Its removal can conserve soil moisture and improve nutrition (Sutton 1975). Where grass is present on old cutovers or burns it can be removed concurrently with other vegetation on the site by blading and V-ploughing. On old fields, ploughing furrows at intervals is the traditional approach, followed by planting in the furrow, or by hand on the furrow slice if drainage is poor. Deep furrows can leave the area difficult to negotiate with machines in future tending operations, but seem the only option for planting wet fields. Scalping by turning back a 10- to 12-inch (25.4- to 30.5-cm) square of sod with a shovel is another approach to grass removal in hand planting (Staley 1970).

Machine planting without a furrow on well-drained grassy sites with simultaneous application of 5 lb per ac (5.6 kg per ha) of simazine 50W in an 18-inch (45-cm) strip has given effective protection to white spruce on Larose Forest in eastern Ontario. Sutton (1970) recommended the application of herbicides in combination, e.g. simazine plus amino triazole, for long-term control of grass.

More intensive mechanical treatment prior to planting, such as deep cultivation (Sutton 1968), may be justified in some situations, particularly where site fertility is such as to result in dense competition. For example, von Althen (1970) found that plowing and tilling increased 3-year height growth of white spruce, planted on a hayfield with clay soil, by 37%, or about 7% per dollar expended in 1964. In Connecticut, Stephens (1965) obtained excellent early height growth of white spruce planted on old fields by mulching with salt marsh hay, which eliminated the sod competition.

Container Planting

Site preparation, no less than for bare-root stock, will usually be required. It is considered necessary in New Brunswick[15] and Nova Scotia (Levy 1972, Routledge 1974). Even on some drier Ontario sites vegetation may close again in three years, and in one year on richer sites, after preparation, so planting of white spruce should follow quite soon (Scarratt 1974), although a year's delay to allow loose soil to settle may help survival. MacKinnon (1970) recommended prescribed burning or scarification with spiked drums in Ontario; containers should be inserted in the organic layer rather than mineral soil (to avoid heaving), and on the northeast side of rocks, stumps, etc. for a cooler microclimate. Similarly, for white spruce in the British Columbia interior, Van Eerden (1972) advised light burning on highly productive sites, leaving the organic mat intact. However in west-central Alberta, on cutovers with a moist duff layer up to 24 in. (61 cm) deep, North Western Pulp & Power, Limited, blade the humus and

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[15]Redmond, R.A. 1971. Reforestation techniques being used in the Province of New Brunswick. Paper Presented at 53rd Annual Meeting, Woodlands Section, Canadian Pulp & Paper Association.

and slash to one side in parallel windrows, seeding or planting the intervening areas (Crossley 1975).

Planting Season

Spring planting is normally to be preferred, when soil moisture conditions are generally most favourable and the growing season is about to begin. If planted while dormant, the seedling is less subject to mechanical injury and physiological shock, and is best able to make the necessary adjustment to its new environment -- particularly underground. Most white spruce planting in Canada is carried out in spring although problems of logistics and labour supply often compel large programs to be completed later in the year.

One method of extending the planting season is by planting with stock held in cold storage: e.g., in Ontario until as late as the end of June, and in the British Columbia interior throughout the growing season, except during the hottest part of the summer. Pollard (1973) pointed out that this treatment reduces the time available for shoot extension, and while Burgar and Lyon (1968) reported good survival of cold-stored white spruce transplants for planting May to September in western Ontario, they noted serious height losses for stock planted in August and later. Planting as late as the end of May with frozen-stored stock appears possible in southern Ontario without loss of field performance (Mullin and Parker 1974).

For early spring planting in northern Ontario, stock shipped the previous fall from a southern nursery and cold-stored over winter showed greater resistance to frost damage than seedlings spring-lifted from the same beds, according to one study (Jorgensen and Stanek 1962). Lifting actively growing stock from nursery beds is often practised towards the end of "spring" planting. If continued later, field survival may be acceptable, but again height growth tends to be increasingly inhibited as the date of planting is delayed (Ackerman and Johnson 1962, Mullin 1971).

Fall planting is considered less reliable than spring planting, owing to the risks of frost heaving, particularly on bare and heavy soils, or lack of autumn rain which may limit essential root growth before the onset of plant dormancy. Transplants have been found better able than seedlings to cope with the unfavourable conditions experienced after fall planting.

One of the expected advantages of container stock is that the seedlings receive minimal root disturbance when planted, allowing a great deal of flexibility as to planting date. Consequently container seedlings are often planted until late in the growing season. In Alberta container planting is carried out in the period May-August, depending on the local climate (Ferdinand, Kay and Hellum 1974). For northern Ontario, Scarratt (1974) felt that early season planting would be essential to take advantage of the spring root-surge of late-produced, overwintered seedlings, but otherwise a 12-week planting season ending in mid-August would be most favourable. In Quebec, planting usually begins in late April or early May and is completed as quickly as possible. In Nova Scotia, Routledge (1974) reported a 6-week planting period, beginning in early May.

Spacing

The spacing interval[16] at which seedlings are planted markedly affects individual tree growth, the rapidity of crown closure, timing of thinnings, yield by type of product, and the size of cone crops. Numbers of trees per unit area is a major element in the cost of establishing a plantation, and without a knowledge of the appropriate spacings for particular purposes or products, economical use of planting stock is not possible. Although it has a lasting influence on stand development, and can be readily and precisely controlled at the time of planting, the spacing interval is often arbritarily chosen. A few authorities select an initial spacing which

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[16] *See* Tables 6 and 7 for spacing-numbers equivalents.

Table 6. Plantation spacing equivalents

Avg spacing (ft)	Trees per acre		Avg spacing (m)	Trees per hectare	
	Mean	Range		Mean	Range
4 x 4	2,722	2,151 - 3,555	1.2 x 1.2	6,726	5,315 - 8,786
5 x 5	1,742	1,440 - 2,150	1.5 x 1.5	4,304	3,558 - 5,314
6 x 6	1,210	1,031 - 1,439	1.8 x 1.8	2,990	2,548 - 3,557
7 x 7	889	774 - 1,030	2.1 x 2.1	2,197	1,913 - 2,547
8 x 8	681	603 - 773	2.4 x 2.4	1,683	1,490 - 1,912
9 x 9	538	483 - 602	2.7 x 2.7	1,329	1,194 - 1,489
10 x 10	436	395 - 482	3.0 x 3.0	1,077	976 - 1,193
11 x 11	360	329 - 394	3.4 x 3.4	890	813 - 975
12 x 12	302	279 - 328	3.7 x 3.7	746	689 - 812

Based on conversions:

1 ft = 0.3048 m — 1 m = 3.2808 ft

1 tree/ac = 2.4710 trees/ha — 1 tree/ha = 0.4047 trees/ac

they believe will result, through natural processes of self-thinning and other mortality, in a density equivalent to a "well-stocked natural stand" at a particular age. Others relate planted spacing to the stocking standards prevailing in their province for natural reproduction. Little thought seems to be given to probable tree size or yield per acre.

In general terms, closer spacings entail higher planting costs and result, at a given age, in smaller crowns and stem diameters and thinner branches, but greater cubic volume of stem per acre. Comparative development to age 50 years, in terms of average tree size and stand production for planted spacing of 4 x 4, 5 x 5, 6 x 6, 7 x 7, 8 x 8 and 10 x 10 ft (1.2 x 1.2, 1.5 x 1.5, 1.8 x 1.8, 2.1 x 2.1, 2.4 x

Table 7. Plantation stocking conversions

English to Metric: Spacing (ft)	Trees per ac	Trees per ha	Spacing (m)	Metric to English: Spacing (m)	Trees per ha	Trees per ac	Spacing (ft)
20.9 x 20.9	100	247	6.4 x 6.4	10.0 x 10.0	100	40	33.0 x 33.0
17.0 x 17.0	150	371	5.2 x 5.2	8.2 x 8.2	150	61	27.5 x 27.5
14.8 x 14.8	200	494	4.5 x 4.5	7.1 x 7.1	200	81	23.2 x 23.2
13.2 x 13.2	250	618	4.0 x 4.0	6.3 x 6.3	250	101	20.8 x 20.8
12.0 x 12.0	300	741	3.7 x 3.7	5.8 x 5.8	300	121	19.0 x 19.0
11.2 x 11.2	350	865	3.4 x 3.4	5.3 x 5.3	350	142	17.5 x 17.5
10.4 x 10.4	400	988	3.2 x 3.2	5.0 x 5.0	400	162	16.4 x 16.4
9.8 x 9.8	450	1,112	3.0 x 3.0	4.7 x 4.7	450	182	15.5 x 15.5
9.3 x 9.3	500	1,236	2.8 x 2.8	4.5 x 4.5	500	202	14.7 x 14.7
8.9 x 8.9	550	1,359	2.7 x 2.7	4.3 x 4.3	550	223	14.0 x 14.0
8.5 x 8.5	600	1,483	2.6 x 2.6	4.1 x 4.1	600	243	13.4 x 13.4
8.2 x 8.2	650	1,606	2.5 x 2.5	3.9 x 3.9	650	263	12.9 x 12.9
7.9 x 7.9	700	1,730	2.4 x 2.4	3.8 x 3.8	700	283	12.4 x 12.4
7.6 x 7.6	750	1,853	2.3 x 2.3	3.6 x 3.6	750	304	12.0 x 12.0
7.4 x 7.4	800	1,977	2.2 x 2.2	3.5 x 3.5	800	324	11.6 x 11.6
7.2 x 7.2	850	2,100	2.2 x 2.2	3.4 x 3.4	850	344	11.2 x 11.2
7.0 x 7.0	900	2,224	2.1 x 2.1	3.3 x 3.3	900	364	10.9 x 10.9
6.8 x 6.8	950	2,347	2.1 x 2.1	3.2 x 3.2	950	384	10.6 x 10.6
6.6 x 6.6	1,000	2,471	2.0 x 2.0	3.2 x 3.2	1,000	405	10.4 x 10.4
5.4 x 5.4	1,500	3,706	1.6 x 1.6	2.6 x 2.6	1,500	607	8.5 x 8.5
4.7 x 4.7	2,000	4,942	1.4 x 1.4	2.2 x 2.2	2,000	809	7.3 x 7.3
4.2 x 4.2	2,500	6,178	1.3 x 1.3	2.0 x 2.0	2,500	1,012	6.6 x 6.6
3.8 x 3.8	3,000	7,413	1.2 x 1.2	1.8 x 1.8	3,000	1,214	6.0 x 6.0
3.5 x 3.5	3,500	8,648	1.1 x 1.1	1.7 x 1.7	3,500	1,416	5.5 x 5.5
3.3 x 3.3	4,000	9,884	1.0 x 1.0	1.6 x 1.6	4,000	1,619	5.2 x 5.2
3.1 x 3.1	4,500	11,120	0.9 x 0.9	1.5 x 1.5	4,500	1,821	4.9 x 4.9
3.0 x 3.0	5,000	12,355	0.9 x 0.9	1.4 x 1.4	5,000	2,024	4.6 x 4.6

Based on conversions:

(a) 1 tree per acre = 2.4710 trees per hectare
(b) 1 tree per hectare = 0.4047 trees per acre
(c) Spacing (feet) = $\sqrt{43{,}560/\text{trees per acre}}$
(d) Spacing (metres) = $\sqrt{10{,}000/\text{trees per hectare}}$.

2.4 and 3.0 x 3.0 m), have been presented by Stiell and Berry (1973) in a series of yield tables for white spruce plantations, which provide a quantitative basis for selecting the spacing appropriate to particular management objectives (Tables 10-13).

In the western provinces the aim, as a rule, is to space trees at about 8 x 8 or 9 x 9 ft (2.4 x 2.4 or 2.7 x 2.7 m), but because of stumps and other obstacles, or advance growth, only 400 to 500 trees per ac (988 to 1,236 per ha) are usually planted. From Ontario eastward, spacings are mostly 6 x 6 to 8 x 8 ft (1.8 x 1.8 to 2.4 x 2.4 m). Where machine planting is employed behind a bulldozer or V-plough, the rows are usually further apart and the trees within the rows closer, but utilize about the same numbers of trees per acre as hand planting. Staley (1970) reported on the trend to wider spacings in southern Ontario for improved ease of felling, and later first thinning which will produce larger, more merchantable material and reduce the *Fomes annosus*[17] problem.

Methods

Field Storage

The care taken in keeping planting stock in good condition after lifting at the nursery and in transit to the planting site must be maintained until the seedlings are in the ground. Failure to do so will certainly result in reduced survival, and perhaps below normal height growth persisting for many years as well (Mullin 1973). Essentially, the stored stock must be kept cool, with the roots moist, and handled as little as possible. Where the truck haul from the nursery and the interval before planting are short, seedlings may simply be kept in the shipping containers and placed in the shade. In New Brunswick, for example, where the holding periods are usually not

[17] A problem in planted red pine in Ontario, and anticipated, but not yet discovered, in white spruce plantations.

more than 24 hours, bulk shipments with the roots covered in moss are merely stored at roadside, covered with kraft paper and tarpaulins.

For longer periods, large loads are often stored in local depots, from which the daily planting quotas are removed. In British Columbia, "coolers", i.e. buildings held at ca. 34°F (1°C) with portable units, are used extensively. Lacking such facilities, stock can be heeled in and shaded until required for planting: the bundles of plants are spread out along the sloping side of a shallow trench, and the roots covered with soil and watered. In eastern Manitoba plants are heeled in in moss and sand on trailers which are towed directly to the planting crews. "Circle piling" is an Ontario practice in which seedling bundles are placed root to root in a circle, the roots covered with moss, and another circle piled on top of the first, etc., until a mound several feet high has been formed. This rapid and convenient method, which allows easy watering and removal of bundles, with a minimum of root damage, has been recommended where up to three weeks field storage are required (Mullin 1962). Stock shipped in "plant fresh" bags (described under Nursery Practice) does not have moss packed around the roots, but can be stored in a cool, shady location for up to a week provided the bags are kept closed and not piled up (Bunting 1975).

Labour Supply

The seasonal nature of tree planting tends to put a strain on local labour resources, particularly in more remote areas (Dancause 1974), and planting foremen often complain of the manpower shortage and the low quality of crews available to them. Sources of extra labour include university students, transients, inmates of federal minimum security institutions, junior forest wardens or rangers, and even school children. Regular use of native labour is made in many northern areas. Female workers, long known to excel in forest nursery work, are being increasingly hired for tree planting, notably in the British Columbia interior. One approach, particularly appropriate for company planting, is to form silvicultural crews from employees engaged in logging at other times of the year, thereby ensuring continuous employment and a core of experienced planters or foremen (Armstrong 1963, Routledge 1972).

A different approach, one which obviates the need for recruiting workers, and reduces supervision, is contract planting. This system has been used more widely in British Columbia than elsewhere in Canada. The contractor is usually provided with nursery stock, and paid so much per seedling for planting; he pays his crews by the hour. Contract work must of course be inspected and in some cases the contractor merely supplies the labour, without being responsible for supervision. It is advisable to limit inexperienced contractors to small jobs, e.g. 100,000 trees.

Planters are paid by the hour ($2.40 to $3.50 in 1972), by piecework (2¢ to 7¢ per bare-root seedling) or by a combination of the two systems. Rates are highest in British Columbia. Production ranges between 250 and 2,500 seedlings per man-day, and probably averages about 750 for bare-root stock.

Crew Organization

Planting crew size varies from ca. 4 to 20 men under a crew boss. Besides supervising the quality of the planting job he marks out the area, keeps crews aligned and ensures that they are kept supplied with planting stock and drinking water. In small crews, he usually plants trees as well.

Planters work singly, or, less commonly, in pairs with one man digging the hole and the other carrying the seedlings and inserting them. If the planting job is made up of small irregular areas or narrow strips, these are assigned to individual planters or pairs. On large, open tracts the crew usually works in line abreast, traversing back and forth. They may be guided by poles marked with flagging, or, as on some jobs in New Brunswick, the outside man may unroll string from a haversack, which forms the guideline for the return sweep.

Efficient planting depends chiefly on thorough instruction and close supervision of crews, plus well-planned logistics. J.D.

Irving Co., in New Brunswick offers a good example: 250-seedling bales are dumped at a central location before daybreak, and trucked along roads to a point close to the planting sites; skidders transport the seedlings and water supplies off the roads, and boys deliver buckets of plants, and water, to the planters. The latter work singly, and in line across strips 240 ft (73 m) wide, defined by rows of stakes, and supervisors check the planting intervals, and tally the number of trees planted.

Hand Planting Bare-root Stock

Planting with hand tools remains by far the principal reforestation method in Canada, adverse topography or obstacles on the site precluding mechanization of the operation in most circumstances, at least under the present state of technology as discussed later.

The planters carry the seedlings in buckets, shoulder bags, or panniers on belts, with the roots in water or covered with wet moss; in Nova Scotia the sodium alginate dip applied in the nursery keeps the roots wet. Numerous tools are used for planting, of which "mattocks" (grub hoes), planting bars, and shovels of various patterns are most popular.

The important points in hand planting are that the seedling roots must be prevented from drying out between removal from the carrying receptable and placement in the ground; that the planting hole be large enough so that the roots need not be doubled up; and that it be closed firmly, leaving no air pockets around the roots. Depth of planting does not appear to be critical, provided the root collar is at or below the soil surface (Sutton 1968). On unprepared sites with heavy sod or deep humus the planter may first scalp to mineral soil, particularly for seedlings with small root systems.

Various planting techniques have been tested experimentally with white spruce, but none seems inherently inferior provided it is carried out carefully and is appropriate to the particular soil conditions (Brace 1964, MacArthur 1964, Mullin 1966, Schantz-Hansen 1945, Stiell 1960, Stoeckeler and Limstrom 1950). Therefore the more rapidly and easily executed methods are preferred as more economic. Most used are the various **slit methods** (Ontario Department Lands and Forests 1969), implying vertical or sloping cuts in the ground, pried open by the planting tool for insertion of the roots, followed by closure with the foot, all without removal of any soil material. Slit planting is often the only feasible method in stoney or rooty soil, and is adaptable to planting in sod as well. These methods do have limitations for heavy soils in which the slit is difficult to close (Staley 1970), and for stock with very long roots.

Wedge planting, in which a tapering slab of soil is removed by making two converging cuts, and then returned to its original position, jambing the seedling roots against one wall of the soil cavity, is used in Ontario for planting in turf or on the over-turned furrow slice (Ontario Department Lands and Forests 1969), and a variant is favoured in Nova Scotia. Straight **hole planting** has given better results than slit planting in the Mixedwood Forest Section B.18a (Jarvis *et al.* 1966), and is still performed in Manitoba wherever soil conditions permit digging.

Container Planting

Few firm conclusions concerning field-planting container seedlings are yet possible, owing to limited operational experience.

While planting has occasionally been done with mattocks or shovels, tools designed for the particular container are almost invariably used. The simplest types are long-handled dibbles, which punch a hole in the soil of the same dimensions as the container. They have curved, T-shaped or spade hand grips and the depth of the hole is controlled by a flange, or a projection which serves also as a foot bar. The dibble may be welded to the back of a planting hoe if scalping is needed (Flavelle 1972, MacKinnon 1970), or the foot bar widened for use as a screefer (Sjoberg 1974). A drawback to straight dibbles is that the planter must stoop to place the seedling in the hole, and a planting stick which inserts the container from a trigger-released clip mounted parallel to a retractable dibble has been devised for Ontario tubes (Ontario Department Lands and Forests 1967).

A criticism of solid-point dibbles is that they severely compact the soil, which, if it is clayey, tends to swell when rain-soaked and heave out the container, and to clog its lower end, preventing drainage; a hollow-pointed dibble, which removes a core of soil, is therefore preferred and has been devised for Swedish Multipot plugs (Levy 1972). A coring dibble with a tube mounted parallel to the shaft, and allowing stand-up planting, is available for Japanese Paperpots (Scarratt 1973). Another planting stick for Paperpots has a split point which is driven into the ground and then spread apart with a pedal; the container is dropped, through the hollow handle of the stick, into the hole so formed (Bonin 1973, Scarratt 1973). Split-point types may snag in slash or brush, and like coring dibbles, are inefficient in stoney soils (Scarratt and Ketcheson 1974).

The gun developed for planting Bullets has evolved into several repeating and single-shot models (Vyse 1971, Walters 1969). Essentially it is a tubular device, loaded at the top or side, and drives the container into the ground when downward force is applied by pressing a foot bar and/or handles. Cutting wheels score the cylindrical type bullet as it is planted, to facilitate root egress, but are not needed for the more recent square-section type (Walters 1974). The Research Council of Alberta peat Sausage is another container which is mechanically split during planting (Mitchell, Hocking and Kay 1971).

Containers are usually carried in the field in trays on belts, packboards or special back packs, for which several designs have been described (Carman 1967, Ontario Department Lands and Forests 1967, Scarratt 1973, Vyse 1971, Walters 1968). Styroblocks have been similarly back-packed (Vyse, Birchfield and Van Eerden 1971), but with extraction of plugs at the nursery 25-plug belt pouches are considered the most acceptable (Sjoberg 1974). Single trays of Ontario tubes may be carried by hand with a loop handle (MacKinnon 1970). Planters mostly work singly, carrying their own planting tool and supply of containers. However at Hinton, Alberta, Northwestern Pulp & Paper Ltd.

use 4-man crews in which one man carries the stock and provides the three planters with handfuls of containers as they need them (Carman 1967, Ferdinand 1972).

One anticipated advantage which does seem to have been realized with containers is rapid planting, in the range of 800 (Ferdinand, Kay and Hellum 1974) to 3760 (Vyse and Ketcheson 1974) seedlings per man-day (depending on type, method, spacing and site) and averages ca. 1400 per day, or about twice the average rate for hand-planting bare-root stock. Since piecework rates paid to container planters are lower (1.3¢ to 4.5¢), planting costs per acre show a considerable reduction. Further significant cost improvements seem unlikely until mechanization of container planting is achieved.

Machine Planting

Where direct comparisons are possible, planting by machine is usually cheaper than by hand (Anon. 1970). Mechanizing the planting operation, therefore, becomes increasingly desirable as labour costs rise and the scarcity of suitable labour is yearly more acute (Haig and Scott 1972, Robinson 1973).

Planting machines, of an essentially similar pattern, have been in use for bare-root stock for many years. They are tractor-drawn and consist basically of a tandem sequence of (a) rolling or knife coulter to cut the sod and make a vertical incision in the ground, (b) a "shoe" which spreads apart the slit to a depth of several inches, and (c) a pair of diverging packing wheels, a few inches apart at ground level, which close the slit after the seedling has been planted in it. The operator is seated just above the packing wheel axle, and inserts the seedling roots to the correct depth into the slit, which is immediately pressed together by the packing wheels. The wheels pass on either side of the seedling, leaving it upright in the soil. Tubs of seedlings are carried in racks within reach of the operator. A planting crew commonly consists of a tractor driver, machine operator, and helper to fill in blanks behind the machine and spell the operator. Containers are not planted with these machines in Canada.

The simplest, earliest versions were pulled by farm tractors and used to plant old fields which were level and without serious obstacles. Considerable modification has since taken place, making machines safer, more rugged and better able to cope with difficult sites. Attachments which have been developed include a plough share mounted behind the coulter when it is desirable to plant in a furrow; sod scalper to remove grass competition; canopy to protect the operator when underplanting or planting through brush; crank axles to permit continuous planting despite surface obstacles; various applications of hydraulics, e.g. lowering and raising the planting machine, providing stability on sidehills, and maintaining downward pressure on the plough and coulter; devices to signal the spacing interval; spray tanks to apply herbicide concurrently with planting; planting wheels or chains which insert the seedling into the slit. Some recent developments of these as well as of auger and digging types little known in Canada have been described by Bagley (1973), Cameron (1975), Edwards (1974), Noecker (1973) and Scott (1975).

Staley (1970) described machine planting on old fields in Ontario: **slit planting** is most effective on sites with light turf, on heavier soils providing chemical control is applied, and on wetter and brushier sites where furrowing is too difficult or would place the seedling roots in poorly drained soil. **Furrow planting** is used to remove competing grass and weeds, and on drier sites to get the seedling down to moister layers of soil. With a 3-man crew, production was 4,000 to 9,000 trees per day and costs $20 to $30 per thousand.

Planting on **forest sites**, e.g. cutovers or burns, demands heavier, stronger machines, adapted in some of the ways previously mentioned. Tractors of up to 130 hp (97 kW) may be needed if, besides pulling the planter, they are front-mounted with a V-blade or other site-preparing implement. Costs of $25 to $40 per ac ($62 to $99 per ha) (Dancause 1974) and $32 per thousand (Paquet 1974) have been reported for this type of operation in Quebec. Riley (1975) cited costs of $37 to $46 per ac ($91 to $114 per ha), and $54 to $83 per thousand, at 1971 dollar values, for operational trials in northern

Ontario. Planting with such equipment is carried out on forest land in all provinces except British Columbia and Prince Edward Island but is necessarily confined to sites where excessive numbers of stumps, roots or rocks do not defeat the continuous slit-opening mode of conventional planters. Thus, despite improvements in other design aspects, mechanization only accounts for about 15% of planting in Canada (Haig and Scott 1972). Improvement will require a machine with a discontinuous, digging or punching action allowing some degree of selection as to exactly where the seedling will be planted. The "Ontario Planter" now under development by the Ontario Ministry of Natural Resources is designed with this capability (Anon. 1973*b*, Grinnell 1972). When fully operational the machine will be able to perform on sites much too difficult for current planters, will sense subsurface objects, and will handle containers as well as bare-root stock; the ultimate objective is a fully automatic, multi-row machine (Scott 1975).

Post-planting Assessment

Survival

Survival counts within a short period after planting are essential if the plantation is to be maintained at its intended stocking level. Seedlings are most vulnerable to extremes of weather and soil moisture during the first few seasons when mortality associated with those factors mainly occurs. Early assessment is also important if the cause of mortality is to be identified; because replacing dead trees is not effective once the original survivors get too much of a head start; and because the benefits of site preparation diminish rapidly with time. In Ontario, five years is considered a maximum delay (Ontario Department Lands and Forests 1969).

Frequency of survival counts varies throughout Canada from as often as every year for the first five years to none until after the fifth year. Common practice is to tally seedlings at the end of the first, second or third, and fifth growing seasons. Action can thus be taken as soon as one of these counts indicates unacceptable mortality. The action might be a more intensive survey to delineate the affected area, or immediate refilling (replacing failures). After about five years, numbers are assumed to have stabilized reasonably well, and further examination, if any, need only be made at much longer intervals.

Survival counts should be made between growing seasons, and late fall and early spring have been recommended for best seedling visibility (Ontario Department Lands and Forests 1969). Spring and fall would be ideal to determine weather-associated causes of mortality, but would be too onerous except for problem situations.

Samples should be permanently marked on the ground to ensure an accurate estimate of mortality. They may take the form of fixed-area plots, or initially include a fixed number of seedlings, and should be well distributed over the planting area to include all site conditions. In British Columbia 1/100-ac (0.025-ha) plots are established at the time of planting; since stocking aims at 500 seedlings per ac (1,236 per ha), a plot should contain five, and this allows a check of spacing efficiency while the planting crews are still in the vicinity, as well as providing the basis for keeping track of survival. Another approach is to stake units of 10 to 100 consecutive trees along the row, in a staggered arrangement across the plantation. Morgan (1963) described a method which involves laying a 2-chain (40-m) tape across the rows and at right angles to them, and counting the live trees within the limits of a 6.6-ft (2.0-m) stick laid along each row and centred on the tape. The data so collected allow calculation of numbers of trees surviving, per cent survival, per cent stocking at a specified spacing, and spacing within and between rows.

Few sampling intensities are reported. In Quebec they are 0.2% for planting on crown lands, 0.125% for private lands (Boissinot 1973), in Ontario 0.2% on crown lands, and in Saskatchewan range from 0.25% to 1.0%. It is obviously important to increase the number of samples for a plantation with every change in site, nursery source, or other factor likely to result in differential survival, and for this reason it does not seem possible to specify particular sampling rates as universally suitable. In a survey of plantations in the Prairie Provinces, Froning (1972) used ten 10-tree plots per stratum for determining the total number required to give an estimate of mean survival with a standard error not greater than ±10% at a probability of 90%.

Refilling

Rudolf (1950) pointed out that the percentage of planted trees surviving measures the success of the planting operation, but the number of living trees per acre indicates the success of producing a plantation. It is the latter which is important when deciding whether or not to refill. It is assumed that a minimum stocking level (MSL) has been determined before planting, which (including naturally established seedlings) is to be maintained after the initial establishment period during which some failures are inevitable. To allow for this, trees are often planted somewhat closer than the MSL equivalent, e.g. may be at 8 x 8 ft = 681 trees per ac (2.4 x 2.4 m = 1,683 per ha) when 500 surviving per ac, between 9 x 9 and 10 x 10 ft, (1,236 per ac, 2.7 x 2.7 to 3.0 x 3.0 m) is the objective.

Per cent survival itself will not indicate if the MSL has been achieved -- the initial planted stocking must also be known. For example, 500 seedlings per ac (1,236 per ha) found during a count would represent 73% survival if planting had been at 681 per ac (1,683 per ha), but only 56% survival if planting was 889 per ac, 7 x 7 ft (2,197 per ha, 2.1 x 2.1 m) (Stiell 1968). For these reasons reported acceptable survival percentages vary widely from one province to another (31% to 95%), reflecting different MSL's.

Diagnosis of causes of failure ought to precede a decision to refill. If associated with the planting operation, methods should be corrected. If due to site factors, and therefore likely to recur, change to another species or abandonment of planting may be indicated.

Distribution of mortality is of practical importance. Reforestation organizations are unwilling to replace failure which occurred uniformly throughout a plantation, and often prefer to accept a lower than planned MSL. Heavy localized mortality requires complete replanting of that area, which is considered cheaper than the time-consuming job of seeking out individual failures, and is of course the only possible approach if machines are to be used.

In practice, most authorities profess themselves well satisfied with survival, and refilling a white spruce plantation seems to be an unusual occurrence despite the indifferent results reported by some surveys, e.g. Froning (1972).

References to Planting

Ackerman, R.F. and H.J. Johnson. 1962. Continuous planting of white spruce throughout the frost-free period. Can. Dep. For., For. Res. Branch Tech. Note 117.

Ahlgren, Clifford E. and Henry L. Hansen. 1957. Some effects of temporary flooding on coniferous trees. J. For. 55(9):647-650.

Albert, Rene. 1966. Report on the performance of brush choppers. Ont. Dep. Lands For., Timber Branch, Silvic. Sect. Silvic. Notes No. 9.

Anon. 1970. Provincial legislation and policies on reforestation: a survey. For. Chron. 46(6):491-496, 494a-c, 498a and b.

Anon. 1973*a*. New Brunswick acquires a Finnish plow. Pith to Periderm 6(6):72.

Anon. 1973*b*. How Ontario and federal foresters are mechanizing silviculture work. Can. For. Ind. 93(8):82-87.

Armit, D. 1970. Comparison of mattock- and bar-planting methods with white spruce in north-central British Columbia. B.C. For. Serv. Res. Notes No. 53.

Armstrong, R.H. 1963. The history and mechanics of forest planting and aerial spraying. Pulp Pap. Mag. Can., Woodlands Rev., June. p. WR268-WR270.

