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GROWTH AND YIELD OF WHITE SPRUCE PLANTATIONS IN THE LAKE STATES (A LITERATURE REVIEW)

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This summary of the white spruce literature covers the structure, site relations, population dynamics, and cultural practices applicable to *established* plantations in the Lake States. The objective of this paper is to assemble and organize all information relevant to the silviculture, growth, and yield of white spruce plantations in the Lake States. Information from other regions in North America was included to fill gaps in the literature or to provide comparisons. The following topics have been avoided in this paper because they are adequately covered in the cited reviews: artificial regeneration (Stiell 1976), insect and disease damaging agents (Nienstaedt and Zasada 1983), and genetics (Nienstaedt and Teich 1972, Nienstaedt 1982).

White spruce (*Picea glauca* (Moench) Voss) occurs in a broad band from the Atlantic coast to Alaska and northward to the limit of trees. The southern boundary, where the population intensity of spruce is between 30 and 60 percent of the total stand, coincides roughly with the southern boundary of the Boreal Forest (Halliday and Brown 1943). South of this boundary, which includes the Lake States of the U.S., white spruce usually comprises no more than 30 percent of natural stands (Halliday and Brown 1943). In natural fir-spruce-birch forests of the Lake States, white spruce is usually present as scattered individials and its present reproduction does not indicate that it can be otherwise (Buell and Niering 1957). The botanical and commercial range of white spruce in the Lake States has been mapped by Rudolf and Andresen (1965). Kingsley and Mayer (1972) reported the results of the latest broadscale compilation of conifer plantation data. They estimated there were about 38,400 acres of spruce plantations in Michigan and 92,200 acres in Minnesota. In both States, 45 percent of the acreage was in the seedling-sapling size class (0-5 in.) (0-12.7 cm), 45 percent was in poletimber stands (5-9 in.) (12.7-22.9 cm), and 10 percent was in sawtimber-size stands (9+in.) (22.9+cm). The average size of all plantations was less than 5 acres.

The Wisconsin Department of Natural Resources conducted a survey of coniferous plantations established prior to December 31, 1978 (State of Wisconsin 1980). They only included plantations more than 5 acres in size with a minimum stocking of 300 trees per acre as a seedling, sapling, or pole stand and 100 trees per acre as a sawtimber stand. The results showed 47,492 acres of white spruce plantations. About 9 percent of the established plantation acreage of Wisconsin (537,222 acres) was in white spruce, 69 percent was in red pine, 5 percent in white pine, 14 percent in jack pine, and the remaining 3 percent in other conifers. The age class distribution of Wisconsin white spruce plantations by acreage was found to be 21 percent ages 1-10; 38 percent ages 11-20; 9 percent ages 21-30; 14 percent ages 31-40; 18 percent ages 41-50; and less than 1 percent ages 51+years.

STAND STRUCTURE

Structure refers to the arrangement of all parts of a whole. Stand structure may then be defined as the arrangement of stand components. The stand structural components discussed in this section are: density, height, diameter, crown branches, crown foliage, roots, biomass, and volume.

Density

Stand density affects individual tree growth, the rapidity of crown closure in juvenile stands, the timing of thinnings, and the potential product mix (Stiell 1976). Higher density generally produces trees with smaller crowns and stem diameters, crowns with thinner branches, and greater stand cubic foot volumes than lower density. Common planting densities in eastern Canada are from 1,210 (6 × 6 ft)(1.8 × 1.8 m) to 681 (8 × 8 ft)(2.4 × 2.4 m) trees/acre. The best planting density for a particular site will depend on management objectives and the marginal cost of planting each additional tree once the requirement for full stocking has been met.

Height

Height prediction equations are found in Appendix A. An inspection of the equations shows that one (A4) is based on knowing the cation exchange capacity (CEC) of the soil, one (A2) is based on breast height age, and two (A1 and A3) are based on total age. Without a good predictive relation between breast height age and total age, which is not yet available, it is not possible to compare equation A2 with A1 and A3. By trial and error I have found that equation A1 begins to systematically underpredict height beginning with age 40 and younger. The underprediction gets more and more severe as age 20 is approached. Equation A3 seems reasonable at all ages, however, it was developed from natural white spruce stands in Saskatchewan, Canada. We have no idea how well suited it is for the conditions prevalent in the Lake States.

It appears that height growth of white spruce cannot be predicted reliably until the prolonged period of minimal height growth, called "check," has been passed (Stiell and Berry 1973). This usually occurs somewhere between ages 6 and 18.

Shoot growth potential is predetermined by bud morphogenesis (Pollard and Logan 1977, Fraser 1962). Sutton (1969) reported that a severe deficiency in rainfall during the period of seedling height growth will retard or entirely curtail it. However, as the tree grows older and its root system exploits an increasingly larger volume of soil, its ability to achieve its growth potential increases (Sutton 1969). Seasonal height growth occurs during a short period of the current year's favorable growing season (Fraser 1962, Hellum 1967). Seedling height growth has been observed to occur during only 66 percent of the average frost-free season in central Alberta (Hellum 1967). It usually begins in May and ends in July. In Manitoba, Jameson (1963) reported that 70 percent of the season's height growth occurred in June. Thus growing season length would seem to be a poor predictor of current year shoot growth.

Temperature, soil moisture, and light intensity significantly influence bud morphogenesis and, hence, shoot growth potential (Pollard and Logan 1977). Photoperiod also influences bud morphogenesis[1]. The effects of nutrient regime has not been examined (Pollard and Logan 1977).

Primordial bud diameter and seedling height account for most of the variation in seedling leader growth. "As a seedling grows taller it produces increasingly larger buds which in turn are capable of producing subsequently longer leaders" (Hellum 1967). Within a local population, neither genetic variability nor site differences accounted for a significant part of the overall variability in seedling leader growth (Hellum 1967). However, the variation in the *periodicity* of seedling leader growth is probably caused by genetic and site differences (Hellum 1967). Climate controls times of flushing but different trees may vary by 2 weeks or longer within a local population on apparently homogeneous sites. This variation has survival value because it makes the population less susceptible to frost damage (Sutton 1969).

Shoot growth occurs mainly at night with the rate controlled directly by night temperature (Sutton 1969). Three distinct patterns of seedling height growth have been observed (Sutton 1969): (1) height growth in one spurt and quickly completed by the first week in June; (2) growth as in (1), followed in 2 to 4 weeks by a second flush; and (3) indeterminate height growth continuing through July. After the third growing season, the number of seedlings exhibiting indeterminate height growth decreases rapidly.

White spruce is shade tolerant enabling it to endure long periods of suppression before succumbing to competition. Therefore, individuals in even-aged white spruce plantations can differ greatly in height (Stiell 1976). A coefficient of variation on the order of 31 percent can be expected.

White spruce has acquired the reputation of being a slow starting species. At Petawawa, Ontario, planted white spruce took between 6 (for all but dry sites) and 12 years (for the dry sites) to reach breast height (Stiell and Berry 1973). In the Lake States, Carmean and Hahn (1981) reported time to reach breast height for natural white spruce depended on site index:

Site index	Time to reach breast height (yrs)
30	15
40	13
50	11
60	10
70	9
80	8

Rudolf (1950) reported that plantation stock (not specifically white spruce) took between 5 and 15 years to reach breast height in the Lake States.

White spruce exhibits a period of retarded height growth that has been labeled "check." After an initial annual leader growth of only 3 to 4 inches the first year after planting, growth usually levels off at about 10 inches per year for a period of 6 to 10 years (Russell

[1]*Personal communication with Hans Nienstaedt, U. S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Rhinelander, Wisconsin.*

1963). Then suddenly 1 year the leader will grow 18 to 30 inches or more. Nienstaedt[1] maintains that check is not an inherent characteristic of white spruce but rather it is a management problem. A seedling from a genetically superior seed source planted on a suitable and well-prepared site with little competition, can grow from 10 to 14 inches in height the first year, and by the third year after planting such seedlings can grow from 18 to 24 inches per year in height.

Sutton (1975) describes the typical symptoms of check in white spruce seedlings: short, greenish yellow (10 Y 5-6/6) (Notation of Munsell Color Co., Baltimore, MD) needles, poor retention of needles 2 or more years old, small buds, and very slow growth.

Russell (1963) postulated that the rapid growth following check represented trees escaping a frost zone. He found that spruce planted under a nurse canopy of aspen or paper birch providing about 30 percent shade for the first 10 to 12 years were usually taller than those in the open. Beyond this age, overhead cover has a negative effect on height growth (Russell 1963, Stiell 1976). Logan (1969) found that white spruce can maintain its full height growth potential anywhere between 45 and 100 percent sunlight. Olson and Perala (1981) corroborated that shading of 3- to 4-year-old white spruce seedlings has a positive effect on height growth. They found that overhead cover helped protect the seedlings from attacks by the yellowheaded spruce sawfly (*Pikonema alaskensis*) without affecting height growth.

Diameter

Just as tree height varies greatly within stands, so does tree diameter. A 10 inch spread in diameter about the mean value is common for plantations with a mean d.b.h. from 5 to 7 inches (Stiell 1976).

The mean stand diameter is predictable using the independent variables of density (average spacing) and dominant height. Stiell and Berry (1973) give an example regression equation derived from the Petawawa plantations in Ontario, Canada:

$$D = 1.2553 + 0.0154SH - 0.00000642(SH)^2 \quad (R^2 = 0.927) \tag{1}$$

where:

D = mean stand d.b.h. (in.)
SH = average spacing (ft) × dominant height (ft)
Dominant height = mean height of tallest 10 percent, and
Average spacing (ft) = sqrt(43,560/trees per acre).

Crown Branches (paraphrased from Stiell 1969)

The crowns of white spruce trees contain main, internodal, and epicormic branches. Main branches develop annually from lateral buds at the apex of the leader and form annual whorls or nodes. The total number of live and dead branches on a white spruce tree is a function of the number of whorls, which depends on age. Plantation white spruce at Petawawa, Ontario had an average of 3 (range 1 to 6) main branches per whorl. Internodal branches are much smaller and are produced from buds distributed along the leader. Internodal branches are more than three times more numerous than main branches but contribute only 35 percent of the total crown branch cross-sectional area. Epicormic branches develop from dormant buds on the stem or branches and are normally present in white spruce crowns even without changes in the tree's environment.

White spruce crowns can be divided into three sections. The *dead crown* contains whorls with no living branches. It extends from the ground to a height that is a function of tree age and stand density. The whorls in the dead crown contain from 3 to 5 branches per whorl that persist and remain sound for 26 years and more.

The *partially live crown* contains both living and dead branches. It averages only 3 whorls and only 1.2 live branches per whorl.

The *live crown* begins at the first totally live whorl and continues to the top of the tree. Plantations ranging from age 13 to 41 contain an average of 12 live whorls per crown. The dominant trees average 14 live whorls per crown and suppressed trees average only 10.

Crown Foliage

Closed canopy white spruce plantations allow as little as 2 percent full sunlight to filter through resulting in a forest floor usually devoid of understory vegetation except for shade-tolerant mosses (Stiell 1976). Plantations from 30 to 40 years old have a maximum live crown ratio of 54 percent, an average ratio for dominants of 36 percent, and an average ratio for suppressed trees of 7 percent (Stiell 1976).

Crown foliage is borne primarily by the main branches (66 percent, range 37 to 99 percent), secondarily by the internodal branches (33 percent, range 62 to 1 percent), and finally by the main stem (about 1 percent of total foliage) between the top 5 to 10 internodes (Stiell 1969). Needles are retained for about 8 years. Shade needles weigh about half and have half as many stomates as sun needles (Logan 1969).

Roots

White spruce has four main root forms (Wagg 1967). An *elongated taproot* develops on well-drained soils of uniform texture. A *restricted taproot* develops on soils with textural changes between horizons or a compact horizon. A *monolayered* root system develops when excessive moisture constricts the roots near the soil surface. Finally, a *multilayered* root system develops with increasing moss layers or periodic alluvial or lacustrine deposition (Wagg 1967).

Rooting depth in white spruce is commonly between 90 and 120 cm (36 and 48 in.) (Nienstaedt and Zasada 1983). Although some taproots and sinkers descend 3 m (10 ft) into the soil, 85 percent of the root mass is in the top 30 cm (1 ft) (Stiell 1976). Safford and Bell (1972) determined that 43 percent of the fine roots reside in the top 5 cm (F and H horizons) of the soil and that a further 43 percent reside in the 5 to 15 cm layer (corresponding to the A mineral soil horizon).

The amount of intertree root grafting appears to vary greatly (USDA 1980). One study indicates that grafting is common on wet sites but rare on dry sites (USDA 1980). At Petawawa, Ontario, Stiell (1976) found 26 percent of trees in an unthinned plantation had root grafts compared to 37 percent in a thinned plantation. At least 10 percent of cut stumps were kept alive 7 years by root grafts.

Rapid penetration of roots to deeper soil layers is critical to seedling establishment because it assures access to a constant moisture supply and good competitive position vis'a'vis roots of other plants (USDA 1980).

Root and shoot growth occurs concurently in the spring (USDA 1980). Root elongation peaks at the end of May, drops sharply in early June, increases gradually during late June and July, and peaks again near the end of August (USDA 1980). The depressed rate of elongation in early June occurs during the period of rapid shoot elongation. This coincidence suggests a competitive relation between shoot and root for the available carbohydrates and nutrients.

Although it is the fine roots and their mycorrhizal associations that supply most of the water and nutrients to the trees, most studies concentrate on the large roots. In a continual search for new sources of water and nutrients, the fine-root component may lose and regain a substantial portion of its biomass in a single growing season (USDA 1980). Following severe drought, water and nutrient uptake may remain diminished even for a long time after conditions return to normal because a large portion of the fine root system may have died and must be regenerated (USDA 1980).

Reductions in light intensity (crown competition) or in the amount of tree foliage (pruning or insect defoliation) inhibits root growth more severely than shoot growth (USDA 1980). Trees with well-developed crowns have deeper and denser root systems than those of their smaller-crowned competitors. Therefore, managing stands for good crown development may be the best way to protect tree vigor (USDA 1980).

Within the range of moisture tolerance of white spruce, low soil moisture can be expected to impede shoot growth more than root growth. Consequently, on dry soils the root system usually comprises a higher proportion of the total plant biomass than it would on wet soils. In soils where water tables come within the reach of tree roots, a dense concentration of fine roots occurs in the zone of frequent water saturation (USDA 1980).

Biomass

Biomass equations for natural and plantation-grown white spruce trees in North America have been accumulated in Appendix B. An examination of these equations shows a wide variation in predictions for total, live, and above-ground biomass and a somewhat lesser, but still significant, variation in predictions for the biomass of the bole (wood and bark). Even the two biomass prediction equations developed from plantation-grown trees in the Lake States diverge sharply in their predictions. At present, therefore, I do not know which equation to recommend for predicting biomass in the upper Great Lakes region. Research to determine the causes of the variation in the predictions of white spruce biomass equations is being undertaken.

