STRUCTURE, BIOMASS PRODUCTION AND DYNAMICS OF FOUR WHITE SPRUCE (*Picea glauca* [MOENCH] VOSS) PLANTATIONS NEAR THUNDER BAY, ONTARIO

by

William Donald Towill ©

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requirements of the degree of
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ABSTRACT

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Stand structure, biomass production and dynamics of white spruce (Picea glauca (Moench) Voss) were investigated in four plantations, ages 4, 10, 18, and 28 years, respectively, on similar lacustrine soils. Dry matter partitioning of the white spruce component at the individual tree and stand levels and under varying densities of trembling aspen (Populus tremuloides Michx.) was analyzed.

A general pattern of stand development tied to: (1) the timing and severity of site preparation preceding plantation establishment; (2) the nature and distribution of the post-cut vegetation; (3) soil and site conditions; and (4) the successional processes in the tree strata, was proposed which may also be applicable to plantations other than those in the study.

Major differences in stand structure, biomass partitioning and distribution, within the white spruce populations of each plantation existed. This variation was attributed to differences in micro-site condition and the density of trembling aspen and other herbaceous vegetation surrounding the planted white spruce. Severe scarification using a modified V-plough prior to establishment of the two youngest plantations resulted in highly variable early height and diameter growth and survival of the planted white spruce.

Both planted white spruce and second-growth aspen produced maximum height growth and biomass on micro-sites with deep surface horizons (Ah) where mixing of organic matter with the surface mineral soil has occurred. The presence of trembling aspen, graminoids, wild raspberry (Rubus idaeus L.), prickly rose (Rosa acicularis Lindl.), and other woody tall shrubs during the stand initiation and the stem exclusion stage were correlated with the decreased height and diameter growth of the surviving planted white spruce.

Total standing crop for all species and the white spruce component of the plantations each increased with plantation age; partitioning of biomass to stemwood and foliage on individual spruce trees was significantly reduced under high aspen densities and where the standing crop biomass of graminoids, herbaceous plants and woody shrubs was greatest.

Spruce foliage efficiencies for wood production generally increased with stand age, decreasing aspen density and increasing dominance (crown class). A clearly defined and fully integrated biological model relating foliage efficiency of the individual white spruce growing in association with trembling aspen could not be developed. However, white spruce foliage, stemwood and total tree dry weights were explained in multiple regression models which incorporated the biomass of competing species, soil/site characteristics, and a measure of the percent cover of the spruce seedling by competing vegetation.

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INTRODUCTION

Natural forests containing both hardwoods and softwoods occupy 45 to 50 percent of the productive forest land area in northern Ontario (Weingartner and Basham 1979), and account for 46 percent of Ontario's primary growing stock (McClain 1980). The mixedwood forest commonly occupies fresh, well-to rapidly-drained sites which support excellent stand and individual tree growth for several boreal tree species. It has been common practice to plant white spruce (Picea glauca (Moench) Voss) and black spruce (Picea mariana (Mill.) B.S.P.) on these cutover sites. The purpose has been to convert these to pure conifer stands and to avoid creating second-growth hardwoods.

The performance of spruce in these plantations is ultimately determined by many factors, including: (1) the condition of the site following harvest and site preparation; (2) the nature, size, and spatial distribution of the pre- and post-harvest hardwood stand component; (3) the amount of herbaceous and woody shrub competition in the understory, and (4) the type, intensity and frequency of subsequent crop release and protection for the planted conifers.

Unfortunately the structure, development and dynamics of these proceeding young stands has rarely been described, much less understood. In northwestern Ontario, studies on spruce

(Picea spp.) plantation growth and development are particularly sparse (Curry 1961; Armson 1975; Gordon and Morrow 1979).

Case studies were developed to examine and contrast the species' composition, stand structure and growth of the trembling aspen and white spruce components associated with four white spruce plantations of differing ages near Thunder Bay, Ontario. The dynamics of the tree strata and understory vegetation with respect to stand age and structure was also examined.