Bagley, Walter, T. 1973. Heavy duty tree planting machine developed in Nebraska. Tree Plant. Notes 24(3):27-28.

Boissinot, Guy. 1973. Le reboisement et ses techniques au Québec. Pulp Pap. Mag. Can. 74(1):110-112, 114-116.

Bonin, Pierre. 1973. Etat des travaux concernant les plants en tube. Ministère des Terres et Forêts, Québec, Direction générale des Forêts, Direction de l'Aménagement, Service de la Restauration, Division des Pépinières.

Brace, L.G. 1964. Early development of white spruce as related to planting method and planting stock height. Can. Dep. For. Publ. 1049.

Brown, G. 1966. A modified barrel scarifier. Ont. Dep. Lands For., Timber Branch, Silvic. Sect. Silvic. Notes No. 6.

Bunting, W.R. 1975. Modern tree packaging. Your Forests 8(1):32-33.

Burgar, R.J. and N.F. Lyon. 1968. Survival and growth of stored and unstored white spruce planted through the frost-free period. Ont. Dep. Lands For., Res. Branch Res. Rep. 84.

Cameron, D.A. 1975. Testing and evaluation of mechanical tree planters. *In* Mechanization of Silviculture in Northern Ontario. Proc. Symp. Sault Ste. Marie, Ont. Oct. 1, 2, 1974. Dep. Environ., Can. For. Serv. Symp. Proc. O-P-3:59-69.

Canada Weed Committee. 1970. Report of the research appraisal and research planning committees for eastern Canada. Can. Weed Comm. East. Sect. Meet., London, Ont. Nov. 5, 6, 7, 1969. Mimeo.

Carman, R.D. 1967. An industrial application of the container-planting technique. Pulp Pap. Mag. Can., Woodlands Rev. 68(4): WR181-WR188.

Cayford, J.H. 1957. Influence of the aspen overstory on white spruce growth in Saskatchewan. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 58.

Crossley, D.I. 1975. Case history in forest management: first 20-year cycle at North Western. Pulp Pap. Can. 76(5):42-48.

Cunningham, G.C. 1953. Growth and development of coniferous plantations at Grand'Mère, P.Q. Can. Dep. Resour. Dev., For. Branch, For. Res. Div. Silvic. Res. Note 103.

Dancause, Alain. 1974. Les utilisateurs et la régénération des forêts. Forêt-Conservation 40(10):17-21.

Duffy, P.J.B. and J.W. Fraser. 1963. Local frost occurrences in eastern Ontario woodlands. Can. Dep. For., For. Res. Branch Publ. 1029.

Edwards, Jerry L. 1974. Methods and machines for planting containerized trees. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:269-274.

Eis, S. 1970. Root-growth relationships of juvenile white spruce, alpine fir, and lodgepole pine on three soils in the interior of British Columbia. Dep. Fish. For., Can. For. Serv. Publ. 1276.

Ferdinand, S.I. 1972. Container planting program at North Western Pulp and Power Ltd. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:21-25.

Ferdinand, S.I., W.C. Kay and A.K. Hellum. 1974. Container program in Alberta. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:44-52.

Flavelle, F. 1972. Container planting program in Saskatchewan. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:15-17.

Froning, K. 1972. An appraisal of recent plantations in forests of the Prairie Provinces. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-31.

Fraser, J.W. 1965. Frost and regeneration. *In* Minutes Conf. Artif. Regeneration Ont. Feb. 23, 1965. Ont. Dep. Lands. For., Res.

Branch. Mimeo.

Gagnon, J.D. and J.D. MacArthur. 1959. Ground vegetation as an index of site quality in white spruce plantations. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 70.

Gemmell, J.R. 1975. The integration of site preparation with mechanical regeneration. *In* Mechanization of Silviculture in Northern Ontario. Proc. Symp. Sault Ste. Marie, Ont., Oct. 1, 2, 1974. Dep. Environ., Can. For. Serv. Symp. Proc. O-P-3:47-54.

Grinnell, W. Ross. 1972. Silviculture in Ontario. Pap. Presented 7th World For. Congr., Buenos Aires.

Haig, R.A. 1969. Operational trials of site preparation and planting methods in the Goulais River Area, Ontario. Dep. Fish. For., Can. For. Serv. Inf. Rep. O-X-111.

Haig, R.A. and J.D. Scott. 1972. Mechanized silviculture in Canada. Spec. Pap. Prep. 7th World For. Congr., Buenos Aires.

Hall, J. Peter. 1970. Ten-year development of planted conifers in western Newfoundland. Dep. Fish. For., Can. For. Serv. Publ. 1273.

Hall, John. 1970. Site preparation in Ontario. For. Chron. 46(6): 445-447.

Heiberg, S.O. and D.P. White. 1951. Potassium deficiency of reforested pine and spruce stands in northern New York. Soil Sci. Soc. Am. Proc. 1950, 15:369-376.

Heikurinen, J.K.K. 1975. Powered vs nonpowered site-preparation equipment. *In* Mechanization of Silviculture in Northern Ontario. Proc. Symp. Sault Ste. Marie, Ont., Oct. 1, 2, 1974. Dep. Environ., Can. For. Serv. Symp. Proc. O-P-3:37-46.

Hills, G.A. 1952. The classification and evaluation of site for forestry. Ont. Dep. Lands For., Div. Res., Res. Rep. 23.

Hills, G.A. 1959. A ready reference to the description of the land of Ontario and its productivity. Ont. Dep. Lands For., Div. Res.

Prelim. Rep.

Illingworth, K. and J.W.C. Arlidge. 1960. Interim report on some forest site types in lodgepole pine and spruce-alpine fir stands. B.C. For. Serv. Res. Notes No. 35.

Jarvis, J.M., G.A. Steneker, R.M. Waldron and J.C. Lees. 1966. Review of silvicultural research. White spruce and trembling aspen cover types, Mixedwood Forest Section, Boreal Forest Region, Alberta-Saskatchewan-Manitoba. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1156.

Jorgensen, E. and W.K.L. Stanek. 1962. Over-winter storage of coniferous seedlings as a means of preventing late frost damage. For. Chron. 38(2):192-202.

Jurdant, M., J.C. Dionne, V. Gerardin and J. Beaubien. 1969. Inventaire bio-physique de la Région Mistassini-Roberval-Herbertville (Québec). Ministère des Pêches et des Forêts, Direction générale des Forêts, Rapport d'Information Q-X-12.

Lafond, A. 1954. Les déficiences en potassium et magnesium des plantations de *Pinus strobus*, *Pinus resinosa* et *Picea glauca* de la province de Québec. Assoc. Ing. For. Prov. Québec. Texte des Conf. 34 Assem. Ann. p. 65-82.

Lees, J.C. 1964. Tolerance of white spruce seedlings to flooding. For. Chron. 40(2):221-225.

Levy, D.M. 1972. Container planting program in Nova Scotia. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:42-43.

Logan, K.T. 1969. Growth of tree seedlings affected by light intensity. IV. Black spruce, white spruce, balsam fir and eastern white cedar. Dep. Fish. For., Can. For. Serv. Publ. 1256.

Love, D.V. and J.R.M. Williams. 1968. The economics of plantation forestry in southern Ontario. Dep. Reg. Econ. Expans., Can. Land Inventory Rep. 5.

MacArthur, J.D. 1959. Growth of jack, red and Scots pine and white spruce plantations, 1922 to 1956 at Grand'Mère, Que. Pulp Pap. Mag. Can., Woodlands Rev. Sect., Conv. Issue. p. 14, 16, 18.

MacArthur, J.D. 1964. Field planting trials in the Clay Belt - Quebec. Pulp Pap. Mag. Can., Woodlands Rev. Sect., Conv. Issue. p. WR58-WR61.

MacKinnon, George E. 1970. Container planting in Ontario. For. Chron. 46(6):470-472.

McLeod, J.W. 1956. Plantations of the Acadia Forest Experiment Station. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 31.

McMinn, R.G. 1974. Effect of four site treatments on survival and growth of white spruce and lodgepole pine seedlings. Bi-mon. Res. Notes 30(3):19-20.

Mitchell, D.L., D. Hocking and W.C. Kay. 1971. Reforestation with tree seedlings grown in extruded peat cylinders. Part 1. Mechanical aspects of the process. Rep. Presented 1971 Annu. Meet. Am. Soc. Agric. Eng. Washington State Univ., Pullman, Wash. Pap. 71-169.

Morawski, J.R. 1967. Site preparation methods and recommendations for equipment usage. Ont. Dep. Lands For., Timber Branch, Silvic. Sect. Silvic. Notes No. 8, Revised.

Morgan, Roy B. 1963. Row segment stocking - a new concept of plantation sampling. Tree Plant. Notes 59:13-14.

Mullin, R.E. 1962. Storage of planting stock in the field. For. Chron. 38(3):318-326.

Mullin, R.E. 1966. Influence of depth and method of planting on white spruce. J. For. 64(7):466-468.

Mullin, R.E. 1971. Some effects of root dipping, root exposure and extended planting dates with white spruce. For. Chron. 47(2): 90-93.

Mullin, R.E. 1973. Moisture retaining materials, storage duration for unrefrigerated bales of nursery stock studied for effects on survival and growth. Tree Plant. Notes 24(3):24-26.

Mullin, R.E. and J.D. Parker. 1974. Bales *versus* polybags in cold and frozen overwinter storage of nursery stock. Can. J. For. Res. 4(2): 254-258.

Nicholson, J. 1970. Development of white spruce provenances from the Great Lakes-St. Lawrence Forest Region in Newfoundland. Dep. Fish. For., Can. For. Serv. Inf. Rep. N-X-52.

Noecker, Norbert. 1973. Wildland tree planter does king-size job. Tree Plant. Notes 24(3):29-30.

Ontario Department Lands and Forests. 1967. Provisional instructions for growing and planting seedlings in tubes. Revised 1967.

Ontario Department Lands and Forests. 1969. Forest tree planting. Timber Branch Bull. C-5-10M.

Paquet, Gaétan. 1974. Travaux de régénération artificielle sur les terres publiques de Québec. Forêt-Conservation 40(4):7-10.

Pierpoint, G. 1962. The sites of the Kirkwood Management Unit. Ont. Dep. Lands For., Res. Branch, Res. Rep. 47.

Pollard, D.F.W. 1973. Growth of white spruce seedlings following cold storage. For. Chron. 49(4):183.

Popovich, S. 1972. Survival and growth of three indigenous conifers planted in the Clay Belt, northwest Quebec. Dep. Environ., Can. For. Serv. Inf. Rep. Q-X-27.

Popovich, Stevo et Normand Houle. 1970. Etude préliminaire de trois plantations du Québec (croissance, rendement et productivité). Ministère des Pêches et des Forêts, Service canadien des Forêts, Rapport d'Information Q-F-X-3.

Post, L.J. 1966. Experimental establishment of spruce on tolerant hardwood lands. Can. Dep. For. Inf. Rep. M-X-6.

Riley, L.F. 1975. Operational testing of planting machines in the boreal forest of Ontario. I. Reynolds-Lowther heavy duty crank axle planter. Dep. Environ., Can. For. Serv. Inf. Rep. 0-X-219.

Robinson, Fred C. 1973. Forest regeneration in Ontario. Pulp Pap. Mag. Can. 74(2):29-32, 35.

Routledge, Hollis T. 1972. Silviculture for the New Forest. Pulp. Pap. Mag. Can. 73(5):85-86, 88.

Routledge, Hollis T. 1974. Boreal species on short rotation. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Contaninerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:119-123.

Rowe, J.S. 1955. Factors influencing white spruce reproduction in Manitoba and Saskatchewan. Can. Dep. North Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 3.

Rowe, J.S. 1972. Forest regions of Canada. Dep. Environ., Can. For. Serv. Publ. 1300.

Rudolf, Paul O. 1950. Forest plantations in the Lake States. U.S. Dep. Agric. Tech. Bull. 1010.

Scarratt, J.B. 1973. Japanese paperpots for containerized planting of tree seedlings. I. Production facilities. Dep. Environ., Can. For. Serv. Inf. Rep. 0-X-188.

Scarratt, John B. 1974. Performance of tubed seedlings in Ontario. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:310-320.

Scarratt, J.B. and D.E. Ketcheson. 1974. Japanese paperpots for containerized planting of tree seedlings. II. Preliminary evaluation of planting tools. Dep. Environ., Can. For. Serv. Inf. Rep. 0-X-204.

Schantz-Hansen, T. 1945. The effect of planting methods on root development. J. For. 43(6):447-448.

Scott, J.D. 1975. Recent developments in mechanized planting and the future for Ontario. *In* Mechanization of Silviculture in Northern Ontario. Proc. Symp. Sault Ste. Marie, Ont., Oct. 1, 2, 1974. Dep. Environ., Can. For. Serv. Symp. Proc. 0-P-3:70-85.

Sims, H.P. and D. Mueller-Dombois. 1968. Effect of grass competition and depth to water table on height growth of coniferous tree seedlings. Ecology 49(4):597-603.

Sjoberg, N.E. 1974. The styroblock container system. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:217-228.

Smyth, J.H. and B.W. Karaim. 1972. An economic analysis of reforestation costs in Alberta. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-41.

Staley, R.N. 1970. Conventional hand and machine planting in southern Ontario. For. Chron. 46(6):473-476.

Stephens, George R. Jr. 1965. Accelerating early height growth of white spruce. J. For. 63(9):671-673.

Stiell, W.M. 1958. Pulpwood plantations in Ontario and Quebec. Can. Pulp Pap. Assoc., Woodlands Sect. Index 1770 (F-2).

Stiell, W.M. 1960. A co-operative experimental planting project in Ontario. Woodlands Rev. Sect. Pulp Pap. Mag. Can. 61(2):4-114, 5-115, 6-116, 7-117.

Stiell, W.M. 1968. Spacing and survival tables for plantations. Tree Plant. Notes 19(3):18-21.

Stiell, W.M. and A.B. Berry. 1973. Development of unthinned white spruce plantations to age 50 at Petawawa Forest Experiment Station. Dep. Environ., Can. For. Serv. Publ. 1317.

Stoeckeler, J.H. and G.A. Limstrom. 1950. Reforestation research findings in northern Wisconsin and Upper Michigan. U.S. Dep.

Agric., For. Serv., Lake States For. Exp. Stn., Stn. Pap. 23.

Sutton, R.F. 1965. Stand improvement with white spruce planted with concurrent Dybar (fenuron) herbicide treatment. For. Chron. 41(1): 108-111.

Sutton, R.F. 1968. Ecology of young white spruce (*Picea glauca* (Moench) Voss). Thesis, Cornell Univ. 500 p.

Sutton, R.F. 1969. Silvics of white spruce (*Picea glauca* (Moench) Voss). Can. Dep. Fish. For., For. Branch Publ. 1250.

Sutton, R.F. 1970. Chemical herbicides and forestation. For. Chron. 46(6):458-465.

Sutton, R.F. 1974. White spruce group planting in herbicide-treated, overmature mixedwood:11-year results. For. Chron. 50(1):35-37.

Sutton, Roy F. 1975. Nutrition and growth of white spruce outplants: enhancement by herbicidal site preparation. Can. J. For. Res. 5(2):217-223.

Teich, A.H. and M.J. Holst. 1974. White spruce limestone ecotypes. For. Chron. 50(3):110-111.

Tucker, R.E., J.M. Jarvis and R.M. Waldron. 1968. Early survival and growth of white spruce plantations, Riding Mountain National Park, Manitoba. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1239.

Van Eerden, E. 1972. Influences affecting container seedling performance near Prince George, British Columbia. *In* R.M. Waldron (ed.) Proc. Workshop Container Plant. Can., Dep. Environ., Can. For. Serv. Inf. Rep. DPC-X-2:92-100.

von Althen, F.W. 1970. Methods for successful afforestation of a weed infested clay soil. For. Chron. 46(2):139-143.

Vyse, A.H. 1971. Planting rates increased in British Columbia with new planting gun and bullets. Tree Plant. Notes 22(1):1.

Vyse, A.H., G.A. Birchfield and E. Van Eerden. 1971. An operational trial of the styroblock reforestation system in British Columbia. Dep. Environ., Can. For. Serv. Inf. Rep. BC-X-59.

Vyse, A.H. and D.E. Ketcheson. 1974. The cost of raising and planting containerised trees in Canada. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:402-411.

Walters, J. 1968. Planting gun and bullet. Agric. Eng. 49:336-339.

Walters, John. 1969. Container planting of Douglas-fir. For. Prod. J. 19(10):10-14.

Walters, John. 1974. Engineering for injection planting. *In* Richard W. Tinus, William I. Stein and William E. Balmer (eds.) Proc. North Am. Containerized For. Tree Seedling Symp. Denver, Colo. Great Plains Agric. Counc. Publ. 68:241-243.

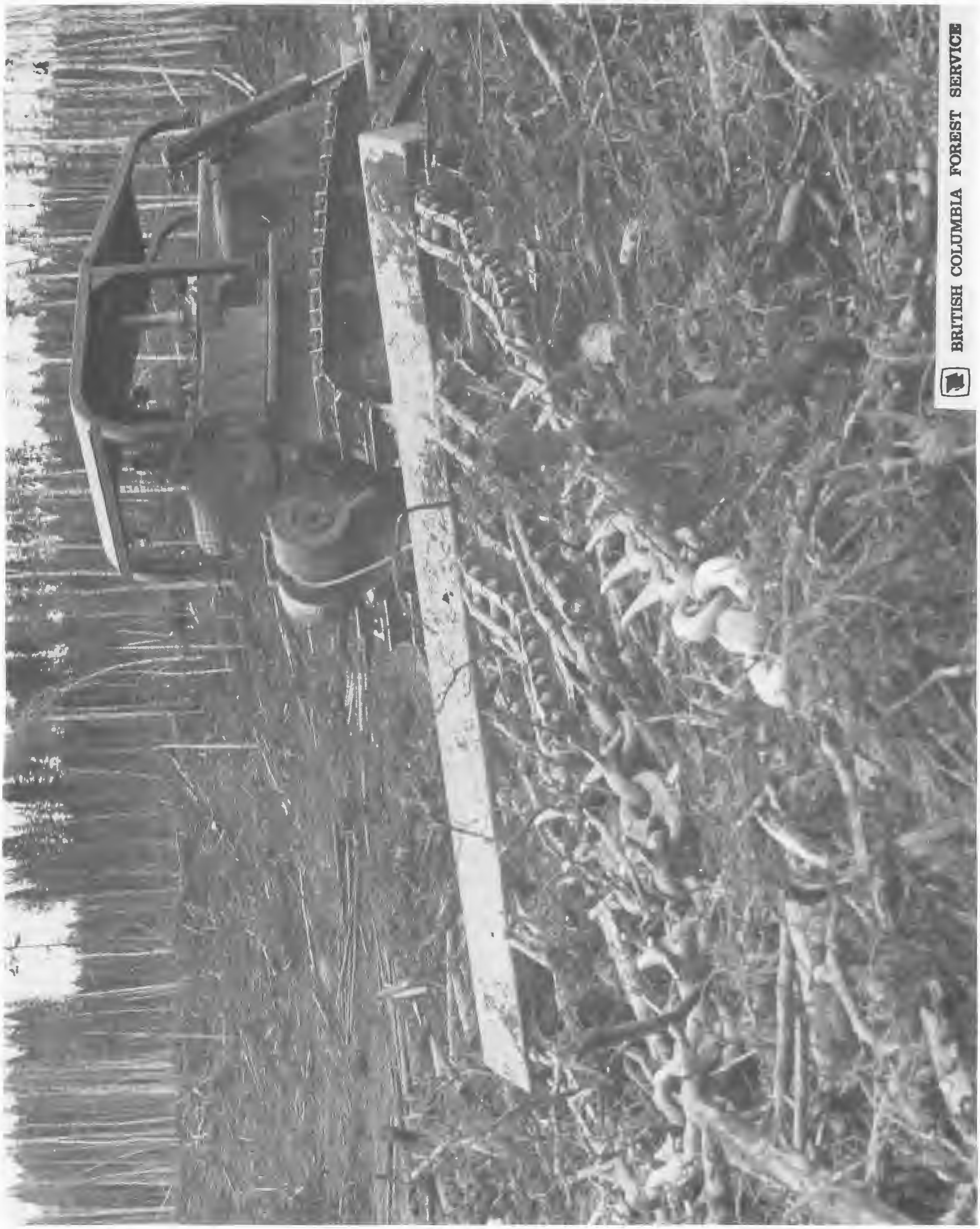
Wang, B.S.P. and K.W. Horton. 1968. An underplanting experiment with white pine and white spruce seedling and transplant stock. For. Chron. 44(4):36-39, 50-51.

Whitney, R.D. 1962. Studies in forest pathology. XXIV. *Polyporus tomentosus* Fr. as a major factor in tand-opening disease of white spruce. Can. J. Bot. 40(12):1631-1658.

Whitney, R.D. 1972. Root rot in white spruce planted in areas formerly heavily attacked by *Polyporus tomentosus* in Saskatchewan. Bi-mon. Res. Notes 28(4):24.

Wilde, S.A. 1966. Soil standards for planting Wisconsin conifers. J. For. 64(6):389-391.

Williams, J.R.M. 1955. A guide to choosing tree species for planting in the Middle Ottawa River-Lake Huron Site Region (Site Region 5) of Ontario. Rep. to 8th Northeast. For. Soils Conf. at Dorset, Ont. Mimeo.



Chain and tractor pad drag scarifier.

V. SEEDING

Prospects for Success

Foresters are prone to wish that they could establish stands simply by applying the seed to the site, bypassing the whole complex nursery and greenhouse operation, and reducing the manpower needed for field-planting. Very large financial savings would accrue: e.g., one study in Alberta estimated a cost per ac of ca. $21 (including seed and site preparation) to establish a stand by seeding versus ca. $56 (including seedlings and site preparation) for hand or machine planting, i.e. ca. $52 vs $138 per ha (Smyth and Karaim 1972). These savings are thought sufficient to offset the main disadvantage of a seeded stand, i.e. irregular distribution of stems over the site, or clumps of seedlings if a seed-spotting technique were used. If successful seeding did lead to a large expansion of the method, available seed supply would probably set the limit to the scale of operations.

In fact, results of artificial seeding in Canada have been erratic, with most programs for white spruce classed as failures (Waldron 1974). Up until 1972, ca. 142,000 ac (57,500 ha) had been seeded to white spruce, mostly in the Prairie Provinces, and the principal effort now is in Alberta (Hellum 1974, Waldron 1974). White spruce appears to be excluded from plans for operational direct seeding in Ontario (Rauter 1974).

The difficulties entailed in direct seeding are often underestimated, the assumption being made that since all natural stands were established from seed, man should be able to duplicate the process. Sometimes he does but usually and unpredictably he fails to do so. In the latter cases he might succeed if he were willing to repeat his efforts often enough, but by then the cost advantages would be lost. Nature succeeds in the long run, but only from the superabundance of seed shed, together with a random coincidence of a good crop and favourable soil and weather conditions such as may occur occasionally, perhaps after years of unproductive seedfall.

Successful establishment of a seeded stand depends on a number of conditions, each of crucial importance, being met, but so far man has learnt to fulfil or control only some of them, and even with these his technique is imperfect. He has achieved more or less success in such matters as preparing a suitable seedbed; in testing and storing the seed to determine and maintain its viability; in protecting the seed from some of its biological enemies by coating it with repellents and fungicides; and in distributing the seed effectively over the site and at the right season. But he cannot ensure that suitable temperature and soil moisture will prevail to ensure germination, or that thereafter the highly vulnerable young seedlings will not be subjected to drought, flooding, intense insolation, or attacks by insects, rodents, etc. It is the unpredictability of these and other hazards (well-controlled in a nursery) that make direct seeding white spruce such a chancy affair. And so it will remain until a much greater measure of environmental control and seedling protection can be exercised in the forest. Current programs of basic and applied research actively pursue this objective.

The following deals with conditions necessary for successful seeding of white spruce, and ways of providing some of them; however, it is emphasized that the general method is still unreliable.

Site Conditions

Optimum conditions for germination may differ somewhat from those for early seedling development.

Seedbeds

The most favourable seedbeds for white spruce are considered to be mineral soil, mixed soil and humus, and decayed wood (Arnott, MacArthur and Demers 1971, Eis 1967, Horton and Wang 1969, Jarvis *et al.* 1966, Lees 1971, Prochnau 1963, Rowe 1955, Waldron 1966). A charred surface may get too hot in dry years for good germination

(Place 1955), and may delay germination until fall, with consequent overwinter mortality of unhardened seedlings (Rowe 1953).

The soil needs to be moist near the surface during the germination period (Shirley 1937), a condition made possible by snow melt or spring rain. Other germination requirements for white spruce include optimum temperatures in the range 65°F to 75°F (18°C to 24°C), but varying with the environment at the latitude of seed source (Fraser 1971); pH unimportant in a wide range from very acid to alkaline (Vaartaja 1963); and the value of shade *per se* debatable, although it may prevent excessive temperatures from developing.

Seedling Environment

Survival and growth of germinants also are highly dependent on adequate soil moisture, owing to succulence and shallow root penetration (Eis 1965). Spring and summer rain are important in this regard (Place 1955) on all but very moist sites, and are critical for organic materials and coarser-textured soils which dry out rapidly. Excessive heat is damaging in that it desiccates surface layers, and in full sunlight can bring them to lethal temperatures. According to Shirley (1937) surface temperatures of 120°F (49°C) are fatal to small seedlings in one hour, and such levels were "often exceeded" in one seeding trial in the British Columbia interior (Eis 1965), and in another the burnt surfaces reached 133°F (56°C) (Smith 1955). In such circumstances in New Brunswick, Place (1955) considered a cover of juniper hair-cap moss to be beneficial in the open -- offering little competition, but providing shade to seedling stems, and discouraging larger competitors. Stumps or slash also would afford protective shade, but except in drought periods seedlings do better in sunlight. Competition from dense ground cover, particularly grass, is detrimental to growth. Nevertheless, frost heaving can be severe on bare mineral soils, particularly those with heavy texture and high moisture regime (Place 1955).

Biotic Influences

Small mammals have been widely recognized as an important cause of failure in forest tree seeding (Abbott 1961). In Canada, the principal culprits are deer mice, red-backed and meadow voles, chipmunks and shrews (Radvanyi 1970*a*). Depredations by these animals seem more prevalent in the western provinces; Scott (1970), for example, considered rodents only of secondary importance as a threat to seeding success in Ontario. By contrast, for the British Columbia interior, Smith (1955) reported that rodents were an important cause of spruce seed and seedling losses, and Prochnau (1963) felt that protection against rodents was essential in spruce seeding. Blyth (1955) expressed the same opinion after white spruce broadcast and seedspot trials in the Subalpine Region of Alberta.

In studies with caged animals, Wagg (1963) observed that individual red-backed voles and deer mice could consume 2,000 white spruce seeds per day, and voles would eat young seedlings as well. In Alberta, numbers of seed-eating mammals on white spruce clear-cuts were found to vary from ca. 3 per ac (7 per ha) after cutting in spring to 18 per ac (44 per ha) five years later in grassy vegetation which had invaded the site; it was thought that populations would never fall to safe levels; much more damage was caused to spring-sown than to fall-sown seed (Radvanyi 1966, 1970*b*, 1974).

Coating with a mixture containing endrin was generally thought the best means of protecting the seed from rodents, although efficacy in the case of white spruce was questioned (Radvanyi 1970*b*), and in any case the substance has been declared illegal because of the hazards of handling it. A substitute, yet to be perfected, consisting of R-55, graphite and acidified latex, shows promise (Radvanyi 1970*a*, 1974, 1975). There seems to be no way of preventing small mammals from eating **seedlings** except by cages over individual seed spots -- practical only for experimental work.

Seed-eating birds doubtless cause some damage to artificially sown seed in the forest, but to what extent is unknown. Smith (1955) trapped three birds (vs 19 rodents) in three nights on a 0.4-ac (0.16-ha) quadrat in a seed-spot trial near Bolean Lake, British Columbia. Both Radvanyi (1974) in Alberta and Scott (1970) in Ontario considered losses from birds to be minor. Arasan has been widely applied to the seed as a bird-repellent, however. This substance is a fungicide also, and as such may be useful in direct seeding, since at least one instance of serious seedling mortality from damping-off has been reported following seeding with (Engelmann) spruce (Smith 1955).

Seedlings are subject to browsing by hares which cause extensive damage, when repeated year after year and intensified during the peak of a population cycle. As discussed previously, in the section on site selection for planting, prevalence of hare damage is associated with specific habitats, e.g. aspen stands in the Prairie Provinces, and attempts to establish spruce regeneration in such areas seem certain to fail. Hence seeding has been abandoned in aspen and poplar stands in northern Alberta, pending development of satisfactory control methods (Hellum 1974).

Site Preparation

Sites must be given a presowing treatment to provide the necessary seedbed of exposed mineral soil. Wildfire can achieve this, but a burn hot enough to consume the organic layers seldom results from prescribed fires, mainly because they are not applied in sufficiently high-hazard weather (Endean and Johnstone 1974, Scott 1970, Smith 1955). Burning of slash piles may be more successful, although the total treated area would be limited.

The alternative of scarification is generally used. For small areas, in the absence of brush or heavy slash, hand methods to prepare spots by scalping or scraping the organic layers with mattocks, fire rakes or planting hoes may be feasible, and would be used in conjunction with hand sowing. Spots should be not less than 1 ft (0.3 m) square, to avoid edge competition, and several times as large would be more effective (Arlidge 1967). If concave, they are subject to flooding. Hand scarification is time consuming and labour intensive, and except on steep slopes is seldom used operationally.

Mechanical scalping is performed by machines which combine scarification and sowing in the same operation, as described in the next section. Furrowing or strip scalping prepares the site for seeding in rows, and can be accomplished with a straight blade, V-blade with a scalping point, fireline plough or finned barrel, with a tandem seeding device, and is adapted for use in scrub stands (Brown 1974, Graber and Thompson 1969, Horton and Flowers 1965, Horton and Wang 1969).

Heavy mechanical equipment, of the types described for planting-site preparation, is mainly used for seedbed scarification, prior to broadcast seeding. The aim is to expose mineral soil, or provide a mixture of mineral soil and humus, on ca. 30 to 70% of the site, as evenly distributed over the area as possible[18] (Arlidge 1967, Clark 1969, Hellum 1974). Medium and heavy bulldozers with straight blades are most commonly used, particularly in British Columbia and Alberta. On moist and wet sites with deep organic layers, in west-central Alberta, North Western Pulp and Power Limited blade off the duff in parallel windrows and seed or plant between them (Crossley 1975). The main objective to blading is that it may dig too deeply, which with heavy soils gives a glazed, compacted surface, unsatisfactory as a seedbed and subject to baking in summer and heaving in winter. V-blades were also popular in Alberta (Hellum 1974), but have been found to result in impeded surface drainage; brush rakes and angle blades are now preferred. In Ontario scarifying teeth are used for backlog areas with light brush and dense herbaceous cover (Hall 1970), and the Marttiini plow has given "encouraging results" with white spruce on clay soils (Gemmell 1975). Anchor chains are not

[18] Ferdinand, S.I. 1971. Reforestation of cutover lands at North Western Pulp and Power Ltd. Paper Presented at 53rd Annual Meeting, Woodlands Section, Canadian Pulp & Paper Association.

effective in deep duff, but finned barrels are (Hall 1970) and are favoured in Manitoba[19]. However, neither chains nor barrels are considered appropriate for preparing sites for white spruce under Alberta conditions, i.e. on heavy clay tills (Hellum 1974).