The distribution of average total tree biomass of 183 t/ha in a 39- and a 41-year-old plantation in Minnesota has been reported as follows (Perala and Alban 1982a): foliage, 8 percent; branches, 18 percent; bole bark, 6 percent; bole wood, 50 percent; stump and roots, 18 percent. Fine roots (5 mm diameter) were not included in this study. They usually comprise between 10 percent and 20 percent of the total root biomass (Stiell 1976, Safford and Bell 1972). A satisfactory approximation of the fine root biomass of individual conifer trees would be 2 to 3 kg (Safford and Bell 1972).

About 30 percent of a 1-year-old tree's biomass is in the root system (USDA 1980). This increases to about 50 percent for a 2-year-old tree. But as the tree ages, this proportion decreases to a steady-state value of approximately 20 percent (USDA 1980, Stiell 1976, Perala and Alban 1982a).

The weight of the foliage borne by individual whorls increases gradually from the top downwards, peaking in the lower third or quarter of the live crown (Stiell 1969). The heaviest whorl of suppressed trees bore 30 percent of the total crown weight (Stiell 1969).

The best estimator of foliage weight is stem diameter at the base of the live crown (Appendix B) (Stiell 1969). In cases where optical calipers are not available and trees cannot be felled, the next best estimator—d.b.h. multiplied by live crown length—may be used instead (Stiell 1969).

Specific gravity must be considered when converting between volume and dry weight (Schlaegel 1975). Volume and weight are directly related but differences in specific gravity within and between species substantially influence the weight per cubic meter. Schlaegel (1975) demonstrated that in one case, specific gravity of white spruce was only 83 percent of that reported by Panshin *et al.* (1964), a standard reference. Schlaegel (1975) reported a specific gravity value of 0.34 for a 40-year-old white spruce plantation in Minnesota. The average specific gravity of 22 white spruce seed sources in a 15-year-old north central Minnesota plantation was 0.325 (range: 0.303 to 0.389) (Stellrecht *et al.* 1974). Based on 78 trees from 26 plantations between 18 and 75 years old form a 70 mile radius around Grand Rapids, MN, Tjader (1978) reported a specific gravity mean of 0.357 (range: 0.273 to 0.449). Trees were categorized as (1) dominants, (2) equal to the mean basal area of the plot, and (3) intermediate or suppressed. The dominants had a mean specific gravity of 0.335 (range: 0.301 to 0.388), trees of mean basal area had a mean specific gravity of 0.337 (range: 0.273 to 0.397), and the intermediate and suppressed trees had a mean specific gravity of 0.376 (range: 0.330 to 0.440). Specific gravity tends to be lower in trees of the upper diameter classes and higher in trees of the lower diameter classes.

In two locations in Ontario, Alemdag (1982) reported an average specific gravity of 0.386. A sample of 232 white spruce trees from plantations throughout southern Ontario produces a mean specific gravity of 0.335 (range: 0.270 to 0.422) with a coefficient of variation of 8 percent (Chang and Kennedy 1967). Taylor *et al.* (1982) found that the average specific gravity for white spruce in Alberta, Canada, was 0.388 (range: 0.290 to 0.380). Radial growth rate is the most important factor affecting the amount of dry wood production per tree. Reduction in density due to increase in growth rate is negligible compared with the increase in tree volume (Chang and Kennedy 1967).

Volume

Appendix C contains board foot, cubic foot, and cordwood volume equations for plantation and natural stand white spruce trees. An examination of the cubic foot volume equations revealed much less variation in the predictions than that found when predicting bole biomass. Equations C1 and C2 form one group yielding similar results. Equations C4, C5, and C7 form a second group, consistent within, but yielding between 20 and 30 percent lower volume than group one. Equations C8 and C10, both formulations of the tables prepared for the Lake States by Gevorkiantz and Olsen (1955), form a third group, which generally predict like group one for the intermediate and larger trees and like group two for the smaller trees. We are currently evaluating each of these equations and their companion board-foot volume equations in order to support a choice between them. I could only find one stand level volume equation (C12) in the literature.

The stem volume of seedlings may be computed from the formula for the volume of a right cone: 1.047 r^2 h, where r is the stem radius at ground level and h is the height (Sutton 1975).

SITE RELATIONS

In this section I will discuss the interrelation between the abiotic components of a forest ecosystem and the biotic components discussed in the previous section. To actually *manage* a white spruce plantation, we must understand the role of each abiotic component in determining the behavior of the biological system, i.e., the stand. An excellent example of the complexity of these interrelations was presented by Stephens (1965). He found that the effects of soil temperature and moisture on white spruce seedling height growth varied from year to year reflecting the influence of that and the previous year's climate. In a moist year, height growth was greater on warmer soils while in a dry year, soil temperature was unimportant. In dry years, soil moisture was the growth-limiting factor and seedlings grew best on the moister soils.

Climate

White spruce generally grows in regions where the growing season is longer than 60 days (range 20 to 180) (Nienstaedt and Zasada 1983).

Because it is difficult to establish and grow white spruce in frost-prone areas, such areas should be avoided for plantations (Russell 1963, Stiell 1976). Typical frost-prone areas are depressions with insufficient drainage to prevent cold air from accumulating, sites immediately uphill from belts of trees on otherwise cleared slopes, and shelfs or plateaus on long slopes (Stiell 1976). The unseasonal browning of bracken fern foliage can help identify frosty locations.

Solar Radiation

White spruce seedlings grown in full and half sunlight are about equal in height growth. Three-quarters sunlight produces maximum height growth, and one-quarter sunlight yields minimum height growth (Logan 1969). A nurse-canopy of aspen or white birch, that reduces full sunlight by 25 to 30 percent, would allow maximum height growth of seedlings while protecting the seedlings from frost damage. However, a nurse-canopy decreases seedling vigor and biomass because root, shoot, and foliage weight increases progressively with increasing light intensity up to a maximum of full sunlight (Logan 1969). Logan (1969) found that 1 g of foliage produces a constant 2 g of shoot mass regardless of light intensity. The increased growth of white spruce seedlings in higher light intensities results from a greater foliage mass per seedling and not an increase in production per unit foliage.

Topography

Harding (1982) found that in Minnesota white spruce plantations growing on slopes greater than 10 percent tended to be low in productivity. Seedlings growing in depressions also have reduced height growth possibly either because the depressions aggravate the excessive moisture effects of sites with high water tables or because they create frost pockets (Olson and Perala 1981).

Soils

Significant differences in white spruce plantation productivity have been identified at the soil order and suborder classification levels. Alfisols supported more productive plantations than Inceptisols, and boralfs were more productive than aqualfs and ochrepts. No significant differences were found on the lower soil classification levels or between site index and taxonomic units (Harding 1982).

Soil moisture, fertility, structure, and texture are all interrelated in their influence on tree growth. On non-phreatic soils (water table deeper than 6 feet), Russell (1963) reported optimum growth on soils with a silt plus clay content between 20 and 60 percent and with moisture-retaining bands of silt or clay. The silt plus clay percentage had little relation to growth when the bands were missing. Wilde *et al.* (1965) reported low productivity when silt plus clay was less than 15 percent and organic matter was less than 3 percent (table 1). On these soils, moisture deficiency is the overwhelming growth-limiting factor. Olson and Perala (1981) compared average total height at the end of the fourth growing season to soil texture for 12 plantations growing in northern Minnesota and Wisconsin:

Soil texture	Total height (cm)
Sands	42
Loamy sands	43
Sandy loams	46
Loams	50
Sandy clay loams	52
Clay loams	71
Clay	35

In Quebec, soil fertility and texture have affected the performance of white spruce plantations (Truong dinh Phu 1975). On medium- to heavy-textured soils derived from fluvial deposits and till, growth was vigorous and rapid. On sandy soils developed on fluvio-marine and outwash deposits, growth was poor accompanied by a high failure rate.

As soil moisture increases up to some optimal level, availability of nutrients becomes increasingly growth limiting. Wilde *et al.* (1965) found that growth of plantations was related to soil profile constituents instrumental in water retention and nutrient availability. These constituents are the mineral and organic colloidal particles, whose effects may be measured by the cation exchange capacity (CEC). Highly productive sites are associated with large supplies of colloids (high CEC), organic matter, and nutrients. On such sites spruce grows so well that it overcomes the competition of volunteer trees and shrubs (Wilde *et al.* 1965). Average productivity is associated with soils providing only adequate moisture retention and a low to moderate CEC. On these sites competition from other species contributes to reduced productivity.

Nutrients

Foliar analysis has been used to determine the nutrient status of white spruce trees. Swan (1971) offered a set of provisional standards against which white spruce seedling foliar analysis data may be compared (table 2). These standards may be used for

Table 1.--Fertility of soils supporting white spruce plantations in Wisconsin (Wilde 1966)

Site quality	Approx site index	Silt plus clay	Organic matter	Exchange capacity	Total N	Available P_2O_5	Available K_2O	Exchangeable Ca	Exchangeable Mg	Height growth
		Percent	Percent	Me/100 g	Percent	Lbs/A	Lbs/A	Me/100 g	Me/100 g	In./yr
Low	30	12.4	3.3	5.8	0.110	78	113	1.94	0.59	5.7
Medium	48	36.6	4.3	12.2	0.156	75.8	126	3.69	0.74	10.1
High	57	44.2	4.6	14.3	0.173	96	161	4.48	0.88	13.3
Recommended minimum soil fertility standards	52	40	3.5	12.0	0.12	90	150	3.0	0.7	--

mature trees if it can be shown that optimum nutrient concentrations in foliage are independent of tree age. In contrast to the values reported by Swan (1971), Sutton (1975) found that low nutrient concentrations in current-year foliage of seedlings equates to less than 1.00 percent for N, 0.10 percent for P, and 0.3 percent for K.

On low productivity sandy soils in Quebec, Truong dinh Phu (1975) reported the following foliar nutrient concentrations:

Nutrient	Concentration (Percent)	Coefficient of variation
Nitrogen	1.12	6.7
Phosphorus	0.19	7.6
Potassium	0.42	26.4
Magnesium	0.1	8.6

Table 2.--Suggested standards for foliar element concentrations of white spruce (Swan 1971)1/, 2/

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
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 substantial response should be anticipated in this range

1/ These values refer to the results of analyses made of the current year's needles collected in the fall (mid-September to mid-November) from the upper one third of the crown.

2/ These suggested standards are essentially judgments; they are based both on the results of greenhouse studies and on experience gained from the use of foliar analysis in field studies.

Growth on these sites was primarily limited by potassium-foliar potassium concentration of 0.6 percent is needed for good growth on these sites (Truong dinh Phu 1975).

Soil fertility levels along with suggested minimum soil fertility standards have also been published (table 1). Harding (1982) found that low levels of phosphorus may be associated with low productivity of white spruce plantations in Minnesota.

Tables 3 and 4 show the distribution of nutrients by tree component for plantation white spruce in Minnesota and natural white spruce in Nova Scotia, respectively.

A comparison of nitrogen concentrations of white spruce foliage in natural stands in Saskatchewan, Canada, yielded further evidence that the interaction between abiotic and biotic components of an ecosystem often produces enigmatic results. Van Groenewoud (1965) contrasted upland and lowland white spruce communities with soil texture by looking at foliage nitrogen concentration and height growth. Lowland community types had foliage nitrogen concentration of 1.07 percent (acute deficiency range) compared to 1.25 percent (moderate deficiency range) for the upland communities. Lowland communities on clay or loam soils, representing poor aeration and permeability, had poor height growth. Lowland communities on sandy soils, representing improved aeration and permeability, had good height growth. The lowland community white spruce trees on the sandy soils showed this good height growth despite having

Table 3.--Distribution of nutrients by tree component as a percentage of whole tree content for plantation white spruce in north central Minnesota (Perala and Alban 1982a)

A. Loam soil, 39 years old, 41.1 m^2/ha basal area, 19.7 m site index, 2,187 trees/ha density

Element	Tree component: Total tree component	Foliage	Branches	Bole bark	Bole wood	Root and stump
Nitrogen	209	33	29	10	13	15
Phosphorus	30	41	27	13	8	11
Potassium	119	33	32	12	13	10
Calcium	378	31	27	20	11	11
Magnesium	21	28	30	16	14	12

B. Sand soil, 41 years old, 44.9 m^2/ha basal area, 18.6 m site index, 2,718 trees/ha density

Element	Tree component: Total tree component	Foliage	Branches	Bole bark	Bole wood	Root and stump
Nitrogen	168	35	27	12	15	11
Phosphorus	19	35	29	14	8	14
Potassium	72	33	29	13	13	12
Calcium	267	19	28	25	15	13
Magnesium	18	23	33	18	14	12

Table 4.--Distribution of nutrients by tree component as a percentage of whole-tree nutrient content for natural white spruce in central Nova Scotia (Freedman et al. 1982) 1/

		Tree component					
Nutrient	Whole tree weight	Wood merchantable stem	Bark merchantable stem	Wood + bark unmerchantable stem	Dead branches	Wood + bark live branches	Foliage
Nitrogen	375	27	14	1	6	18	35
Phosphorus	48	25	16	1	4	20	34
Potassium	144	8	21	1	3	26	41
Calcium	487	18	37	1	10	18	16
Magnesium	54	27	22	1	7	20	23

1/ Percent distribution was calculated as the weighted average of sample trees having dbh greater than 15 cm. Whole tree weight was calculated as an unweighted average.

the same "acutely deficient" foliar nitrogen concentration as the poorly growing lowland community on the clay or loam soils. Furthermore, some upland communities grew as poorly as the clay/loamlowland community despite a much higher foliar nitrogen concentration.

Jameson (1963) compared height and diameter growth in two natural white spruce-aspen stands in Manitoba, Canada; one growing on a moist site and one growing on a fresh site. The height growth on the moist site was less than that on the fresh site. Jameson (1963) contended that poor soil aeration and low soil temperatures during the early growing season, when white spruce experiences 60 and 70 percent of its seasonal height growth, retarded height growth of trees on the moist site. On the other hand, diameter growth was better on the moist site than the fresh site for all but the largest diameter classes. This resulted from low moisture levels on the fresh site after June 20, when 70 percent of the season's diameter growth occurred. There is no substitute for an intimate knowledge of the biological organism, the white spruce tree, and the environment in which it lives.

Tree nutrition is fundamentally different from the nutrition of annual agronomic crops. The conservation of nutrients in forests by internal cycling provides an important portion of the annual nutrient demand. For example, Perala and Alban (1982b) found that nutrients on an infertile sandy soil were recycled more rapidly than on a richer loamy soil. "This compensated somewhat for the lower inherent fertility of the sand and forest productivity was comparable to the more fertile loam soil" (Perala and Alban 1982b).