OBJECTIVES

The specific objectives of this study were to:

(1) Compare and contrast the structure and composition of the white spruce plantations;

(2) Investigate the pattern of above-ground dry matter accumulation in the white spruce plantations;

(3) Investigate the potential influence of trembling aspen on the growth and dry matter production of the planted white spruce;and,

(4) Evaluate the influence of foliage quantity, stand age and surrounding vegetation on wood production of individual planted white spruce and at the stand level.

LITERATURE REVIEW

Measurement of changes in dry matter production and its accretion, age and size classes of various species, and species composition are important variables in identifying and describing the dynamic processes that direct forest development. A review of pertinent literature related to the stand structure, biomass production and wood production of natural and plantation origin white spruce/trembling aspen boreal forest ecosystems follows.

DYNAMICS OF CHANGE IN STAND STRUCTURE AND SPECIES COMPOSITION

The stand dynamics of planted white spruce occurring either as a pure stand or in mixture with trembling aspen in northwestern Ontario has not been formally documented. In contrast, the interaction and growth of these two species occurring throughout the natural Mixedwood Forest Section (B 18.a) (Rowe 1972) on the prairies has been extensively examined. Johnson (1986) provides a review of available information on the release of white spruce from trembling aspen overstorys and shrub competition in the context of the related subjects of ecological, biological and growth relationships.

Since white spruce normally grows on the most productive forest soils it often grows in association with aspen (Rauscher 1984). Haig (1959), Froning (1972) and Johnson (1973) all report that an aspen overstory can lead to the failure of white spruce plantations. The effects of aspen on the height growth of white spruce begins when the spruce are very young. Cayford (1957) noted that the time required for naturally established white spruce to grow to breast height from stump height was 7.1 years for an open grown seedling and 8.7 years for suppressed seedlings. In general, the height growth of trembling aspen exceeds that of open grown spruce for the first 30 years, and that of suppressed spruce for the first 30 to 40 years (Cayford 1957).

Further investigations of species' growth, stand in-growth with increasing stand age, below-ground competition for rooting space, crown geometry and species growth economy are still required if the stand dynamics of plantation white spruce growing with trembling aspen are to be better understood.

Forest Biomass Production

Biomass distribution within and among species of a stand is one aspect of stand structure and dynamics. Ovington (1962) and Baskerville (1965b) have each shown that the flow of organic matter, energy, nutrients, and moisture must be accounted for when describing the functioning and productivity of forest ecosystems. Those parameters most commonly studied in comparing levels of productivity on different kinds of forest land include total wood volume and biomass per unit area or unit time, and height of dominant trees in relation to age.

Peet (1981) has hypothesized that forest biomass increases during forest succession from near zero at the stage of stand initiation to a maximum level defined by site, species, and site occupancy. In late successional stages, standing biomass drops with development of the community climax and following stand breakup. Data from a study of New Brunswick jack pine (*Pinus banksiana* Lamb.) and mixed hardwood forests confirms that this does indeed occur (MacLean and Wein 1976).

It would seem that major patterns of biomass change can be most easily understood in terms of time lags in regeneration and associated mortality changes. Following disturbance, total stand biomass should increase. During this period, recruitment, tree growth, and mortality are the dominant processes. Stagnation in biomass accumulation then coincides with the onset of total site occupancy. Mortality following the onset of full site occupancy would then contribute to a decrease in stand biomass. Peet (1981) has suggested that once an uneven-aged forest structure is created by the processes of mortality and replacement, peak biomass production can not again be reached without major disturbance.

Support for this view could not be found in the boreal forest literature.

Net primary production also increases from zero to some positive value during succession, although not necessarily parallelling biomass accretion. Moller (1947) theorized that gross forest production increased with increasing stand density until full site occupation was achieved. Increasing the stand density beyond the point of full occupancy had no effect on stand production. Moller (1947) also suggested that forest stands of a given species composition, maintained relatively constant amounts of foliage, regardless of density, as long as they occupied sites of similar quality. Further, he suggested that only in very high density stands would the quantity of non-photosynthetic respiring area be sufficient to cause respiration to limit production.

In contrast, Assman (1970) and Baskerville (1965b) have suggested that only over a narrow optimal density range is production maximal. The range of these optimal densities would vary with species, site quality and age. If we accept the latter view, then there would be a peak in stand production followed by a decrease at the point where the optimal density is reached during the self-thinning process.