Once a site has been prepared, sowing should not be long delayed. In Ontario, the best success with seeding has been obtained within a year of preparation (Brown 1974). In the British Columbia interior, Arlidge (1967) found stocking to be unsatisfactory if seeding were deferred more than one year. In Alberta, Hellum (1974) considered scarification to be effective for up to four years; delay for one year after site preparation is often recommended to allow the soil to settle and prevent the seed being buried.

Season

Seeding white spruce seems possible at any time of the year, although summer and early fall offer undue risks of seedling mortality from drought and unseasonable frost respectively. From experiments in Manitoba, Rowe (1953) concluded that white spruce germination normally is at a peak in early summer, but may be delayed until later summer on burned sites. Late fall or winter sowing takes advantage of natural stratification, and in an Alberta study by Radvanyi (1970*b*) was accompanied by less rodent damage, and gave better germination, than June sowing. Crossley (1975) noted that winter-sowing, by placing the seed up in the snow mantle, gave protection from rodents. In Ontario, aerial seeding is carried out from mid-October to mid-November when the best flying weather is experienced (Scott 1970). Winter is of course necessary for snowmobile sowing operations. Hellum (1974) recommended seeding in early spring (March) on fresh snow.

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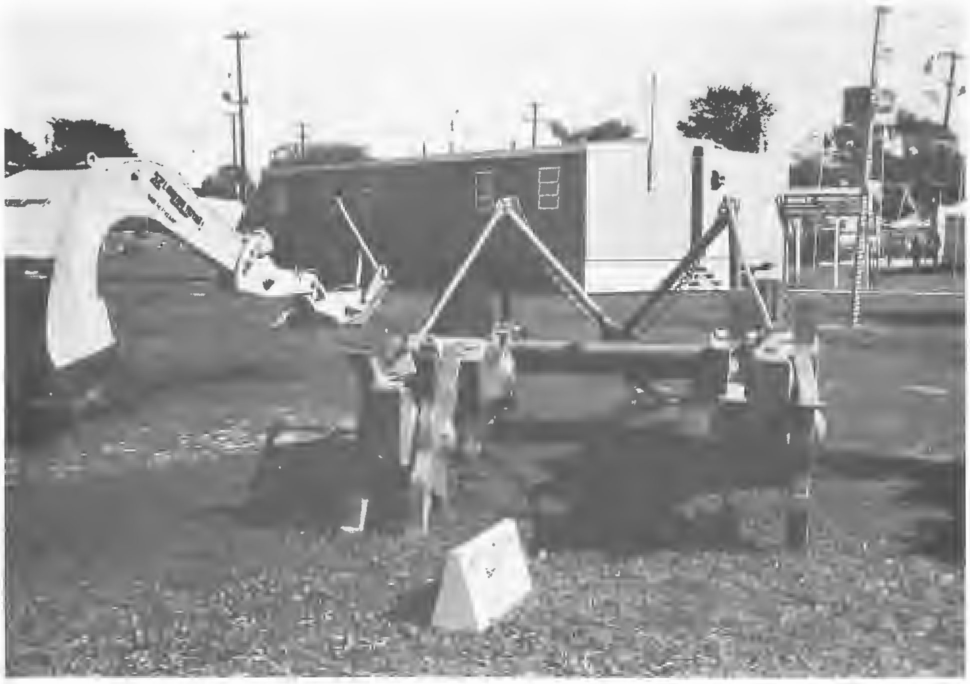
[19] Kaye, Michael. 1971. Manitoba reforestation program levels out. Paper Presented at 53rd Annual Meeting, Woodlands Section, Canadian Pulp & Paper Association.

Scarifying clearcut strip with blade and ripper teeth. Aleza Lake, B.C. B.C. Forest Service photo.

Swedish scarifier with ripper teeth. Aleza Lake, B.C. B.C. Forest Service photo.



Brackekultivatorn scarifying spot seeder. Canadian Forestry Service photo.

Seeding bomb. Ontario Ministry of Natural Resources. Canadian Forestry Service photo.

Barrel seeder. Ontario Ministry of Natural Resources. Canadian Forestry Service photo.

Snowmobile-mounted seeder. Ontario Ministry of Natural Resources. Canadian Forestry Service photo.

Methods

Sowing Rates

The amount of seed sown depends basically on viability, early survival rates, and stocking standards for established seedlings. Since germination in the field is considerably less than the viability rate indicated by laboratory test, and losses of seeds and germinants are difficult to predict, the quantity of seed applied supposedly includes a very large safety margin, the adequacy of which can only be guessed at. Concern has recently been expressed that sowing rates for white spruce have been much too light (Hellum 1974, Johnson 1973). Recommendations made in the United States for seeding (other species than white spruce) range from between 3- to 10-to-1 ratios of viable seed to numbers of desired stems per unit area (Anon. 1956), to a ratio of 20-to-1 (Rindt *et al.* 1953, cited by Weetman 1958). Protecting the seed from predators would certainly reduce the number needed, and spot sowing is more economical of seed than broadcast methods.

For seeding in spots, Krewaz (1958) calculated (for a range of seedlot viabilities) the **total** number of seeds required per spot so that no fewer than the minimum number of **viable** seeds would be expected in 99 out of 100 spots (Table 8); these values can be taken as a starting point. Waldron (1974) estimated that most spot seeding of white spruce in Canada was at a rate of ca. 50,000 seeds per ac (123,550 per ha) with a viability of ca. 50%. Assuming an 8' x 8' distribution of spots, or 681 per ac (2.4 x 2.4 m, or 1,683 per ha), this would mean 37 viable seeds per spot. In the Gaspé and Quebec North Shore, Arnott, MacArthur and Demers (1971) sowed ca. 42 viable white spruce seeds per spot (not protected) for each established seedling. In Central Ontario, Horton and Wang (1969) felt that "considerably" more than 15 viable and repellent-treated white spruce seed would be needed for each established seedling. In Saskatchewan about 1/4-lb of white spruce seed per ac (0.28 kg per ha) is sown in seed spotting. This would require, say, 66,750 seeds per ac (164,940 per ha), equivalent to 98 seeds per spot if spaced at 8 x 8 ft (2.4 x

Table 8. Required number seeds per spot to provide minimum viable specified

Mininum No. viable seeds per spot*	Viability of seed lot in per cent									
	100	90	80	70	60	50	40	30	20	10
	Total no. seeds per spot									
1	1	2	3	4	6	7	10	13	21	
2	2	4	5	7	8	11	14	20		
3	3	5	7	9	11	14	18	25		
4	4	7	9	11	13	17	21	over 25 seeds		
5	5	8	10	12	15	19	25	per spot		

*Probability of 99% or more.
(From Krewaz, J. 1958. A standard for spot seeding. For. Chron. 34(4):380-381).

2.4 m) -- but the viability is not specified. The most favourable ratios seem to have been obtained in the British Columbia interior, where seed spot trials with protected white and Engelmann spruce required only 4 to 13 viable seeds for each established seedling (Prochnau 1963, Smith and Clark 1960). It is extremely difficult to generalize from these data, but for operational as opposed to experimental seed spotting, and using seed treated with rodent repellent, then 50 viable seeds per spot might serve as a rough guide. Assuming 50% viability, and spots spaced at 8 x 8 ft (2.4 x 2.4 m) this would entail applying 68,100 seeds (ca. 1/4-pound) per ac (168,275 per ha, 0.28 kg).

Broadcast seeding requires a much more lavish application of seed, since so many fall on the unprepared parts of the site, at least if aerial or cyclone methods are used, and even those seeds that do reach scarified ground will not have the benefit of a soil covering (often applied in spot seeding). Broadcast rates for white spruce vary from 1/8- to 1/4-pound (33,375 to 66,750 seeds) per ac (0.14 to 0.28 kg, 82,470 to 164,940 seeds per ha) for hand sowing, which presumably gives some control over where the seed falls, to 1/2-pound per ac, 133,500 seeds (0.56 kg, 329,878 seeds per ha) for cyclone seeders. In aerial seeding with white spruce in Maine, on a recent wildfire burn, the ratio of viable, rodent-protected seed sown to the number of established seedlings six years later was 68 to 1 (Griffin and Carr 1974). In Alberta, North Western Pulp and Power Ltd. aerially sow 100,000 to 130,000 untreated seeds per ac (247,100 to 321,230 per ha)[18]; for that province Johnson (1973) has recommended 1 pound, 267,000 seeds (1.1 kg, 659,757 seeds per ha), and Hellum (1974) 60,000 to 90,000 viable seeds per ac (148,000 to 222,000 per ha). Thus from 1.5 to 5 times as much seed would likely be needed for broadcast as for spot seeding.

Costs of white spruce seed have been variously cited as $5.00 per lb ($11.02 per kg)[18]; $6.40 per lb ($14.00 per kg) by Smyth and Karain (1972); and $10.00 per lb ($22.05 per kg) by Hellum (1974). Retail prices in Alberta were as high as $25.00 per lb ($55.11 per kg) in 1975[20].

Seed Treatment

The importance of protecting the seed from predators and disease has been stressed, and even if accurate information on the severity of these hazards in local situations is lacking, the insurance value of treatment seems well worth while. Arasan as bird-repellent and fungicide, together with aluminum flakes as drier and lubricant, and latex as binder, may still be applied as a coating, but the biocide

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[18] Ibid.

[20] Personal communication from A.K. Hellum.

endrin is illegal and without it there is no satisfactory protection available against seed-eating mammals. It is to be hoped that the all-purpose substitute of R-55 + graphite + acidified latex will prove as efficacious, as well as harmless to the seed, as preliminary work suggests (Radvanyi 1974, 1975).

For aerial seeding, it is feasible to pellet the seeds, i.e. coat them additionally with an inert substance to make them a uniform size and spherical shape, so that the seeding mechanism can dispense them evenly. Further tests of effects on the seed seem necessary before endorsing the practice (Fraser 1974).

Spot Seeding

Sowing on spots or scalps requires minimal site preparation, is economical of seed, ensures uniform distribution of seed over the site, and simplifies assessment of results. If the seed is pressed into the soil, or lightly covered, additional protection is afforded. Germination was better, too, for covered seed in a New Brunswick experiment which used sawdust for the purpose (McLeod 1953). Best results from spot seeding should be expected on light soils where competition is light. The method has an obvious tendency to produce clumps of seedlings, since successful establishment is virtually impossible without "overkill".

Various manually operated devices have given satisfactory results; several (including oil-can type and plastic bottle dispensers, shakers and seeding sticks) were developed in Ontario where they have been largely abandoned because they are labour intensive (Brown 1974). Hand sowing, using pinches of seed, or shakers, is still practised to a limited extent in Alberta and Saskatchewan. Spot seeding by hand has been the main method used in research into seedbed and environmental effects, and is no doubt appropriate for small reforestation jobs, if impractical on a large scale.

Mechanical spot seeders which prepare a scalp and seed it in one operation are more economical, performing both functions for less than ca. $10 per ac ($25 per ha) (Gemmell 1975). The S.F.I. scarifier and Brackekultivatorn are Swedish machines of this type which have been tested in Canada, originally in Ontario; they prepare and seed ca. 1,000 scalps per ac (2,471 per ha) at 2 to 3 ac (0.8 to 1.2 ha) per hour, towed by a 190-dbhp (142-kW) wheeled skidder equipped with tyre chains (Brown 1974). These duplex machines consist of two supporting wheels each of which, by a chain drive, revolves a set of rear-mounted radial steel arms terminating in scalping teeth. The teeth gouge out patches of ca. 2 ft^2 (0.2 m^2) at 6-ft (1.8-m) intervals. Seeding units attached behind the scalpers are synchronized to release a controlled number of seeds onto the scalp (Anon. 1970). Although not yet adapted for sowing white spruce seed, these machines perform effectively over a range of site conditions in Ontario, where the Bracke, at least, is sufficiently rugged as manufactured (Parker 1972). This equipment has not proved successful in Alberta, however.

Row Seeding

This method, intermediate between spot and broadcast seeding, involves ploughing or scoring a shallow furrow into which the seed is automatically deposited at controlled intervals. The one-pass technique and superior distribution of seed along the seedbed are seen as advantages (Mattice 1975). One row-seeding machine which might be suited to eastern Canadian conditions is a **furrow seeder** developed and tested in Maine (Graber and Thompson 1969). This is a modified beet planter coupled behind a fireline plough and towed by a small tractor. The seed is sown in a groove at the bottom of the 6-inch (15.2-cm) deep, 38-inch (1-m) wide furrow, pressed into the soil by a packing wheel and covered by a dragged length of chain. The equipment performed satisfactorily even on stoney soils and was considered effective for seeding brushy sites and off-site hardwood stands at rates of 1 to 4 ac (0.4 to 1.6 ha) per hour and $7 to $15 per ac ($17 to $37 per ha).

A similar **furrow seeder**, consisting of a converted corn seeding unit towed by a bulldozer with front-mounted V-plough, was devised for seeding scrub forest sites in Ontario and seemed capable of sowing white spruce at ca. $10 per ac ($25 per ha) (Horton and Flowers 1965). Further development of this type of equipment to improve the seeding action, and performance on cutovers, has been reported by Mattice (1975). However, in Ontario ground-seeding operations now mainly utilize the scalping spot seeders already described (Scott 1970), and the seeding cone, attachable to the back of a barrel scarifier, which combination has a production rate of 1 to 2 ac (0.4 to 0.8 ha) per hour when towed by a heavy tractor (Brown 1974). This, and similar devices being tested by the Ontario Ministry of Natural Resources (Haig and Scott 1972), might prove feasible for seeding white spruce.

Broadcast Seeding

Seed distributed broadcast is scattered more or less indiscriminately, if uniformly, over the entire site, and while the method is usually unselective as to seedbed target, and profligate as to sowing rate, it is cheap to execute.

Hand scattering, with or without shakers, is the simplest approach. If applied on machine-scarified sites, reasonable disposition of the seed onto the prepared seedbed is possible, with correspondingly less waste. Cyclone seeders are portable hand-cranked machines, modified from agricultural patterns, which sow a swath about 20 ft (6.1 m) wide and allow a somewhat more uniform distribution of the seed than hand scattering, although confining them less effectively to the prepared seedbed. Rates are similar for both methods -- a maximum of about 2 ac (0.8 ha) per hour (Hellum 1974), and costs are variable but average ca. $1.50 per ac ($3.70 per ha). Cyclone seeders were found most efficient for areas no larger than 200 ac (81 ha) for sowing pine seed in the southeastern United States, where it was suggested that they could be mounted advantageously on tractors and run by a power takeoff or auxiliary electric motor (Anon. 1956).

Snowmobiles, when mounted with powered cyclone or other automatic seeders, provide a rapid means of sowing in winter, with the advantage to the operator of being able to see exactly what area has been treated. This method is used operationally in Manitoba and

Ontario and on a trial basis elsewhere. Larson and Jamrock (1969) described a **fully automatic seeder,** with variable sowing rate and uniform width of swath, used for snowmobile seeding white spruce on prepared sites in Minnesota; production rate was 20 ac (8.1 ha) per hour, at an average cost of $1.40 per ac ($3.50 per ha). The **Motorized Tree Seed Broadcaster,** designed by the Ontario Department of Lands and Forests especially for use on snowmobiles, is mounted behind the operator and applies seed over a 50-ft (15.2-m) swath, treating up to 60 ac (24 ha) per hour in ideal snow conditions at a cost of ca. $0.55 per ac ($1.35 per ha) (Brown 1969, 1974, Scott 1970). This device is a variant of the aerial seeder described below.

Seeding from the air is economical for "large" or remote areas, has low application costs, and much the fastest rate of production, but is most vulnerable to adverse weather and requires careful planning and ground preparations. At lease one authority (Hellum 1974) considers that aerial seeding in Alberta will be too expensive with current site preparation methods, because so much seed is needed for success, most being wasted on unscarified ground. Although broadcast distribution is the rule, an aerial row-seeding technique is under development (Mann, Campbell and Chappell 1974).

The area to be seeded should be delineated on an air photo or 20-chain to 1-in. (15,840:1) map for the pilot, and the boundary of the area, if greater than ca. 100 to 150 ac (40 to 60 ha), and some indication of progress across it, must be visible to him -- e.g. a line of flags moved by a ground crew. Radio contact with the pilot is desirable. Wind speed should not exceed 5 mph (8 km/h). A system of sampling seed distribution attained, by setting out tarpaulins or plastic sheets, serves as a check on performance and is obviously important for contract seeding (Anon. 1956, Griffin and Carr 1974, Worgan 1974).

The key to successful aerial seeding is the seed-dispensing equipment. A highly successful device, the powered **Brohm Aerial Seeding Unit,** developed in Ontario originally for helicopters but adapted for fixed-wing aircraft as well, is used in various parts of

Canada and the United States. It is a centrifugal broadcaster consisting of a container from which a variable-speed auger feeds the seed to a cross-shaped dispenser (the slinger) revolving at 1,000 rpm. Sowing rate is controlled by adjusting the auger speed (Scott 1970, Worgan 1974).

Helicopters were first used for aerial seeding, and are still used by both industry and the provincial government in Alberta. Helicopters have advantages of low-altitude performance over steep and rugged terrain, and minimal landing-ground requirements. The Brohm seeder dispenses seed in a 90-ft (27-m) circular pattern, can be lowered by drum and cable to clear the landing skids, and in a recently described seeding operation with white spruce in Maine, the Bell 47-D-1 aircraft flew at 50 mph (80 km/h) and altitudes of 150 to 200 ft (45 to 60 m) (Griffin and Carr 1974). Production rates of over 150 ac (61 ha) per hour have been cited by Hellum (1974) with application costs of $0.75 or less per ac ($1.85 per ha). Other reported costs are $1.25 per ac ($3.10 per ha) by Scott (1970); $1.41 per ac ($3.48 per ha) by Smyth and Karaim (1972); and an estimated $1.50 to $2.00 per ac ($3.70 to $4.90 per ha)[18]. The most recent innovation is aerial row-seeding with helicopters, a method which would result in considerable economies in quantity of seed applied. Trials in Louisiana indicated that precision sowing in rows, from altitudes of 50 ft (15 m) or less would be attainable following modification of seeding equipment (Mann, Campbell and Chappell 1974).

Fixed-wing aircraft, ompared to helicopters, are cheaper to operate, are faster, have greater range and endurance, and are best suited to large, level tracts. They do need a runway, however. They are, or have been, used to some extent in Manitoba and Quebec for forest seeding. In Ontario they have superseded helicopters for this purpose (Brown 1974). Operating techniques for commercial seeding with a Brohm unit from a Piper Super Cub in eastern Canada have been

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[18]Ibid.

described in detail by Worgan (1974): the area is usually covered progressively in 75-ft (23-m) swaths, normally parallel to its long axis, flying at ca. 80 mph (130 km/h) and altitude of 75 feet (23 m); the plane can operate from 700- to 1,000-ft (210- to 305-m) runways often prepared from logging roads by brushing out on each side for ca. 25 ft (7.6 m). Costs for seeding with fixed-wing aircraft are ca. \$0.75 to \$0.90 per ac (\$1.80 to \$2.20 per ha) (Scott 1970, Worgan 1974).

Regeneration Survey and Reseeding

Post-seeding assessment begins with sampling seedfall, as referred to previously, to determine efficacy of the sowing job. Thereafter, evaluation of seedling distribution and stocking usually follows the standards and sampling methods used for surveys of natural regeneration. That is to say, sampling is by quadrats, usually 1/1,000-acre, 6.6' x 6.6', (4.0 m^2) plots, which are classed as stocked (containing at least one "established" seedling) or unstocked, and the seeded area is rated according to the overall percentage of stocked quadrats. Standards vary between provinces both for the age of "established" seedlings (usually 2 or 3 years) and acceptable stocking levels -- usually 40 to 50%. Survey lines are run systematically across the seeded area, if possible at right angles to the direction of scarified strips, with quadrats located at regular intervals. Sequential sampling, a method which minimizes the amount of field work for a required degree of accuracy in areas of uniform stocking (Dick 1963, Smith and Ker 1958), has had some application in Canada. For example Johnson (1973), in a survey of 200-acre (80-ha) blocks seeded to white spruce in Alberta, used an adaptation of sequential sampling which indicated the number of quadrats (not less than 50) required for the estimated stocking level.

As soon as the need for restocking is indicated, action should be taken promptly before the quality of the seedbed deteriorates. For example, Hellum (1974) recommended immediate reseeding of any project that fails within a year. Richardson (1974) suggested that complete reseeding from the air would be cheapest in cases where seedbeds were still receptive, otherwise planting would be necessary.

References to Seeding

Abbott, Herschel G. 1961. White pine seed comsumption by small mammals. J. For. 59(3):197-201.

Anon. 1956. Proceedings Southeastern Direct Seeding Conference, August 22-23, 1956, Savannah, Georgia. Union Bag-Camp Paper Corp., Woodlands Res. Dep.

Anon. 1970. SFI scarifier-seeder does lightweight, low-cost job. Can. For. Ind. 90(8):59, 61.

Arlidge, J.W.C. 1967. The durability of scarified seedbeds for spruce regeneration. B.C. For. Serv., Res. Div. Res. Notes No. 42.

Arnott, J.T., J.D. MacArthur and A. Demers. 1971. Seeding of five conifers on prepared seedspots in Quebec. Pulp Pap. Mag. Can. 72(7):90-92.

Blyth, A.W. 1955. Seeding and planting of spruce on cut-over lands of the Subalpine Region of Alberta. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 2.

Brown, G. 1969. A motorized tree seed broadcaster. Ont. Dep. Lands For., Timber Branch, Silvic. Sect. Silvic. Notes No. 12.

Brown, G. 1974. Direct seeding in Ontario. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:119-124.

Clark, M.B. 1969. Direct seeding experiments in the southern interior region of British Columbia. B.C. For. Serv. Res. Notes No. 49.

Crossley, D.I. 1975. Case history in forest management: first 20-year cycle at North Western. Pulp Pap. Can. 76(5):42-48.

Dick, James. 1963. Forest stocking determined by sequential stocked-quadrat tally. J. For. 61(4):290-294.

Eis, Slavoj. 1965. Development of white spruce and alpine fir seedlings on cut-over areas in the central interior of British Columbia. For. Chron. 41(4):419-431.

Eis, S. 1967. Establishment and early development of white spruce in the interior of British Columbia. For. Chron. 43(2):174-177.

Endean, F. and W.D. Johnstone. 1974. Prescribed fire and regeneration of clearcut spruce-fir sites in the foothills of Alberta. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-126.

Fraser, J.W. 1971. Cardinal temperatures for germination of six provenances of white spruce seed. Dep. Fish. For., Can. For. Serv. Publ. 1290.

Fraser, J.W. 1974. Seed treatments (including repellents). *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:77-90.

Gemmell, J.R. 1975. The integration of site preparation with mechanical regeneration. *In* Mechanization of Silviculture in Northern Ontario. Proc. Symp. Sault Ste. Marie, Ont. Oct. 1, 2, 1974. Dep. Environ., Can. For. Serv. Symp. Proc. O-P-3:47-54.

Graber, Raymond E. and Donald F. Thompson. 1969. A furrow-seeder for the Northeast. U.S. Dep. Agric., For. Serv. Res. Pap. NE-150.

Griffin, Ralph H. and Bernard W. Carr. 1974. Aerial seeding of spruce in Maine. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:131-138.

Haig, R.A. and J.D. Scott. 1972. Mechanized silviculture in Canada. Spec. Pap. Prep. 7th World For. Congr., Buenos Aires.

Hall, John. 1970. Site preparation in Ontario. For. Chron. 46(6): 445-447.

Hellum, A.K. 1974. Direct seeding in western Canada. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:103-111.

Horton, K.W. and J.F. Flowers. 1965. Mechanized forest seeding method promises lower costs. Can. For. Ind. 85(3):66-69.

Horton, K.W. and B.S.P. Wang. 1969. Experimental seeding of conifers in scarified strips. For. Chron. 45(1):22-29.

Jarvis, J.M., G.A. Steneker, R.M. Waldron and J.C. Lees. 1966. Review of silvicultural research. White spruce and trembling aspen cover types, Mixedwood Forest Section, Boreal Forest Region, Alberta-Saskatchewan-Manitoba. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1156.

Johnson, H.J. 1973. An evaluation of scarification and direct seeding in Alberta. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-71.

Krewaz, J. 1958. A standard for spot seeding. For. Chron. 34(4): 380-381.

Larson, Hubert and Eugene Jamrock. 1969. Snowmobile seeding. Tree Plant. Notes 19(4):1-3.

Lees, J.C. 1971. Site factors contributing to the spruce regeneration problem in Alberta's mixedwoods. *In* R.G. McMinn (ed.) White Spruce: the Ecology of a Northern Resource. Proc. Symp. June 21, 1971; Can. Bot. Assoc. Edmonton, Alta. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-40:8-14.

Mann, W.F. Jr., T.E. Campbell and T.W. Chappell. 1974. Status of aerial row seeding. For. Farmer 34(2):12-13, 38-40.

Mattice, C.R. 1975. Mechanized row seeding. *In* Mechanization of Silviculture in Northern Ontario. Proc. Symp. Sault Ste. Marie, Ont. Oct. 1, 2, 1974. Dep. Environ., Can. For. Serv. Symp. Proc. O-P-3:86-97.

McLeod, J.W. 1953. Direct seeding of white spruce on a controlled burn in southern New Brunswick. Can. Dep. North. Aff. Natl. Resour., For. Branch, Div. For. Res. Silvic. Leafl. 97.

Parker, D.R. 1972. Report on the Brackekultivatorn scarifier-seeder. Ont. Minist. Nat. Resour., Div. For., Timber Manage. Branch, Silvic. Notes No. 13.

Place, I.C.M. 1955. The influence of seed-bed conditions on the regeneration of spruce and balsam fir. Can. Dep. North. Aff. Natl. Resour., For. Branch Bull. 117.

Prochnau, A.E. 1963. Direct seeding experiments with white spruce, alpine fir, Douglas fir, and lodgepole pine in the central interior of British Columbia. B.C. For. Serv. Res. Notes No. 37.

Radvanyi, Andrew. 1966. Destruction of radio-tagged seeds of white spruce by small mammals during summer months. For. Sci. 12(3): 307-315.

Radvanyi, Andrew. 1970*a*. A new coating treatment for coniferous seeds. For. Chron. 46(5):406-408.

Radvanyi, Andrew. 1970*b*. Small mammals and regeneration of white spruce forests in western Alberta. Ecology 51(6):1102-1105.

Radvanyi, Andrew. 1974. Seed losses to small mammals and birds. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:67-75.

Radvanyi, A. 1975. Effect of storage on germination of R-55 repellent-treated seed of white spruce. For. Chron. 51(1):21-23.

Rauter, R. Marie. 1974. The genetic considerations of direct seeding. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:49-54.

Richardson, J. 1974. Direct seeding the spruces. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13,

1973. Dep. Environ., Can. For. Serv. Publ. 1339:157-166.

Rindt, C.A. *et al.* 1953. Direct seeding of forest lands. Chap. III. Recommended reforestation practices and techniques. West. For. Conserv. Assoc., Portland, Ore. *Cited in* G.F. Weetman, 1958. Forest Seeding and Planting Techniques and Equipment. Pulp Pap. Res. Inst. Can. Tech. Rep. 74:77.

Rowe, J.S. 1953. Delayed germination of white spruce seed on burned ground. Can. Dep. Resour. Dev., For. Branch, Div. For. Res. Silvic. Leafl. 84.

Rowe, J.S. 1955. Factors influencing white spruce reproduction in Manitoba and Saskatchewan. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 3.

Scott, J.D. 1970. Direct seeding in Ontario. For. Chron. 46(6): 453-457.

Shirley, H.L. 1937. Direct seeding in the Lake States. J. For. 35(4):379-387.

Smith, J.H.G. 1955. Some factors affecting reproduction of Engelmann spruce and alpine fir. B.C. For. Serv., For. Res. Div. Tech. Publ. T.43.

Smith, J.H.G. and J.W. Ker. 1958. Sequential sampling in reproduction surveys. J. For. 56(2):107-109.

Smith, J. Harry G. and M. Bruce Clark. 1960. Growth and survival of Englemann spruce and alpine fir on seed spots at Bolean Lake, B.C. 1954-59. For. Chron. 36(1):46-49.

Smyth, J.H. and B.W. Karaim. 1972. An economic analysis of reforestation costs in Alberta. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-41.

Vaartaja, O. 1963. Germination of white spruce seed not affected by extreme pH. Can. Dep. For., For. Entomol. Pathol. Branch Bi-mon. Prog. Rep. 19(3):2-3.

Wagg, J.W. Bruce. 1963. Notes on food habits of small mammals of the white spruce forest. For. Chron. 39(4):436-445.

Waldron, R.M. 1966. Factors affecting natural white spruce regeneration on prepared seedbeds at the Riding Mountain Forest Experimental Area, Manitoba. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1169.

Waldron, R.M. 1974. Direct seeding in Canada 1900-1972. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:11-27.

Worgan, Doug. 1974. Aerial seeding by fixed-wing aircraft. *In* J.H. Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:125-129.

Interior of 41-year-old white spruce plantation. Dominant height ca. 60 ft (18.3 m). Petawawa Forest Experiment Station. Canadian Forestry Service photo.

VI. STAND DEVELOPMENT

Growth and Yield

Survival

Newly planted seedlings are highly vulnerable to unfavourable factors of their environment. In a survey of pulpwood plantations (mainly white spruce) in Ontario and Quebec, Stiell (1958) found that the bulk of mortality had usually occurred within four years of planting. The commonest causes were those connected with site or weather, including drought, frost-heave, flooding and exposure; various establishment factors, including improper planting and out-size or non-dormant stock; and competition -- chiefly from grass. A study of plantations one to six years old in the Prairie Provinces indicated competition, owing to inadequately prepared sites; planting and planting stock factors; and drought, to be the leading causes of mortality (Froning 1972).

In effect, this type of early mortality occurs in seedlings which have not become properly established. Sutton (1968) has pointed out that survival depends on early inception of root growth, which would seem most likely to occur with a combination of healthy plants and favourable soil conditions. And while the planting and competition factors cited can largely be controlled by good management, the risk of adverse climatic events which are overriding must still be accepted. Thus some early losses are inevitable, and despite best efforts they are occasionally catastrophic.

For these reasons, prediction of survival for a given plantation is scarcely a reasonable undertaking, although general expectations may be developed after long experience with a particular planting situation. MacKinnon (1974) presented early survival values by species, class of stock and district for plantations on Crown lands in Ontario. These he felt would be useful references. Average survival of planted white spruce after five years was 61% for bare-root stock, with 20 out of every 100 plantations having 80% or better survival, 42 having 70% or better and 65 having 60% or better; average survival of tubed seedlings after five years was 33%.

On completion of the establishment phase, subsequent mortality rates are normally low until well after stand closure and the development of intense intertree competition. (Of course, attacks from biological and other agents can occur in plantations at any age, but these are mostly unpredictable, and many are unrelated to health or vigour of the trees. Some of the commonest insects and diseases afflicting white spruce are discussed later under "Damage".)