Water

In general, white spruce will tolerate dry sites if they are fertile, and no fertile site is too moist unless the soil water is stagnant (Sutton 1969). Kenety (1917) concluded that available moisture is the best single predictor of white spruce productivity. Wilde *et al.* (1965), finding no relation between soil nutrients and productivity, concluded that available moisture was the governing factor in white spruce plantation growth. They found that soil cation exchange capacity best predicted growth of white spruce because it combined a measure of water retention ability with a measure of soil fertility. Stiell (1958) concluded that white spruce is not suited to dry sites, and the future of plantations established on them is not bright. The key to good growth of white spruce is a season-long dependable supply of well-aerated water (Nienstaedt and Zasada 1983). The worst possible combination is a dry and infertile site.

White spruce growth varies on phreatic sites (water table influenced). Kenety (1917) concluded that a water table near the surface is favorable for growth allowing white spruce to occupy rather sandy and coarse soils. In contrast, Russell (1963) found that a water table less than 6 feet deep retarded growth for plantations in northeastern Wisconsin and the upper peninsula of Michigan. Flat, open areas had poorer growth than did gently rolling slopes that allowed better drainage and warmer spring temperatures (Russell 1963). It may be that on phreatic sites white spruce grows well only on coarse soils, which have good aeration and high permeability.

Site Quality

The height of dominant trees at a given age is widely used as an index of site quality and productivity. But because of the difficulties in establishing white spruce plantation seedlings, total height may be an unreliable index of site quality (Stiell 1958). By the time white spruce seedlings reach breast height, check and the rapid growth spurt following it are past (after Russell 1963) and more or less uniform, rapid height growth is attained (Stiell 1958). Then, average annual height growth of dominants may be used as a measure of site quality and productivity (Stiell 1958). Although true dominance has not been expressed by trees in young, unclosed plantations, the tallest trees will include almost all the future dominants (Stiell 1958). Stiell (1958) proposed using the mean height of the tallest 10 percent of the trees in a stand (or plot) as the dominant height. Average annual height growth is computed by dividing the mean height above breast height of the tallest 10 percent by mean age of those same trees (Stiell 1958).

Using average annual dominant height growth of white spruce plantations at Petawawa, Ontario, Canada, Stiell (1958) produced a standard site quality classification for evaluating white spruce plantation growth:

Poor	1.17 to 1.37 ft/yr
Average	1.38 to 1.58 ft/yr
Good	1.59 to 1.77 ft/yr

Wilde *et al.* (1965) also used average annual height growth to establish three site quality classes for white spruce plantations in Wisconsin. They used total height and total age to compute average annual height growth of dominant and codominant trees of average diameter. Their classes are defined as:

Poor	4 to 8 in/yr	
Average	9 to 11 in/yr	
Good	12 to 19 in/yr	(SI = 57)

Of the 44 white spruce plantations Wilde *et al.* (1965) surveyed, 16 percent were in the poor class, 50 percent were in the average class, and 34 percent were in the good class. These guidelines were developed for 15- to 33-year-old white spruce plantations. As the plantations get older, the average annual height growth rates will decrease.

Stiell and Berry (1973) presented anamorphic site index curves for the Petawawa white spruce plantations at index age 50 (Appendix D). Berry (1978) presented the metric versions of these curves, which indicate that height growth rates begin to decline at about 35 years of age. Other published site index curves are for natural white spruce trees in Minnesota (Gevorkiantz 1957) and for planted white spruce in southern Ontario (Love and Williams 1968).

Site index equations are available to quantify the Gevorkiantz curves for the Lake States (Carmean and Hahn 1981) (Appendix D). Payandeh (1974) presented a formulation of the site index curves developed for natural white spruce stands in Saskatchewan by Kabzems (1971). Wilde (1970) reported a site index equation for white spruce plantations in Wisconsin using soil textural and chemical variables as predictors. I found that the site index predictions using Payandeh's equation and Stiell's curves agreed well. Predictions based on Love's curves were about 5 feet higher than the other two. Predictions using the Carmean and Hahn equation agreed with the first two after age 40. When total stand age was less than 40 years, the Carmean and Hahn equations gave progressively erratic results. Gevorkiantz's site index curves are based on breast height age and therefore are difficult to compare with systems based on age from planting. I cannot at this time recommend which site index prediction to use, but research is underway to resolve this question.

The problem of predicting white spruce plantation productivity in the absence of white spruce on a given site has not yet been solved. But it is possible to extrapolate from experiments that report site indices of multiple species growing on similar adjacent sites. One such study reported the site indices of 40-year-old stands growing on the same very fine sandy loam soil in north-central Minnesota as: 22.9 m for aspen, 20.7 m for red pine, 21.3 m for jack pine, and 18.3 m for white spruce (base age for site index is 50 years) (Alban *et al.* 1978).

POPULATION DYNAMICS

Productivity

Russell (1963) found tremendous productivity differences among white spruce plantations of equal age. These differences reflect variation in site quality, genotypes, stocking levels, and level of volunteer competition (Russell 1963, Kingsley and Mayer 1972).

Olson and Perala (1981) noted that choosing a sensitive and meaningful measure of productivity is difficult and results of experiments will differ greatly between growth measures.

Yield estimates for white spruce plantations are meager. Yield tables are available for the Petawawa plantations in Ontario (Stiell 1976) (Appendix E). These tables represent unmanaged, high survival plantations. Berry (1978) reported the metric version of these tables. The values in these tables probably represent the highest stocking that can be expected for a given planted spacing and show maximum yields for the site indices given.

Love and Williams (1968) produced yield tables for three productivity classes in southern Ontario using single measurements and stem analysis (table 5 and Appendix E). Wilde *et al.* (1956) prepared volume over age curves for three site index classes for plantations of white spruce in Wisconsin. The curves project to age 80 although the oldest plantations were only 33 years. No other plantation yield tables have been published. Even the tables that are available are incomplete because plantations are not yet old enough to have reached rotation age (Stiell 1976)—plantations at Petawawa did not reach their maximum mean annual increment until age 55 (Stiell 1980).

In Wisconsin, plantations achieving poor height growth were either on droughty and infertile sites or on fertile sites with heavy volunteer competition (Wilde *et al.* 1965). At age 23, these plantations produced an annual increment of only 6 cubic ft/acre/year and were not expected to yield merchantable wood by age 60. In contrast, Stiell (1958) found that it took only 13 to 14 years on the best sites for white spruce plantations to achieve merchantability. At the same age, plantations of medium productivity (height growth rate) averaged 24 cubic ft/acre/year with an expected yield of 30 to 35 cords/acre at age 60. Highly productive plantations grew 40 cubic ft/acre/year and promised to yield 50 cords/acre at age 60.

Five species established in adjacent strips on the same soil type 40 years earlier had drastically different yields (Schlaegel 1975). A black spruce stand had 183 cubic meters/ha (29 cds/ac), aspen, jack pine, and white spruce had 268 cubic meters/ha (43 cds/ac), and red pine had 408 cubic meters/ha (65 cds/ac). Total tree biomass was greatest for red pine (243 tonnes/ha) followed by aspen, spruce, and jack pine, (205, 185, and 175 tonnes/ha, respectively) (Alban *et al.* 1978).

Frogness (1975) presented expected yield at age 50 for the same soil type having a site index for hardwoods between 60 and 65:

Species	**Yield at age 50** (Cds/acre)
Hardwoods	20 to 25
Birch	25 to 30
Red pine	40 to 50
Spruce	35 to 45
Aspen	30 to 40

Wilde *et al.* (1965) postulated that the soil organic matter content and nutrient availability cease to be growth-limiting factors as aging forest stands correct the temporary soil deficiencies caused by logging, fire, and farming. The rate of growth, timber quality, and reproductive capacity is expected to become more and more closely related to the climatic, physiographic, and soil profile features of the site. They contend that organic matter content of the soil is the best indicator of forest productivity through its strong correlation with cation exchange capacity and the supply of nitrogen and other nutrients.

When I examined the yield tables, I found they varied greatly. First, no plantation yield tables have been derived from research in the Lake States. The empirical yield tables resulting from the USDA Forest Service Survey, combines natural stands and plantations and reports an average across all site quality classes. It appears that yields from natural

Table 5.--White spruce production classes (Love and Williams 1968)

Potential production class	Total volume production at 50 years		Mean annual increment at 50 years		Dominant height at 50 years	
	Range	Average	Range	Average	Range	Average
	1,000 cu ft/acre		cu ft/acre		feet	
I	7.01-8.50	7.75	140-170	155	62+	64
II	5.49-7.00	6.25	110-140	125	56-62	59
III	4.00-5.50	4.75	80-110	95	48-56	52

stands in Alaska and the Canadian prairie provinces are not useful indicators of expected plantation yields in the Lake States. Plantation yields reported for Petawawa, Ontario (tables 13-16), and for plantations in southern Ontario (table 12) may be more useful.

Competition

Young white spruce plantations profit significantly when removed from competition, especially grasses (Stephens 1965, Sutton 1975). Survival, height growth, and seedling vigor are all increased. The benefit to seedlings relieved from competitive stress has often been attributed to the greater availability of soil moisture. "In dry seasons, on densely vegetated sites, the soil moisture conserved by weed control can mean the difference between life and death" (Sutton 1975).

For white spruce, the ratio of leader length to the length of the lateral shoots in the uppermost whorl is usually a good indicator of tree vigor (Sutton 1975). The greater the ratio, the greater the vigor. Another indicator of tree vigor is periodic diameter growth rate based on periods not less than 2 years and not more than about 5 or 10 years (Buchman and Lentz [in press]). Diameter growth rates for white spruce have been computed and usually fall between 0 and 0.2 in/yr.

White spruce can withstand overhead shade but diameter growth is impaired (Wilde *et al.* 1965, Stiell 1976). However, open-grown plantations suffer damage by late spring frosts (Wilde *et al.* 1965). White spruce is more shade tolerant than aspen or paper birch and equally or less tolerant than black or red spruce, hemlock, balsam, sugar maple, and beech (Nienstaedt and Zasada 1983). White spruce plantations, if overtopped, will survive and eventually outgrow competitors on suitable sites but at the expense of excessive mortality and a prolonged rotation (Stiell 1976).

Lateral crown competition curtails diameter growth without negatively affecting height growth (Stiell 1976).

As a result of working with the Petawawa plantations in Ontario, Stiell (1976) concluded that competition below the ground was more growth limiting to productivity than competition above the ground. He noted that trees responded to thinning by a greater increase in foliage weight relative to fine root weight. The crown was better able to take advantage of the reduction in competition than the root system could.

Olson and Perala (unpublished) found indications that white spruce is more sensitive to root competition when growing in clay soils possibly due to the limited soil moisture and aeration.

Mortality

Most seedling mortality occurs within the first 5 years after planting (Stiell 1958). During these years, seedlings are most susceptible to extremes of climate and soil moisture (Stiell 1976). Stiell (1976) found an average survival of 61 percent for bare-rooted stock in Ontario. One-fifth of the plantations had better than 80 percent survival, 42 percent had better than 70 percent survival, and 65 percent had better than 60 percent survival. Subsequent mortality rates are normally low except due to climate- or soil-induced drought or volunteer competition (Stiell 1958, 1976). After stands close, competition between white spruce trees contributes to mortality. For modeling purposes, mortality should be predicted separately for the following phases: establishment, ages 1-5; immature, ages 6-30; mature, ages 31-80; and overmature, ages 81+.

Stiell (1958) found that site or climatic factors such as drought, frost-heaving, flooding, or exposure, caused plantation failure most frequently. Next in frequency were failures attributable to establishment factors such as improper planting, planting too late in the season with active stock, and poor quality or overly large planting stock. Less frequently, competition from other vegetation, notably grasses, caused plantation failure. Finally, other biotic factors such as browsing, girdling, defoliating, or fire also caused some failures.

Stiell and Berry (1973) related mortality due to mutual competition to stand density and height. The height variable incorporated the effects of both age and site:

$$M = -75.3706 + 0.3552\ NH + 0.0067\ NH^2 \quad (R^2 = 0.645)$$

where:

M = number of trees dying for the next 1-meter increase in dominant height, and

NH = present trees/ha × (dominant height/100).

Mortality increases with greater heights and greater density.

The onset of mortality can also be predicted (Stiell and Berry 1973):

$$Y = 0.7871 + 16717.7715 / X \quad (R^2 = 0.999)$$

where:

Y = the dominant height at which mortality begins, and

X = the initial number of trees per hectare.

The above equations allow predictions for the total number of trees in a stand. Evert (1981) developed models to predict the 5-year mortality in total number of trees per hectare and its distribution by tree size. The tree-size distribution was obtained by dividing the number of trees in each plot into five groups of equal numbers, which are ranked by diameter from smallest to largest (Appendix F).

Buchman and Lentz (in press) developed an individual tree survivor model for plantation-grown white spruce based on permanent plot data from two research plantations in the Lake States (Appendix F). This model uses current DBH and past diameter growth rate (DGR) to determine the probability of a tree surviving one more year. DGR was based on periodic diameter growth with a period not less than 2 years and no more than 6 years. Using this system, it is easy to compute the likelihood of mortality for any given tree in a stand. For example, suppose we have a 2 inch tree with a 5 year DGR of 0.02 in/yr. By solving the equation or using the table (Appendix F), we find that the probability of this tree surviving one more year is 0.7996. For predictive purposes, one could take every tree in a stand or plot, calculate the survival probability, generate a random number between 0 and 1, and call a tree dead if the random number is greater than the survival probability.

CULTURAL PRACTICES

Thinning

Two major decisions must be made before thinning—(1) the type of tree to be cut, and (2) the intensity of the thinning, which involves the volume removed as well as the residual stand stocking (Stiell 1976). Three thinning methods are common: (1) row thinning, in which a fixed proportion of the rows in a stand are removed; (2) basal area, in which the goal is to leave a fixed residual stand basal area; and (3) percent of height, in which the stand is maintained at a spacing between residual trees corresponding to a fixed percentage of average tree height (Day and Rudolph 1970).

The basal area method may be implemented by thinning from below, in which the smaller trees in the stand are removed, or by crown thinning, in which dominant and codominants are removed in order to release selected crop trees. Thinning on at least three sides of white spruce is needed before a significant effect can be realized (Frank 1973). The minimum distance between the crown of a selected crop tree and the crowns of competitors on each thinned side should be equal to the crown diameter of the tree being released (Frank 1973). Stands denser than about 800 trees/acre and more than 40 feet tall must be thinned either by row removal and/or cutting of crosswise skidding trails (Stiell 1976).

At Petawawa, removing every second row produces better thinning results than removing every third row (Stiell 1976). Removing every second row in 30- to 35-year-old plantations at Petawawa yielded 10 to 19 cds/ac and left a residual basal area between 109 and 120 ft^2/ac (Stiell 1976). Removing every second row in a 30-year-old plantation in Michigan yielded 18 cds/ac and left a residual basal area of 87 ft^2/ac (Day and Rudolph 1970).

Plantations of 33-year-old white spruce can be thinned from below to basal areas between 100 and 140 ft^2/ac without reducing volume growth per acre (Stiell 1976). These thinnings represent stocking of 64 percent to 79 percent of the original basal area of the stands and yielding of 8 to 3 cds/ac, respectively (Stiell 1976). Reducing basal area to 52 percent of original stocking significantly reduced productivity. Based on results from 15 years of growth following a thinning from below at age 23, Wambach and Cooley (1969) concluded that volume growth appears to increase with higher residual basal area up to about 100 or 120 ft^2/ac before dropping off.