Other factors which could limit net stand production include individual tree senescence and its influence on photosynthetic efficiency. As the original trees age, they lose their capacity for high levels of production. Net stand production is thereby reduced until such time as new, young, vigorous trees enter the stand (Kira and Shidei 1967).

Biomass Production in Spruce Stands

Stanek and State (1978) have recorded only seven biomass studies in natural boreal white spruce stands and none relate to northwestern Ontario. An examination of these studies showed a wide variation in production of 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 fewer studies of biomass distribution in natural white spruce dominated mixedwood stands exist (e.g. Baskerville 1965b; Stiell 1969; Kimmins 1974; Schaerer 1978; Cushon 1980).

Berry's (1987) recent description of the above-ground biomass production of unthinned 60 year-old white spruce plantations at the Petawawa National Forestry Institute includes data from four site index classes and six spacing classes. Biomass production had peaked at 364 t/ha at 60 years at a 1.25 m spacing and with SI=24 (metres/age 50).

Biomass Production in Trembling Aspen Stands

Many biomass studies completed since 1960 have focused on the standing crop and primary production of trembling aspen resulting in numerous sets of tables and predictive biomass equations of regional applicability (e.g. Bella and Jarvis 1967; Young and Carpenter 1967; Bella 1968; Einspahr and

Benson 1968; Peterson et al. 1970; Perala 1973; Schlaegel 1975; Crow 1978; Johnstone and Peterson 1980; Bella and DeFranceschi 1980). In many instances these studies pertained to single clone conditions or single stands growing on a single soil or site condition.

Most of the above-ground biomass of mature aspen trees is made up of woody bole, bark and branches. A sampling of trees in northern Utah and western Wyoming showed that the woody bole made up 50 percent or more of the above-ground biomass, the bark from 20 percent to 25 percent, and live branches from 10 percent to 17 percent of the biomass (Bartos and Johnston 1978). In general the dry weight ratio of branchwood to bolewood decreases modestly with age from ages 20 to 50 years (Zavitkovski 1971; Schlaegel 1975).

Foliage and Wood Production

Tree growth depends on photosynthesis, which is directly related to the amount, distribution, age and morphological characteristics of foliage on an individual tree (Cushon 1980). The amount of foliage maintained by an individual tree will vary with: (1) age, (2) size, (3) crown class, (4) site,(5) climate, and (6) environmental stress. Assman (1970) considered that the same factors will influence the efficiency of foliage in producing wood.

Weetman and Harland (1964), Stiell (1967) and Stiell and Berry (1967) in their studies of natural black spruce and plantation red pine (Pinus resinosa Ait.) and white spruce, respectively, demonstrated that wood production was closely related to the amount of foliage supported by a single tree. Baskerville (1965b), Doucet et al. (1976) and Phillion (1980) have also demonstrated that wood production and foliage quantities on a per hectare basis for pure black spruce and jack pine, respectively, were closely related. The relationship between foliage quantity and wood production for tolerant conifers growing in mixture with trembling aspen has not been investigated.

WHITE SPRUCE GROWTH AND YIELD

Wood Production in Naturally-regenerated White Spruce Stands

Wood production from naturally-regenerated white spruce stands in Ontario has received little study because of the meager representation of pure stands in older age classes. Similar data are also lacking for the white spruce component of Ontario's boreal mixedwood stands (Payandeh and Field 1986). Plonski's (1981) black spruce Normal Yield Tables are routinely employed in the evaluation of white spruce site quality and stand yield.

Nienstaedt (1957) has reported that a 54 year-old pure white spruce stand in northern Michigan produced 440 m^3/ha. In contrast, a similar volume production was not achieved until between ages 90 to 150 years in uneven-aged mixedwood stands near Sault Ste. Marie, Ontario (Stiell 1976).

In the B.18a forest section of Saskatchewan, white spruce stands on good, average and poor sites have yielded merchantable conifer volumes of 374, 276 and 179 m^3/ha respectively, at 100 years (Kabzems 1971). The largest conifer yields were found to occur at 135 years, 150 years and 175 years on each of the respective site classes (Kabzems 1971). Kabzems (1971) did not discuss the effect varying densities of trembling aspen might have had on the volume production of the white spruce component.