Height

White spruce is considered a slow-starting species, seedlings often taking several years after planting to assume a rapid or even reasonable rate of height growth. Time to reach breast height was found to vary from 6 to 12 years in white spruce plantations at the Petawawa Forest Experiment Station, independent of site (Stiell and Berry 1973). Average heights for white spruce five years after planting on Crown lands in Ontario were reported as 24 in. (61.0 cm) for bare-root stock, 10 in. (25.4 cm) for tubed seedlings; there was a good deal of variation between and within districts, but the effects of site or other contributory factors were not indicated (MacKinnon 1974).

Sometimes the period of minimal height growth is prolonged, and the seedlings are said to be "in check". This phenomenon is widely recognized but seems to be most prevalent in the Maritimes where some authorities consider it serious enough to disqualify white spruce as a useful plantation species; i.e., the extension of a planned short rotation of 40 years by a preliminary 10-year check period is unacceptable. The usual attitude elsewhere in Canada is that planted white spruce naturally grows slowly for a few years, but that real check, i.e. virtually arrested top growth, is rare. Some postulated causes of the condition when it does occur are bunching of roots at planting, grass around the roots (particularly heavy sod), bladed mineral soil, planting when the roots are actively growing, planting when the roots are dormant, or too deep planting. Sutton (1968), who made an exhaustive study of the check problem, concluded from experimental evidence that it was not caused directly by root system damage or deep planting. He explained check in terms of nutrient stress resulting from the roots' inability to develop in the planting zone. The tree dies if adequate nutrient relations are not eventually improved by the roots exploiting more "effectively fertile" layers, but if and when they do, check is broken and good growth ensues. Even accepting this model, it is still difficult to predict or prevent check.

If any case, delayed and irregular inception of good growth have certain practical results. Planting in mixture with a species which gets off to a quicker start may lead to the spruce being suppressed and in some cases eventually shaded out. This is the case, for example, on drier sandy soils in Ontario when white spruce is interplanted with red pine; although on similar sites, if the two species are planted pure in adjacent blocks, the spruce will ultimately attain as rapid leader growth as the pine (Stiell 1955). Since it is so difficult to predict early growth rates, site index curves for planted white spruce cannot be reliably extended below about 15 years (Figure 10). Height growth above that age is fairly uniform until it starts to decline between 25 and 35 years. At Petawawa, dominant height growth in the period 45 to 50 years was still about 1 ft (0.3 m) per year on the best sites (Stiell and Berry 1973).

Another feature of height growth in white spruce plantations is the large variability shown by individuals within a stand. One sample of plantations (ranging in average height from 5 to 30 ft (1.5 to 9 m) showed a fairly constant coefficient of variation in height of about 31% (Stiell 1955). This unequal growth is perhaps due to the differential effects of check, to variability within the seed lot, or the use of ungraded planting stock. The wide range of height is ultimately reduced at its lower end by suppression and death of the smallest trees, but owing to the spruce's tolerance they are able to survive until long after crown closure.

Mortality from mutual competition is a function of stocking

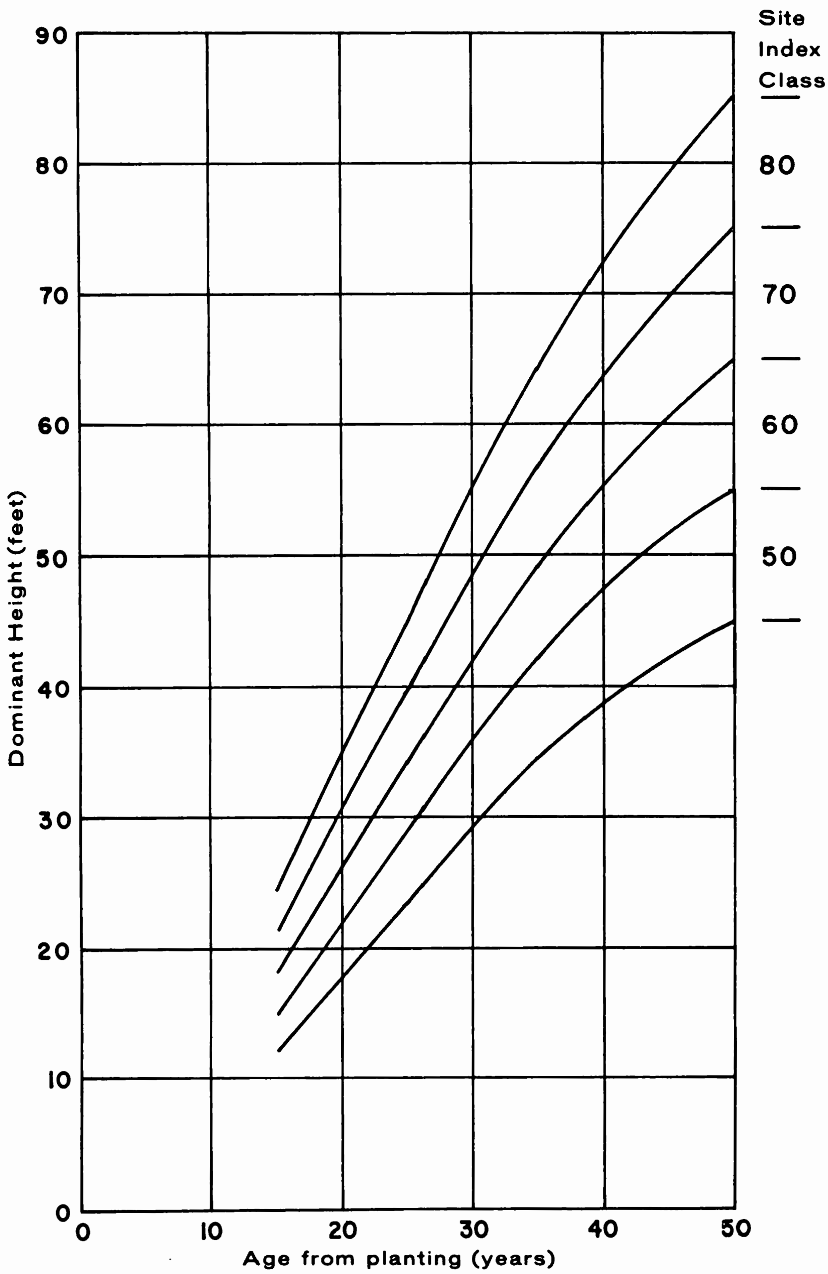

Figure 10. Site index curves at base age 50 years for planted white spruce. From Stiell and Berry 1973.

level and height, increasing with greater heights and closer spacings. For example, competition-caused mortality will begin in a plantation established at 4 x 4 ft (1.2 x 1.2 m) before the stand is 20 ft (6 m) tall, but not until height is ca. 40 ft (12 m) if the initial spacing was 8 x 8 ft (2.4 x 2.4 m) (Figure 11).

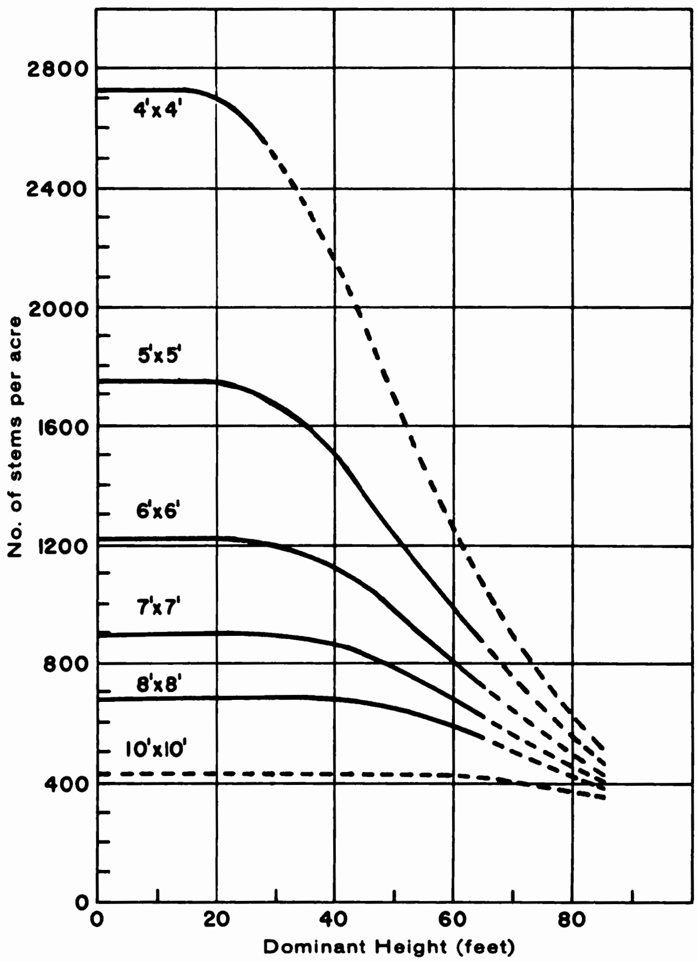

Figure 11. Relationship of numbers of trees to dominant height, by initial spacing, for planted white spruce. From Stiell and Berry 1973.

Diameter

The range of diameters within the stand parallels that of height, and increases with mean dbh. Diameter distributions about the mean, presented by Love and Williams (1968) and Stiell and Berry (1973), indicate that a 10-inch (25.4-cm) spread is not unusual for plantations with mean dbh of 5, 6 or 7 in. (12.7, 15.2 or 17.8 cm) (Table 9). The mean itself ($\overline{D}$, in inches) is strongly influenced by stocking level, increasing with wider spacings, and is closely related to the product of average spacing and dominant height (SH, in ft) from which it can be estimated as follows:

$$\overline{D} = 1.2553 + 0.0154SH - 0.00000642(SH)^2$$ (Stiell and Berry 1973).

Crowns

Slow to develop, white spruce plantations eventually close, forming a dense canopy beneath which as little as 2% of full sunlight may reach the ground[21]. As a result the forest floor is virtually devoid of minor vegetation except for shade-bearing mosses. White spruce form annual whorls of branches, and (usually much smaller) internodal branches as well, and epicormic branches may develop from dormant buds on stems or limbs. In a study of closed plantations 30 to 40 years old, it was found that the ratio of live crown length to tree height was a maximum of 54%, and the higher the crown class the greater the ratio: e.g. 36% for dominants versus only 7% for suppressed trees in one 5' x 5' (1.5-m x 1.5-m) plantation (Stiell 1969). Beneath the live crown, dead branches persisted to the base of the stem and remained sound for at least 26 years. The main whorl branches totalled more than 100 per tree, reaching a maximum diameter of ca. 1.2 in. (3.0 cm) near the base of the crown before dying from suppression.

Oven-dry foliage weights (W) of up to 25 kg (55 lb) for individual crowns, and 5,900 kg/ac (32,000 lb/ha) were found at the Petawawa Forest Experiment Station, and can be estimated for single trees from the diameter at the base of the live crown (DBC, in inches) as follows:

$$W = 410.39 - 688.37DBC + 550.53(DBC)^2$$ (Stiell 1969).

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[21]Unpublished data, Petawawa Forest Experiment Station, Project P-246.

Table 9. Percentage stem distribution about mean diameter class (D) in white spruce plantations

Mean dbh class (in.)	Spacing class (ft)	One-inch diameter classes D-5	D-4	D-3	D-2	D-1	D	D+1	D+2	D+3	D+4	D+5	ΣD-	ΣD+
2	6 x 6					43.1	51.9	5.0					43.1	5.0
3	5 x 5				12.8	26.0	34.9	16.8	7.3	2.0	0.1	0.1	38.8	26.3
	6 x 6				10.7	29.0	37.5	18.1	4.0	0.7			39.7	22.8
	7 x 7				14.0	29.0	44.1	11.8	1.1				43.0	12.9
4	5 x 5			3.0	13.9	24.9	29.5	17.3	8.3	2.8	0.3		41.8	28.7
	6 x 6			3.2	12.1	23.3	30.5	21.0	7.5	2.1	0.3		38.6	30.9
	7 x 7			2.9	5.6	20.2	31.8	29.6	8.7	1.2			28.7	39.5
5	5 x 5		1.1	5.1	18.0	26.9	21.0	15.7	8.9	2.7	0.6		51.1	27.9
	6 x 6		1.3	7.7	16.8	22.9	23.5	15.4	8.3	3.0	0.8	0.3	48.7	27.8
	7 x 7		0.8	4.2	12.3	21.0	26.4	20.9	9.9	4.0	0.5		38.3	35.3
6	6 x 6		1.1	11.0	21.4	18.3	17.7	14.0	9.8	4.7	1.3	0.7	51.8	30.5
	7 x 7	0.6	0.7	4.9	14.4	24.7	25.5	18.4	8.3	2.2	0.2	0.1	45.3	29.2
7	7 x 7		1.7	13.5	19.1	18.0	19.7	13.5	8.4	4.5	1.1	0.5	52.3	28.0
	8 x 8	0.7	5.4	8.8	19.7	13.6	18.4	15.7	12.2	4.1	1.4		48.2	33.4

(Data from Petawawa Forest Experiment Station. From Stiell and Berry 1973).

Roots

Root form of white spruce is highly variable, depending largely on soil texture, moisture and fertility, with restricted drainage near the surface tending to limit development of a taproot (Sutton 1969, Wagg 1967).

A detailed study of root systems in thinned and unthinned 39-year-old white spruce plantations growing on deep sands at the Petawawa Forest Experiment Station was made 1966-67[22]. It revealed a mean radial spread of lateral roots of up to 44 ft (13.4 m) for a dominant 56 ft (17.1 m) tall, and lateral roots currently extending at a rate of ca. 1 ft (0.3 m) per year. About 85% of the total weight of roots occupied the top foot (0.3 m) of soil, where most laterals occurred, with extensive intermingling between neighbouring root systems. Taproots and sinkers were common, some descending to a depth of 10 ft (3.0 m). Intertree grafting involved 26% of trees in the unthinned stand, and 37% in the thinned stand where at least parts of about 10% of stumps were thus kept alive (seven years after cutting). Total oven-dry weight of roots in the unthinned stand was ca. 11.93 tons/ac (26,740 kg/ha) versus 5.82 tons/ac (13,050 kg/ha) for foliage, and 50.04 tons/ac (112,170 kg/ac) for all above-ground material. The root components included 1.19 tons/ac (2,670 kg/ha) fine material less than 0.1 in. (0.25 cm) in diameter (the main absorbing roots). (In comparison, ca. 6,960 kg/ha (3.1 tons/ac) fine roots of about the same size were reported in the top 45 cm (17.7 in.) of soil in a similar plantation in Maine (Safford and Bell 1972).

While crown competition is mainly a matter of withholding light from neighbouring trees, root competition is more difficult to understand owing to the intermingling of roots at considerable distances from their respective stems. In the Petawawa study[22], it was

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[22]Grose, R.J. 1968. Crown and root relationships in white spruce plantations. Paper Presented to the Fifth General Conference, Institute of Foresters of Australia. October 14-18, 1968, Perth, Western Australia.

concluded that trees responded to thinning by a greater increase in foliage weight relative to fine root weight, indicating that this ratio is influenced by competition, and that below-ground factors are more limiting to total production than above-ground factors, for these plantations.

Yields

Most white spruce plantations in Canada have been established with one of two main ends in view. East of Manitoba the usual expectation is a crop of pulpwood to be clear-cut at the end of a fairly short rotation, estimated at from 35 years (in New Brunswick) to 70 years (in northwestern Ontario). Further west there is an increasing concern with sawlog production, culminating in British Columbia where it is intended to grow all white spruce to sawtimber-size, at rotations of 80 to 100 years, with pulpmills to be supplied entirely from chipsaw residues. Apart from British Columbia, anticipated utilization is somewhat more flexible, the Prairie Provinces planning for some roundwood production for pulp, and in eastern Canada it is acknowledged that some sawlogs will be available by age 40 to 50 years.

Information on yields that can be obtained from plantations is incomplete, owing to the meagre representation of older planted stands in most regions. Yield tables for white spruce plantations have been prepared in Ontario only. Tables from remeasurement data of permanent sample plots of the Petawawa Forest Experiment Station were prepared by Stiell and Berry (1973). These are for unmanaged, high-survival plantations, and present stand values by 5-year age classes from 20 to 50 years from planting, for six initial spacings, 4 x 4, 5 x 5, 6 x 6, 7 x 7, 8 x 8, and 10 x 10 ft (1.2 x 1.2, 1.5 x 1.5, 1.8 x 1.8, 2.1 x 2.1, 2.4 x 2.4 and 3.0 x 3.0 m), and four site index classes. These tables indicate comparative development for the various planted spacing in terms of trees per acre, mean dbh, and basal area, total volume and merchantable volume per acre at the successive ages (Tables 10-13). Love and Williams (1968) produced yield tables for

Table 10. Yield table for unmanaged white spruce plantations (Site Index Class 50)

Age from planting (yrs)	Dominant height (ft)	Planted spacing (ft)	Trees per acre	Mean dbh (in.)	Basal area (ft^2/ac)	Volume Total (ft^3/ac)	Volume Merch (ft^3/ac)
20	19.8	4 x 4	2717	2.4	87	619	56
		5 x 5	1742	2.7	70	514	87
		6 x 6	1210	3.0	59	439	110
		7 x 7	889	3.3	52	383	123
		8 x 8	681	3.5	46	338	112
		10 x 10	436	4.1	39	272	95
25	25.9	4 x 4	2607	2.8	112	1136	534
		5 x 5	1722	3.2	93	973	516
		6 x 6	1210	3.5	80	850	510
		7 x 7	889	3.8	71	753	497
		8 x 8	681	4.2	65	677	481
		10 x 10	436	4.8	55	565	412
30	32.2	4 x 4	2430	3.2	138	1784	1213
		5 x 5	1643	3.6	118	1548	1084
		6 x 6	1195	4.0	105	1379	1020
		7 x 7	889	4.4	94	1237	977
		8 x 8	681	4.8	86	1121	930
		10 x 10	436	5.5	73	948	806
35	38.3	4 x 4	2205	3.7	164	2489	1917
		5 x 5	1540	4.1	143	2192	1710
		6 x 6	1136	4.5	128	1970	1615
		7 x 7	878	4.9	117	1797	1527
		8 x 8	681	5.4	107	1640	1427
		10 x 10	436	6.2	92	1396	1242
40	43.3	4 x 4	1997	4.1	184	3104	2514
		5 x 5	1420	4.6	162	2760	2291
		6 x 6	1080	5.0	147	2507	2156
		7 x 7	846	5.4	136	2301	2002
		8 x 8	678	5.8	126	2128	1873
		10 x 10	436	6.7	107	1821	1639
45	47.0	4 x 4	1830	4.4	198	3572	2929
		5 x 5	1325	4.9	176	3198	2718
		6 x 6	1025	5.4	161	2923	2543
		7 x 7	820	5.8	149	2704	2380
		8 x 8	665	6.2	139	2516	2239
		10 x 10	436	7.1	119	2168	1951
50	50.0	4 x 4	1680	4.8	208	3942	3272
		5 x 5	1250	5.2	187	3560	3097
		6 x 6	980	5.7	172	3273	2880
		7 x 7	790	6.1	160	3037	2703
		8 x 8	650	6.5	149	2840	2556
		10 x 10	436	7.4	128	2470	2223

(Data from Petawawa Forest Experiment Station. From Stiell and Berry 1973).

Table 11. Yield table for unmanaged white spruce plantations (Site Index Class 60)

Age from planting (yrs)	Dominant height (ft)	Planted spacing (ft)	Trees per acre	Mean dbh (in.)	Basal area (ft²/ac)	Volume: Total (ft³/ac)	Volume: Merch (ft³/ac)
20	24.0	4 x 4	2650	2.7	105	964	337
		5 x 5	1735	3.0	86	818	352
		6 x 6	2310	3.3	74	710	362
		7 x 7	889	3.7	65	627	364
		8 x 8	681	4.0	59	562	348
		10 x 10	436	4.6	50	466	308
25	31.3	4 x 4	2460	3.2	135	1683	1111
		5 x 5	1657	3.6	114	1459	992
		6 x 6	1198	3.9	101	1298	948
		7 x 7	889	4.3	91	1162	895
		8 x 8	681	4.7	82	1052	863
		10 x 10	436	5.4	71	888	746
30	38.8	4 x 4	2188	3.7	166	2551	1964
		5 x 5	1526	4.2	145	2248	1776
		6 x 6	1134	4.6	130	2023	1679
		7 x 7	876	5.0	119	1847	1588
		8 x 8	681	5.4	109	1687	1485
		10 x 10	436	6.3	93	1436	1278
35	45.8	4 x 4	1883	4.3	193	3419	2804
		5 x 5	1353	4.8	171	3052	2564
		6 x 6	1043	5.2	157	2788	2426
		7 x 7	830	5.7	145	2573	2264
		8 x 8	672	6.1	135	2390	2127
		10 x 10	436	7.0	115	2052	1847
40	51.8	4 x 4	1600	5.0	214	4164	3498
		5 x 5	1202	5.4	193	3778	3287
		6 x 6	954	5.9	179	3487	3069
		7 x 7	775	6.3	166	3248	2891
		8 x 8	640	6.7	155	3038	2734
		10 x 10	436	7.5	134	2660	2394
45	56.0	4 x 4	1415	5.4	227	4685	3982
		5 x 5	1100	5.9	207	4303	3744
		6 x 6	880	6.3	192	3982	3504
		7 x 7	730	6.7	179	3741	3329
		8 x 8	615	7.1	169	3524	3172
		10 x 10	436	7.9	147	3129	2816
50	60.0	4 x 4	1245	5.9	238	5166	4494
		5 x 5	985	6.4	219	4775	4202
		6 x 6	805	6.8	203	4454	3964
		7 x 7	680	7.2	191	4206	3743
		8 x 8	590	7.5	181	4006	3605
		10 x 10	436	8.2	159	3610	3249

(Data from Petawawa Forest Experiment Station. From Stiell and Berry 1973).

Table 12. Yield table for unmanaged white spruce plantations (Site Index Class 70)

Age from planting (yrs)	Dominant height (ft)	Planted spacing (ft)	Trees per acre	Mean dbh (in.)	Basal area (ft^2/ac)	Volume: Total (ft^3/ac)	Volume: Merch (ft^3/ac)
20	28.3	4 x 4	2542	3.0	122	1369	780
		5 x 5	1697	3.3	103	1180	708
		6 x 6	1208	3.7	90	1040	686
		7 x 7	889	4.1	80	925	657
		8 x 8	681	4.4	72	835	635
		10 x 10	436	5.1	62	701	554
25	36.9	4 x 4	2265	3.6	158	2322	1742
		5 x 5	1567	4.0	137	2041	1572
		6 x 6	1150	4.4	123	1828	1481
		7 x 7	885	4.8	112	1662	1413
		8 x 8	681	5.2	102	1513	1316
		10 x 10	436	6.1	87	1287	1145
30	45.6	4 x 4	1890	4.3	192	3392	2781
		5 x 5	1353	4.8	171	3024	2540
		6 x 6	1047	5.2	156	2766	2406
		7 x 7	830	5.6	144	2549	2243
		8 x 8	672	6.0	134	2368	2108
		10 x 10	436	6.9	115	2033	1830
35	53.0	4 x 4	1545	5.1	217	4304	3658
		5 x 5	1175	5.6	198	3930	3419
		6 x 6	930	6.0	182	3628	3193
		7 x 7	765	6.4	170	3388	3015
		8 x 8	635	6.8	159	3179	2861
		10 x 10	436	7.6	138	2790	2511
40	59.7	4 x 4	1260	5.9	237	5137	4469
		5 x 5	996	6.3	218	4742	4173
		6 x 6	810	6.8	202	4417	3931
		7 x 7	683	7.1	190	4167	3709
		8 x 8	594	7.4	180	3973	3576
		10 x 10	436	8.2	158	3573	3216
45	65.1	4 x 4	1055	6.6	249	5765	5073
		5 x 5	857	7.0	230	5375	4784
		6 x 6	720	7.4	216	5064	4507
		7 x 7	620	7.7	203	4817	4335
		8 x 8	556	8.0	194	4643	4179
		10 x 10	427	8.6	173	4238	3814
50	70.0	4 x 4	890	7.3	256	6312	5618
		5 x 5	745	7.7	238	5946	5292
		6 x 6	640	8.0	224	5644	5080
		7 x 7	560	8.3	211	5396	4856
		8 x 8	510	8.5	202	5229	4706
		10 x 10	410	9.0	182	4927	4434

(Data from Petawawa Forest Experiment Station. From Stiell and Berry 1973).

Table 13. Yield table for unmanaged white spruce plantations (Site Index Class 80)

Age from planting (yrs)	Dominant height (ft)	Planted spacing (ft)	Trees per acre	Mean dbh (in.)	Basal area (ft^2/ac)	Volume Total (ft^3/ac)	Volume Merch (ft^3/ac)
20	32.2	4 x 4	2430	3.2	138	1784	1213
		5 x 5	1643	3.6	118	1548	1084
		6 x 6	1195	4.0	105	1379	1020
		7 x 7	889	4.4	94	1237	977
		8 x 8	681	4.8	86	1121	930
		10 x 10	436	5.5	73	948	806
25	42.1	4 x 4	2050	4.0	179	2957	2366
		5 x 5	1448	4.5	158	2621	2149
		6 x 6	1095	4.9	143	2374	2018
		7 x 7	855	5.3	131	2176	1893
		8 x 8	681	5.7	121	2009	1768
		10 x 10	436	6.6	104	1714	1543
30	51.8	4 x 4	1600	5.0	214	4164	3498
		5 x 5	1202	5.4	193	3778	3287
		6 x 6	954	5.9	179	3487	3069
		7 x 7	775	6.3	166	3248	2891
		8 x 8	640	6.7	155	3338	2734
		10 x 10	436	7.5	134	2660	2394
35	60.6	4 x 4	1210	6.0	238	5225	4546
		5 x 5	965	6.5	220	4836	4256
		6 x 6	795	6.9	205	4526	4028
		7 x 7	675	7.2	192	4284	3813
		8 x 8	585	7.6	182	4076	3668
		10 x 10	435	8.2	161	3681	3313
40	68.2	4 x 4	942	7.0	254	6102	5370
		5 x 5	780	7.4	235	5727	5097
		6 x 6	673	7.8	222	5445	4846
		7 x 7	582	8.1	209	5183	4665
		8 x 8	530	8.3	200	5022	4520
		10 x 10	418	8.9	179	4632	4169
45	74.4	4 x 4	760	7.9	258	6772	6027
		5 x 5	655	8.2	242	6448	5803
		6 x 6	576	8.5	229	6164	5548
		7 x 7	515	8.8	217	5939	5345
		8 x 8	473	9.0	208	5769	5192
		10 x 10	397	9.4	190	5441	4897
50	80.0	4 x 4	620	8.7	255	7331	6598
		5 x 5	555	8.9	242	7060	6354
		6 x 6	500	9.2	229	6817	6135
		7 x 7	455	9.4	218	6599	5939
		8 x 8	430	9.5	211	6481	5833
		10 x 10	370	9.8	193	6152	5537

(Data from Petawawa Forest Experiment Station. From Stiell and Berry 1973).

three potential production classes in southern Ontario. These were constructed from data obtained by single measurement and stem analysis, and assume an initial spacing of 8 x 8 ft (2.4 x 2.4 m) and minimal mortality. The tables show total production, mortality, and standing volume (all in total cubic feet per acre), by 10-year intervals from age 20 to 70 years (Tables 14-16). Volume/age curves for ages 20 to 80 years and three site index classes, projected from plantations with a maximum age of 33 years, were prepared for planted white spruce in Wisconsin (Wilde *et al.* 1965). There are no other consolidations of plantation growth data for this species, but examples (from older stands and better sites, where available) of plantation growth in a variety of geographic locations are shown in Table 17.

Plantations managers generally assume that yields will be at least as good as those of natural stands of white spruce and probably better, owing to more regular spacing and the presence of fewer volunteer stems of unwanted species. Yields of 30 to 50 cunits per ac (210 to 350 m^3/ha) seem to be anticipated for short-rotation pulpwood, and according to the Petawawa tables 50 cunits (350 m^3) would be possible by age 50 on the better sites, for a planted spacing of 7 x 7 ft (2.1 x 2.1 m). In regions where pure stands of white spruce occur, provincial inventory data are the main sources for predictive purposes, although, in Saskatchewan, yield tables for well-stocked natural stands of white spruce in the Mixedwood Section have been published for three site classes (Kabzems 1971). Site index (dominant height/age) curves, helpful for estimating relative productivity, have been produced for interior spruce by the British Columbia Forest Service[23], and for white spruce in Alberta mixedwoods by Heger (1971).

[23]Smith, J.H.G. and M.B. Clark. 1974. Results of methods of cutting and related studies initiated in Engelmann spruce - subalpine fir forests near Bolean Lake, B.C. in 1950. Progress Report Presented at the Northwest Scientific Association Meeting, Vancouver, B.C., May 9-11, 1974.

Table 14. White spruce plantation yield tables - Potential Production Class I

Age (yrs) (n)	Dom. ht (ft)	Volume (cu ft/ac) Total prod.	Mortality	Standing timber (V)	M.A.I.* (cu ft/ac/yr)	C.A.I.*	Rate of volume increase**
20	29	1,250	-	1,250	62	205	10.2
30	44	3,450	150	3,330	110	180	4.4
40	56	5,800	700	5,100	128	130	2.3
50	64	7,750	1,350	6,400	128	100	1.5
60	71	9,400	2,000	7,400	123	60	0.8
70	76	10,600	2,600	8,000	114		

Table 15. White spruce plantation yield tables - Potential Production Class II

Age (yrs) (n)	Dom. ht (ft)	Volume (cu ft/ac) Total prod.	Mortality	Standing timber (V)	M.A.I.* (cu ft/ac/yr)	C.A.I.*	Rate of volume increase**
20	25	750	-	750	37	165	12.3
30	39	2,500	100	2,400	80	160	5.2
40	50	4,500	500	4,000	100	120	2.7
50	59	6,250	1,050	5,200	104	90	1.6
60	65	7,500	1,400	6,100	101	60	1.1
70	70	8,450	1,750	6,700	96		

Table 16. White spruce plantation yield tables - Potential Production Class III

Age (yrs) (n)	Dom. ht (ft)	Volume (cu ft/ac) Total prod.	Mortality	Standing timber (V)	M.A.I.* (cu ft/ac/yr)	C.A.I.*	Rate of volume increase**
20	22	400	-	400	20	110	14.1
30	34	1,550	50	1,500	50	140	6.8
40	44	3,150	250	2,900	72	125	3.6
50	52	4,750	600	4,150	83	105	2.3
60	58	6,100	900	5,200	87	80	1.4
70	64	7,100	1,100	6,000	86		

*Calculated for standing volume only.
**Compound annual rate of standing volume (V) increase from V_n to V_{n+10}

(Data from southern Ontario. From Love and Williams 1968).