In a crown thinning study at Petawawa, Ontario, Stiell (1976) removed the active competitors of 150 crop trees in 31-year-old, site index 80 plantations. He concluded that thinning to a basal area of 110 ft^2/ac (61 percent of maximum basal area) would produce about 7 cds/ac and give the best combination of growth per tree and growth per unit area. A second crown thinning, again to 110 ft^2/ac, at the end of 10 years yielded about 13 cds/ac.

Untreated plantations are close to their maximum mean annual increment for fiber production at age 55 (Stiell 1980). If cut then, they will have lost about 10 percent of their total volume through natural mortality.

Fertilization

Fertilization has the potential to improve site quality, but many uncertainties concerning the magnitude of response to particular rates on particular sites and the economics of the operation allow for few recommendations to date (Stiell 1976). Benzie (1975) states that to his knowledge, fertilization was not practiced in Minnesota, and it is unlikely that it will be practiced until a comprehensive benefit/cost analysis has been made of fertilization in Lake States plantations.

Referring to very young plantations, Sutton (1975) observed that although foliar nutrient concentrations of seedlings may be readily increased by inorganic fertilization, growth responses are erratic, often small, and commonly negative. Olson and Perala (1981) also found that nitrogen fertilization either was deleterious or had no effect on height growth of young planted white spruce.

Shephard (1981) observed that "fertilization of forest stands to increase growth offers most promise where competition among individual trees for light and water is not so intense that the trees are not able to respond to the improved nutrient conditions brought about by fertilization." He fertilized three row-thinned, Maine white spruce plantations, approximately 50 years old, with three levels of urea (46 percent N). After 3 years, foliar nitrogen had increased from 1.3 percent to 1.6 percent, diameter growth had not increased significantly when all trees were considered, and diameter growth in two of the three plantations increased significantly when only the largest 50 percent of the trees were examined. It is possible that levels of other macronutrients such as phosphorus or potassium limited growth.

Van Cleve and Zasada (1976) reported the basal area growth response of natural white spruce stands in Alaska (site index 85) to four treatments: control, thinned only, fertilized only, and thinned and fertilized. Fertilizer (N-P-K) was applied each spring for 5 years and density was reduced by 77 percent (reduced by 60 percent of basal area). The thinned +fertilized treatment consistently produced the greatest basal area increment. By the end of the first growing season, diameter increment of thinned and thinned +fertilized plots was 2.6 and 3.6 times greater, respectively, than growth in the control or the fertilized plots. Basal area growth in the thinned and thinned +fertilized plots began earlier and continued later than that in the control and fertilized only plots. Nutrient deficiencies were apparently not the sole cause of reduced tree diameter growth in this study. Improved moisture, light, and soil temperature regimes, due to thinning, were also important, and their interaction with improved soil nutrient levels produced maximum growth response. The optimum level of basal area with respect to age and prior stand history has not been established. The question of impact on volume growth of heavy thinning still remains.

Working with white spruce seedlings in sand cultures, Swan (1971) showed pronounced response to increasing nitrogen supply in the range of foliar concentration frequently encountered in the field—i.e., 1.00 to 1.50 percent. Best growth was obtained when foliar nitrogen was in the range from 2.00 to 2.60 percent. This would suggest that a growth response may be expected when foliar nitrogen concentrations are below about 2.00 percent if growth is not limited by some other factor (Swan 1971).

In natural white spruce stands in Alaska, Van Cleve and Zasada (1976) showed that fertilization increased foliage nitrogen concentration from about 1.09 percent in controlled and thinned only plots to 1.57 and 1.59 percent in fertilized only and fertilized and thinned plots, respectively. Graphs of volume growth against foliar N concentration produced an optimum curve with no further increase in growth when N concentration was greater than 1.8 percent. They cautioned that the interaction of multiple nutrient additions and thinning complicates interpretation of foliage nutrient concentrations in relation to increases of basal area and volume.

RESEARCH NEEDS

This literature review revealed many opportunities for research to fill critical information gaps. I have grouped them under four broad categories: growth and yield, check, intermediate silviculture, and silvicultural systems.

1. **Growth and Yield.**—No adequate predictive systems are available to estimate the yield of unthinned or thinned white spruce plantations in the Lake Sates. In addition, we do not have a system to predict yield by white spruce seed sources although it has been clearly demonstrated that a great range exists in yield due to genetic variation. We also do not have plantation site index equations nor regional volume or biomass equations. Several local volume and biomass equations have been developed, but we don't know how well they can be extrapolated to apply to the region as a whole.

2. **Check.**—We need to understand what factors contribute to and how to minimize the reduced growth period called "check." The first part of this research problem is selecting adequate sites for white spruce afforestation. We should develop better guidelines for the practitioner to determine the proper nutrient and moisture regimes for white spruce. We also need more site-specific guidelines to determine the frequency and severity of spring frosts. Once we can identify adequate sites, we need to develop guidelines for competition control, fertilization, seed sources, planting stock, and planting conditions.

3. **Intermediate Silviculture.**—Results from thinning experiments conducted in the Lake States are sparse. By extrapolating from Canadian research results, it is possible to present only general guidelines. We need to develop stocking charts to help us evaluate when to thin and by how much. Stocking

charts also allow us to categorize our stands according to site occupancy, i.e., understocked, well-stocked, or overstocked.

4. **Silvicultural Systems.**—We need to explore the range of silvicultural systems for managing white spruce plantations in the Lake States. Once a stand is established, can we develop natural white spruce regeneration on that site to establish the next stand? Can we develop uneven-aged systems as well as even-aged systems?

If we can learn to consistently select the correct sites and then manage the established plantations properly, white spruce plantations should provide a greatly increased yield and assure a greater role as a favored coniferous species in forest management in the Lake States.

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APPENDIX A. Height Prediction Equations

$$H = 10.8738\ S^{0.5529}\ (1.0-e^{-.0343A})^{34.688S^{-.6139}} \quad \text{(A1)}$$

$R^2 = 0.99$ SE = 2.33

where:

H = Total height of dominant and codominant trees; (ft.)
S = Site index base age 50
A = Total age (yrs.)
e = Base of natural logarithm

(Carmean and Hahn 1981) (Lake States) (Natural)

$$H = 4.5 + 4.552S^{0.73627}\ (1.0-e^{-.028976A})^{26.7334S^{-.638086}} \quad \text{(A2)}$$

SE = .998

H = Total height of dominant and codominant trees (ft.)
S = Site index base age 50
A = Breast height age (yrs.)
e = Base of natural logarithm

(Ek 1971) (Lake States) (Natural)

$$H = 1.8939S^{0.9591}\ (1.0-e^{-.023A})^{1.2765S^{0.005}} \quad \text{(A3)}$$

$R^2 = 0.998$ SE = 1.0

H = Height of dominant and codominant trees (ft.)
S = Site index (base age 50)
A = Total age (yrs.)

(Payandeh 1974) (Canada) (Natural)

$$H = 3.9 + 0.57\ CEC \quad \text{(A4)}$$

$R^2 = 0.632$ SE = 2.15

H = height growth (in/yr)
CEC = cation exchange capacity (me/100 g)

Range of Validity:

1) plantations $\geq$ 700 trees/ac
2) nonphreatic soils
3) overhead tree canopy <30 percent by density

(Wilde *et al.* 1965) (Wisconsin) (Plantation)

APPENDIX B. Biomass Prediction Equations

Table 6.--Biomass equations for predicting ovendry weight for aboveground components of white spruce[1/]

(Weight (W) in kg, Diameter (D) in cm, and Height (H) in m)
(Freedman et al. 1982)

Component Equation	n	R^2	s	c
Wood, merchantable stem				
$\ln W = -5.7344 + 1.1571 \ln D^2H$	19	0.983	0.1723	1.01
$\ln W = -4.2667 + 2.9078 \ln D$	19	.975	.2065	1.02
$\ln W = -5.7889 + 2.2904 \ln D + 1.2019 \ln H$	19	.983	.1776	1.02
$W = -9.1184 - 0.5200\ D + 0.2750\ D^2$	19	.967	--	--
Bark, merchantable stem				
$\ln W = -7.0710 + 1.0777 \ln D^2H$	19	.978	.1806	1.02
$\ln W = -5.7144 + 2.7121 \ln D$	19	.973	.1996	1.02
$\ln W = -6.8715 + 2.2427 \ln D + 0.9136 \ln H$	19	.978	.1854	1.02
$W = -1.8989 + 0.1028\ D + 0.0290\ D^2$	19	.988	--	--
Wood + bark, merchantable stem				
$\ln W = -5.5267 + 1.1475 \ln D^2H$	19	.983	.1707	1.01
$\ln W = -4.0722 + 2.8841 \ln D$	19	.976	.2036	1.02
$\ln W = -5.5560 + 2.2823 \ln D + 1.1716 \ln H$	19	.983	.1759	1.02
$W = -11.0173 - 0.4172\ D + 0.3040\ D^2$	19	.971	--	--
Wood, total stem				
$\ln W = -2.9709 + 0.8444 \ln D^2H$	24	.991	.1928	1.02
$\ln W = -2.6159 + 2.3715 \ln D$	24	.990	.2013	1.02
$\ln W = -2.8267 + 1.9871 \ln D + 0.4799 \ln H$	24	.992	.1861	1.02
$W = 1.9240 - 1.2503\ D + 0.2940\ D^2$	24	.974	--	--
Bark, total stem				
$\ln W = -4.0071 + 0.7322 \ln D^2H$	24	.986	.2074	1.02
$\ln W = -3.7049 + 2.0588 \ln D$	24	.987	.1977	1.02
$\ln W = -3.8315 + 1.8278 \ln D + 0.2884 \ln H$	24	.988	.1962	1.02
$W = -0.0218 - 0.0350\ D + 0.0320\ D^2$	24	.989	--	--
Wood + bark, total stem				
$\ln W = -2.6926 + 0.8268 \ln D^2H$	24	.990	.1973	1.02
$\ln W = -2.3463 + 2.3226 \ln D$	24	.989	.2010	1.02
$\ln W = -2.5395 + 1.9702 \ln D + 0.4399 \ln H$	24	.991	.1894	1.02
$W = 1.9022 - 1.3853\ D + 0.3260\ D^2$	24	.977	--	--
Dead branches				
$\ln W = -4.3333 + 0.7326 \ln D^2H$	24	.892	.5970	1.20
$\ln W = -4.1245 + 2.0979 \ln D$	24	.926	.4926	1.13
$\ln W = -3.3061 + 3.5908 \ln D - 1.8638 \ln H$	24	.963	.3618	1.07
$W = 1.5188 - 0.5481\ D + 0.0510\ D^2$	24	.855	--	--
Wood + bark, live branches				
$\ln W = -4.2909 + 0.7569 \ln D^2H$	24	.834	.7907	1.37
$\ln W = -4.1003 + 2.1778 \ln D$	24	.874	.6877	1.27
$\ln W = -3.0015 + 4.1821 \ln D - 2.5022 \ln H$	24	.932	.5233	1.15
$W = 4.9325 - 1.4654\ D + 0.0970\ D^2$	24	.891	--	--
Foliage				
$\ln W = -4.5415 + 0.7615 \ln D^2H$	24	.862	.7134	1.29
$\ln W = -4.3267 + 2.1816 \ln D$	24	.896	.6191	1.21
$\ln W = -3.4534 + 3.7747 \ln D - 1.9889 \ln H$	24	.933	.5125	1.14
$W = 0.6208 - 0.2722\ D + 0.0390\ D^2$	24	.904	--	--

1/ Sample size = 25 DBH Range (cm) = 1.5 - 29.5 H Range (m) = 1.9 - 21.2

Table 7.--Equations for predicting biomass (kg) of white spruce in the Prairie Provinces of Canada[1] (Singh 1982)

Tree component		Mean	Standard deviation	Equation 2/, 3/	R^2	Standard error of estimate
Stump	Wood	5.61	5.58	$W_1 = -0.01874 + 0.04588D + 0.00377D^2 + 0.00016D^3$	0.98	0.84
				$W_2 = -0.09066 + 0.12803D - 0.07109H - 0.00005D^2H + 0.00400D^2 + 0.00016D^3$	0.98	0.84
				$W_3 = 0.42003 + 0.00043D^2H$	0.96	1.08
	Bark	0.68	0.63	$W_1 = 0.04249 - 0.00610D + 0.00172D^2 - 0.00001D^3$	0.84	0.26
				$W_2 = 0.01382 + 0.02543D - 0.02681H - 0.00002D^2H + 0.00176D^2 - 0.00001D^3$	0.85	0.25
				$W_3 = 0.14292 + 0.00004D^2H$	0.81	0.28
Stem ≥10 cm	Wood	134.31	142.73	$W_1 = 5.36016 - 3.26012D + 0.36508D^2 - 0.00025D^3$	0.98	20.55
				$W_2 = 1.21706 - 3.92214D + 2.63272H + 0.00821D^2H + 0.13148D^2 - 0.00014D^3$	0.99	15.33
				$W_3 = -0.19070 + 0.01103D^2H$	0.99	15.17
	Bark	15.51	16.40	$W_1 = 0.01449 - 0.21177D + 0.03349D^2 + 0.00009D^3$	0.97	2.84
				$W_2 = -0.46285 - 0.21076D + 0.20694H + 0.00078D^2H + 0.01011D^2 + 0.00011D^3$	0.98	2.59
				$W_3 = 0.15757 + 0.00126D^2H$	0.98	2.55
Stem <10≥2 cm	Wood	4.86	2.52	$W_1 = -4.31539 + 1.73267D - 0.07927D^2 + 0.00103D^3$	0.62	1.60
				$W_2 = -3.17164 + 0.91769D + 0.51750H - 0.00018D^2H - 0.06043D^2 + 0.00096D^3$	0.71	1.43
				$W_3 = 5.00505 - 0.00001D^2H$	0.004	2.54
	Bark	1.02	0.47	$W_1 = -0.62114 + 0.26519D - 0.01116D^2 + 0.00014D^3$	0.59	0.31
				$W_2 = -0.39235 + 0.10292D + 0.10258H - 0.00004D^2H - 0.00736D^2 + 0.00013D^3$	0.69	0.27
				$W_3 = 0.91776 + 0.00001D^2H$	0.05	0.46
Live branches >2 cm	Wood	8.89	14.85	$W_1 = 5.74703 - 1.57105D + 0.08764D^2 - 0.00076D^3$	0.60	9.65
				$W_2 = 3.10961 + 0.60984D - 1.56942H - 0.00021D^2H + 0.05800D^2 - 0.00059D^3$	0.64	9.32
				$W_3 = -1.66831 + 0.00087D^2H$	0.56	9.91
	Bark	2.68	4.66	$W_1 = 0.91887 - 0.22848D + 0.00938D^2 + 0.00008D^3$	0.67	2.76
				$W_2 = 0.29357 + 0.29142D - 0.37563H - 0.00006D^2H + 0.00248\ D^2 + 0.00012D^3$	0.69	2.71
				$W_3 = -\ 0.80673 + 0.00029D^2H$	0.62	2.89
Live branches		15.26	15.25	$W_1 = 0.51223 - 0.00578D + 0.02353D^2 + 0.00012D^3$	0.85	6.12
				$W_2 = -4.43410 + 3.06056D - 1.66658H + 0.00175D^2H - 0.07890D^2 + 0.00040D^3$	0.86	5.94
				$W_3 = 2.05618 + 0.00108D^2H$	0.84	6.24
Living tree above ground without foliage[2]		188.87	194.28	$W_1 = 7.69727 - 3.238950D + 0.43412D^2 + 0.00060D^3$	0.98	25.72
				$W_2 = -3.85515 + 1.00044D - 0.24810H + 0.01018D^2H + 0.06119D^2 + 0.00113D^3$	0.99	23.23
				$W_3 = 6.09159 + 0.01499D^2H$	0.99	23.43

1/ Sample size = 46-60
DBH Range (cm) = 0-10 to 31+
H Range (m) = missing

2/ W_1, W_2, and W_3 are dry weight biomass (kg) as estimated from Model 1, Model 2, and Model 3, respectively. D and diameter outside bark at breast height (cm) and the total height of the tree (m).

3/ Coefficients are not additive because living tree above ground without foliage includes stem 2 cm.

Table 8.--Coefficients and statistics of $OM(kg) = b_1 \cdot dbhob^2(cm) \cdot h(m)$ for estimating above ground ovendry mass of white spruce (Alemdag 1982)1/

Tree component	b_1	r^2	Standard error of the estimate	Mean	Range	
			Percent	- - - - kg - - - -		
Stem wood	0.014027	0.993	10.1	53.5	3.5	412.8
Stem bark	0.001438	0.933	24.8	6.2	0.7	37.5
Live branches	0.001097	0.328	84.7	5.5	0.1	28.7
Twigs plus needles	0.001657	0.167	88.3	9.0	0.3	39.7
Whole tree	0.018219	0.967	19.1	74.2	8.1	500.7
Dead branches2/	0.001012	0.810	51.6	4.1	0.1	29.9

1/ Sample size = 77
DBH Range (cm) = 6.3 - 35.8
H Range (m) = 5.0 - 23.2

2/ Ovendry mass of dead branches is not a part of the whole-tree ovendry mass.

Table 9.--Equations for determining biomass of plantation white spruce of the form mass = (kg) $a\,(dbh)^b$ (cm) (Harding 1982)1/

Component	Sample size	a	b	R^2	$S_{y \cdot x}$ (kg)
Live tree biomass (bole + bark + branches + needles)	115	0.07769	2.4715	0.98	12.699
Dead tree biomass (Live tree biomass - needles)	115	.06387	2.5022	.97	12.724
Total stem (bole + bark)	115	.03965	2.5363	.95	11.258
Bole	115	.02961	2.5932	.94	10.654
Bark	115	.01484	2.1386	.96	1.087
Needles	115	.01620	2.2223	.78	3.601
Branches	115	.02476	2.4302	.90	7.959

1/ DBH Range (cm) = not given
H Range (m) = not given

Table 10.--Equations for predicting ovendried mass for white spruce components in central Newfoundland (Lavigne and van Nostrand 1981)[1/]

Component	Equation[2/]	R^2	S^2
Total	$2.85965 + 0.02349\ D^2H$	0.9806	$0.134\ (D^2H)^{0.8648}$
Bole	$.60394 + .01633\ D^2H$	0.9795	$0.001\ (D^2H)^{1.3648}$
Branches	$.27815 + .00378\ D^2H$	0.8224	$0.001\ (D^2H)^{1.2850}$
Foliage + twigs	$1.97756 + .00338\ D^2H$	0.8771	$0.347\ (D^2H)^{0.5560}$

1/ Sample size = 53
DBH Range (cm) = 3.0 - 30.5
H Range (m) = 2.8 - 18.0
2/ Equation form:

$$\text{ovendry mass (kg)} = b_1 + b_2\ D^2\ H$$

where: D = dbh (cm) and
H = total height (m)

Table 11.--Tree biomass equations for white spruce (dbh 2.1 to 32.3 cm) in Cumberland County, Nova Scotia (Ker 1980)1/

Component	Equation	R^2	c
	Oven-dry weight in kg		
Stem wood	$\ln W = -3.3668 + 2.4847 \ln D$ 2/	0.99	1.02
	$\ln W = -3.6074 + 2.7904 \ln D - 0.5667 \ln CW$ 3/	.99	
Stem bark	$\ln W = -4.5138 + 2.1547 \ln D$	.98	1.03
	$\ln W = -4.6944 + 2.3842 \ln D - 0.4255 \ln CW$	.98	
Stem	$\ln W = -3.1114 + 2.4370 \ln D$	.99	1.02
	$\ln W = -3.3493 + 2.7394 \ln D - 0.5606 \ln CW$	.99	
Branches	$\ln W = -3.4995 + 2.1368 \ln D$	.94	1.06
	$\ln W = -3.1538 + 1.6973 \ln D + 0.8145 \ln CW$	.95	
Foliage	$\ln W = -3.2985 + 1.9103 \ln D$	.93	1.05
	$\ln W = -2.9500 + 1.4674 \ln D + 0.8209 \ln CW$	.95	
Crown	$\ln W = -2.7323 + 2.0433 \ln D$	.94	1.05
	$\ln W = -2.3875 + 1.6050 \ln D + 0.8124 \ln CW$	.95	
Total (a.g.)4/	$\ln W = -2.2662 + 2.2907 \ln d$	.99	1.01
	$\ln W = -2.2162 + 2.0782 \ln D + 0.3019 \ln CL$	.99	

1/ Sample size = 44
DBH Range (cm) = not given
H Range (cm) = not given
2/ D = dbh (cm)
3/ CW = crown width (m)
4/ a.g. = above-ground

Biomass - Foliage (B1)

$F = -162.88 + 55.01\,DL + 0.108DL^2$

$R^2 = .95$ SE = 27% of $\bar{F}$

F = oven dry foliage weight; g

D = diameter breast height; in.

L = live crown length; ft.

(Stiell 1969) (Ontario) (Plantation)

$F = 410.39 - 688.37\,DBC + 550.53\,DBC^2$ (B2)

$R^2 = 0.97$ SE = 23% of $\bar{F}$

F = oven dry foliage weight; g

DBC = diameter of stem at base of live crown; in.

(Stiell 1969) (Ontario) (Plantation)

Biomass - Total Tree (B3)

$\ln TT\ -3.616 + 0.902\,(\ln D^2H)$

$R^2 = 0.986$ Sy.x = 0.175

TT = total tree oven dry weight above ground; kg

D = dbh; cm

H = total height; m

ln = natural logarithm

Sample Size = 10

DBH Range (cm) = 5.9-30-34

H Range (m) = not given

(Schlaeger 1975) (Minnesota) (Plantation)

APPENDIX C. Volume Prediction Equations

$$CV = 2.1998 + .00257\ D^2H \tag{C1}$$

CV = gross volume (cu. ft.)
D = dbh (in.)
H = Height to a 4" top (ft.)

(Barnard *et al.* 1973) (NE US)

$$CV = 0.17 - 0.06315\ D^{2.0654} + 0.05122\ D^{2.0264}\ H^{0.3508} \tag{C2}$$

where:
CV = gross cubic-foot volume excluding bark
D = diameter at breast height (in.)
H = bole length from 1 ft. stump to a top diameter of 4 inches (ft.)

(Scott 1981) (NE US)

$$CV = D/\ (328.085 + (23762.19/Ht))\ {*}1000 \tag{C3}$$

) CV = Volume total cubic decimeters stump and top included
D = dbh outside bark (cm)
HT = total height (m)

(Kavanagh 1979) (Central and Eastern Canada)

$$CV = \frac{D^2}{1.44 + \frac{342.175}{H}} \tag{C4}$$

CV = total volume inside bark (cubic feet)
D = diameter breast height outside bark (in)
H = total tree height (ft.)

(Honer 1967) (Central and Eastern Canada)

$$CV\ (65) = (3.049 \times 10^{-5}\ D^2\ H) + (5.713 \times 10^{-5}\ D^2) \quad \text{(C5)}$$

$$CV\ (70) = (3.577 \times 10^{-5}\ D^2\ H) - (2.209 \times 10^{-6}\ DH^2) + (2.202 \times 10^{-5}\ D^2)$$

(·) = total volume (cubic meters)
65, 70 = form class
D = dbh (cm)
H = total height (m)

(Berry 1981) (Canada) (Plantation)

$$CV = 0.0083 + 0.0327\ \frac{D^2H}{1000} \qquad R^2 = 0.992 \quad \text{(C6)}$$

Where:

CV = volume in cubic meters stump and top included
D = diameter wt 1.3 m (cm)
H = total height (m)

(Berry 1980) (Canada) (Plantation)

$$\ln CV = 9.87 + 0.952\ (\ln D^2H) \quad \text{(C7)}$$

$R^2 = 0.988$ SE = 0.171

CV = total volume (cubic meters)
D = diameter at 1.3 m (cm)
H = total height (m)

(Schlaegel 1975) (Lake States) (Plantation)

$$CDV = (3.0086 \times 10^{-3} + S1 + S2 + S3 + S4 + S5 + S6 + S7 + S8) \quad \text{(C8)}$$
$$CV = CDV \cdot 79.0 . SCF$$

Where:
CDV = total gross volume (cords)
CV = total gross volume (cubic feet)
D = diameter breast height (in)
H = merchantable height (ft.)
T = diameter outside bark at merchantable height (in)
$S1 = 2.0355 \times 10^{-3}D$
$S2 = 3.0011 \times 10^{-3}T$
$S3 = 6.2381 \times 10^{-5}D^2$
$S4 = 2.5705 \times 10^{-5}D^2 \cdot H$
$S5 = (-7.009 \times 10^{-6}H^2$
$S6 = 3.6708 \times 10^{-5}\ H \cdot T^2$
$S7 = 8.14 \times 10^{-10}\ D^2 \cdot H^3$
$S8 = -1.9 \times 10^{-9}\ D^2 \cdot H^2T$ (Stone's equation)
SPCF = Species correction factor
= 1.0 for white spruce

(Raile et al. 1982) (Lake States) (Natural)

$$CDV = (0.001D^2)(1.9 + 0.01D)(0.026H - 0.000156H^2 + \frac{0.32)}{H})(SPCF) \qquad (C9)$$

CV = CDV·79.0
CDV = gross volume (cords)
D = dbh (in)
H = merchantable height (ft)
SPCF = species correction factor = <u>1.0</u> for white spruce
79 = cu. ft./cord; conversion factor

(Jones 1966) (Lake States) (Natural)

$$BV = (a + b_1 V_c + b_2D + b_3H + b_4D^2H + b_5H^2 + b_6V_c{}^2 + b_7D^2 + b_8D^2H2 + b_9D^2H^3 + b_{10}D^4H^2)(SPCF) \qquad (C10)$$

BV = gross boardfoot volume (International 1/4-inch rule)

$$VC = H\,(.134463 + .375246R + 1.047198R^2)$$

$$R = (.358333 + \frac{H(\frac{D}{24} - .358333)}{H - 3.5}$$

D = dbh; in
H = merchantable height; ft
SPCF = species correction factor = 0.9 for white spruce

a = - .093
b_1 = -5.980
b_3 = 2.088
b_4 = .031
b_5 = - .014
b_6 = - .009
b_7 = .351
b_8 = .00007
b_9 = 5.89 E-7
b_{10} = 3.0 E-8

(Jones 1966) (Lake States) (Natural)

$$BV = -13.03 - 0.05197D^{2.5248} + 0.12D^{2.1999}H^{0.4227} \qquad (C11)$$

BV = gross board foot volume (International 1/4-inch rule)
D = dbh (in)
H = total bole length (ft)

(Scott 1979) (NE US) (Natural)

$$CV = -153.0892 + 2.4852\ HS + 4.76046\ (HS)^2 \quad \text{(C12)}$$

$$R^2 = 0.947$$

where:

CV = gross volume (cu ft/ac)
HS = [dominant height/cube root (average spacing)] (ft)
Dominant height = mean height of tallest 10 percent
Average spacing (ft) = Sqrt (43.560/trees per acre)

(Stiell and Berry 1973) (Ontario, Canada) (Plantation)

APPENDIX D. Site Index Equations and Curves

$$S = 0.0833\, H^{1.3965} (1 - e^{-.0196A})^{-8.0895\, H^{-0.3659}} \qquad \text{(D1)}$$

$R^2 = 0.98$ SE = 3.22

Where:

S = site index as total height of dominant and codominant trees at age 50
H = total height of dominant and codominant trees (ft.)
A = total age (years)

(Carmean and Hahn 1981) (Lake States US)

$$S = 0.4891\, H^{1.055} (1 - e^{-0.024A})^{-2.0929\, H^{-0.0922}} \qquad \text{(D2)}$$

$R^2 = .996$ SE = 0.9

Where:

S = site index base age 50
H = total height of dominant and codominant trees (ft.)
A = total age (years)

(Payandeh 1974) (Canada)

$$S = 1.8\,(8.1 + 0.2F + 2.3H + 0.03P_2O_5 + 0.01\,K_2O) \qquad \text{(D3)}$$

S = site index as average heights of stands at age 50
F = percent fine soil particles
H = percent organic matter
P_2O5 = available phosphorus, lbs/acre
K_2O = available potassium, lbs/acre

(Wilde 1970) (Wisconsin)

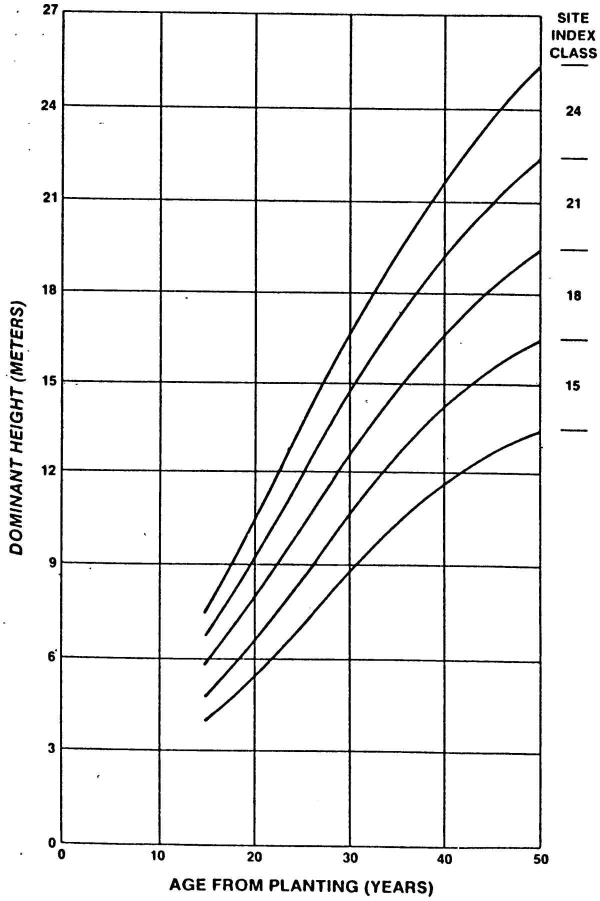


Figure 1.—*Site index curves at base age 50 years for planted white spruce (Berry 1978).*