Table 17. Examples of white spruce plantation development

Years planted	Initial spacing ft (m)	Location	Site	Number trees per ac (per ha)	Dominant height ft (m)	Avg. height ft (m)	Avg. dbh inches (cm)	Basal area ft^2/ac (m^2/ha)	Total volume ft^3/ac (m^3/ha)	Merch. volume ft^3/ac (m^3/ha)	Remarks	Source
40	5 x 5 (1.5 x 1.5)	Grand'Mere, Que.	Moderately drained alluvial clay	870 (2,150)	59 (18.0)	49 (14.9)	6.4 (16.2)	195 (44.8)	4,550 (318.4)	- -		Popovich 1974
40	5 x 5 (1.5 x 1.5)	Grand'Mere, Que.	Moderately drained alluvial clay	605 (1,495)	68 (20.7)	64 (19.5)	8.7 (22.1)	247 (56.7)	7,215 (504.8)	- -	Thinned	Popovich 1974
28	7 x 7 (2.1 x 2.1)	Drummondville, Que.	Old field	715 (1,767)	42 (12.8)	37 (11.2)	6.0 (15.2)	151 (34.7)	2,647 (185.2)	2,296 (160.7)		Popovich and Houle 1970
57	- -	Paipoonge Twp., Ont.	Old field	137 (339)	- -	- -	14.4 (36.6)	155 (35.6)	5,000 (349.9)	4,300 (300.9)	Planted white and black spruce and balsam fir at 275/ac (680/ha), but 85% of volume white spruce at this age	Love and Williams 1968
46	5 x 5 (1.5 x 1.5)	Chalk River, Ont.	Very fresh sandy loam	1,000 (2,471)	61 (18.6)	- -	6.7 (17.0)	246 (56.5)	5,919 (414.2)	5,277 (369.2)		Petawawa Forest Experiment Station records
38	7 x 7 (2.1 x 2.1)	Chalk River, Ont.	Fresh, windblown fine sand	790 (1,952)	56 (17.1)	- -	6.5 (16.5)	181 (41.6)	3,723 (260.5)	3,300 (230.9)		Petawawa Forest Experiment Station records
40	6 x 6 (1.8 x 1.8)	Kirkwood Twp. Ont.	Deep sand	659 (1,628)	ca.45 (13.7)	- -	5.6 (14.2)	112 (25.7)	- -	- -	Basal area estimate for inside bark	A. Crealock, personal communication
54	4 x 8 (1.2 x 2.4)	Turtle Mtns., Man.	Fresh clay-loam till	776 (1,917)	58 (17.7)	- -	6.7 (17.0)	193 (44.3)	4,633 (324.2)	4,072 (284.9)	Originally 4 x 4 ft (1.2 x 1.2 m) but alternate rows of Scots pine did not survive	Bella 1968
33	- -	Wisconsin, USA	Superior Clay Loam	340 (840)	- -	53 (16.2)	8.3 (21.1)	136 (31.2)	- -	2,883 (201.7)		Wilde *et al.* 1965
ca.31	6 x 6 (1.8 x 1.8)	Maloneck, Sask.	Sandy and stoney sandy loam	1,012 (2,501)	- -	36 (11.0)	4.4 (11.2)	109 (25.0)	- -	- -		P. Etheridge, Saskatchewan Forestry Branch. Unpubl.
21	6.6 x 6.6 (2.0 x 2.0)	Bolean Lake, B.C.	-	- -	- -	13 (4.0)	2.5 (6.4)	- -	- -	- -		Smith and Clark 1974
11	6 x 6 (1.8 x 1.8)	North Pond, Nfld.	Loamy, variable moisture	- -	- -	7.2 (2.2)	0.8 (2.0)	- -	- -	- -	Provenance was Grandes Piles, Que.	Khalil 1974

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42-year-old white spruce, planted at 5 x 5 ft, 9 years after thinning. Basal area 149 ft^2/ac (34.2 m^2/ha). Petawawa Forest Experiment Station. Canadian Forestry Service photo.

34-year-old white spruce, planted at 5 x 5 ft. Basal area 175 ft^2/ac (40.2 m^2/ha). Petawawa Forest Experiment Station. Canadian Forestry Service photo.

42-year-old white spruce, planted at 7 x 7 ft, 10 years after thinning. Basal area 155 ft^2/ac (35.6 m^2/ha). Petawawa Forest Experiment Station. Canadian Forestry Service photo.

Volume Tables

Standard volume tables based on natural stands may not be too applicable to white spruce plantations, which differ in their usually younger average age, much more regular spacing, and, in central and eastern Canada at least, in their unmixed composition. Tables derived from measurements of planted white spruce would seem preferable, and three such sets, all based on stem analysis data, have been published, one from Ontario and two from Quebec.

The most comprehensive tables are those prepared by Berry (1969), covering the range of 1-in. (2.5-cm) dbh classes from 3 to 13 in. (7.6 to 33.0 cm), and 5-ft (1.5-m) height classes from 25 to 65 ft (7.6 to 19.8 m), and including total cubic feet; merchantable volume in cubic feet for 50- and 100-in. (1.3- and 2.5-m) pulpwood; board feet by Ontario and International log rules for sawlogs not less than 8 ft (2.4 m) long (Tables 18-21). Popovich presented total volumes (Tables 22-23) for trees 2 to 11 in. (5.1 to 27.9 cm) dbh, and 15 to 50 ft (4.6 to 15.2 m) tall for which spruce plantations at Drummondville, Quebec (1972*a*); and total and merchantable volumes (Tables 24-25) for trees ranging from 3 to 12 in. (7.6 to 30.5 cm) dbh, and 20 to 70 ft (6.1 to 21.3 m) tall for plantations at Grand'Mère, Quebec (1972*b*). (Total volumes in the Quebec tables vary from 1 to 11% greater than those given by Berry).

Table 18. Plantation white spruce total volume[1] in cubic feet

DBH class (ob) (in.)	Height class - ft								
	25	30	35	40	45	50	55	60	65
3	.57	.69							
4	1.02	1.22	1.46	1.70					
5	1.60	1.92	2.23	2.56	2.95	3.22			
6	2.30	2.75	3.16	3.61	4.10	4.53	4.95	5.40	
7			4.20	4.82	5.40	6.00	6.60	7.20	
8			5.43	6.20	6.95	7.70	8.50	9.30	10.1
9			6.75	7.75	8.55	9.55	10.6	11.5	12.5
10					10.3	11.6	12.7	13.9	15.2
11					12.1	13.7	15.2	16.6	18.2
12						16.2	17.8	19.5	21.3
13							20.6	22.6	24.6

[1]Stump and top included.
Basis 445 trees.

(Data from Petawawa Forest Experiment Station. From Berry 1969).

Table 19. Plantation white spruce merchantable volume[1] in cubic feet

DBH class (ob) (in.)	Bolt length (in.)	Height class - ft								
		25	30	35	40	45	50	55	60	65
4	50	.6	.6	.9	.9					
	100	.6	.6	.6	.6					
5	50	1.2	1.3	1.6	2.0	2.4	2.6			
	100	.9	1.0	1.6	1.8	2.4	2.4			
6	50	1.6	2.2	2.6	2.9	3.3	3.9	4.1	4.6	
	100	1.3	2.2	2.3	2.6	3.3	3.9	4.1	4.3	
7	50			3.5	4.2	4.7	5.2	5.8	6.4	
	100			3.1	4.2	4.4	5.2	5.5	6.4	
8	50			4.6	5.3	6.1	6.8	7.5	8.3	9.1
	100			4.1	5.3	5.7	6.8	7.1	8.3	8.8
9	50			6.0	6.9	7.5	8.5	9.7	10.5	11.3
	100			6.0	6.6	7.1	8.5	9.7	10.3	11.0
10	50					9.0	10.4	11.6	12.7	14.0
	100					8.5	10.4	11.6	12.4	14.0
11	50					10.9	12.3	13.9	15.1	16.8
	100					10.9	12.3	13.9	14.8	16.8
12	50						14.5	16.2	17.9	19.5
	100						14.5	16.2	17.5	19.5
13	50							18.8	20.6	22.4
	100							18.8	20.3	22.4

[1]Volume for 50-in. and 100-in. bolts to the nearest whole bolt to a top dib of not less than 3 in. above a stump height of 6 in.
Basis 423 trees.

(Data from Petawawa Forest Experiment Station. From Berry 1969).

Table 20. Plantation white spruce merchantable board foot[1] (Ontario Log Rule) and cubic foot[2] volume

DBH class (ob) (in.)			Height class - ft						
			35	40	45	50	55	60	65
7	Fbm		8	8	9	9	12	12	
	Cu ft	(A)	1.7	2.1	2.5	3.1	3.2	3.8	
		(B)	1.3	2.1	2.1	3.1	3.2	3.5	
8	Fbm		13	16	16	17	20	23	24
	Cu ft	(A)	1.2	1.5	1.7	2.1	2.5	2.5	2.6
		(B)	1.2	1.2	1.3	2.1	2.3	2.3	2.3
9	Fbm		15	23	25	28	33	38	39
	Cu ft	(A)	1.1	1.1	1.5	1.6	2.0	2.0	2.2
		(B)	1.1	1.1	1.2	1.3	2.0	2.0	2.2
10	Fbm				30	33	37	50	56
	Cu ft	(A)			1.1	1.2	1.6	1.6	2.0
		(B)			1.1	1.2	1.3	1.2	2.0
11	Fbm				40	43	48	56	72
	Cu ft	(A)			1.1	1.2	1.5	1.5	1.6
		(B)			1.1	1.2	1.2	1.1	1.2
12	Fbm					46	61	68	75
	Cu ft	(A)				1.1	1.1	1.5	1.5
		(B)				1.1	1.1	1.2	1.2
13	Fbm						67	88	90
	Cu ft	(A)					1.1	1.6	1.1
		(B)					1.1	1.3	1.1

[1]Board foot, Ontario Log Rule, for logs not less than 8 ft 3 in. to a top dib of not less than 6.0 in., above a stump height of 6 in.

[2]Merchantable cubic foot volume is remainder of tree, in (A) 50-in. bolts to the nearest whole bolt to a top dib of not less than 3.0 in., or (B) 100-in. bolts to the nearest whole bolt to a top dib of not less than 3.0 in. Basis 264 trees.

(Data from Petawawa Forest Experiment Station. From Berry 1969).

Table 21. Plantation white spruce board foot[1] (International Log Rule) and cubic foot[2] volume

DBH class (ob) (in.)			Height class - ft						
			35	40	45	50	55	60	65
7	Fbm		10	15	15	20	20	20	
	Cu ft	(A)	1.3	1.4	1.8	1.9	2.2	2.4	
		(B)	1.1	1.1	1.8	1.9	2.0	2.1	
8	Fbm		15	20	25	30	30	40	45
	Cu ft	(A)	1.0	1.0	1.3	1.4	1.4	1.7	1.9
		(B)	1.0	1.0	1.0	1.1	1.1	1.7	1.9
9	Fbm		20	30	30	40	40	50	55
	Cu ft	(A)	0.9	0.9	1.0	1.0	1.4	1.4	1.4
		(B)	0.9	0.9	1.0	1.0	1.1	1.1	1.1
10	Fbm				40	50	55	65	70
	Cu ft	(A)			0.8	1.0	1.0	1.3	1.3
		(B)			0.8	1.0	1.0	1.0	1.0
11	Fbm				50	50	70	75	85
	Cu ft	(A)			0.5	0.9	0.9	1.0	1.0
		(B)			0.0	0.9	0.9	1.0	1.0
12	Fbm					65	75	80	105
	Cu ft	(A)				0.9	0.8	1.0	1.0
		(B)				0.9	0.8	1.0	1.0
13	Fbm						90	105	130
	Cu ft	(A)					0.9	0.9	0.9
		(B)					0.9	0.9	0.9

[1]Board foot, International Log Rule, for logs not less than 8 ft 3 in. to a top dib of not less than 5.5 in. above a stump height of 6 in.

[2]Merchantable cubic foot volume in remainder of tree in (A) 50-in. bolts to the nearest whole bolt to a top dib of not less than 3.0 in. or (B) 100-in. bolts to the nearest whole bolt to a top dib of not less than 3.0 in.
Basis 264 trees.

(Data from Petawawa Forest Experiment Station. From Berry 1969).

Table 22. Total volume table (bark included) for white spruce (*Picea glauca* (Moench) Voss)

dbh ob (in.)	Total tree height (ft)							
	15	20	25	30	35	40	45	50
	Total volume ft^3 (stump, top and bark included)							
2	.215	.286	.358					
3	.435	.580	.724	.869				
4		.976	1.22	1.46	1.71			
5		1.47	1.84	2.21	2.58	2.95		
6		2.07	2.59	3.11	3.63	4.15	4.67	
7			3.47	4.17	4.86	5.56	6.25	6.95
8				5.38	6.27	7.17	8.06	8.96
9					7.86	8.99	10.11	11.23
10					9.63	11.01	12.38	13.76
11						13.23	14.89	16.54

$$VTCF = \frac{(0.049 + 0.268 \text{ dbh} + 0.369 \text{ dbh}^2) H}{144}$$

Basis 121 trees (Drummondville plantations).
Accuracy 5% level (% + or - 8.0).

(From Popovich 1972*a*).

Table 23. Total volume table (bark not included) for white spruce (*Picea glauca* (Moench) Voss)

dbh ob (in.)	Total tree height (ft)							
	15	20	25	30	35	40	45	50
	Total volume ft^3 (stump, top included, inside bark)							
2	.191	.255	.319					
3	.387	.516	.644	.773				
4		.869	1.09	1.30	1.52			
5		1.31	1.64	1.97	2.30	2.63		
6		1.84	2.30	2.77	3.23	3.69	4.16	
7			3.09	3.71	4.32	4.95	5.56	6.19
8				4.79	5.58	6.38	7.17	7.97
9					6.99	8.00	9.00	9.99
10					8.57	9.80	11.02	12.25
11						11.77	13.25	14.72

(Data from Drummondville plantations. From Popovich 1972*a*).

Table 24. Plantation white spruce (*Picea glauca* (Moench) Voss) Grand'Mère, Quebec. Volume total ft^3, stump and top included

dbh class	Total height class 10	15	20	25	30	35	40	45	50	55	60	65	70	75
1														
2														
3			.51	.64	.76	.89								
4			.87	1.09	1.30	1.52								
5				1.66	1.99	2.32	2.65	2.98						
6				2.34	2.81	3.28	3.75	4.22	4.69					
7					3.78	4.41	5.05	5.68	6.31	6.94	7.57			
8						5.72	6.53	7.35	8.16	8.98	9.80	10.61		
9							8.21	9.23	10.26	11.29	12.31	13.34		
10									12.60	13.86	15.12	16.37	17.63	
11									15.17	16.69	18.20	19.72	21.24	
12									17.99	19.78	21.58	23.38	25.18	

$$VTCF = \frac{(0.02345 + 0.17977\ dbh + 0.34456\ dbh^2)\ H}{144}$$

Accurary at the 5% level.
% + or - 3.8.
Based on felled trees from Grand'Mère plantations.

(Reprinted from Popovich 1972*b*).

Table 25. Plantation white spruce (*Picea glauca* (Moench) Voss) Grand'Mère, Quebec. Volume merchantable ft^3, stump height 0.5 ft, top dib 3 inches

dbh class	Total height class 10	15	20	25	30	35	40	45	50	55	60	65	70	75
1														
2														
3														
4			.52	.66	.79	.93								
5				1.32	1.58	1.84	2.11	2.37						
6					2.44	2.85	3.25	3.66						
7						3.98	4.56	5.13	5.69	6.26				
8							6.01	6.77	7.51	8.27	9.03			
9								8.60	9.56	10.52	11.47	12.43		
10									11.83	13.01	14.20	15.37	16.55	
11									14.31	15.75	17.17	18.61	20.04	
12										18.73	20.43	22.14	23.84	

$Vmcf = Vtcf\ (A + B\ x + C\ x^2)$ Honer (1967)

A = +0.9604
B = -0.1660
C = -0.7868
$X = [(\text{top dib}/\text{dbhob})^2 \times (1.0 + (\text{stump Ht}/\text{total Ht})]$

Based on 271 felled trees from Grand'Mère plantations.

(From Popovich 1972*b*).

Budworm defoliation. Canadian Forestry Service photo.

Plantation spraying with mistblower. Canadian Forestry Service photo.

Spruce budworm control with trailer-mounted hydraulic sprayer. Rocky Lake, Man. Canadian Forestry Service photo.

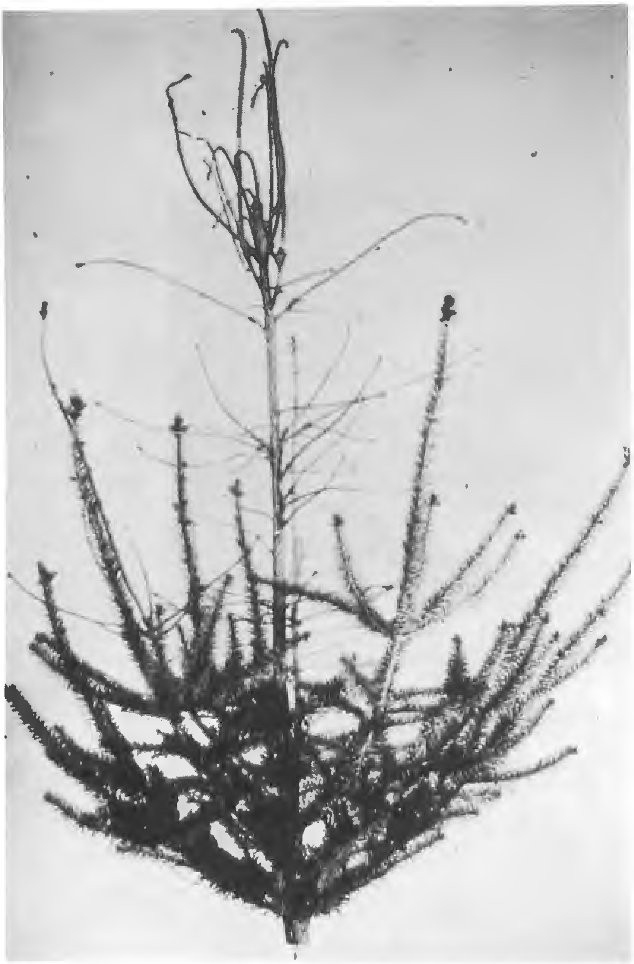
Spruce budworm control by hydraulic spray with foaming adjuvant. Plantation at Grand'Mère, P.Q. Canadian Forestry Service photo.

Backpack mistblower. Canadian Forestry Service photo.

Backpack compressed-air sprayer. Canadian Forestry Service photo.

Piper Pawnee spraying spruce budworm. Sprucewoods Forest Reserve, Man. Canadian Forestry Service photo.

Flagmen for aircraft guidance in spraying operation. Canadian Forestry Service photo.



Weevil damage to spruce. Canadian Forestry Service photo.

Stearman fitted with micronair emission system. Canadian Forestry Service photo.

Damage

The intensification of forest management is inevitably accompanied by a sharper awareness of forest enemies. While these are usually present, even if unheeded, the forester becomes acutely conscious of them when they frustrate his plans and silvicultural practices. Their impact often looms most prominently in plantations, where it is readily perceived and where the costs of stand establishment are best appreciated.

In these circumstances there is often a greater impulse to try to protect plantation values than might be the case for natural stands. The advisability of applying control measures depends on the net cost of the treatment being less than the anticipated net benefits that treatment would ensure. This relationship is often not clear, requiring as it does information on probable extent of damage if control is withheld, likelihood of damage recurring, and efficacy of prescribed treatment -- often disappointing. Cost of replacing a plantation, particularly where trees are dead or badly deformed but still standing, must be considered. For example, very young plantations might be more cheaply replaced than protected, in some instances. Christmas tree plantations are additionally vulnerable to damage which affects appearance. Recurring attacks by any agent may indicate the advisability of a change of species or abandonment of the site.

Of the many agents listed by Sutton (1969) as injurious to white spruce, a limited number have been reported to cause significant damage to plantations. A discussion of the most serious follows.

Insects

Infestations are recognized through the sudden appearance of the insects en masse or signs of their feeding. Detection of large numbers in a prefeeding stage, e.g. as egg-laying adults or the eggs themselves, can be invaluable in anticipating damaging attacks. Immediate recourse to the protection staff of provincial or federal government agencies is recommended, for identification and information on likely degree of damage, and advice on control. In many cases only prompt action will be effective. It is likely that other outbreaks of a particular insect have occurred elsewhere in the region, and treatments (if indicated) can be coordinated to advantage.

Most insect control is accomplished with chemicals, some of which are not available to private citizens and can only be obtained and applied under the aegis of forestry officials; some substances are not produced in small lots suitable for treating limited areas (Chemical Control Research Institute 1975, DeBoo and Campbell 1972*a*).

Spruce budworm has a Canada-wide distribution and is highly destructive of several coniferous species, including white spruce. There is an extensive literature on its biology, population behaviour and control (e.g. Balch 1960, Blais 1968, 1974, Brown 1970, Morris 1963, Prebble and Carolin 1967). The insect is endemic in spruce-fir forests, serious outbreaks in eastern Canada occurring at intervals in mature stands following several years of early summer drought and usually collapsing only when the food supply is reduced, or when weather or natural biological controls supervene. Vulnerable species in associated stands suffer also during outbreaks. In the Prairie Provinces white spruce is commonly attacked in the absence of balsam fir, e.g. Hildahl and DeBoo (1973).

Overwintered larvae emerge in spring to feed on old needles, buds and staminate flowers and then concentrate on the new foliage which may all be consumed in heavy outbreaks. Partially eaten needles turn a red-brown at midsummer, making injured trees very conspicuous.

At the Petawawa Forest Experiment Station, 45-year-old plantation white spruce did not show a measurable loss in diameter growth after two years of heavy budworm attack[21]. Similarly, the first reduction in diameter growth of white spruce in northwestern Ontario generally occurred at the earliest in the second year, and at the

[21] Ibid.

latest in the fourth year of severe defoliation (Blais 1958). However, mortality can be expected after a few years of heavy attack and for white spruce may reach as high as 60% in a persistent infestation, as reported in the Algoma forest area of Ontario (Turner 1952). Control measures should probably be considered after two years of defoliation if the outbreak does not show signs of abating.

Plantations of white spruce are not usually subject to serious budworm attack until ca. 20 ft (6 m) tall, unless located immediately adjacent to an infested taller stand. Treatment of small or isolated plantations up to ca. 60 ft (18 m) can be applied effectively with ground equipment. At present there are three insecticides available to the private individual and registered for budworm control by ground application[24]. **Dimethoate** may be applied by hydraulic sprayer; if the larvae are mainly in the fourth instar, rates of ca. 8.0 to 9.6 oz active ingredient (a.i.) in 100 gal water per ac (0.56 to 0.67 kg in 11.2 hl/ha) for trees under 6 ft (1.8 m) tall, or up to 200 gal per ac (22.4 hl/ha) for large trees, should reduce populations 80 to 100%. Such results were obtained with an even lower dosage of dimethoate, delivered by truck-mounted mistblower at 25 psi (172 kPa), to a 25-year-old white spruce plantation near Shawville, Quebec (DeBoo and Campbell 1972*a*). The recommended application of **carbaryl** for spraying small trees up to 15 ft tall (4.5 m) from the ground is as a wettable powder at 8.5 to 17.0 oz a.i. in 100 to 200 gal water per ac (0.59 to 1.19 kg in 11.2 to 22.4 hl/ha). **Malathion** is registered for domestic use, to be applied at 0.5 oz a.i. per gal (3.1 g/ℓ) as soon as the larvae appear. Unless a thorough drench is made, a second application in five to seven days may be necessary (Chemical Control Research Institute 1975).

Ground application of insecticides is expensive, at least $10/ac ($25/ha) including labour, chemicals and equipment. It should

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[24] The Canadian Forestry Service should always be consulted for the latest information on insecticides, dosages and application techniques, as recommendations may change from year to year.

be emphasized that success of chemical treatments depends on good coverage, population density of the pests and tree condition. If initial larval populations were high, even a large percentage reduction by spray could still leave enough survivors to kill trees weakened by previous attacks. Where initial larval concentrations exceed ca. 20 per 18-in. (46-cm) branch tip, then spraying may have to be repeated in three to seven days.

Aerial spraying is the most economical method of application for large areas. When chemicals are applied, costs are about $4 per ac ($10/ha) for single plantations of less than 500 ac (200 ha), or at least $2.50 to $3 per ac ($6 to $7.40/ha) for amalgamated blocks. The degree of control with treatment from the air is less certain, however, owing partly to greater dependence on favourable weather and partly, perhaps, to protection afforded the larvae by the terminal shoot budcap, which in white spruce is retained for a period after shoot extension. Aerial application is the usual method for outbreaks in forest stands, and will become increasingly important for spruce plantations as their extent and age increase, and as the currently imperfect operational technique is improved. DDT, formerly used with success in budworm control but now generally withdrawn from use because hazardous to other organisms, has been replaced mainly by fenitrothion[25] for aerial spraying. This chemical is only produced in quantity, for large-scale operations, and should be used only after consultation with regional authorities (Chemical Control Research Institute 1975). Application, in one treatment of 4 oz a.i. in 1/2-gal water per ac (0.28 kg in 5.6 ℓ per ha), or two treatments of 2 to 3 oz (0.14 to 0.21 kg/ha) four to six days apart, is recommended. Aerial spraying with carbaryl should be at rates of 8.0 to 16.0 oz per ac (0.56 to 1.12 kg/ha) in a suspension of oil; good results were obtained at the latter rate in scattered stands of the Spruce Woods Provincial

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[25] Other effective chemicals (phosphamidon, mexacarbate, aminocarb, trichlorfon) may not be readily available, if at all, to the small property owner.

Forest and Park, Man. (Hildahl and DeBoo 1973), and in La Mauricie National Park, Que. (Foisy, Benoit and DeBoo 1975). Several other chemicals show promise for aerial application but have yet to be registered. Other substances that may be applied from the air are pathogens which infect the budworm, and should have the advantage of being less harmful than chemicals to non-target organisms. The bacterial insecticide *Bacillus thuringiensis*, B.t., has been most successful to date (Chemical Control Research Institute 1974), treatments costing ca. $5 to $10 per ac ($12 to $25 per ha).

Operating procedures for aerial application of insecticides have much in common with other types of forestry spraying, and some of the principles are dealt with in the sections "Fertilization" and "Broadcast Seeding". Both fixed-wing aircraft and helicopters are used, the latter mainly for smaller jobs or over rugged terrain. The trend for aerial application on small areas seems to be towards increasing the volume of spray mix by dilution, to deliver the same amount of active intredient per unit area, and give better coverage, if with individually weaker droplets. Spray emission systems are usually equipped with rotary atomizers to deliver a finely divided spray. Rigorous precautions should be taken in dealing with toxic spray chemicals, especially in their concentrated state (National Research Council of Canada 1972). Some examples of recent aircraft spray operations and equipment used in treating white spruce plantations, including budworm population sampling, and evaluation of spray patterns and extent of defoliation, are given in Armstrong and Nigam (1975), Howse, Harnden and Sippell (1971, 1972, 1973, 1975), DeBoo and Campbell (1972*a*), Hildahl and DeBoo (1973). Howse *et al.* (1973) deal with the application of viruses, and Chemical Control Research Institute (1974) with B.t.

The **yellow-headed spruce sawfly** is a defoliator which attacks mainly young plantations, shelterbelts, and larger but open-grown trees. It is not a problem in closed stands. This coast-to-coast species is reported yearly as attacking planted white spruce in sporadic outbreaks of varying severity (Forest Insect and Disease

Survey Annual Reports, Canadian Forestry Service). Adult sawflies appear in late spring and lay eggs in slits in the new needles. Larvae feed first on the young foliage, later eating the older needles as well. The first symptom of damage is a yellowing of the upper crown, and later the tree turns a reddish brown. Two to four consecutive years of severe defoliation kill or seriously weaken the tree (Baker 1972, Hildahl and Peterson 1970). Similar species causing like damage to white spruce are the green-headed spruce sawfly and balsam-fir sawfly.

The recommended control of continuing sawfly infestations, according to Hildahl and Peterson (1970), is spraying when the larvae are small with malathion 50% concentrate. This can be applied at 16 fl oz/40 gal water (2.5 ml/ℓ) to tall trees with a high-pressure, 400 psi (2,758 kPa) power sprayer. For knapsack mistblowers, 4 tablespoon/gal water (16 ml/ℓ) is appropriate; and for truck-mounted mistblowers the mixture should be 96 fl oz/40 gal water (15.0 ml/ℓ). Again, aerial spraying may be more economical for large plantation areas, and advice on methods and chemicals should be sought.

The white pine weevil attacks and kills leaders, resulting in crooks or forks where one or more lateral shoots take over, or in multiple stems after repeated infestation, and seriously degrades tree form for lumber purposes (Godwin and Reeks 1967). White pine is the preferred target in central and eastern Canada where other conifers, including white spruce, are occasionally attacked as well. Damage to the spruce is increasingly serious west of Ontario, and what appears to be an ecotype of the species, sometimes called the Engelmann-spruce weevil (Smith and Sugden 1969), has proved to be an important pest in plantations in the British Columbia interior and on natural spruce regeneration in British Columbia and Alberta.

The weevil is a light-loving insect which in white pine concentrates on large-diameter leaders growing in full light, where the adults feed and lay eggs in late spring; larvae feed under the bark, girdling the cambium. Dead and drooping leaders signal infestation. Shade from an overstory often limits the amount of weevil attack in natural stands, but plantations (whether pure or mixed) in the open are very vulnerable. The nature of attack and injury to white spruce seems similar, and the extent of damage can be expected to increase with the scale of planting except where appreciable hardwood cover is present on the site and is allowed to remain, or unless insecticides are applied.

Good protection of white pine leaders can be obtained by spraying them, when the adult weevils become active in late April or early May, with methoxychlor applied with a hydraulic sprayer at 1 to 2 lb a.i. per ac (1.1 to 2.2 kg/ha) in spray volumes of 100 gal/ac (11.2 hl/ha) (DeBoo and Campbell 1972*b*). Aerial application would require more active ingredient, cost at least $5 to $6 per ac ($12 to $15 per ha) and be somewhat less effective owing to the difficulties in obtaining good coverage of the leaders (DeBoo and Campbell 1972*c*, 1974). Useful though methoxychlor appears to be against this weevil, its use is not permitted in British Columbia and no good substitute is yet available.

The black army cutworm[26] has recently become a serious problem in newly established white spruce plantations in British Columbia, defoliating and killing the young seedlings, and has caused similar damage in northern New Brunswick. The moths lay their eggs in the fall, often on dry sites and in new clearings, especially those blackened by fire. The black, white-striped 1/4-in. (6.5-mm) long larvae emerge in spring and feed, during the day, on ground vegetation, until about mid-June. Recently logged and slash-burned areas are suspect, and if the larvae are detected or the sites seem hazardous, planting could be delayed until about the middle of June. Infested plantations can be sprayed with mistblowers, or from aircraft, with 1 to 3 lb a.i./ac (1.1 to 3.4 kg/ha) of trichlorfon at the rate of 20 to 30 oz per 100 gal water (1.25 to 1.88 ml/ℓ).

Somewhat similar behaviour by two other species of cutworm, the variable caterpillar and garden army worm, was reported near

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[26] Information on this insect is from Canadian Forestry Service, Pacific Forest Research Centre Fact Sheet, Feb., 1974.