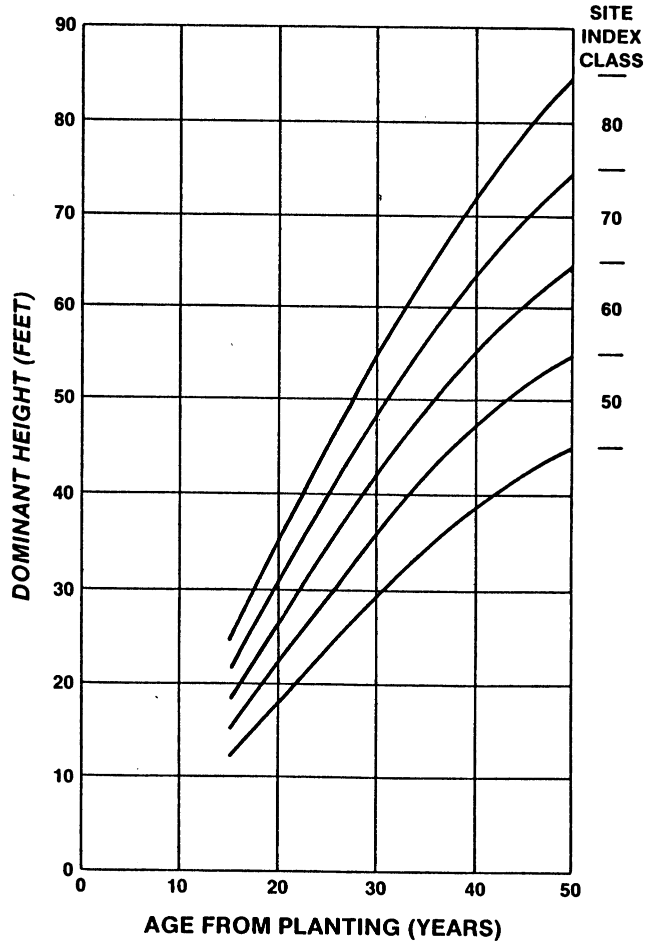


Figure 2.—*Site index curves at base age 50 years for planted white spruce (Stiell and Berry 1973).*

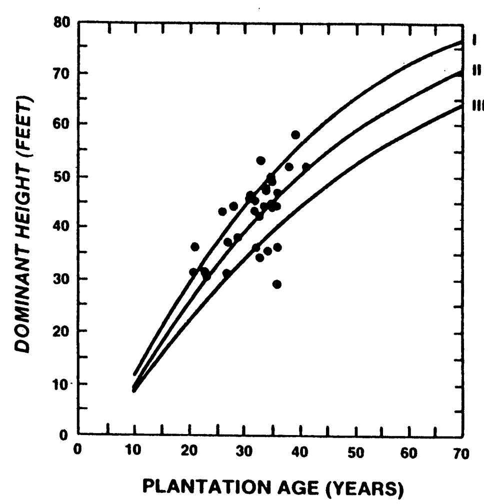
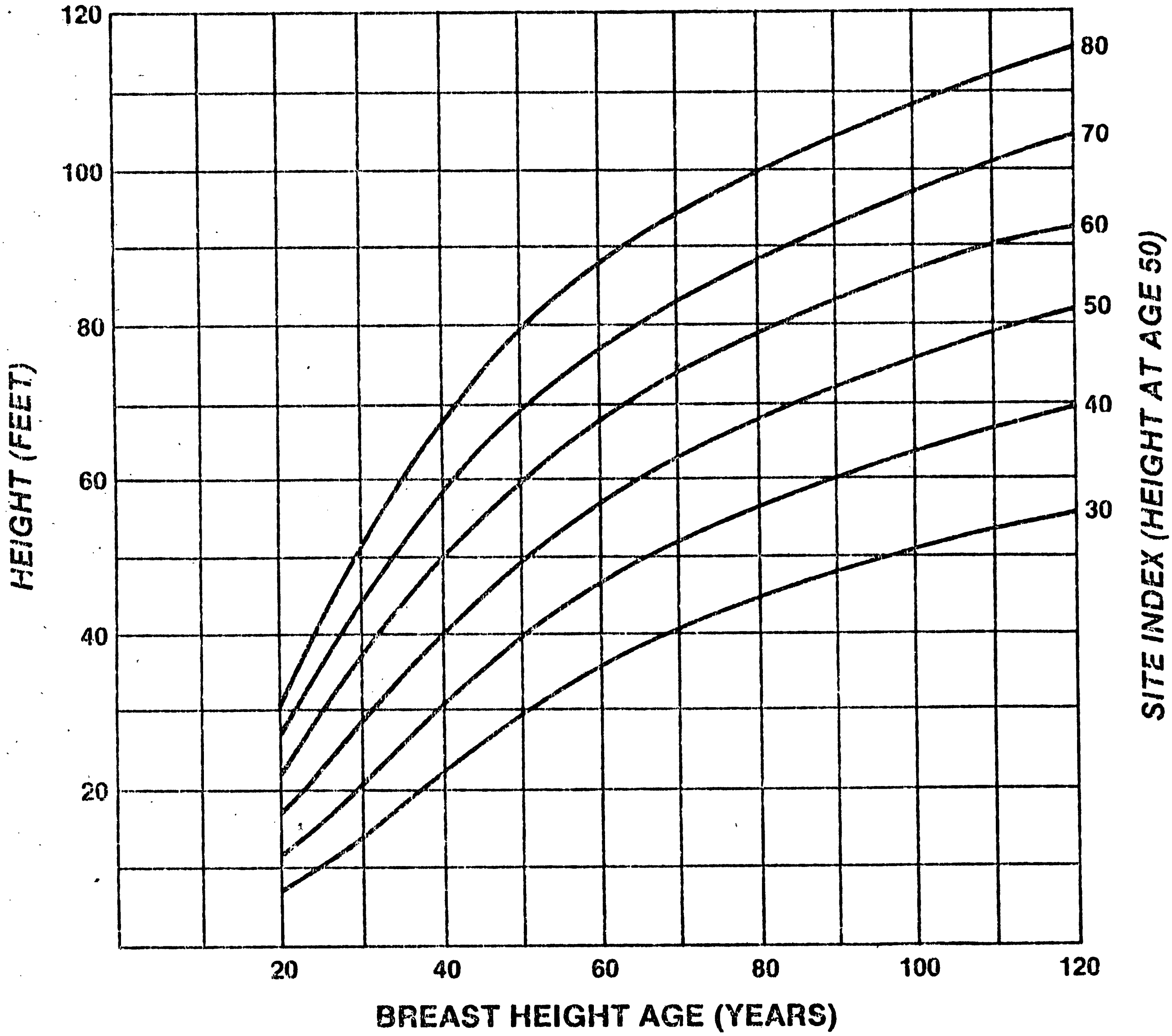


Figure 3.—*Dominant height development for white spruce divided into Potential Production Classes I, II, and III (Love and Williams 1968).*



Source: Based on forest survey data collected in Minnesota from 1947 to 1949 by the Lake States Forest Experiment Station and the Office of Iron Range Resources and Rehabilitation.

Figure 4.—*Site index curves based on trees from natural white spruce stands.*

APPENDIX E. Yield Tables

Table 12.--Expected yields from white spruce plantations (Love and Williams 1968)

Age	Ht.	Volume: Total production	Volume: Mortality	Volume: Standing timber	M.A.I.1/	C.A.I.1/	Rate of volume increase2/
	Ft		cu ft/acre		cu ft/acre/year		
CLASS I							
20	29	1,250	--	1,250	62		
30	44	3,450	150	3,300	110	205	10.2
40	56	5,800	700	5,100	128	180	4.4
50	64	7,750	1,350	6,400	128	130	2.3
60	71	9,400	2,000	7,400	123	100	1.5
70	76	10,600	2,600	8,000	114	60	0.8
CLASS II							
20	25	750	--	750	37		
30	39	2,500	100	2,400	80	165	12.3
40	50	4,500	500	4,000	100	160	5.2
50	59	6,250	1.050	5,200	104	120	2.7
60	65	7,500	1,400	6,100	101	90	1.6
70	70	8,450	1,750	6,700	96	60	1.1
CLASS III							
20	22	400	--	400	20		
30	34	1,550	50	1,500	50	110	14.1
40	44	3,150	250	2,900	72	140	6.8
50	52	4,750	600	4,150	83	125	3.6
60	58	6,100	900	5,200	87	105	2.3
70	64	7,100	1,100	6,000	86	80	1.4

1/ Calculated for standing volume only. MAI=mean annual increment. CAI=current annual increment.

2/ Compound annual rate of standing volume (V) increase from V_n to $V_n + 10$.

Table 13.--Expected yield from unmanaged white spruce plantations (site index class 50) (Stiell 1976)

Age from planting	Dominant height	Planted spacing	Trees	Mean dbh	Basal area	Volume Total	Volume Merchantable
	Ft	Ft	No./acre	In.	Ft^2/ac	Ft^3/ac	Ft^3/ac
20	19.8	4 x 4	2,717	2.4	87	619	56
		5 x 5	1,742	2.7	70	514	87
		6 x 6	1,210	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	2,607	2.8	112	1,136	534
		5 x 5	1,722	3.2	93	973	516
		6 x 6	1,210	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	2,430	3.2	138	1,784	1,213
		5 x 5	1,643	3.6	118	1,548	1,084
		6 x 6	1,195	4.0	105	1,379	1,020
		7 x 7	889	4.4	94	1,237	977
		8 x 8	681	4.8	86	1,121	930
		10 x 10	436	5.5	73	948	806
35	38.3	4 x 4	2,205	3.7	164	2,489	1,917
		5 x 5	1,540	4.1	143	2,192	1,710
		6 x 6	1,136	4.5	128	1,970	1,615
		7 x 7	878	4.9	117	1,797	1,527
		8 x 8	681	5.4	107	1,640	1,427
		10 x 10	436	6.2	92	1,396	1,242
40	43.3	4 x 4	1,997	4.1	184	3,104	2,514
		5 x 5	1,420	4.6	162	2,760	2,291
		6 x 6	1,080	5.0	147	2,507	2,156
		7 x 7	846	5.4	136	2,301	2,002
		8 x 8	678	5.8	126	2,128	1,873
		10 x 10	436	6.7	107	1,821	1,639
45	47.0	4 x 4	1,830	4.4	198	3,572	2,929
		5 x 5	1,325	4.9	176	3,198	2,718
		6 x 6	1,025	5.4	161	2,923	2,543
		7 x 7	820	5.8	149	2,704	2,380
		8 x 8	665	6.2	139	2,516	2,239
		10 x 10	436	7.1	119	2,168	1,951
50	50.0	4 x 4	1,680	4.8	208	3,942	3,272
		5 x 5	1,250	5.2	187	3,560	3,097
		6 x 6	980	5.7	172	3,273	2,880
		7 x 7	790	6.1	160	3,037	2,703
		8 x 8	650	6.5	149	2,840	2,556
		10 x 10	436	7.4	128	2,470	2,223

Table 14.--Expected yield from unmanaged white spruce plantations (site index class 60) (Stiell 1976)

Age from planting	Dominant height	Planted spacing	Trees per/ac	Mean dbh	Basal area	Volume Total	Volume Merchantable
	---- Ft ----		No.	In.	Ft^2/ac	--- Ft^3/ac ---	
20	24.0	4 x 4	2,650	2.7	105	964	337
		5 x 5	1,735	3.0	86	818	352
		6 x 6	1,210	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	2,460	3.2	135	1,683	1,111
		5 x 5	1,657	3.6	114	1,459	992
		6 x 6	1,198	3.9	101	1,298	948
		7 x 7	889	4.3	91	1,162	895
		8 x 8	681	4.7	82	1,052	863
		10 x 10	436	5.4	71	888	746
30	38.8	4 x 4	2,188	3.7	166	2,551	1,964
		5 x 5	1,526	4.2	145	2,248	1,776
		6 x 6	1,134	4.6	130	2,023	1,679
		7 x 7	876	5.0	119	1,847	1,588
		8 x 8	681	5.4	109	1,687	1,485
		10 x 10	436	6.3	93	1,436	1,278
35	45.8	4 x 4	1,883	4.3	193	3,419	2,804
		5 x 5	1,353	4.8	171	3,052	2,564
		6 x 6	1,043	5.2	157	2,788	2,426
		7 x 7	830	5.7	145	2,573	2,264
		8 x 8	672	6.1	135	2,390	2,127
		10 x 10	436	7.0	115	2,052	1,847
40	51.8	4 x 4	1,600	5.0	214	4,164	3,498
		5 x 5	1,202	5.4	193	3,778	3,287
		6 x 6	954	5.9	179	3,487	3,069
		7 x 7	775	6.3	166	3,248	2,891
		8 x 8	640	6.7	155	3,038	2,734
		10 x 10	436	7.5	134	2,660	2,394
45	56.0	4 x 4	1,415	5.4	227	4,685	3,982
		5 x 5	1,100	5.9	207	4,303	3,744
		6 x 6	880	6.3	192	3,982	3,504
		7 x 7	730	6.7	179	3,741	3,329
		8 x 8	615	7.1	169	3,524	3,172
		10 x 10	436	7.9	147	3,129	2,816
50	60.0	4 x 4	1,245	5.9	238	5,166	4,494
		5 x 5	985	6.4	219	4,775	4,202
		6 x 6	805	6.8	203	4,454	3,964
		7 x 7	680	7.2	191	4,206	3,743
		8 x 8	590	7.5	181	4,006	3,605
		10 x 10	436	8.2	159	3,610	3,249

Table 15.--Expected yield from unmanaged white spruce plantations (site index class 70) (Stiell 1976)

Age from planting	Dominant height	Planted spacing	Trees	Mean dbh	Basal area	Volume Total	Volume Merch
	- - - - Ft - - - -		No./ac	In.	Ft^2/ac	- - - Ft^3/ac - - -	
20	28.3	4 x 4	2,542	3.0	122	1,369	780
		5 x 5	1,697	3.3	103	1,180	708
		6 x 6	1,208	3.7	90	1,040	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	2,265	3.6	158	2,322	1,742
		5 x 5	1,567	4.0	137	2,041	1,572
		6 x 6	1,150	4.4	123	1,828	1,481
		7 x 7	885	4.8	112	1,662	1,413
		8 x 8	681	5.2	102	1,513	1,316
		10 x 10	436	6.1	87	1,287	1,145
30	45.6	4 x 4	1,890	4.3	192	3,392	2,781
		5 x 5	1,353	4.8	171	3,024	2,540
		6 x 6	1,047	5.2	156	2,766	2,406
		7 x 7	830	5.6	144	2,549	2,243
		8 x 8	672	6.0	134	2,368	2,108
		10 x 10	436	6.9	115	2,033	1,830
35	53.0	4 x 4	1,545	5.1	217	4,304	3,658
		5 x 5	1,175	5.6	198	3,930	3,419
		6 x 6	930	6.0	182	3,628	3,193
		7 x 7	765	6.4	170	3,388	3,015
		8 x 8	635	6.8	159	3,179	2,861
		10 x 10	436	7.6	138	2,790	2,511
40	59.7	4 x 4	1,260	5.9	237	5,137	4,469
		5 x 5	996	6.3	218	4,742	4,173
		6 x 6	810	6.8	202	4,417	3,931
		7 x 7	683	7.1	190	4,167	3,709
		8 x 8	594	7.4	180	3,973	3,576
		10 x 10	436	8.2	158	3,573	3,216
45	65.1	4 x 4	1,055	6.6	249	5,765	5,073
		5 x 5	857	7.0	230	5,375	4,784
		6 x 6	720	7.4	216	5,064	4,507
		7 x 7	620	7.7	203	4,817	4,335
		8 x 8	556	8.0	194	4,643	4,179
		10 x 10	427	8.6	173	4,238	3,814
50	70.0	4 x 4	890	7.3	256	6,312	5,618
		5 x 5	745	7.7	238	5,946	5,292
		6 x 6	640	8.0	224	5,644	5,080
		7 x 7	560	8.3	211	5,396	4,856
		8 x 8	510	8.5	202	5,229	4,706
		10 x 10	410	9.0	182	4,927	4,434

Table 16.--Expected yields from unmanaged white spruce plantations (site index class 80) (Stiell 1976)

Age from planting	Dominant height	Planted spacing	Trees	Mean dbh	Basal Area	Volume Total	Volume Merchantable
	- - - Ft - - -		No./ac	In.	Ft²/ac	- - - Ft³/ac - - -	
20	32.2	4 x 4	2,430	3.2	138	1,784	1,213
		5 x 5	1,643	3.6	118	1,548	1,084
		6 x 6	1,195	4.0	105	1,379	1,020
		7 x 7	889	4.4	94	1,237	977
		8 x 8	681	4.8	86	1,121	930
		10 x 10	436	5.5	73	948	806
25	42.1	4 x 4	2,050	4.0	179	2,957	2,366
		5 x 5	1,448	4.5	158	2,621	2,149
		6 x 6	1,095	4.9	143	2,374	2,018
		7 x 7	855	5.3	131	2,176	1,893
		8 x 8	681	5.7	121	2,009	1,768
		10 x 10	436	6.6	104	1,714	1,543
30	51.8	4 x 4	1,600	5.0	214	4,164	3,498
		5 x 5	1,202	5.4	193	3,778	3,287
		6 x 6	954	5.9	179	3,487	3,069
		7 x 7	775	6.3	166	3,248	2,891
		8 x 8	640	6.7	155	3,038	2,734
		10 x 10	436	7.5	134	2,660	2,394
35	60.6	4 x 4	1,210	6.0	238	5,225	4,546
		5 x 5	965	6.5	220	4,836	4,256
		6 x 6	795	6.9	205	4,526	4,028
		7 x 7	675	7.2	192	4,284	3,813
		8 x 8	585	7.6	182	4,076	3,668
		10 x 10	435	8.2	161	3,681	3,313
40	68.2	4 x 4	942	7.0	254	6,102	5,370
		5 x 5	780	7.4	235	5,727	5,097
		6 x 6	673	7.8	222	5,445	4,846
		7 x 7	582	8.1	209	5,183	4,665
		8 x 8	530	8.3	200	5,022	4,520
		10 x 10	418	8.9	179	4,632	4,169
45	74.4	4 x 4	760	7.9	258	6,772	6,027
		5 x 5	655	8.2	242	6,448	5,803
		6 x 6	576	8.5	229	6,164	5,548
		7 x 7	515	8.8	217	5,939	5,345
		8 x 8	473	9.0	208	5,769	5,192
		10 x 10	397	9.4	190	5,441	4,897
50	80.0	4 x 4	620	8.7	255	7,331	6,598
		5 x 5	555	8.9	242	7,060	6,354
		6 x 6	500	9.2	229	6,817	6,135
		7 x 7	455	9.4	218	6,599	5,939
		8 x 8	430	9.5	211	6,481	5,833
		10 x 10	370	9.8	193	6,152	5,537

Table 17.--Volume of white spruce larger than 4.5 inches d.b.h. from a 1-foot stump to a 4-inch top inside bark, by age and site index, interior Alaska (Farr 1967)

In cubic feet/acre

Breast-height age	Site index (feet)					
	50	60	70	80	90	100
30	--	--	--	--	92	544
40	--	--	141	602	1,092	1,611
50	--	263	742	1,257	1,807	2,393
60	192	675	1,201	1,769	2,379	3,032
70	485	1,007	1,578	2,199	2,870	3,590
80	726	1,287	1,904	2,578	3,309	4,096
90	933	1,533	2,197	2,924	3,715	4,569
100	1,117	1,756	2,465	3,245	4,096	5,018
110	1,283	1,961	2,716	3,550	4,461	5,450
120	1,437	2,153	2,954	3,841	4,812	5,868
130	1,580	2,335	3,183	4,122	5,154	6,277
140	1,715	2,510	3,403	4,396	5,487	6,678
150	1,845	2,678	3,617	4,663	5,814	7,072
160	1,969	2,841	3,826	4,925	6,137	7,462
170	2,089	3,000	4,031	5,183	6,455	--
180	2,205	3,155	4,232	5,437	6,769	--

1/ Volume = 158.90 + 24,953 S + 0.0035378 S^2 A 85625.0/A

Where: S = site index
A = average breast-height age of at least the six tallest white spruce trees.

R^2 = 0.883 Basis, number of plots = 98.

Table 18.--Yield per hectare of fully stocked spruce-aspen stands in Alberta, Canada (Johnstone 1977)

Site index 12.5 (@ stump age 70 years)

Softwood component, mainly spruce					Volume inside bark of trees with dbh outside bark of:				Hdwd. comp., mainly aspen	entire stand
Stump age	Height	Mean diameter	Basal area	Stems >1.5 cm	>1.5 cm	>11.7 cm	>14.2 cm	>21.8 cm	Volume >1.5 cm dbh	Volume >1.5 cm dbh
	M	Cm	M^2	No.	M3					
20	3.4	3.7	1.0	870	0.0	0.0	0.0	0.0	112.3	112.3
30	5.1	3.9	3.7	3,159	7.1	0.0	0.0	0.0	120.3	127.4
40	6.7	4.9	9.0	4,675	29.2	3.8	0.0	0.0	132.9	162.0
50	8.5	6.2	13.5	4,424	55.0	20.5	3.9	0.0	142.9	197.9
60	10.4	7.7	17.2	3,709	82.1	42.4	21.4	0.0	149.4	231.5
70	12.5	9.3	20.1	2,997	109.3	67.1	43.9	0.0	152.8	262.1
80	14.6	10.9	22.6	2,410	136.3	93.4	69.2	9.7	153.7	290.0
90	16.7	12.7	24.6	1,956	162.7	120.2	96.1	33.3	152.8	315.5
100	18.7	14.4	26.4	1,612	188.3	147.1	123.5	58.9	150.4	338.7
110	20.5	16.2	28.0	1,352	213.1	173.6	151.0	85.6	146.9	360.0
120	21.9	18.0	29.4	1,154	237.0	199.5	178.1	112.6	142.4	379.4
130	23.1	19.7	30.7	1,003	259.9	224.7	204.6	139.5	137.3	397.2
140	24.1	21.4	31.9	886	282.0	249.0	230.4	166.0	131.5	413.5

Table 19.--Yield per hectare of fully stocked spruce-aspen stands (Johnstone 1977)

Site index 15.0 (@ stump age 70 years)

Softwood component, mainly spruce					Volume inside bark of trees with dbh outside bark of:				Hdwd. comp., mainly aspen	Entire stand
Stump age	Height	Mean diameter	Basal area	Stems >1.5 cm	>1.5 cm	>11.7 cm	>14.2 cm	>21.8 cm	Volume >1.5 cm dbh	Volume >1.5 cm dbh
	M	Cm	M^2	No.	M3					
20	3.9	3.7	1.2	1,143	0.0	0.0	0.0	0.0	113.8	113.8
30	6.0	4.4	6.2	4,031	16.9	0.0	0.0	0.0	127.1	144.1
40	8.2	5.8	11.8	4,441	44.7	13.8	0.0	0.0	140.5	185.3
50	10.5	7.4	16.1	3,750	74.9	37.1	17.6	0.0	149.6	224.4
60	12.8	9.2	19.4	2,956	105.3	64.5	42.3	0.0	154.5	259.8
70	15.0	11.1	22.1	2,305	135.3	93.9	70.7	13.1	156.3	291.6
80	17.2	13.0	24.3	1,818	164.4	123.8	100.7	40.0	155.7	320.1
90	19.2	15.1	26.2	1,465	192.4	153.5	131.3	69.0	153.4	345.8
100	21.0	17.1	27.8	1,209	219.3	182.6	161.5	98.8	149.7	369.0
110	22.6	19.1	29.3	1,021	245.0	210.7	191.1	128.6	144.9	389.8
120	24.0	21.0	30.6	883	269.5	237.7	219.7	157.8	139.2	408.7
130	25.1	22.8	31.9	779	292.8	263.6	247.2	186.2	132.9	425.1
140	26.0	24.5	33.0	700	315.0	288.2	273.4	213.5	126.0	441.1

Table 20.--Yield per hectare of fully stocked spruce-aspen stands (Johnstone 1977)

Site index 17.5 (@ stump age 70 years)

Softwood component, mainly spruce: Stump age	Height	Mean diameter	Basal area	stems >1.5 cm	Volume inside bark of trees with dbh outside bark of: >1.5 cm	>11.7 cm	>14.2 cm	>21.8 cm	Hdwd. comp., mainly aspen Volume >1.5 cm dbh	Entire stand Volume >1.5 cm dbh
	M	Cm	M^2	No.	M^3					
20	4.4	3.7	1.9	1,791	1.0	0.0	0.0	0.0	117.3	118.3
30	7.0	4.9	8.3	4,362	26.5	3.0	0.0	0.0	133.3	159.8
40	9.7	6.5	13.8	4,089	58.8	24.7	8.1	0.0	146.7	205.5
50	12.5	8.4	17.8	3,200	92.2	53.5	32.8	0.0	154.8	247.0
60	15.1	10.5	20.9	2,413	125.1	85.2	63.1	9.0	158.6	283.7
70	17.5	12.7	23.3	1,836	156.9	117.9	95.8	37.9	159.3	316.3
80	19.7	15.0	25.3	1,433	187.4	150.3	129.1	69.6	157.8	345.2
90	21.6	17.3	27.0	1,153	216.3	181.8	162.1	102.2	154.6	370.9
100	23.3	19.5	28.6	956	243.9	212.1	194.0	134.6	149.9	393.8
110	24.8	21.6	30.0	815	270.0	241.1	224.8	166.2	144.2	414.2
120	26.0	23.6	31.3	714	294.8	268.6	254.1	196.6	137.6	432.4
130	27.0	25.4	32.5	640	318.3	294.7	281.9	225.5	130.3	448.6
140	27.8	27.0	33.7	586	340.6	319.4	308.2	252.9	122.4	462.9

Table 21.--Yield per hectare of fully stocked spruce-aspen stands (Johnstone 1977)

Site index 20.0 (@ stump age 70 years)

Softwood component, mainly spruce: Stump age	Height	Mean diameter	Basal area	Stems >1.5 cm	Volume inside bark of trees with dbh outside bark: >1.5 cm	>11.7 cm	>14.2 cm	>21.8 cm	Hdwd. comp., mainly aspen Volume >1.5 cm dbh	Entire stand Volume >1.5 cm dbh
	M	Cm	M^2	No.	M^3					
20	4.9	3.8	2.8	2,485	4.1	0.0	0.0	0.0	120.0	124.1
30	7.9	5.3	9.9	4,462	35.3	8.4	0.0	0.0	138.6	173.9
40	11.2	7.2	15.2	3,754	71.0	35.5	17.5	0.0	151.9	222.9
50	14.4	9.3	18.9	2,772	106.7	68.5	47.7	0.0	159.4	266.1
60	17.4	11.7	21.7	2,022	141.2	103.3	82.2	27.9	162.6	303.8
70	20.0	14.2	23.9	1,512	174.1	138.2	117.9	61.4	162.8	336.9
80	22.2	16.7	25.8	1,173	205.1	172.0	153.2	96.2	160.8	365.9
90	24.1	19.2	27.4	945	234.5	204.5	187.5	131.0	157.0	391.5
100	25.6	21.6	28.8	790	262.3	235.5	220.4	164.8	151.7	414.1
110	26.9	23.7	30.2	681	288.6	264.8	251.6	197.2	145.3	434.0
120	28.0	25.7	31.5	605	313.5	292.5	281.1	228.0	137.9	451.4
130	29.0	27.5	32.7	551	337.1	318.6	308.9	257.0	129.6	466.7
140	29.7	29.0	33.9	514	359.4	343.1	335.0	284.0	120.7	480.1

Table 22.--Yield per hectare of fully stocked spruce-aspen stands (Johnstone 1977)

Site index 22.5 (@ stump age 70 years)

Softwood component, mainly spruce: Stump age	Height	Mean diameter	Basal area	Stems >1.5 cm	Volume inside bark of trees with dbh outside bark: >1.5 cm	>11.7 cm	>14.2 cm	>21.8 cm	Hdwd. comp., mainly aspen: Volume >1.5 cm dbh	Entire Volume >1.5 cm dbh
	M	Cm	M^2	No.	M^3					
20	5.4	3.9	3.7	3,105	7.4	0.0	0.0	0.0	122.8	130.1
30	8.9	5.6	11.1	4,477	42.9	14.0	1.2	0.0	143.3	186.2
40	12.7	7.7	16.1	3,468	81.1	45.4	26.9	0.0	156.6	237.7
50	16.4	10.1	19.5	2,443	118.4	81.5	61.4	11.9	163.8	282.2
60	19.7	12.7	22.1	1,736	153.7	118.4	98.6	45.6	166.9	320.6
70	22.5	15.5	24.1	1,283	186.9	154.5	136.1	82.0	167.1	353.9
80	24.7	18.2	25.8	993	218.1	189.0	172.6	118.8	164.9	383.0
90	26.5	20.8	27.3	804	247.6	221.9	207.4	154.6	160.8	408.3
100	27.9	23.2	28.7	677	275.4	253.0	240.6	189.0	155.1	430.4
110	29.1	25.4	30.1	592	301.7	282.4	271.9	221.7	148.0	449.7
120	30.1	27.4	31.4	533	326.6	310.0	301.4	252.3	139.8	466.4
130	30.9	29.0	32.7	494	350.2	336.0	329.0	281.0	130.6	480.8
140	31.6	30.3	34.0	470	372.6	360.3	354.7	307.4	120.5	493.1