Chapleau, Ont., where a heavy infestation destroyed 40% of container-planted white spruce (Lindquist 1970). The planting site was a recent burn, and the larvae fed on other plants (their normal food) as well as the spruce. The reason for the large population of cutworms was not clear, but the risk of planting a spring burn was indicated here also.

White grubs, the larvae of the June beetle, feed on roots of seedlings in nurseries and young plantations, causing extensive mortality or sustained growth losses. The following is taken chiefly from Baker (1972), Rudolf (1950), Sutton (1968), and Sutton and Stone (1974). Eggs are laid underground at depths of a few inches, and larvae may remain in the soil for several years. Most damage is caused by second-year larvae. White grubs are occasionally a problem on loams and silt loams, but mainly on light soils, particularly where there is a grassy cover, with old fields the most susceptible sites. Populations persist until crown closure shades out the ground vegetation. Presence of a tap root renders the young tree especially vulnerable, since, if severed, most of the root system is lost; a fibrous root habit offers some protection. Depressed growth, perhaps continuing for many years, appears to be the major harmful consequence of larval root-feeding to young white spruce.

Control is not possible in a plantation once damage is recognized, and the only feasible approaches are avoidance of infested sites or treatment at the time of planting. An effective method practised in eastern Ontario is the placement of 1/2 oz (14 g) 25% a.i. chlordane[27] in each planting hole. Treatment is considered warranted if the grub population is found by preliminary sampling to be greater than 5/yd^2 (6/m^2).

Spruce-gall aphids cause pineapple-shaped galls on twigs, and while not often considered a problem from a growth standpoint, are very disfiguring to Christmas tree crops. An eastern aphid confines itself

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[27] The use of chlordane is now under review by Canada Department of Agriculture.

to spruce species; another (Cooley) gall aphid occurs across Canada and infests Douglas-fir, when present, as an alternate host, but can perpetuate itself on the spruce. Feeding behaviour and type of injury are similar for both species. The eggs are laid on needles in spring, hatch in one or two weeks, and the nymphs feed at the base of the buds or new needles. The galls begin to develop immediately, and eventually enclose the nymphs which continue to grow, and emerge as adults in late summer (Baker 1972, Holms 1968). Recommended treatment for Christmas tree plantations is miscible oil applied at a rate of 2.5 pt/10 gal water (1 ℓ/32 ℓ) with a hydraulic sprayer in spring before the buds swell (Smith and Newell 1969).

Disease

The most damaging diseases affecting spruce plantations are root rots. Generally, avoidance of planting sites known to harbour infected stumps or root material is the best preventive. Pathologists tend to assert that vigorous, thrifty trees are less prone to attack, and to recommend a combination of productive sites and silvicultural treatments to maintain rapid diameter growth as hopefully prophylactic measures. There seems to be no practical treatment of individual trees once infected, although their removal may arrest spread of certain diseases in the rest of the stand.

Stand-opening disease was referred to under "Site Selection" where the danger of seedling infection by diseased root material present in the soil was stressed. The causal fungus, which acts on the roots and lower bole and is eventually fatal, is spread by root-to-root contact, either from living trees or from residual roots in which the inoculum can remain viable for at least 16 years (van Groenewoud and Whitney 1969, Whitney 1962, 1972). In Manitoba and Saskatchewan, root wounds caused by insect girdling (Whitney 1961), and in Quebec strangulation of primary roots, presumably by twisting at planting (Ouellette, Bard and Cauchon 1971), have been reported as common entry points of infection.

Groups of dead or dying trees are characteristic (giving the disease its name), and symptoms include dwarfed and chlorotic needles, reduced terminal growth, and dead lower crown; tan or brown velvety-textured fruiting bodies occur on surface roots, or stem near the root collar (Gross 1970). In natural stands of white spruce in Manitoba and Saskatchewan, van Groenewoud and Whitney (1969) found that up to 70% of the root system might be decayed before the advent of noticeable crown symptoms; all crown classes were affected, and dead trees occurred singly or in groups; factors associated with the presence of the disease were dry, acid (pH 4 to 5) low-nutrient soils, stand densities of 90 to 100 ft^2/ac of basal area (21 to 25 m^2/ha), and intense root competition. On the other hand, in white spruce plantations at Grand'Mère, Quebec, the disease was found on good as well as poor sites (Ouellette, Bard and Cauchon 1971).

van Groenewoud and Whitney (1969) did not consider direct control feasible in infected plantations but recommended early cutting to reduce losses, and early thinning (before age 40) of "susceptible" stands.

Armillaria root rot often kills young conifers, singly or in groups, and commonly in plantations, following invasion of tree roots by the fungus' rhizomorphs which grow freely through soil and can penetrate unwounded bark by mechanical pressure (Patton and Bravo 1967). Reduced terminal and diameter growth and "dieback symptoms", and chlorotic foliage or thin crowns, are characteristic; mycelial fans grow between the bark and the wood, and yellow or brown fruiting bodies occur at the base of dead or dying trees in the fall (Gross 1970). Infection occurs in a variety of situations, the fungus invading dead or moribund root systems as well as those apparently healthy (Whitney, Dorworth and Buchan 1974). It can survive for long periods in dead wood, and hardwood stumps on planting sites are common sources of infection.

Suggested control or preventive measures include the usual alleviation of stress through silvicultural treatments aimed at maintaining vigorous growth; removal of infected stumps; and, in stand conversion, girdling the standing trees a year or two before felling with the object of depleting the supply of carbohydrates available to the fungus in residual roots and stumps (Foster and Baranyay 1971, Huntly, Cafley and Jorgensen 1961).

Cytospora canker is a disease of stems and branches, common in white spruce plantations in eastern Canada, and attaining a high rate of occurrence in some (Jorgensen and Cafley 1961, Ouellette 1967, Ouellette, Conway and Bard 1965). Symptoms include, most prominently, pitch flows from localized sites on stems and branches, but also browning of needles and dying of individual branches (Lavallée 1972). Cankers on the stem may girdle it and kill the tree, but this is not inevitable and quite serious lesions sometimes heal over (Stiell 1970). A predisposing factor may be drought which weakens trees with poorly developed root systems, causing reduced diameter growth and increasing susceptibility to infection; hence, site selection to ensure favourable soil moisture, together with thinning to remove weaker individuals, could be preventives (Jorgensen and Cafley 1961). In cankered stands, removal of diseased trees might reduce the rate of infection.

Fire

Fire can easily travel into a young plantation via grass or other suitable fuel between the young trees, which are very vulnerable to scorch and desiccation by reason of their thin bark and full length green crowns. However, a fire is probably difficult to start in a white spruce plantation once it has closed and shaded out other vegetation, owing to the lack of fuel on the ground to carry it. Fallen spruce needles do not accumulate, as do those of red pine for example, into thick layers of undecomposed material, highly flammable when dry, but break down rapidly and are incorporated into the humus. On the other hand, dead spruce branches remain on the stem down to the ground for years (unlike pine), and would easily carry a going fire into the crown.

Thus, to gain entry to the plantation, a fire would need an edge exposed to the wind, and some means of igniting the crown. After a plantation has been opened by thinning, the presence of slash on the ground and the freer movement of air occasioned by reduced stocking and cutting of skidding trails, would increase the hazard.

Fireguards around the perimeter, kept free of vegetation by discing or spraying with herbicides, would help prevent a fire from entering a plantation, and if provided internally as well, would help contain the spread and give access for suppression. Planning at planting should ensure that roadways are left at intervals.

References to Stand Development

Armstrong, J.A. and P.C. Nigam. 1975. The effectiveness of the aerial application of Orthene® against spruce budworm at Petawawa Forest Experiment Station during 1974. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-82.

Baker, Whiteford L. 1972. Eastern forest insects. U.S. Dep. Agric., For. Serv., Misc. Publ. 1175.

Balch, R.E. 1960. Forest entomology. *In* T. Ewald Maki (ed.) Proc. Spec. Field Inst. For. Biol., July 25 - Aug. 19, 1960. School For., Raleigh, N.C. p. 161-213.

Berry, A.B. 1969. Revised volume tables and taper curves for plantation white spruce. Can. Dep. Fish. For., For. Branch Inf. Rep. PS-X-9.

Blais, J.R. 1958. Effects of defoliation by spruce budworm (*Choristoneura fumiferana* Clem.) on radial growth at breast height of balsam fir (*Abies balsamea* (L.) Mill.) and white spruce (*Picea glauca* (Moench) Voss). For. Chron. 34(1):39-47.

Blais, J.R. 1968. Regional variation in susceptibility of eastern North American forests to budworm attack based on history of outbreaks. For. Chron. 44(3):17-23.

Blais, J.R. 1974. The policy of keeping trees alive via spray operations may hasten the recurrence of spruce budworm outbreaks.

For. Chron. 50(1):19-21.

Brown, C.E. 1970. A cartographic representation of spruce budworm, *Choristoneura fumiferana* (Clem.), infestation in eastern Canada, 1909-1966. Dep. Fish. For., Can. For. Serv. Publ. 1263.

Chemical Control Research Institute. 1974. Evaluation of commercial preparations of *Bacillus thuringiensis* with and without chitinase against spruce budworm. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-59.

Chemical Control Research Institute. 1975. Compendium on pesticides registered for use in Canada against pests of forests, trees and shrubs. Revised ed. - 1975. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-19.

DeBoo, R.F. and L.M. Campbell. 1972*a*. Plantation research: V. Mist-blower applications of dilute insecticide solutions for control of *Choristoneura fumiferana* on white spruce in Quebec, 1972. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-21.

DeBoo, R.F. and L.M. Campbell. 1972*b*. Plantation research: VI. Hydraulic sprayer applications of insecticides for control of white-pine weevil *(Pissodes strobi)* in Ontario, 1972. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-24.

DeBoo, R.F. and L.M. Campbell. 1972*c*. Plantation research: VII. Experimental aerial applications of methoxychlor for control of white-pine weevil *(Pissodes strobi)* in Ontario, 1972. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-25.

DeBoo, R.F. and L.M. Campbell. 1974. Plantation research: X. Experimental aerial applications of methoxychlor and Gardona® for control of white pine weevil *(Pissodes strobi)* in Ontario, 1973. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-68.

Foisy, L., P. Benoit et R.F. DeBoo. 1975. Rapport concernant les opérations de lutte contre la tordeuse des bourgeons de l'épinette dans les secteurs d'aménagement intensif des parcs nationaux

Forillon et La Mauricie, 1975. Parcs Canada, Service de la Conservation des Ressources naturelles, Division du Fonctionnement.

Forest Insect and Disease Survey. Various dates. Annual Reports. Dep. Environ., Can. For. Serv.

Foster, A.T. and J.A. Baranyay. 1971. Armillaria root rot. Dep. Environ., Can. For. Serv., For. Insect Dis. Surv., Pest Leafl. 35.

Froning, K. 1972. An appraisal of recent plantations in forests of the Prairie Provinces. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-31.

Godwin, P.A. and W.A. Reeks. 1967. White-pine weevil *Pissodes strobi* (Peck). *In* A.G. Davidson and R.M. Prentice (eds.) Important Forest Insects and Diseases of Mutual Concern to Canada, the United States and Mexico. Can. Dep. For. Rural Dev. Publ. 1180: 148-151.

Gross, H.L. 1970. Root diseases of forest trees in Ontario. Dep. Fish. For., Can. For. Serv. Inf. Rep. O-X-137.

Heger, L. 1971. Site-index/soil relationships for white spruce in Alberta mixedwoods. Dep. Environ., Can. For. Serv. Inf. Rep. FMR-X-32.

Hildahl, V. and R.F. DeBoo. 1973. Aerial applications of chemical insecticides against the spruce budworm in Manitoba, 1973. Man. Entomol. 7:6-14.

Hildahl, V. and L.O.T. Peterson. 1970. Spruce and balsam fir sawflies in the Prairie Provinces. Dep. Fish. For., Can. For. Serv., Liaison Serv. Note MS-L-10.

Holms, John. 1968. Cooley spruce gall aphid in British Columbia. Can. Dep. For. Rural Dev., For. Branch, For. Insect Dis. Surv., For. Pest Leafl. 6.

Howse, G.M., A.A. Harnden and W.L. Sippell. 1971. The spruce budworm situation in Ontario, 1970. Dep. Fish. For., Can. For. Serv. Inf. Rep. O-X-147.

Howse, G.M., A.A. Harnden and W.L. Sippell. 1972. The 1971 spruce budworm situation in Ontario. Dep. Environ., Can. For. Serv. Inf. Rep. O-X-163.

Howse, G.M., A.A. Harnden and W.L. Sippell. 1973. The 1972 spruce budworm situation in Ontario. Dep. Environ., Can. For. Serv. Inf. Rep. O-X-173.

Howse, G.M., A.A. Harnden and W.L. Sippell. 1975. The 1974 spruce budworm situation in Ontario. Dep. Environ., Can. For. Serv. Inf. Rep. O-X-228.

Howse, G.M., C.J. Sanders, A.A. Harnden, J.C. Cunningham, F.T. Bird, and J.R. McPhee. 1973. Aerial application of viruses against spruce budworm, 1971. Dep. Environ., Can. For. Serv. Inf. Rep. O-X-189.

Huntly, J.H., J.D. Cafley and E. Jorgensen. 1961. Armillaria root rot in Ontario. For. Chron. 37(3):228-232, 234-236.

Jorgensen, E. and J.D. Cafley. 1961. Branch and stem cankers of white and Norway spruces in Ontario. For. Chron. 37(4):394-400, 404.

Kabzems, A. 1971. The growth and yield of well stocked white spruce in the Mixedwood Section in Saskatchewan. Sask. Dep. Nat. Resour., For. Branch Tech. Bull. 5.

Khalil, M.A.K. 1974. Fifteen years growth of Great Lakes-St. Lawrence Region white spruce (*Picea glauca* (Moench) Voss) provenances in Newfoundland. Dep. Environ., Can. For. Serv. Inf. Rep. N-X-120.

Lavallée, André. 1972. Le chancre cytosporéen de l'épinette. Ministère de l'Environnement, Service canadien des Forêts, Feuillet d'Information No. 1.

Lindquist, O.H. 1970. Cutworm damage to summer-planted white spruce tubelings. Bi-mon. Res. Notes 26(6):56.

Love, D.V. and J.R.M. Williams. 1968. The economics of plantation forestry in southern Ontario. Dep. Reg. Econ. Expans., Can. Land Inventory Rep. 5.

MacKinnon, G.E. 1974. Survival and growth of tree plantations on crown lands in Ontario. Ont. Minist. Nat. Resour., Div. For., For. Manage. Branch.

Morris, R.F. (ed.) 1963. The dynamics of epidemic spruce budworm populations. Mem. Entomol. Soc. Can. 31.

National Research Council of Canada. 1972. Handbook on chemical safety in the aerial application of chemical materials. Natl. Res. Counc. Can., Assoc. Comm. Agric. For. Aviat. AFA Tech. Rep. 12.

Ouellette, G.B. 1967. Quelques maladies importantes des plantations de conifères dans le Québec. Phytoprotection 48(2):86-91.

Ouellette, G.B., G. Bard and R. Cauchon. 1971. Self-strangulation of roots: points of entry of root-rot fungi in the Grand'Mère, white spruce plantations. Phytoprotection 52(3):119-124.

Ouellette, G.B., J.M. Conway et G. Bard. 1965. Fréquence et intensité du chancre cytosporéen dans les plantations d'épinette du Québec. For. Chron. 41(4):444-453.

Patton, R.F. and R. Vasquez Bravo. 1967. Armillaria root rot *Armillaria mellea* (Vahl ex Fr.) Kummer. *In* A.G. Davidson and R.M. Prentice (eds.) Important Forest Insects and Diseases of Mutual Concern to Canada, the United States and Mexico. Can. Dep. For. Rural Dev. Publ. 1180:36-38.

Popovich, S. 1972*a*. Total cubic volume table for white spruce plantations Drummondville, Quebec. Dep. Environ., Can. For. Serv. Inf. Rep. Q-X-28.

Popovich, S. 1972*b*. Volume tables for plantation white spruce Grand'Mère, Quebec. Dep. Environ., Can. For. Serv. Inf. Rep. Q-X-29.

Prebble, M.L. and V.M. Carolin. 1967. Spruce budworm *Choristoneura fumiferana* (Clem.). *In* A.G. Davidson and R.M. Prentice (eds.) Important Forest Insects and Diseases of Mutual Concern to Canada, the United States and Mexico. Can. Dep. For. Rural Dev. Publ. 1180:75-80.

Rudolf, Paul O. 1950. Forest plantations in the Lake States. U.S. Dep. Agric., For. Serv., Tech. Bull. 1010.

Safford, L.O. and Susan Bell. 1972. Biomass of fine roots in a white spruce plantation. Can. J. For. Res. 2(3):169-172.

Smith, C.C. and W.R. Newell. 1969. Christmas tree management in the Maritime Provinces. Part 2: Common insects and diseases and their control. Dep. Fish. For., Can. For. Serv. Inf. Rep. M-X-20.

Smith, S.G. and B.A. Sugden. 1969. Host trees and breeding sites of native North American *Pissodes* bark weevils, with a note on synonymy. Ann. Entomol. Soc. Am. 62(1):146-148.

Stiell, W.M. 1955. The Petawawa plantations. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 21.

Stiell, W.M. 1958. Pulpwood plantations in Ontario and Quebec. Can. Pulp Paper Assoc., Woodlands Sect. Index 1770 (F-2).

Stiell, W.M. 1969. Crown development in white spruce plantations. Can. Dep. Fish. For., For. Branch Publ. 1249.

Stiell, W.M. 1970. Thinning 35-year-old white spruce plantations from below: 10-year results. Dep. Fish. For., Can. For. Serv. Publ. 1258.

Stiell, W.M. and A.B. Berry. 1973. Development of unthinned white spruce plantations to age 50 at Petawawa Forest Experiment Station. Dep. Environ., Can. For. Serv. Publ. 1317.

Sutton, R.F. 1968. Ecology of young white spruce (*Picea glauca* (Moench) Voss). Thesis, Cornell Univ. 500 p.

Sutton, R.F. 1969. Silvics of white spruce (*Picea glauca* (Moench) Voss). Can. Dep. Fish. For., For. Branch Publ. 1250.

Sutton, R.F. and E.L. Stone Jr. 1974. White grubs: a description for foresters, and an evaluation of their silvicultural significance.

Dep. Environ., Can. For. Serv. Inf. Rep. O-X-212.

Turner, K.B. 1952. The relation of mortality of balsam fir, *Abies balsamea* (L.) Mill., caused by the spruce budworm, *Choristoneura fumiferana* (Clem.), to forest composition in the Algoma forest of Ontario. Can. Dep. Agric. and Ont. Dep. Lands For. Publ. 875.

van Groenewoud, H. and R.D. Whitney. 1969. White spruce mortality in Saskatchewan and Manitoba. Pulp Pap. Mag. Can. 70(7):101-103.

Wagg, J.W. Bruce. 1967. Origin and development of white spruce root-forms. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1192.

Whitney, R.D. 1961. Root wounds and associated root rots of white spruce. For. Chron. 37(4):401-411.

Whitney, R.D. 1962. Studies in forest pathology. XXIV. *Polyporus tomentosus* Fr. as a major factor in stand-opening disease of white spruce. Can. J. Bot 40(12):1631-1658.

Whitney, R.D. 1972. Root rot in white spruce planted in areas formerly heavily attacked by *Polyporus tomentosus* in Saskatchewan. Bi-mon. Res. Notes 28(4):24.

Whitney, R.D., E.B. Dorworth and P.E. Buchan. 1974. Root rot fungi in four Ontario conifers. Dep. Environ., Can. For. Serv. Inf. Rep. O-X-211.

Wilde, S.A., J.G. Iyer, Christian Tanzer, W.L. Trautmann and K.G. Watterson. 1965. Growth of Wisconsin coniferous plantations in relation to soils. Univ. Wis. Res. Bull. 262.

Skidding tree-lengths in white spruce plantation row-thinning. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

VII. STAND TENDING

Release Treatments

Release as used here means the removal of any other vegetation impeding the growth of the planted spruce. Need for such treatment could often be lessened or obviated by adequate site preparation, usually a simpler, cheaper operation (e.g. Haig and Curtis 1974).

Competition Effects

Other species in a plantation divert soil moisture and nutrients from the planted trees and, if of equal or greater stature, withhold some light from them (Sutton 1969). The degree to which growth of the spruce will suffer depends on the density and relative size of competitors.

A light or moderate ground cover, e.g. of meadow plants such as goldenrod, is considered to give protection from exposure. On the other hand dense low vegetation, particularly grasses, offers severe competition to newly planted seedlings, and can have a lasting effect on their development. In Wisconsin red pine plantations, Wilde (1970) estimated that sufficient quantities of water were consumed by evapotranspiration from a heavy cover of heath plants, up until the time that crown closure shaded them out, to cause a loss of 16 cords per ac (ca. 95 m^3/ha) in a 40-year rotation; presumably white spruce would suffer at least some reduction in yield under like circumstances. However, the spruce can respond vigorously to weed control, particularly on less fertile soils (Sutton 1968, 1969, 1975).

Lateral crown competition from other conifers, brush, or hardwood sprouts of similar size inevitably curtails diameter growth, and a closed overhead canopy will limit height growth as well (e.g., Vincent 1954). A considerable component of the spruce plantation is often able to survive and eventually outgrow competitors, but at the expense of excessive mortality, delay in the time taken to reach merchantable sizes, and a prolonged rotation.

Besides growth losses occasioned by the diversion of site resources to undesirable species, mechanical damage is incurred in some circumstances. Common examples are crushing and smothering of seedlings in winter by the collapse of tall grasses and perennials, and leader breakage and stem deformation from whipping by codominant hardwoods.

White there is much experimental evidence of adverse effects from competing vegetation, and release is applied routinely in some quarters (e.g., Grinnell 1968), the seriousness of a given situation may be difficult to judge and frequently is not appreciated. Rather, the acknowledged persistence of white spruce is commonly counted on to produce an adequate stand in the long run, without the expense of release.

Ground Cover

In western Canada, concern for excessive competition to young white spruce by reed-grasses and fireweed has been expressed if not acted upon. In central and eastern Canada spruce planted on old fields are sometimes freed from dense grass, particularly in Christmas tree plantations where rapid early growth and maintenance of foliage on lower branches is important.

On level sites, with suitable surface conditions and regularly spaced trees, mechanical cultivation may be feasible for ridding the plantation of low vegetation, although there will be difficulties in removing grass from close to the seedlings. Sutton (1969) recommended subsequent treatment with the herbicide simazine, applied at 2 to 4 lb active ingredient (a.i.) in 30 to 100 gal water per ac (2.2 to 4.5 kg in 3.4 to 11.2 hl/ha) for grass and weed control, (the spruce foliage need not be protected from the spray). A post-planting chemical treatment prescribed for New Brunswick Christmas-tree plantations[28] involves a mixture of 1/2 pt (0.28 ℓ)

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[28] Chemical weed control: post-planting treatments (cont'd next page)

Gramoxone and 1/2 lb (0.23 kg) simazine 50W, in 7 gal (31.8 ℓ) water per 1000 trees, applied in spring with a knapsack or compressed air hand sprayer at ca. 25 psi (172 kPa), in 2-ft (0.6-m) squares around each seedling which itself must not be sprayed; 3/4 lb (0.34 kg) Amizine in 8 gal (36.4 ℓ) water can be used in the same way. Alternatively, stronger concentrations of these chemicals can be applied with a field sprayer in 2-ft-wide (0.6-m) strips along the seedling rows.

The most promising chemical for controlling bracken fern in young plantations appears to be asulam, formulated as a water-soluble salt. In the United Kingdom, recommended dosages were 2.0 to 4.0 kg acid equivalent/ha (1.8 to 3.6 lb/ac) in water at spray volumes of 90 to 700 ℓ/ha (8 to 62 gal/ac), applied after the fronds have fully expanded and before they show signs of senescence (Brown 1975). Results are not visible until the following year, but control is often long term because of the effects on the regenerative capacity of the rhizomes. The spruce species tested (Norway and Sitka) showed good tolerance of the chemical, and in any case the bracken canopy prevents most of the spray from reaching the seedlings.

Brush

Hardwood brush or saplings of similar or greater size than the planted trees cannot feasibly be controlled by machines, nor economically by hand tools, although manual methods are sometimes resorted to for make-work projects. Hardwood species can be foliage-sprayed during the period of full leaf expansion with emulsifiable 2,4-D or 2,4,5-T (effective against more species), and Sutton (1969) reported high-volume sprays of 2 to 4 lb acid equivalent in 50 to 150 gal water per ac (2.2 to 4.5 kg in 5.6 to 16.8 hl/ha) as giving most consistent results. A 1:1 mixture of the two chemicals

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28 (cont'd) using Paraquat-Simazine 50W mixture. Chemical weed control: post-planting treatments using Amizine. Forest Extension Service, P.O. Box 518, Fredericton, N.B.

("brush killer") at 76.8 oz in 100 gal per ac (5.4 kg in 11.2 hl/ha) applied in August when conifer foliage has hardened off, has been recommended in New Brunswick[29]. The end of the second season after planting is considered a suitable time for spraying hardwood sprouts on cutover sites, both for Crown land forests in Ontario and by J.D. Irving Co. in New Brunswick where a single such treatment is considered sufficient.

Foliage spraying by ground application may be feasible for woody vegetation up to 7 ft (2.1 m) tall at most; available equipment includes tractor-mounted hydraulic sprayers and mistblowers and a variety of portable back pumps and power packs. For taller brush, or large tracts, aerial release is most economical. In the Clay Belt of northern Ontario, Spruce Falls Power & Paper Co. have systematically released spruce, planted on recent cutovers, from mountain maple, hazel, alder, willow, white birch and poplar, by contract aerial spraying with iso-octyl ester of 2,4,5-T at per ac rates of 1 1/2 lb acid equivalent in 3 1/3 gal water (1.7 kg in 37.4 ℓ per ha), and costs of $4 to $5 (ca. $10 to $12 per ha) (Armstrong 1963, 1968).

Small conifers (not often a problem in plantation release work) may be cut by axe if up to ca. 1 in. (2.5 cm) in diameter, or if larger by circular brushsaw, provided there is room to manoeuvre. Insertion of cacodylic acid into cuts with a hatchet injector delivering 1.5 ml (0.05 fl oz) per cut is efficacious in treating eastern conifer species 2 to 4 in. (5.1 to 10.2 cm) dbh with two cuts, or 5 in. (12.7 cm) dbh with three cuts; this method takes about three man-hours to kill 500 trees per ac (7.4 man-hours for 1240 trees/ha) (Brown 1970). A simpler approach is to squirt the chemical from plastic squeeze bottles into an axe cut, although dosage is not so precise.

Responses of numerous central and eastern Canadian species to

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[29] Chemical weed control: brush and weed trees using brush killer 76 L.V. Forest Extension Service, P.O. Box 518, Fredericton, N.B.

various chemical treatments are detailed in Ontario Herbicide Committee (1974).

Overstory

Trials in the Prairie Provinces have shown that even partial removal of overstory aspen has resulted in greatly increased diameter and height growth of the released white spruce, with volume production in some cases almost doubled over 20 years (Lees 1966, Steneker 1963). In some circumstances merchantable-sized hardwoods can be harvested at a profit (Ross 1969, Steneker 1967). Otherwise, closed-canopy hardwoods should be sprayed from the air. Pratt (1966) described one such trial in Manitoba where trembling aspen, balsam poplar and white birch were treated with 5 gal aqueous solution containing 48 oz acid equivalent of 2,4-D per ac, (56.2 ℓ with 3.4 kg/ha), from a Super Piper Cub with 80-gal (3.64-hl) spray capacity. About 75% of the hardwoods were "severely top killed". Cost was ca. $6 per ac for 280 ac ($15/ha for 113 ha), but it was thought possible to lower this to $3 per ac ($7.50/ha) for larger areas. In Nova Scotia, 3 lb per ac phenoxyacetic herbicide in a 6-gal water and oil carrier (3.4 kg in 67.4 ℓ/ha) proved the most effective mixture, removing up to 80% of hardwoods at a cost applied of $12 per ac ($30/ha); stands treated with lesser amounts had to be resprayed (Ross 1969).

Scattered large wolf trees are best treated singly. One comparison of methods for dealing with 50 jack pine per ac, averaging 4 in. dbh (125/ha, 10.2 cm) showed $1.52 per ac ($3.76/ha) total cost for hatchet injection with cacodylic acid; $2.40 ($5.93/ha) for chainsaw girdling; $3.90 ($9.64/ha) for axe-girdling; and $13.78 ($34.05) for chainsaw felling and bucking, and piling (DeBoo, Teskey and Copeman 1971). Very much larger wolf trees would be more likely to cause problems in spruce plantations, but could also be treated with cacodylic acid, with dosage proportional to dbh, or by chainsaw girdling.

Moderate cover of meadow plants, tolerated by planted white spruce. Chalk River, Ont. Canadian Forestry Service photo.

Dense competition, from trembling aspen suckers, to white spruce planted on cutover. Montreal Lake, Sask. Canadian Forestry Service photo.

Felling white spruce in plantation row-thinning. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

Limbing white spruce in plantation row-thinning. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

Decking tree-length white spruce thinnings. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

Melrose Bobcat feller buncher, with Morbark shear, row-thinning red pine plantation. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

Crop trees (white-banded) pruned to 17 ft (5.2 m) in crown-thinned white spruce plantation. Petawawa Forest Experiment Station. Canadian Forestry Service photo.

45-year-old white spruce planted on nutrient-deficient soils. Ca. 25 ft (7.6 m) tall. Grand'Mère, P.Q. Canadian Forestry Service photo.

Codominant Stand

This condition refers to a stand where planted trees and competitors alike are of merchantable size and approximately the same height class. Such a situation would indicate a long period of *laissez faire*, yet response from release might still be expected. Benefits of competition removal by girdling the hardwoods in natural mixedwood stands aged 41 and 56 years were demonstrated in northern Ontario by markedly greater merchantable volume growth by the residual spruce on the treated plots (Armstrong 1963). Age of white spruce may limit its ability to increase growth after treatment. Steneker (1974), reporting on a study of release cutting in Saskatchewan white spruce-aspen stands where the spruce occupied a subdominant to codominant position, concluded that white spruce in the 70- to 80-year range was too old to respond significantly to release. On the other hand, in mixed conifer stands in Maine, even 70- to 75-year white spruce showed significant diameter-growth response if competitors were removed on three or four sides (Frank 1973). The different behaviour by the spruce in this instance may be a result of the greater release afforded by removal of coniferous, as opposed to hardwood, lateral competition, some evidence for which was found in the Saskatchewan study.

In a plantation, physical removal of competitors in conjunction with a thinning would seem the most feasible approach in circumstances where all material was saleable. Otherwise aerial spraying (for large numbers of hardwoods), or chemical injection (for competing conifers and scattered hardwoods) would be appropriate.

Thinning

Thinning is here defined as the deliberate reduction of the number of planted trees.

Pre-Commercial Thinning (P-C T)

This treatment, also called "spacing" and "cleaning" in Canada, does not produce merchantable material, but is applied in heavily overstocked young stands to reduce the level of mutual competition, hasten the attainment of commercial size and shorten the rotation. In several provinces where natural regeneration of various species is over-dense, these benefits are considered worth the immediate costs incurred (Ainscough 1968, Bella 1966, 1972, Robertson 1971). Heavily stocked young natural stands 2,500 to 40,000 stems per ac (6,200 to 99,000/ha), 6 to 12 ft (1.8 to 3.7 m) tall in Nova Scotia exemplify situations where stocking reduction of white spruce to ca. 681 trees per ac, 8 x 8 ft (1,683/ha, 2.4 x 2.4 m) is considered not only justified but necessary (Axelsson and Routledge 1970).

Insofar as artificially created stands are concerned, only those established by direct seeding could possibly be dense enough to require P-C T. This does not appear to have occurred yet in seeded white spruce. When needed, various techniques will be available.

Hatchet-cut injection with cacodylic acid is one possibility for trees up to ca. 2 in. (5.1 cm) dbh (Brown 1970). Trials in densely seeded Ontario jack pine indicated that P-C T in stands 6 ft (1.8 m) tall, 1-in. (2.5-cm) dbh and ca. 5,000 trees per ac (12,000/ha), to 6 x 6 ft (1.8 x 1.8 m) with circular brush saws cost ca. $16 per ac ($40/ha), which was much less than chainsaw, hatchet injection, or axe treatments of older stands, 23 to 33 ft (7 to 10 m) tall, and 3 in. (7.6 cm) dbh, and was expected to provide the best benefit/cost ratio as a result of reduced costs of harvesting at age 60 years (Riley 1973). Much denser spruce-fir stands in eastern Nova Scotia, averaging 10,000 stems per ac (25,000/ha), cost $43 per ac ($106/ha) to space out to 8 x 8 ft (2.4 x 2.4 m) by manual methods (Axelsson and Routledge 1970). Trees must be cut below the level of live crowns, otherwise stump branches will turn upwards and develop into new stems.

Large-scale operations should benefit from mechanization, and would involve strip thinning with or without manual treatment of the residual strips. Drum choppers, towed on gentle slopes and stone-free soils, have performed successfully in this way in Alberta lodgepole pine and Manitoba jack pine at costs of $6 per ac ($15/ha) and less (Bella 1972, Bella and DeFranceschi 1971). In central and eastern

Canada, tests have been made on a variety of self-propelled and skidder-mounted rotary and flail mowers, some of which show promise for treating stands on sites free of rocks and high, sound stumps and with slopes less than ca. 15 degrees (Dunfield 1974). Riley (1974) cited an Ontario P-C T trial with herbicides applied from the air to jack pine not readily accessible in other ways. The chemical, picloram, delivered by helicopter in 7-ft (2.1-m) swaths, was reasonably effective at rates of 2 gal per ac (22.5 ℓ/ha), and it was thought that the cost of $23 to $28 per ac ($57 to $69/ha) could be considerably reduced.

Commercial Thinning

Thinnings are made in merchantable stands to yield an immediate financial return and concentrate growth on the best remaining stems; while growth rate per tree is accelerated owing to additional light and space available to the crown, total production per acre is not normally altered (unless lowered by drastic overcutting). However, greater yields can be recovered through thinnings by forestalling mortality which would otherwise take place from natural suppression. Thinnings can provide an interim wood supply from plantations grown solely for pulpwood production, but have greater application where sawlogs will be the ultimate crop and there is a premium on the early development of large sizes.

Most thinning experience with white spruce plantations has been obtained from stands first treated between ages 30 and 40 years, where appreciable numbers of trees have reached merchantable size. However available information is meagre, owing to the scarcity of older, treated plantations.

The principal considerations in thinning are the marking system which determines the type of tree to be cut; and the intensity which controls the volume of material removed and the stocking of the residual stand, which in turn influences diameter growth rate of the individual trees. These are considered together in the following.

Row thinning removes entire rows of trees at regular intervals throughout the plantation. It is the least expensive method, entailing a minimum of marking, easy felling and extraction, with least damage to the stand when skidding with machines, and provides permanent access routes. Row thinning removes trees as they come and does not alter the diameter distribution or quality of the remaining stand. It does not offer a wide choice of residual stocking levels from wide initial spacings, and might leave too few well-formed potential crop trees. Trials with various species, including white spruce, indicate that per-acre growth response following row thinning does not differ from that following thinning to similar stand densities by other methods (Little and Mohr 1963, Spurr 1948, Wambach 1969, Williston 1967). In red pine, release has been observed even in the second row away from the one removed (Day and Rudolph 1966). Exclusive whole-row removal is usually confined to the first thinning operation.

High-site 35-year-old white spruce plantations, average dbh 5.7 in. (14.5 cm), dominant height 57 ft (17.4 m), growing at ca. 6 x 6 ft (1.8 x 1.8 m) at the Petawawa Forest Experiment Station, Chalk River, Ont., were thinned by removing every second or every third row[28]. Most material was pulpwood, but since diameters ranged up to 11 in. (27.9 cm) some sawlogs were included. In the following four years best per-acre growth was made where every second row was cut, yielding 19 cords per ac (ca. 120 m^3/ha), leaving a residual basal area of 109 to 120 ft^2 per ac (25.0 to 27.6 m^2/ha). Untreated plots made no net growth in basal area owing to heavy natural mortality.

Similar experimental thinnings were made on the Hiawatha National Forest, Michigan, in 30-year-old white spruce spaced at ca. 6 x 6 ft (1.8 x 1.8 m), with average dbh 5.5 in. (14.0 cm) and average height of dominants 40 ft (12.2 m). Treatments included removal of every second and every third row, respectively yielding 18 and 13 cords per ac (ca. 101 and 73 m^3/ha), and leaving basal areas of 87 and 131

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[28] Stiell, W.M. 1970. Row thinning white spruce plantations at the Petawawa Forest Experiment Station. Establishment Report, Project P-266. Dep. Fish. For., Can. For. Serv. Intern. Rep. PS-19.

ft^2 per ac (20.0 and 30.1 m^2/ha) (Day and Rudolph 1970). On the Larose Forest, eastern Ontario, initial thinnings are made in planted white spruce at ca. 30 to 35 years when every second row is cut, producing 10 to 15 cords per ac (ca. 63 to 94 m^3/ha).

Other marking systems are selective. In the first thinning operation they are often augmented by removal of some entire rows to facilitate extraction. **Thinning from below**, or low thinning, removes the smaller trees in the stand, and as these have been providing the least competition, diameter growth of larger residuals is not greatly stimulated unless the cut is very heavy. However the average diameter is automatically raised by this type of thinning, and because damaged or poorly formed individuals are usually taken as well, average quality is improved. A low-thinning experiment, started in 33-year-old white spruce, dominant height 42 ft (12.8 m), planted at 5 x 5 and 7 x 7 ft (1.5 x 1.5 and 2.1 x 2.1 m) at the Petawawa Forest Experiment Station, indicated that thinnings to basal areas in the range 100 to 140 ft^2 per ac (23.0 and 32.1 m^2/ha) could be made without reducing volume growth per acre over the next decade, and the operation would yield 3 to 8 cords (ca. 19 to 50 m^3/ha), mostly pulpwood, depending on the intensity of the cut. Volume growth was reduced where the residual basal area was 80 ft^2 per ac (18.4 m^2/ha). A second thinning to the same basal area levels made 10 years later removed ca. 9 cords per ac (57 m^3/ha) -- considerably less than growth made during the period (Stiell 1970*a*).

The Michigan study, referred to previously, included treatments which combined row and selective thinning. Those removing every second row and reducing the remaining stand to 300 or 400 stems per ac (740 or 990/ha), or removing every third row and reducing to 300 stems per ac (741/ha), gave stumpage returns which exceeded the accumulated costs of establishing and carrying the plantations to age 30 years, at 4%; it was anticipated that the residual basal areas of 64 to 77 ft^2 per ac (14.7 to 17.7 m^2/ha) would be adequate for future growth (Day and Rudolph 1970) -- although the Petawawa experience just mentioned suggests that this would be less than maximum growth.

Crown thinning is made amongst the dominants and codominants with the object of favouring selected crop trees. Because of the large size of the thinned trees this system is economically more attractive. All residual stems adjacent to those removed receive some release, but average stand diameter is slightly lowered. In an experiment at the Petawawa Forest Experiment Station with 31-year-old white spruce growing at 6 x 6 ft (1.8 x 1.8 m), with dominant height 42 ft (12.8 m), 150 crop trees per ac (370/ha) were released by removing active competitors in the upper crown classes. From interim results it was concluded that thinning to a basal area of 110 ft^2 per ac (25.3 m^2/ha) by this system would produce about 7 cords per ac (44 m^3/ha) and give the best combination of growth per tree (2 in. (5.1 cm) in diameter for crop trees) and per unit area (20 cords per ac - 126 m^3/ha) over the next ten years. A second thinning at the end of that period to 110 ft^2 per ac (25.3 m^2/ha) yielded ca. 13 cords (82 m^3/ha) (Berry 1974).

On the Larose Forest, Ontario, white spruce plantations have been thinned at ages 35 to 38 years by cutting out every sixth row and thinning in the intervening rows to remove about 6 cords per ac (38 m^3/ha) (MacArthur 1967). (It is assumed that this was a crown thinning, since crop trees were high-pruned).

Thinning procedures are complicated by the density of plantations, caused in part by the long live crowns and persistent dead branches below them characteristic of white spruce, and also by the close spacings, 5 x 5 and 6 x 6 ft (1.5 x 1.5 and 1.8 x 1.8 m), at which most plantations thinned hitherto were established. At the Petawawa Forest Experiment Station difficulties were only experienced in selective felling at spacings closer than 7 x 7 ft (2.1 x 2.1 m). It appears that for stands denser than ca. 800 trees per ac (2,000/ha) and 40 ft (12.2 m) tall, thinning will only be feasible with some row removal and/or cutting of crosswise skidding trails in the early operations.

In low-thinning white spruce plantations at Grand'Mère, P.Q., crews of Consolidated-Bathurst Corp. cut roads 60 ft (18 m) apart, bucked wood at the stump to 4-ft (1.2-m) lengths and hauled it out with Bombardier tracked vehicles. At Larose Forest also, thinnings were stump-bucked, and horses, farm tractors and small crawlers used to skid the pulpwood and logs to roadside -- a maximum distance of 500 ft (150 m) (MacArthur 1967). In the Petawawa row-thinning experiment, trees were felled in sequence along the row, limbed and topped, and extracted from the plantation by wheeled skidder for bucking at the landing.

A novel approach to selectively cutting previously thinned (Norway) spruce in New York State, which halved normal felling and bucking time, was described by Cook (1971): a marked tree is cut through by chainsaw at a height of 4 ft (1.2 m), the severed tree dropping vertically, but remaining upright; the stump is next cut flush with the ground; the lower section of the standing stem is limbed, and another 4-ft (1.2-m) stick cut off etc. until no merchantable length remains.

Mechanization will obviously be desirable for large-scale operations, and the technicalities involved have been discussed at length, e.g. by Adamovich (1968) and Myhrman (1973). An important biological consideration is that decay in residual trees, resulting from wounds to surface roots and lower stems caused by logging, is a definite risk with spruce species (Pawsey and Gladman 1965). Equipment will therefore have to be small, e.g. 5 ft (1.5 m) narrower than the extraction route, according to Nilsson and Hippel (1968). Row thinning, where the initial spacing was not too close, should be less conducive to this type of injury in that machines are not obliged to turn and manoeuvre within the stand. An investigation of shortwood, long-log and whole-tree row-thinning systems in Florida slash pine plantations, which related productivity to stocking level, average dbh, log length and number of bolts (Anderson and Granskog 1974), is an example of the type of study required to estimate costs for thinning under specific stand conditions.

In Canada, the Timberjack RW-30, a wheeled tree-length harvester capable of removing a row of trees directly ahead, and of reaching into rows to the side for selective cutting, and the Melrose M-174 feller buncher, are two machines which have been used in thinning trials in pine plantations (Dunfield 1975). Yarding out the felled material might be less damaging in plantations still too dense after row thinning to allow easy machine access. This approach, using a small tractor-mounted steel tower, has been tested for thinning second-growth stands on the British Columbia Coast (Anon. 1974).

Pruning

Objectives

Forest tree pruning cuts off branches flush with the stem. Its objective is to allow the formation of knot-free wood from which high quality lumber or veneer can be produced. No plantation of white spruce would be retained long enough for natural processes of branch mortality and decay to accomplish this end. Dead branches of white spruce are durable and have even been found persisting in a partially sound condition at the base of 34-year-old trees planted at 4 x 4 ft (1.2 x 1.2 m) (Stiell 1955).

Although a major lumber species, white spruce has traditionally been confined to construction grades, owing to its naturally knotty character, and to date pruning experience with this species has been largely experimental. The possibility of upgrading the final crop trees in plantations managed for sawlog production should be considered, however, despite certain acknowledged difficulties. One study with young white spruce concluded that pruning would be profitable, considering costs, carrying charges, and probable premium to be paid for the resulting clear lumber, provided of course that premium could be passed on to the plantation owner or operator; this might entail introduction of log grading in some provinces, direct interest in a sawmill or at the least some log-buyer education (Berry 1964).

Crown Characteristics

White spruce is not an easy tree to prune, compared, for example, to the eastern species most commonly so-treated. In a trial of pruning plantation red pine and white spruce, 4 to 7 in. (10.2 to

17.8 cm) dbh, to a height of 17 ft (5.2 m) with a polesaw, the spruce required an average of 9.9 minutes per tree, the pine 4.2 minutes; production rates per hour, including walking time, were four spruce versus eight pine. The difference was due to the much more numerous branches of the spruce, including many small ones between annual whorls (Berry 1964). It may also take twice as long to prune white spruce as white pine, owing to the former's thicker, "larger", and harder branches, according to Baldwin (1952)[29].

White spruce may develop excessive numbers of adventitious shoots (epicormics) on boles abruptly exposed by pruning green branches or by thinning, necessitating moderation in these treatments if the pruning effort is not to be nullified (Berry and Innes 1967).

Methods

The pruning operation should not leave a projecting stub, which would of course delay the time until knot-free wood is produced, but care should be taken to avoid wounding the thin bark of the spruce.

Pruning the first 17 ft (5.2 m) of stem to produce one clear 16-ft (4.9-m) log-length is usual eastern Canadian practice when plantation pines are pruned. If only dead branches are removed, no growth loss results, and even one or two live whorls at the base of the crown, which contribute little to the tree in closed stands, can be sacrificed without adverse effects. Pruning can be accomplished in stages, say the first 7 ft (2.1 m) as soon as branches in that section have died, 7 to 12 ft (2.1 to 3.7 m) some years later, and finally up to 17 ft (5.2 m), an approach which will result in the smallest knotty core (Ralston and Lemien 1956). In the long run, however, it is probably more economical to select trees for pruning at the time of the first thinning when heights will be 35 to 40 ft (10.7 to 12.2 m) and

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[29] Baldwin considered spruce crowns so dense and impenetrable that pruning to a height of 6 ft (1.8 m) would be justified simply to facilitate access for thinning operations.

approximately the lower half of the crown will be dead, permitting pruning to 17 ft (5.2 m) in one operation.

It is presumed that only a relatively small part of the stand would be pruned, probably from 100 to 200 of the best trees per ac (250 to 500/ha), to be retained until the final harvest. Thinning would be such as to promote their rapid diameter growth, reducing the time for carrying the pruning investment, and maximizing the volume of clear wood. In a crown-thinning experiment in 31-year-old planted white spruce at the Petawawa Forest Experiment Station, 150 selected crop trees per ac (370/ha) were pruned to 17 ft (5.2 m), removing mostly dead branches but an average of 13% of the live-crown length as well. Thinning removed large competitors next to the crop trees. In the next ten years occlusion of the branch stubs was rapid, particularly with heavier thinning treatment. However, up to 55% of crop trees developed epicormics, also with greater numbers associated with heavier thinning. These were removed quite easily, and did not reoccur then or within a year after a second thinning (Berry 1974, Berry and Innes 1967), but the additional operation certainly added to the pruning investment.

Equipment

The conventional pruning tool is a curved sawblade mounted on a handle of variable length. A convenient approach is to equip members of a crew with different-sized saw-handles and make each responsible for pruning a particular stem section. That above 12 ft (3.7 m) is hardest to prune, owing to the difficulty of manoeuvring the long polesaw and to the thicker branches occurring at that height. A handsaw and ladder for this section may make a more careful job possible.

What appears to be a very efficient saw has been reported from Germany (Sterzik and Heil 1969). This has two narrow triangular blades fixed together at a 10^{o} angle to form a V with the teeth in the inner edges. One arm of the V is longer than the other and has a handle attached to it. The blade is hooked over the branch, and in effect, saws two opposite sides of it at once. Rapid pruning and less operator fatigue were claimed.

Mechanization of forest tree pruning has not been wholly successful. The most promising machine seems to be a self-propelled climbing device from Switzerland, which prunes with a small chainsaw while ascending the bole at about 11.5 ft (3.5 m) per minute (Fazio 1968, Sutton 1971). This type of machine, according to Smith (1971), would be desirable for pruning spruce with its numerous small branches between the main whorls.

Fertilization

Objectives

Fertilization is carried out to improve the nutrient status of planted trees, and can thereby increase their performance in terms of:

(1) **flowering**, for better seed yields (*see* section "Seed Production Areas")

(2) **foliage production** and **colour**, for Christmas tree crops

(3) **growth rate**,

- (a) to stimulate young trees in a stagnated condition, or prevent their stagnation
- (b) in closed stands,
  - (i) to increase yields, shorten rotations and enlarge allowable cuts
  - (ii) to reduce costs, per unit of volume, of mechanized harvesting and transportation.

Background

Fertilization in effect improves site productivity and hence increases the amount of wood produced in a given time. Enough is known in general about stand fertilization to ensure a growth response in some Canadian forest situations, but the many uncertainties concerning the magnitude of the response to particular rates of application, and the economics involved, allow few specific and quantitative recommendations to be made for treatment, let alone predictions of cost/benefit ratios. A decision to undertake a program of fertilization should only be made after consultation with specialists in forest soils and/or tree nutrition.

While much research in forest fertilization has been conducted in Canada (Rennie (1974) alluded to 11 field trials with white spruce alone) and some concrete results obtained, there appears to be only one ongoing operational program, and that is not with spruce species (Crown 1974). Pending further information from current trials, it is worthwhile examining experience gained elsewhere but with similar climate, soils and tree species for additional clues as to what fertilizing white spruce might achieve.

Benefits, Needs

There are two general conditions where fertilization could benefit growth (Hagner 1971). The first is where one or more nutrients essential to normal growth are in short supply in the soil. This is typified by old fields impoverished by years of cropping without attempts to maintain fertility. Conifers planted on such sites are stunted and unable to produce a merchantable stand unless fertilized with the element in question. An example of these soil conditions is the approximate 600,000 ac (243,000 ha) of abandoned farmland north of the St-Lawrence River, between Montreal and Quebec, where potassium deficiencies have been demonstrated (Lafond 1958, Gagnon 1973). Fertilization is mandatory under these circumstances if plantations are to succeed.

By contrast, the second condition is one where tree growth appears reasonable, yet addition of (principally) nitrogen fertilizer will improve it. This response has been found so widely with conifers in northern temperate forests (Gessel 1968, Hagner 1967, Krause 1973) that it seems likely the majority of upland sites in Canada could be made more productive in this way. Exceptions might be high quality hardwood sites in southern Ontario or first class agricultural soils, but neither of these are likely to be planted to white spruce. This type of fertilization can only be profitable where the wood supply is insufficient, or is located excessively far from the mill. Each individual situation should be considered on its merits to determine if the dollar value of increased growth per acre per year can justify the expense of fertilization (Swan 1965*a*). Tucker (1974) gave an example of one such analysis, but the necessary inputs for these calculations are in most instances incomplete.

Diagnosis

The first step in corrective fertilization is to determine the nature of the deficiency. While simple tests to determine nutrient status of the soil in relation to the crop seem to be lacking (Rennie 1972, White 1968), various approaches to the problem are used, often in combination. Morrison (1974) has made a detailed review of the literature on this subject, including numerous references to work with Canadian tree species.

The condition or nature of vegetation present on the planting site may reflect deficiencies. Sparse or stunted ground cover, for example, indicates some unsatisfactory condition. Impoverished old-field soils in Quebec were characterized by an association of hair-cap moss and grey birch (Lafond 1958).

Visible tree symptoms include restricted growth and abnormal foliage. On potassium-deficient outwash soils of depleted old fields in Quebec and New York State, planted white spruce showed very poor height and diameter growth, and needles that were short, retained for fewer than normal number of years, and became chlorotic before turning brown and dying (Heiberg and White 1951, Lafond 1958); in nutrient culture studies with seedlings, Swan (1960) noted that white spruce grown in "very low" levels of potassium suffered 40% mortality and survivors were undersized with some yellow tipping on lower primary needles. In the same study very low nitrogen resulted in small, pale green seedlings with some purple/brown discoloration at the end of the growing season; with very low phosphorus seedlings were small, some tinted deep purple; and with very low magnesium needles were pale yellow/green, with the tips brown at the end of the growing season.

Despite the value of visible symptoms, some degrees of deficiency can inhibit dry matter production without evident abnormalities of the foliage. In fact in the above nutrient culture experiment, merely "low" concentrations of some elements reduced seedling weight but without revealing needle discoloration (Swan 1960). Quantitative methods are necessary to detect deficiencies at these levels.

The usefulness of **soil analysis** is limited by difficulties of relating availability to the tree of the nutrient concentrations determined by chemical methods; lack of knowledge of the levels giving optimum growth; and problems presented by root distribution and other vegetation present (Armson 1973, Sutton 1968). Yet Wilde's (1958) standards of 0.12% total N, 31 lb available P per ac (34.7 kg/ha), and 186 lb available K per ac (208.5 kg/ha) for conifers in Lake States nursery soils may be helpful. According to Gessel (1968) less than 0.10% total N in the top 6 in. (15.2 cm) of glacial forest soils in the northwest United States may be critical.

Foliage analysis is said to be most effective in detecting severe, single deficiencies, and Lafond (1958) showed a close correlation between potassium content of needles and per acre volume of white spruce plantations established on potassium-deficient soils. Swan (1971) grew white spruce seedlings for 26 weeks in nutrient solutions of known composition, and derived provisional standards for evaluating results of foliar analysis (Table 26). Presumably these would be most applicable to very young plantations, but could have relevance for older trees "if one accepts the hypothesis that optimum nutrient concentrations in foliage are largely independent of tree age". Swan's "sufficiency" values for nitrogen, phosphorus and potassium are similar to the ranges found for 2-0 and 3-0 white spruce by Armson and Sadreika (1974) and cited herein under the section "Soil Management". However, foliage analysis is reportedly less successful for identifying moderate or multiple deficiencies, since this approach defines what is present in the tree rather than availability in the

Table 26. Suggested provisional standards for the evaluation of the results of foliar analysis of white spruce

Element	Range of acute deficiency	Range of moderate deficiency	Transition zone from deficiency to sufficiency	Range of sufficiency for good to v. good growth	Range of luxury to excess (toxic) consumption
			Foliar Concentrations as % of Dry Matter		
Nitrogen	Below 1.10	1.10 - 1.30	1.30 - 1.50	1.50 - 2.50	2.50 and up
Phosphorus	Below 0.11	0.11 - 0.14	0.14 - 0.18	0.18 - 0.32	0.32 and up
Potassium	Below 0.19	0.19 - 0.30	0.30 - 0.45	0.45 - 0.80	0.80 and up
Magnesium	Below 0.04	0.04 - 0.06	0.06 - 0.10	0.10 - 0.20	0.20 and up
Calcium	Below 0.05	0.05 - 0.10	0.10 - 0.15	0.15 - 0.40	0.40 and up
Probability of response to applied fertilizer(s)	Response to the addition of appropriate fertilizers probable in these ranges, provided that growth is not being limited by some other factor or factors			Response may be anticipated at the lower end of this range	No substansial response should be anticipated in this range

(1) The above values refer to the results of analyses made on the current year's needles collected in the fall (mid-September to mid-November) from the upper one third of the crown.

(2) It should be recognized that these suggested standards are essentially judgements; they are based both on the results of greenhouse studies and on experience gained from the use of foliar analysis in field studies.

(From Swan 1971).

soil (Sutton 1968); and while nutrient levels in the foliage can be fairly readily related to tree growth (Morrison 1974), present data are said to be inadequate for determining the levels for optimum growth (Leaf 1974).

Analysis of plant and soil materials is a specialized endeavour and, unless standard sampling and laboratory procedures are followed, comparison of results, and their interpretation, become difficult.

Direct trials with fertilizers containing the element suspected of being deficient should probably be made as a follow-up to the results of diagnosis for confirmation and to determine optimum dosage, but might be tried in the first instance if experience suggested a particular nutrient requirement.

Response

The effect of nutritional correction is obviously to restore foliage to normal colour and luxuriance and to stimulate growth rates (Heiberg and White 1951, White 1968). Positive gains by white spruce following treatment for specific nutrient deficiencies have been reported in height (Gagnon 1971 and 1974, Lafond 1958) and in diameter (Gagnon and Boudoux 1968, Swan 1969). Fertilizing 35-year-old plantations on potassium-deficient soils near Grand'Mère, P.Q. with K_2SO_4 at 84 lb/ac (94 kg/ha) of elemental K produced an extra 4.0 cunits/ac (27.8 m^3/ha) of merchantable wood in ten years; the treatment was considered profitable since the cost of producing the extra wood was $6.72/cunit ($2.36/m^3) and stumpage in the plantations was valued at $18.00/cunit ($6.36/m^3) (Gagnon, Conway and Swan 1976).

Nitrogen fertilization for general growth improvement is reflected first by an increase in leaf area (Sutton 1968), providing a greater photosynthetic capacity. The effects are primarily produced by the nitrogen consumed by the tree in the first year of fertilization and stored in the needles (Hagner 1967). In a study with jack pine it was found that while much of the nitrogen (applied in the urea form) remained in the soil, only 1% was available to plant growth after one year (Morrison and Foster 1974). Experience with Norway spruce stands in Sweden, fertilized with 107 lb per ac (120 kg/ha) of nitrogen as urea, indicated a 40% increase in basal area growth by the end of the seventh year from application; strong and extended response in height growth; slight reduction in wood density, but in terms of dry matter the net volume increase was 90% of the gross; and the degree of response increased with tree and stand vigour, i.e. current annual increment (Hagner 1967). In a review of forest fertilization effects on wood quality, Gladstone and Gray (1973) concluded that an increase in uniformity of wood is produced, and strength properties of pulps from fertilized trees are not diminished.

Stand Age

If it is thought necessary, for some reason, to plant where serious deficiencies are known to occur, fertilization should be carried out close to the time of stand establishment, possibly as part of site preparation or during planting, as with herbicides in machine operations. On old-field sites it is advantageous to fertilize in conjunction with cultivation (which alone can be beneficial to growth of white spruce for the first few years (Gagnon 1969, Sutton 1968)). If an acute nutritional problem is only recognized later, treatment should not then be delayed (Gagnon, Conway and Swan 1976).

If the object of fertilization is a general improvement of growth rates on moderate or better sites, application should be deferred at least until the stand has closed and shaded out lesser vegetation; otherwise the latter benefits as much as the trees, and subjects them to intensified competition, and interest on treatment costs must be carried for a very long period (Sutton 1968, White 1968). For improving the foliage of Christmas tree crops, including spruce species, White (1968) recommended fertilizing only a year or two before harvesting.

In closed plantations containing appreciable numbers of volunteers, fertilizer treatment should be delayed until after a cleaning to avoid wasting chemicals on unwanted species, since the widespreading nature of tree roots makes it impossible to apply fertilizer selectively (Stiell 1970*b*, Weetman and Hill 1973). Similarly, treatment after a thinning may be advantageous in that the plantation will then be accessible to ground application if preferred, and the response to fertilizer will be concentrated on fewer and larger trees (Weetman 1971).

Essentially two stages of closed stand development offer economically attractive opportunities for fertilization. The first is when stands are immature and it is possible to achieve substantially shorter rotations, as is now favoured with pine and Norway spruce in Scandinavia (Hagner 1967). The second is near maturity, ten years or less before harvesting, when carrying charges will be minimized, added volume is placed on large trees, and logging costs thereby reduced -- considerations of particular relevance in the economics of Canadian forestry (Rennie 1974).

Fertilizers

Specific nutrient elements can be provided in various chemical compounds. Choice is governed by cost, supply, soil conditions and availability to the tree (Beaton 1973, 1974). Application rates of the element alone are usually between 20 and 150 lb per ac (22 to 168 kg/ha), but much higher in terms of total fertilizer. For example, the 200 lb per ac (224 kg/ha) potassium cloride applied to white spruce plantations in Quebec (Lafond 1958) would have included only 104 lb K (117 kg/ha).

The most widespread fertilizer treatment of closed stands has been with nitrogen in urea form (Hagner 1971). This fertilizer contains 46% N, and offers advantages of cost and supply, as against the drawback of some post-application losses by volatilization (Beaton 1973). There is a trend towards applying nitrogen as ammonium nitrate (33% N) in Scandinavia where this chemical has become more cost competitive and is now thought to effect a better growth response (Hagner 1971). Levels of application in terms of elemental nitrogen in Scandinavia for Norway spruce (and other species) are between 120 and

175 kg per ha (107 and 156 lb/ac) (Hagner 1971); for Douglas-fir on Vancouver Island, 150 to 200 lb per ac (168 to 224 kg/ha) (Crown 1974); trials with jack pine in western Ontario showed increasing response to levels well above 200 lb per ac (224 kg/ha) (Hegyi 1974); for balsam fir in Parc des Laurentides, P.Q., 200 lb per ac (224 kg/ha) gave better growth than 100 or 300 lb (112 or 336 kg/ha) (Gagnon 1974); "good responses" were made by young stands of (red?) spruce and (balsam) fir in Nova Scotia at 100 to 200 lb per ac (112 to 224 kg/ha) (Ross 1969). It is presumed that white spruce also would benefit in the general range 150 to 200 lb N per ac (168 to 224 kg/ha). Some investigators advise against the assumption that nitrogen alone will give optimum results, yet except where acute deficiencies were evident, addition of other elements as well as nitrogen seems usually to have afforded little added response in closed stands (e.g. Gagnon, Conway and Swan 1976). A shortage of nitrogen fertilizer in Canada does not seem likely to develop (Beaton 1974), although the cost may go up -- urea was estimated to reach $125 per ton ($138/t) by 1974 on Vancouver Island (Crown 1974), and did reach $160 per ton ($176/t) by 1975.

Organic fertilizers are little used in forest stands. Although they confer benefits associated with slow nutrient release and good water retention, and improve the physical condition of sandy soils, the content of chemical elements by weight is very small. White spruce fertilized at planting in 1920 on old fields near Grand'Mère, P.Q., with 15 tons per ac (34 t/ha) of barnyard manure, made three times the radial growth of unfertilized trees from the fifth to the tenth year (Gagnon and Boudoux 1968). However, farmyard manure is not now available in large quantities, and in any case the cost and weight of the required amount of this fertilizer to supply a given quantity of nitrogen are many times that for chemical fertilizers (Armson 1959). A more promising alternative is human waste, which, produced at the rate of 50 lb (22 kg) dry matter per person per year (Gagnon 1973), is indisputably a renewable resource and one likely to increase rather than decline in total supply. Application of this material in the form of digested, air-dried sewage sludge at 500 lb per ac (560 kg/ha) to

10-year-old white spruce growing on depleted, sandy soils, resulted in 50% better height growth than the controls over a 6-year period; it was concluded that this material, perhaps upgraded by adding inorganic elements, has considerable potential as a forest fertilizer (Gagnon 1973, 1974).