Table 23.--Yield per hectare of fully stocked spruce-aspen stands (Johnstone 1977)

Site index 25.0 (@ stump age 70 years)

Softwood component, mainly spruce: Stump age	Height	Mean diameter	Basal area	Stems >1.5 cm	Volume inside bark of trees with dbh outside bark: >1.5 cm	>11.7 cm	>14.2 cm	>21.8 cm	Hdwd. comp., mainly aspen: Volume >1.5 cm dbh	Entire stand Volume >1.5 cm dbh
	M	Cm	M^2	No.	M^3					
20	5.8	3.9	4.4	3,641	10.4	0.0	0.0	0.0	125.4	135.8
30	9.8	5.8	11.9	4,472	49.3	19.3	5.4	0.0	147.4	196.7
40	14.2	8.1	16.7	3,238	89.2	54.1	35.7	0.0	161.0	250.2
50	18.4	10.7	19.8	2,192	127.2	92.3	73.1	24.4	168.5	295.7
60	22.0	13.6	22.1	1,525	162.7	130.3	112.1	61.1	171.9	334.5
70	25.0	16.5	24.0	1,118	195.8	166.8	150.4	99.2	172.2	368.0
80	27.3	19.4	25.6	866	226.8	201.5	187.2	136.8	170.1	396.9
90	28.9	22.1	27.0	705	256.0	234.3	222.2	173.0	165.9	421.9
100	30.2	24.5	28.4	600	283.6	265.2	255.2	207.4	159.8	443.4
110	31.2	26.7	29.8	532	309.9	294.5	286.3	239.8	152.2	462.0
120	32.1	28.5	31.1	487	334.8	322.0	315.5	270.1	143.1	477.9
130	32.9	30.0	32.5	460	358.6	347.8	342.9	298.2	132.8	491.4
140	33.4	31.1	33.9	445	381.2	372.0	368.3	324.0	121.5	502.6

Table 24.--Volume of growing-stock trees for all site index classes in the white spruce forest type by species group and stand-age class, Minnesota, 1977[1] (Hahn and Raile 1982)

(In cubic feet per acre)

Species	Average[2]	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121+
		Stand-age class (years)											
Softwoods													
White pine	25	0	0	0	100	0	15	32	0	188	0	0	0
Red pine	21	0	31	0	124	0	0	78	0	0	0	0	0
Jack pine	35	0	0	41	0	27	70	159	0	0	0	C	0
White spruce	302	0	21	161	188	453	364	525	56	575	948	593	0
Black spruce	21	0	0	0	0	53	28	76	0	0	0	0	0
Balsam fir	85	0	9	32	102	124	93	202	217	114	0	111	0
Tamarack	10	0	0	0	0	30	0	65	0	0	0	0	0
Northern white-cedar	34	0	0	0	44	0	24	0	799	90	0	0	0
Other softwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	535	0	62	235	558	686	593	1,137	1,071	966	948	705	0
Hardwoods													
Select white oaks	1	0	0	0	0	0	0	0	0	12	0	0	0
Select red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Other red oaks	0	0	0	0	0	0	0	0	0	0	0	0	0
Hickory	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow birch	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft maple	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0	0
Balsam poplar	12	0	0	0	0	9	11	81	0	29	0	0	0
Paper birch	83	19	11	21	204	119	55	22	180	79	390	181	0
Bigtooth aspen	0	0	0	0	0	0	0	0	0	0	0	0	0
Quaking aspen	105	0	0	88	114	232	138	0	0	313	0	0	0
Basswood	0	0	0	0	0	0	0	0	0	0	0	0	0
Elm	0	0	0	0	0	0	0	0	0	0	0	0	0
Select hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Other hardwoods	0	0	0	0	0	0	0	0	0	0	0	0	0
Noncommercial species	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	200	19	11	109	318	360	203	103	180	433	390	181	0
Total all species	735	19	73	344	876	1,046	797	1,240	1,251	1,399	1,338	886	0
Number of plots	40	5	4	3	4	7	9	3	1	2	1	1	0
Standard error[3]	95	19	43	172	328	260	131	308	R	256	R	R	0
Average basal area	65	4	17	62	86	84	80	83	98	104	70	64	0

1/ Table may not add to totals due to rounding. Forest type definitions and species list are in the appendix.
2/ Weighted average for all stand-age classes--the average volume per acre for all ages in the forest type and index range.
3/ R indicates that there was an insufficient number of plots to compute the standard error.

Table 25.--Empirical yields of well-stocked white spruce stands on good sites (Site Index 64) in Saskatchewan (Kabzems 1971)[1]

Main Stand[2]	All species 3.6 inches d.b.h. and larger					
Age	Average height	Trees in stand	Average D.B.H.	Basal area	Merchantable volume per acre	
	Ft	No.	In.	Ft^2	Cu ft[3]	Bd ft[4]
40	50	500	4.2	99	2,020	4,380
50	64	660	6.5	153	2,880	8,020
60	72	550	7.8	182	3,670	11,600
70	78	480	8.6	195	4,350	14,800
80	82	420	9.3	199	4,880	17,200
90	85	370	9.9	200	5,170	19,400
100	88	330	10.5	200	5,340	21,500
110	91	295	11.1	199	5,430	23,100
120	93	265	11.6	196	5,480	24,600
130	95	240	12.2	195	5,510	26,100
140	97	210	12.9	191	5,520	27,500
150	98	190	13.4	187	5,490	28,800
160	99	165	14.3	183	5,460	30,050
170	100	145	15.0	179	5,410	31,250
180	101	130	15.7	175	5,340	32,400
190	102	110	16.9	171	5,260	33,500

1/Average height of dominant and codominant trees at age 50.

2/Dominant and codominant white spruce only.

3/Merchantable cubic foot volume - from a 1-foot stump to a 3-inch top all trees 3.6 inches d.b.h. and larger.

4/Board Foot Volume - (Clark's International Log Rule, 1/4" kerf) from a 1-foot stump to a 6-inch top, inside bark, of all trees 7.6 inches d.b.h. and larger.

Table 26.--Empirical yields of well-stocked white spruce stands on average sites (Site Index 52) in Saskatchewan (Kabzems 1971)1/

Main stand2/		All species 3.6 inches d.b.h. and larger				
Age (years)	Average height	Trees in stand	Average d.b.h.	Basal area	Merchantable volume per acre	
	Ft	No.	In.	Ft^2	Cu Ft3/	Bd Ft4/
40	41	420	5.5	71	1,400	2,170
50	52	535	6.2	112	2.030	4,200
60	59	500	7.1	136	2,630	6,450
70	64	480	7.5	148	3,150	8,700
80	67	455	7.8	153	3,550	10,990
90	70	420	8.2	155	3,800	13,000
100	72	395	8.5	156	3,950	14,800
110	74	370	8.8	156	4,050	16,400
120	76	350	9.0	155	4,100	17,720
130	78	330	9.2	154	4,140	18,890
140	79	315	9.4	151	4,160	19,900
150	80	300	9.5	148	4,165	20,800
160	81	285	9.6	144	4,160	21,510
170	82	270	9.7	140	4,140	22,200
180	83	255	9.8	135	4,110	22,750
190	84	240	9.9	130	4,070	23,200

1/Average height of dominant and codominant trees at age 50.
2/Dominant and codominant white spruce only.
3/Merchantable cubic foot volume - from a 1-foot stump to a 3-inch top all trees 3.6 inches d.b.h. and larger.
4/Board foot volume - (Clark's International Log Rule, 1/4" kerf) from a 1-foot stump to a 6-inch top, inside bark, of all trees 7.6 inches d.b.h. and larger.

Table 27.--Empirical yields of well-stocked white spruce on poor sites (Site Index 40)1/ in Saskatchewan (Kabzems 1971)

Main stand2/		All species 3.6 inches d.b.h. and larger				
Age (years)	Average height	Trees in stand	Average D.B.H.	Basal area	Merchantable volume per acre	
	Ft	No.	In.	Ft^2	Cu ft3/	Bd ft4/
40	32	180	6.5	42	780	--
50	40	350	6.1	71	1,180	500
60	46	485	5.8	90	1,590	1,230
70	49	475	6.2	101	1,950	2,610
80	52	460	6.5	107	2,220	4,220
90	54	445	6.7	110	2,440	6,240
100	56	430	6.9	112	2,560	8,010
110	58	420	7.0	113	2,650	9,640
120	59	410	7.1	114	2,720	10,920
130	60	400	7.2	113	2,770	11,860
140	61	385	7.3	111	2,820	12,520
150	62	375	7.3	109	2,840	12,920
160	62	360	7.3	105	2,860	12,990
170	63	350	7.3	101	2,870	13,010
180	64	325	7.3	95	2,880	12,700
190	64	310	7.3	89	2,860	12,370

1/Average height of dominant and codominant trees at age 50.

2/Dominant and codominant white spruce only.

3/Merchantable cubic foot volume - from a 1-foot stump to a 3-inch top all trees 3.6 inches d.b.h. and larger.

4/Board foot volume - (Clark's International Log Rule, 1/4" kerf) from a 1-foot stump to a 6-inch top, inside bark of all trees 7.6 inches d.b.h. and larger.

APPENDIX F. Mortality Equations and Tables

Table 28.--White spruce plantations mortality equations and their precision, Petawawa (Evert 1981)

Equation model number	Equation	R^2	Standard error of estimate Number	Percent
1 M.1	$= 90.9 + 4.505 \times 10^{-6}(HO)(NO)^2 - 0.1048(NO)$	0.823	84.5	38.8
2 M.1.2	$= 150.7 + 5{,}611 \times 10^{-6}(HO)(NO)^2 - 0.1521(NO)$	0.822	99.9	29.4
3 M.1.2.3.	$= 155.8 + 5.776 \times 10^{-6}(HO)(NO)^2 - 0.1574(NO)$	0.833	99.0	38.2
4 M.1.2.3.4.	$= 162.9 + 5.804 \times 10^{-6}(HO)(NO)^2 - 0.1596(NO)$	0.829	100.1	38.2
5 M.1.2.3.4.5	$= 164.0 + 5.816 \times 10^{-6}(HO)(NO)^2 - 0.1603(NO)$	0.830	99.9	38.1

1/M = mortality in next 5 years in number of trees/ha
1.2. = distribution of mortality by tree sizes, M.1 representing mortality in the smallest-diameter group. M.1.2. in the two smallest-diameter groups, etc. and M.1.2.3.4.5. in the total number of trees/ha.

2/HO = dominant height initial value
NO = Initial number of live trees/ha.

Table 29.--Annual survival rate for white spruce by diameter and diameter growth class; base number of trees was 3,548. Cells used to develop the model are enclosed by a solid line (Buchman and Lentz in press)

Dbh (in.)	DIAMETER GROWTH RATE (in./yr)										
	0.00	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	0.7250	.7585	.8361	.9169	.9691	.9912	.9977	.9991	.9994	.9994	.9994
2	.7701	.7996	.8663	.9334	.9754	.9929	.9981	.9992	.9994	.9994	.9994
3	.8128	.8380	.8935	.9477	.9808	.9944	.9984	.9992	.9994	.9994	.9994
4	.8434	.8652	.9123	.9573	.9844	.9954	.9986	.9993	.9994	.9994	.9994
5	.8639	.8831	.9245	.9635	.9866	.9960	.9987	.9993	.9994	.9994	.9994
6	.8767	.8944	.9321	.9672	.9880	.9963	.9988	.9993	.9994	.9994	.9994
7	.8842	.9009	.9364	.9694	.9887	.9966	.9988	.9993	.9994	.9994	.9994
8	.8877	.9039	.9384	.9704	.9891	.9967	.9988	.9993	.9994	.9994	.9994
9	.8833	.9045	.9388	.9706	.9892	.9967	.9988	.9993	.9994	.9994	.9994
10	.8867	.9031	.9378	.9701	.9890	.9966	.9988	.9993	.9994	.9994	.9994
11	.8833	.9001	.9359	.9691	.9887	.9965	.9988	.9993	.9994	.9994	.9994
12	.8785	.8959	.9331	.9678	.9882	.9964	.9988	.9993	.9994	.9994	.9994
13	.8726	.8908	.9297	.9661	.9875	.9962	.9988	.9993	.9994	.9994	.9994
14	.8659	.8849	.9257	.9641	.9868	.9960	.9987	.9993	.9994	.9994	.9994
15	.8585	.8785	.9214	.9619	.9860	.9958	.9987	.9993	.9994	.9994	.9994
16	.8507	.8716	.9167	.9596	.9852	.9956	.9986	.9993	.9994	.9994	.9994
17	.8427	.8645	.9118	.9571	.9843	.9953	.9986	.9993	.9994	.9994	.9994
18	.8345	.8572	.9069	.9546	.9833	.9951	.9985	.9993	.9994	.9994	.9994
19	.8263	.8500	.9019	.9520	.9824	.9948	.9985	.9993	.9994	.9994	.9994
20	.8183	.8428	.8969	.9495	.9814	.9946	.9984	.9992	.9994	.9994	.9994
21	.8104	.8359	.8920	.9469	.9805	.9943	.9984	.9992	.9994	.9994	.9994
22	.8030	.8292	.8873	.9445	.9796	.9941	.9983	.9992	.9994	.9994	.9994
23	.7958	.8228	.8828	.9421	.9787	.9938	.9983	.9992	.9994	.9994	.9994
24	.7891	.8167	.8785	.9399	.9779	.9936	.9982	.9992	.9994	.9994	.9994
25	.7828	.8111	.8745	.9378	.9771	.9934	.9982	.9992	.9994	.9994	.9994
26	.7770	.8058	.8707	.9358	.9763	.9932	.9981	.9992	.9994	.9994	.9994
27	.7716	.8010	.8672	.9339	.9756	.9930	.9981	.9992	.9994	.9994	.9994
28	.7666	.7965	.8640	.9322	.9749	.9928	.9981	.9992	.9994	.9994	.9994
29	.7621	.7924	.8610	.9306	.9743	.9926	.9980	.9992	.9994	.9994	.9994
30	.7580	.7887	.8583	.9291	.9738	.9925	.9980	.9992	.9994	.9994	.9994

COEFFICIENTS FOR MODEL:

B1=0.99940E+00, THE SURVIVAL RATE FOR FAST-GROWING TREES BASED ON 1784 TREES.
B2=0.97241E+00
B3=0.31418E+03
B4=0.19149E+01
B5=0.28386E+00
B6=0.13021E+01
B7=0.16831E+00

$$SR = B_1 - [1/(1+e^n)]$$

where n is $b_2 + b_3 \cdot DGR^{b_4} + b_5 \cdot (DBH-1)^{b_6} \cdot e^{-b_7 \cdot (DBH-1)}$

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