Application

Season of the year is not considered important in Sweden provided there is no snow on the ground; but losses from run-off are serious if fertilizer is applied during the spring thaw (Hagner 1967). Dormant season application seems preferred on the west coast of North America (Beaton 1973, Crown 1974).

Fertilizing can be carried out at or close to the time of planting by hand spreading or through a flexible tube from a backpack at about 0.4 to 0.8 man-hours per kg of fertilizer (0.17 to 0.35 man-hr/lb); large spreaders mounted on tractors or skidders deliver 9 to 13 tons per day, depending on dosage -- 250 to 450 kg/ha (225 to 400 lb/ac) (Beaton 1973, Hagner 1971). One such unit with a capacity of 3,800 lb (1,655 kg), broadcast at a rate of 14 ac (5.7 ha) per hr (Page and Gustafson 1969). It might be feasible, in machine operations, to synchronize fertilizing with planting as in the application of herbicides. Placing fertilizer directly in planting holes is risky in that seedling roots may be damaged by high concentrations of chemical, and slow-release formulations such as urea-formaldehyde pellets are expensive although they may have merit in Christmas tree plantations (Swan 1965*b*, White 1966). In closed stands, ground fertilization methods might be practicable after a thinning which had made the area generally accessible to equipment, e.g. by row thinning. However for unthinned stands, and for all large-scale operations, aerial fertilization will be most economical.

Fixed-wing aircraft appear to predominate, and increasingly so, in this work for which many of the principles discussed under "Aerial Seeding" apply. Light aircraft with payloads of 1,000 to 3,000 lb (440 to 1,300 kg) are generally used, operating up to 4 miles (6.4

km) from the airstrip. They are equipped with spreaders, and must be loaded quickly, to allow rapid turnaround either from prefilled containers (Hagner 1971) or by gravity from a tractor-mounted hopper which can deliver 1,000 lb (440 kg) in approximately 20 seconds (Crown 1974). Ground control requires that the area to be treated be marked at the corners with helium-filled balloons or pyramid markers anchored above tree level or, as in Scandinavia, by flags fixed to hoops which have been dropped over tree leaders from helicopters (Hagner 1971). Dead crowns of trees killed at 50-ft (15-m) intervals with cacodylic acid can serve to indicate boundaries (Armson 1972). Mobile flagmen, with portable radios, moving over one swath-width after each pass can be used to control flight patterns. Pilots should be equipped with 10-chain-to-1-inch (7,920:1) air photos of the treatment areas. Crown (1974) described fertilizing procedures using a Cessna Aggwagon with 1,000-lb (440-kg) payload to apply urea: the aircraft flew at altitudes of 150 to 300 ft (45 to 90 m), at 105 mph (170 km/h), covering a 60-ft (18-m) swath; the return run overlapped the previous one by 50%; costs for 1974 were estimated to be $18 per 100 lb ($40/100 kg) of nitrogen applied in urea form, of which the fertilizer accounted for 75% of the cost, and handling, application etc. the remainder.

Helicopters are used much less for forest fertilizing, their characteristics for this use vis à vis fixed-wing aircraft being much as described under "Aerial Seeding". Generally they are more expensive to operate, and turbulence from the rotor makes uniform distribution difficult, but they offer advantages for small treatment areas and rugged terrain, and have minimum landing-strip requirements. The fertilizer is usually carried in a pod or conical tank slung beneath the helicopter; the pods are prefilled for rapid turn around between flights (Page and Gustafson 1969).

A check of fertilizer distribution is desirable. This is essentially a sampling problem. Armson (1972) carried out tests for urea fertilizer in the form of 1/16-in. (1.6-mm) prills, and concluded that where the rate of application was 100 lb N per ac (112 kg/ha), 70 randomly distributed one-square-foot (0.09-m^2) catchers would give a good estimate -- ±10 lb per ac (±11.2 kg/ha) of distribution.

References to Stand Tending

Adamovich, Laszlo L. 1968. Problems in mechanizing commercial thinnings. Annu. Meet. Am. Soc. Agric. Eng., Utah State Univ., Logan, Utah, June 18-21, 1968. Pap. 68-127.

Ainscough, G.L. 1968. The forest fertilization program of MacMillan Bloedel Ltd. Pulp Pap. Mag. Can. 69(19):98-101.

Anderson, Walter C. and James E. Granskog. 1974. Mechanized row-thinning systems in slash pine plantations. U.S. Dep. Agric., For. Serv. Res. Pap. SO-103.

Anon. 1974. Spindly, gentle yarder takes on B.C. thinning challenge. Can. Pulp Pap. Ind. 27(11):72.

Armson, K.A. 1959. The use of farmyard manure in forest tree nurseries. For. Chron. 35(2):100-103.

Armson, K.A. 1972. Fertilizer distribution and sampling techniques in the aerial fertilization of forests. Univ. Toronto, Fac. For. Tech. Rep. 11.

Armson, K.A. 1973. Soil and plant analysis techniques as diagnostic criteria for evaluating fertilizer needs and treatment response. *In* For. Fert. Symp. Proc. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. NE-3:155-166.

Armson, K.A. and V. Sadreika. 1974. Forest tree nursery soil management and related practices. Ont. Minist. Nat. Resour., Div. For., For. Manage. Branch.

Armstrong, R.H. 1963. The history and mechanics of forest planting and aerial spraying. Pulp Pap. Mag. Can. 64(6):WR-268-WR-270.

Armstrong, R.H. 1968. Silviculture and regeneration agreements. Pulp Pap. Mag. Can. November 15. p. 83-85, 87.

Axelsson, Ragnar and H. Routledge. 1970. Cleaning young softwood stands: academic exercise or practical solution? Pulp Pap. Mag. Can. 71(16):93-97.

Baldwin, H.I. 1952. Spruce plantations silviculture and harvesting problems. New York For. IX(2):14-16.

Beaton, J.D. 1973. Fertilizer methods and applications to forestry practice. *In* For. Fert. Symp. Proc. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. NE-3:55-71.

Beaton, J.D. 1974. Fertilizer supplies and the energy crisis. *In* Proc. Workshop For. Fert. in Can., Dep. Environ., Can. For. Serv. For. Tech. Rep. 5:65-75.

Bella, I.E. 1966. Strip thinning jack pine thickets with a "drum chopper" in Manitoba. Can. Dep. For. Inf. Rep. MS-X-3.

Bella, I.E. 1972. Growth of young lodgepole pine after mechanical strip thinning in Alberta. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-23.

Bella, I.E. and J.P. DeFranceschi. 1971. Growth of young jack pine after mechanical strip thinning in Manitoba. Dep. Fish. For., Can. For. Serv. Inf. Rep. A-X-40.

Berry, A.B. 1964. A time study in pruning plantation white spruce and red pine. For. Chron. 40(1):122-128.

Berry, A.B. 1974. Crown thinning a 30-year-old white spruce plantation at Petawawa -- 10-year results. Dep. Environ., Can. For. Serv. Inf. Rep. PS-X-49.

Berry, A.B. and M.R. Innes. 1967. Epicormic branching in pruned white spruce. Bi-mon. Res. Notes 23(1):7.

Brown, J.E. 1970. New silvicide proves potent for thinning dense stands. Pulp Pap. Mag. Can. 71(13):77-79.

Brown, R.M. 1975. Chemical control of weeds in the forest. U.K. For. Comm. Booklet 40.

Cook, Dave. 1971. A new idea in plantation thinning. North. Logger Timber Process. 19(8):25, 36-37.

Crown, M. 1974. Fertilizer application on an operational scale. *In* Proc. Workshop For. Fert. in Can., Dep. Environ., Can. For. Serv. For. Tech. Rep. 5:93-99.

Day, M.W. and V.J. Rudolph. 1966. Early growth results of thinning plantation red pine by three methods. Mich. State Univ., Agric. Exp. Stn. Q. Bull. 49(2):183-188.

Day, Maurice W. and Victor J. Rudolph. 1970. Development of a white spruce plantation. Mich. State Univ., Agric. Exp. Stn. Res. Rep. 111.

DeBoo, R.F., A.G. Teskey and A.G. Copeman. 1971. Cost comparison of four methods of eliminating wolf trees from pine plantations. Bi-mon. Res. Notes 27(2):17.

Dunfield, J.D. 1974. Mechanized pre-commercial thinning of dense young trees. Dep. Environ., Can. For. Serv. Inf. Rep. FMR-X-64.

Dunfield, J.D. 1975. Mechanized thinning. *In* Mechanization of Silviculture in Northern Ontario. Proc. Symp. Sault Ste. Marie, Ont., Oct. 1, 2, 1974. Dep. Environ., Can. For. Serv. Symp. Proc. 0-P-3:123-129.

Fazio, Jim. 1968. Tree monkey goes to market. North. Logger Timber Process. Jan. p. 17, 19, 34-35.

Frank, Robert M. 1973. The course of growth response in released white spruce -- 10-year results. U.S. Dep. Agric., For. Serv. Res. Pap. NE-258.

Gagnon, J.D. 1969. Soil improvement trials using scarification and fertilization in stagnant white spruce plantations, Quebec, Canada. Plant and Soil XXX(1):23-33.

Gagnon, J.D. 1971. Effets comparés des ordures ménagères, des boues d'égouts et d'un engrais potassique sur la croissance en hauteur d'une plantation d'épinette blanche âgeé de 10 ans. Ministère de l'Environnement, Service canadien des Forêts Rapport d'Information Q-F-X-19.

Gagnon, J.D. 1973. Environmental aspects of sewage-derived fertilizers. *In* For. Fert. Symp. Proc. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. NE-3:101-107.

Gagnon, J.D. 1974. Results of fertilizer experiments in Quebec. *In* Proc. Workshop For. Fert. in Can., Dep. Environ., Can. For. Serv. Tech. Rep. 5:83-91.

Gagnon, J.D. and M. Boudoux. 1968. Delayed and limited effect of organic fertilizer on growth of white spruce (*Picea glauca* (Moench)). Bi-mon. Res. Notes 24(5):42-43.

Gagnon, J.D., J.M. Conway and H.S.D. Swan. 1976. Growth response following fertilizer application in the Grand'Mère plantations. For. Chron. (in press).

Gessel, S.P. 1968. Progress and needs in tree nutrition research in the Northwest. *In* Forest Fertilization-Theory and Practice. p. 216-225. Tennessee Valley Authority, Natl. Fert. Dev. Center, Muscle Shoals. Ala.

Gladstone, William T. and Richard L. Gray. 1973. Effects of forest fertilization on wood quality. *In* For. Fert. Symp. Proc. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. NE-3:167-173.

Grinnell, W. Ross. 1968. Silvicultural operations in Ontario. Pulp Pap. Mag. Can. May 3. p. 87-90, 92.

Haig, R.A. and F.W. Curtis. 1974. Cost effectiveness of four methods of establishing white spruce on a cut-over mixedwood site in the Goulais River area, Ontario. Dep. Environ., Can. For. Serv. Inf. Rep. O-X-210.

Hagner, Stig O. 1967. Fertilization as a production factor in industrial forestry. H.R. MacMillan Lecture Delivered Univ. B.C. March 29, 1967.

Hagner, Stig. 1971. The present standard of practical forest fertilization in different parts of the world. Summarizing Pap., XV IUFRO Congr., Sect. 32, 15 Feb., 1971, Gainesville, Fla.

Hegyi, F. 1974. What we found: growth-response evaluation of fertilizer trials in jack pine - Dryden field trials. *In* Proc. Workshop. For. Fert. in Can., Dep. Environ., Can. For. Serv. For. Tech. Rep. 5:33-38.

Heiberg, Svend O. and Donald P. White. 1951. Potassium deficiency of reforested pine and spruce stands in northern New York. Soil Sci. Am. Proc. 1950, 15:369-376.

Krause, H.H. 1973. Forest fertilization in eastern Canada, with emphasis on New Brunswick studies. *In* For. Fert. Symp. Proc. U.S. Dep. Agric., For. Serv. Gen Tech. Rep. NE-3:188-205.

Lafond, André. 1958. Les déficiences en potassium et magnésium de quelques plantations de *Pinus strobus*, *Pinus resinosa* et *Picea glauca* dans la Province de Québec. Fonds de Recherches forestières de l'Université Laval Contribution no. 1.

Leaf, A.L. 1974. Where are we in forest fertilization? *In* Proc. Workshop For. Fert. in Can., Dep. Environ., Can. For. Serv. For. Tech. Rep. 5:1-5.

Lees, J.C. 1966. Release of white spruce from aspen competition in Alberta's spruce-aspen forest. Can. Dep. For. Publ. 1163.

Little, S. and J.J. Mohr. 1963. Five-year effects from row thinnings in loblolly pine plantations of eastern Maryland. U.S. Dep. Agric., For. Serv. Res. Pap. NE-12.

MacArthur, J.D. 1967. Larose Forest -- an experiment in co-operation. Pulp Pap. Mag. Can. 68(2):WR-46-WR-49, WR-52.

Morrison, I.K. 1974. Mineral nutrition of conifers with special reference to nutrient status interpretation: a review of literature. Dep. Environ., Can. For. Serv. Publ. 1343.

Morrison, I.K. and N.W. Foster. 1974. Ecological aspects of forest fertilization. *In* Proc. Workshop For. Fert. in Can., Dep. Environ., Can. For. Serv. For. Tech. Rep. 5:47-53.

Myhrman, D. 1973. Techniques for mechanized thinning. *In* Thinning in the Forestry of the Future. Int. Conf. at ELMIA 73, June 5, Jönköping, Sweden, IV:1-15.

Nilsson, P.O. and A. Hyppel. 1968. Studier över rötangrepp i sarskadar hos gran. (Studies on decay in scars of Norway spruce). Sveriges Skogsvards förbunds Tidskrift 8:675-713. *Cited by* G. de Brit in Irish For. 1969, 26:27.

Ontario Herbicide Committee. 1974. Guide to chemical weed control. Ont. Minist. Agric. Food Publ. 75.

Page, Jerry M. and M. Lee Gustafson. 1969. Equipment for forest fertilization. Soc. Automot. Eng. Natl. West Coast Meet., Seattle, Wash., Aug. 11-14, 1969. Pap. 690553.

Pawsey, R.G. and R.J. Gladman. 1965. Decay in standing conifers developing from extraction damage. For. Comm. For. Rec. 54.

Pratt, R.H.M. 1966. Aerial spraying with 2,4-D to eliminate trembling aspen. Pulp Pap. Mag. Can. 67(9):460-462.

Ralston, R.A. and W. Lemien. 1956. Pruning pine plantations in Michigan. Mich. State Univ., For. Dep., Agric. Exp. Stn., Coop. Ext. Serv., Circ. Bull. 221.

Rennie, P.J. 1972. Forest fertilization in Canada. VIIth World For. Congr., Buenos Aires, Argentina.

Rennie, P.J. 1974. Forest fertilization research in Canada. *In* Proc. Workshop For. Fert. in Can., Dep. Environ., Can. For. Serv. For. Tech. Rep. 5:7-15.

Riley, L.F. 1973. Operational trials of techniques to improve jack pine spacing. Dep. Environ., Can. For. Serv. Inf. Rep. 0-X-180.

Riley, L.F. 1974. Silvicultural treatment of seeded stands. *In* J.H.

Cayford (ed.) Direct Seeding Symp., Timmins, Ont. Sept. 11, 12, 13, 1973. Dep. Environ., Can. For. Serv. Publ. 1339:139-155.

Robertson, R.G. 1971. A cleaning guide for Nova Scotia forests. N.S. Dep. Lands For. Ext. Note 74.

Ross, G.K. 1969. A developing silvicultural program in Nova Scotia. Pulp Pap. Mag. Can., June 6. p. 88-91.

Smith, David M. 1971. Current status of pruning in the eastern United States. Basic Pap. Prep. for Tech. Session on "Techniques in silvicultural operations with main emphasis on mechanization", Sect. 32, XV Congr., IUFRO, Gainesville, Fla., March 1971.

Spurr, Stephen H. 1948. Row Thinning. Proc. Soc. Am. For. Meet. 1947. p. 370-377.

Steneker, G.A. 1963. Results of a 1936 release cutting to favour white spruce in a 50-year-old white spruce-aspen stand in Manitoba. Can. Dep. For., For. Res. Branch Publ. 1005.

Steneker, G.A. 1967. Growth of white spruce following release from trembling aspen. Can. Dep. For. Rural Dev., For. Branch, Dep. Publ. 1183.

Steneker, G.A. 1974. Selective cutting to release white spruce in 75 to 100-year-old white spruce-trembling aspen stands, Saskatchewan. Dep. Environ., Can. For. Serv. Inf. Rep. NOR-X-121.

Sterzik, H.K. and K. Heil. 1969. Das STE-Handgerät für Wertästung. Forstarchiv 40(4):75-76.

Stiell, W.M. 1955. The Petawawa plantations. Can. Dep. North. Aff. Natl. Resour., For. Branch, For. Res. Div. Tech. Note 21.

Stiell, W.M. 1970*a*. Thinning 35-year-old white spruce plantations from below: 10-year results. Dep. Fish. For., Can. For. Serv. Publ. 1258.

Stiell, W.M. 1970*b*. Some competitive relations in a red pine plantation. Dep. Fish. For., Can. For. Serv. Publ. 1275.

Sutton, R.F. 1968. Ecology of young white spruce (*Picea glauca* (Moench) Voss). Thesis, Cornell Univ. 500 p.

Sutton, R.F. 1969. Chemical control of competition in plantations. For. Chron. 45(4):252-256.

Sutton, Roy F. 1975. Nutrition and growth of white spruce outplants: enhancement by herbicidal site preparation. Can. J. For. Res. 5(2):217-223.

Sutton, W.R.J. 1971. Mechanization of pruning - a summary. Summary Pap. Presented to Working Group Meet., Gainsville, Fla., March 19, 1971. IUFRO, Sect. 32.

Swan, H.S.D. 1960. The mineral nutrition of Canadian pulpwood species. 1. The influence of nitrogen, phosphorus, potassium and magnesium deficiencies on the growth and development of white spruce, black spruce, jack pine and western hemlock seedlings grown in a controlled environment. Pulp Pap. Res. Inst. Can. Tech. Rep. 168, Woodlands Res. Index 116.

Swan, H. Stewart D. 1965*a*. Reviewing the scientific use of fertilizers in forestry. J. For. 63(7):501-508.

Swan, H.S.D. 1965*b*. Studies of the mineral nutrition of Canadian pulpwood species. Phase II. Fertilizer pellet field trials. 1959-1963. Final report. Pulp Pap. Res. Inst. Can. Tech. Rep. 405, Woodlands Res. Index 163.

Swan, H.S.D. 1969. Fertilizers, their role in reforestation. Pulp Pap. Res. Inst. Can., Woodlands Pap. W.P.9.

Swan, H.S.D. 1971. Relationships between nutrient supply, growth and nutrient concentrations in the foliage of white and red spruce. Pulp Pap. Res. Inst. Can., Woodlands Pap. W.P.29.

Tucker, T.L. 1974. What is it worth? An economic evaluation of fertilizer trials in jack pine at Dryden, Ontario. *In* Proc. Workshop For. Fert. in Can., Dep. Environ., Can. For. Serv. For. Tech. Rep. 5:39-45.

Vincent, A.B. 1954. Release of balsam fir and white spruce reproduction from shrub competition. Can. Dep. North. Aff. Natl. Resour., For. Branch, Div. For. Res. Silvic. Leafl. 100.

Wambach, Robert F. 1969. Compatibility of mechanization with silviculture. J. For. 67(2):104-108.

Weetman, G.F. 1971. Effects of thinning and fertilization on the nutrient uptake, growth and wood quality of upland black spruce. Pulp Pap. Res. Inst. Can., Woodlands Pap. W.P.28.

Weetman, Gordon F. and Stuart B. Hill. 1973. General environmental and biological concerns in relation to forest fertilization. *In* For. Fert. Symp. Proc. U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. NE-3:19-35.

White, D.P. 1966. Fertilization for improved Christmas tree quality. Am. Christmas Tree J. X(1):20-22.

White, Donald P. 1968. Progress and needs in tree nutrition research in the Lake States and Northeast. *In* Forest Fertilization-Theory and Practice. p. 226-233. Tennessee Valley Authority, Natl. Fert. Dev. Center, Muscle Shoals, Ala.

Wilde, S.A. 1958. Forest soils their properties and relation to silviculture. The Ronald Press Co., New York, N.Y. ix + 537 p.

Wilde, S.A. 1970. Weeds and tree planting. Tree Plant. Notes 21(1): 24-26.

Williston, Hamlin L. 1967. Thinning desirable in loblolly pine plantations in West Tennessee. U.S. Dep. Agric., For. Serv. Res. Note SO-61.

APPENDICES

APPENDIX I

Common and Scientific Biological Names

Disease Organisms

Armillaria root rot	*Armillaria mellea* (Vahl ex Fr.) Kummer
B.t.	*Bacillus thuringiensis* Berliner
Cytospora canker	*Valsa kunzei* Sacc.
Fomes root rot	*Fomes annosus* (Fr.) Karst.
Stand-opening disease	*Polyporus tomentosus* Fr.

Plants

Alder	*Alnus* spp.
Alfalfa	*Medicago* spp.
Ash	*Fraxinus* spp.
Aspen	*Populus* spp.
Aspen, largetooth	*Populus grandidentata* Michx.
Aspen, trembling	*Populus tremuloides* Michx.
Beech, American	*Fagus grandifolia* Ehrh.
Birch	*Betula* spp.
Birch, grey	*Betula populifolia* Marsh.
Birch, white	*Betula papyrifera* Marsh.
Blackberry	*Rubus* spp.
Blueberry	*Vaccinium* spp.
Buckwheat	*Fagopyrum esculentum* Gaertn.
Cherry	*Prunus* spp.
Devil's club	*Oplopanax horridum* Sm.
Dogwood, red-osier	*Cornus stolonifera* Michx.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Elderberry	*Sambucus canadensis* L.
Elm	*Ulmus* spp.
Fairybells	*Disporum oregonum* S. Wats.
Fern, bracken	*Pteridium aquilinum* (L.) Kuhn
Fern, oak	*Gymnocarpium dryopteris* (L.) Newm.
Fir	*Abies* spp.
Fir, balsam	*Abies balsamea* (L.) Mill.
Fireweed	*Epilobium angustifolium* L.
Flax	*Linum usitatissimum* L.
Goldenrod	*Solidago* spp.
Grass	*Gramineae* spp.
Hawthorn	*Crataegus* spp.
Hazel, beaked	*Corylus cornuta* Marsh.
Laurel, dwarf	*Kalmia angustifolia* L.
Lupine	*Lupinus* spp.
Maple	*Acer* spp.
Maple, Manitoba	*Acer negundo* L.
Maple, mountain	*Acer spicatum* Lam.
Millet	*Setaria* spp.
Moss, juniper hair-cap	*Polytrichum commune* (= *juniperinum*) Hedw.
Moss, Schreber's	*Pleurozium* (= *Calliergon*) *schreberi* (BSG.) Mitt.
Moss, sphagnum	*Sphagnum* spp.

Oak	*Quercus* spp.
Oats	*Avena sativa* L.
Pine	*Pinus* spp.
Pine, jack	*Pinus banksiana* Lamb.
Pine, loblolly	*Pinus taeda* L.
Pine, lodgepole	*Pinus contorta* Dougl.
Pine, red	*Pinus resinosa* Ait.
Pine, Scots	*Pinus sylvestris* L.
Pine, slash	*Pinus elliottii* Engelm.
Pine, white	*Pinus strobus* L.
Plum, wild	*Prunus* spp.
Poplar, balsam	*Populus balsamifera* L.
Raspberry	*Rubus* spp.
Reed-grass	*Calamagrostis* spp.
Rhododendron (rhodora)	*Rhododendron canadense* (L.) Torr.
Rye	*Secale cereale* L.
Sarsparilla	*Aralia nudicaulis* L.
Sedge	*Carex* spp.
Spiraea	*Spiraea* spp.
Spruce	*Picea* spp.
Spruce, black	*Picea mariana* (Mill.) B.S.P.
Spruce, Engelmann	*Picea engelmannii* Parry
Spruce, Norway	*Picea abies* (L.) Karst.
Spruce, Porsild	*Picea glauca* var. *porsildii* Raup
Spruce, red	*Picea rubens* Sarg.
Spruce, Sitka	*Picea sitchensis* (Bong.) Carr.
Spruce, western white	*Picea glauca* var. *albertiana* (S. Brown) Sarg.
Spruce, white	*Picea glauca* (Moench) Voss
Sumac	*Rhus* spp.
Sweet-fern	*Comptonis peregrina* (L.) Coult.
Viburnum	*Viburnum* spp.
Willow	*Salix* spp.

Insects

Army worm, garden	*Mamestra curialis* Sm.
Aphid, Cooley spruce gall	*Adelges cooleyi* Gill.
Aphid, eastern spruce gall	*Adelgis abietis* L.
Budworm, spruce	*Choristoneura fumiferana* Clem.
Caterpillar, variable	*Pyrrhia exprimens* Wlk.
Cutworm, black army	*Actebia fennica* Tausch.
Grub, white	*Phyllophaga* spp.
Sawfly, balsam-fir	*Neodiprion abietis* complex
Sawfly, green-headed spruce	*Pikonema dimmockii* Cress.
Sawfly, yellow-headed spruce	*Pikonema alaskensis* Rob.
Weevil, Engelmann-spruce	*Pissodes engelmanni* Hopkins
Weevil, white-pine	*Pissodes strobi* Peck
Springtail	*Columbella* spp.

Birds

Crow	*Corvus brachyrhncos* Brehm

Mammals

Chipmunk	*Eutamias* spp.
Hare, snowshoe	*Lepus americanus* Erxl.
Mouse, deer	*Peromyscus* spp.
Shrew	*Sorex* spp.
Squirrel	*Tamiasciurus* spp.
Vole, meadow	*Microtus* spp.
Vole, red-backed	*Clethrionomys* spp.

APPENDIX II

Metric Equivalents for Units of Measurement in Tables 9-25

1 inch	= 2.5400 cm	1 cm	= 0.3937 inch
1 ft	= 0.3048 m	1 m	= 3.2808 ft
1 ft^2	= 0.0929 m^2	1 m^2	= 10.7639 ft^2
1 ft^3	= 0.0283 m^3	1 m^3	= 35.3147 ft^3
1 ac	= 0.4047 ha	1 ha	= 2.4710 ac
1 ft^2/ac	= 0.2296 m^2/ha	1 m^2/ha	= 4.3560 ft^2/ac
1 ft^3/ac	= 0.0700 m^3/ha	1 m^3/ha	= 14.2913 ft^3/ac

APPENDIX III

Names of Pesticides[1]

Common Name	Trade Name[2]	Chemical Name
Fumigants		
allyl alcohol	Calsa, Shell AA Soil Drench	2-propen-1-ol
dazomet	Mylone	tetrahydro-3, 5-dimethyl-2H-1, 3,5-thiadiazine-2-thione
metam	SMDC, Vapam	methyldithiocarbamic acid
methyl bromide	Brom-0-Gas, Dowfume MC2, Meth-0-Gas	bromomethane
-	Vorlex	methyl isothiocyanate
Fungicides		
captan	-	N-[(trichloromethyl)thio]-4-cyclohexene-2,-dicarboximide
thiram	Arasan, Thylate, TMD	bis(dimethylthiocarbamoyl)disulfide

[1] Adapted from:

Anon. Undated. Pesticide safety handbook: a guide for users and agriculturalists. Can. Agric. Chem. Assoc., Montreal, Que.

Chemical Control Research Institute. 1975. Compendium on pesticides registered for use in Canada against pests of forests, trees and shrubs. Revised ed. - 1975. Dep. Environ., Can. For. Serv. Inf. Rep. CC-X-19.

Ontario Herbicide Committee. 1974. Guide to chemical weed control. Ont. Minist. Agric. Publ. 75.

Sutton, R.F. 1970. Chemical herbicides and forestation. For. Chron. 46(6):458-465.

[2] Mention of trade names does not imply endorsement thereof nor approval to the exclusion of comparable products.

Common Name	Trade Name	Chemical Name
Herbicides		
2,4-D	Weedone	2,4-dichlorophenoxyacetic acid
2,4,5-T	-	2,4,5-trichlorophenoxyacetic acid
-	Brushkill	mixture 2,4-D and 2,4,5,-T
amino triazole, amitrole	Amitrol-T, Amizol ATA, Cytrol	3-amino-s-triazole
asulam	Asilan, Asulox	methyl 4-aminobenzene-sulphonyl carbamate
-	Amizine	mixture amitrole and simazine
atrazine	AAtrex	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
cacodylic acid	Silvisar	hydroxydimethylarsine oxide
chlorthal	Dacthal, DCPA	dimethyl tetrachloroterephthalate
diphenamid	Dymid, Enide	N,N-dimethyl-2,2-diphenylacetamide
fenuron	Dybar	NN-dimethyl-N'-phenylurea
paraquat	Gramoxone, Weedrite	1,1'-dimethyl-4,4'-bipyridinium dichloride
picloram	Tordon	4-amino-3,5,6-trichloropicolinic acid
prometryne	Caparol, Gesagard Primatol Q, Promatrex	2,4-bis(isopropylamino)-6-methylthio-s-triazine
simazine	Princep	2-chloro-4,6-bisethylamino-1,3,5-triazine
Insecticides		
aminocarb	Matacil	4-(dimethylamino)-m-tolyl methylcarbamate
carbaryl	Sevin, Sevimol	1-naphthyl methylcarbamate
chlordane, chlordan	Octa-Klor	1,2,4,5,6,7,8,8-octachlora-3a,4,7,7a-tetrahydro-4,7-methanoindane

Common Name	Trade Name	Chemical Name
DDT	-	2,2-bis(p-chlorophenyl)-1,1,1-trichloroethane
diazinon	Basudin	0-0-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate
dimethoate	Cygon, Rogor	0-0-dimethyl phosphorodithioate S-ester with 2-mercapto-N-methylacetami
endrin	-	1,2,3,4,10,10-hexachloro-6-7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene
fenitrothion	Folithion, Sumithion	0-0-dimethyl 0-(4-nitro-m-tolyl) phosphorothioate
malathion	Cythion	diethyl mercaptosuccinate S-ester with 0,0-dimethyl phosphorodithioate
methoxychlor	Marlate, Methoxol	1,1,1-trichloro-2,2-bis(p-methoxyphenyl ethane
mexacarbate	Zectran	4-dimethylamino-3,5-xylyl methylcarbama
phosphamidon	Dimecron	dimethyl phosphate ester with 2-chloro-N,N-diethyl-3-hydroxycrotonami
trichlorfon	Dipterex, Dylox	dimethyl(2,2,2-trichloro-1-hydroxyethyl phosphonate
Rodent repellent		
-	R-55	tertiary-butylsulfenyldimethyldithiocarbamate

SYDNEY