Mortality estimates for pure and mixed stands of white spruce are not readily available. Kabzems (1971) has estimated that the cumulative loss in merchantable spruce volume on the same sites over similar rotation periods amounted to 25.2, 27.9 and 71.4 m^3/ha, respectively. These were equivalent to 7.9, 11.9 and 50.6 percent, respectively, of the net volume of growing stock at a harvested age of 100 years on each site. This stage of stand development is the latest age at which stand improvement cuttings should be considered to stimulate or prolong the period of higher current annual volume production.

Wood Production in White Spruce Plantations

Patterns of wood volume production and accretion in white spruce plantations have been documented for several stands less than 50 years-of-age. Most of these studies were conducted in formal spacing trials: e.g. Rudolph (1950), Stiell (1958, 1967, 1969), Stiell and Berry (1967, 1973), Love and Williams (1968), Wambach and Cooley (1969), Berry (1968), Popovich (1972a, 1972b), and Berry (1987). A comparison of these studies revealed tremendous productivity differences among white spruce plantations of similar age and spacing. These variations most likely reflect differences in site quality, genotypes, stocking levels and levels of competing vegetation.

The most commonly referenced white spruce plantation yield tables have been developed using unmanaged, high survival plantations located at the Petawawa National Forestry Institute, Chalk River Ontario. Yields of 30 to 50 cunits per acre (210 to 350 m^3/ha) are to be commonly expected for short-rotation pulpwood plantations. Stiell (1976) reports that yields of 50 cunits (350 m^3) are possible by age 50 years on the better sites, using spacing of 2.1 x 2.1 m.

In general, the Petawawa studies have shown that as stand density decreases due to mortality precipitated by lack of tending, the breast height diameters of remaining trees increase as do branch diameters and the stem taper. Reductions in stand density also parallel decreases in stand basal area, gross total volume, and gross merchantable volume. The impact of increased stand densities of trembling aspen or other broad-leaved woody species on the growth and yield of the white spruce plantations was not specifically examined.

Wood Production and Foliage Relationships for White Spruce

Analaytical methods for assessing bole wood production efficiency of an individual tree or stand include describing the relationships between the quantity of foliage and the dry matter production at a given time. The efficiency with which canopies can produce wood is of interest since the goal of most silvicultural treatments is to acquire a sustainable and significant increase in the volume production of a single tree or stand.

Most stand improvement treatments depend upon practices that ultimately improve conditions favouring leaf production and increased leaf area index. An increase in the leaf area index can be brought about by increasing the number of leaves in the canopy and/or the leaf size. These measures vary naturally with such factors as stand density, competition, nutrition, and moisture availability. If these factors can be directly controlled through silvicultural manipulation of the site and the attendant vegetation, crop tree growth will be favoured.

Schaerer (1978) examined the relationship between white spruce tree foliage dry weight and its current annual increment over a range of spacings from 1.8 x 1.8 m to 3.6 x 3.6 m. The current annual volume increment was linearly related to the amount of foliage dry weight supported by the tree. As spacing intervals increased the foliage became less efficient in producing stemwood. A larger weight of foliage was required at wider spacings to produce a given amount of stemwood.

Foliage and wood production in unthinned natural black spruce in northern Quebec (Weetman and Harland 1964) displayed similar relationships. Dominant trees were apparently less efficient in the production of stemwood volume per unit weight of foliage than suppressed trees; this lower efficiency could not be related to a greater proportional live branch weight per unit weight of foliage.

TREMBLING ASPEN GROWTH AND YIELD

Wood Production in Naturally-regenerated Trembling Aspen Stands

Merchantable bolewood volumes in mature trembling aspen stands are comparable to those in pure stands of conifers e.g. white spruce and jack pine for most sites. Gross total volume in 100 year-old aspen stands possessing average stocking and densities was reported to vary by 140 m^3/ha from a minimum of 210 m^3/ha (MacLean and Bedell 1955; Maini and Cayford 1968). Ontario's Normal Yield Tables indicate that at 100 years volumes for aspen can vary from 350 m^3/ha on poor sites to 595 m^3/ha on good sites (Plonski 1981).

Although gross total volumes for aspen compare favourably with those from coniferous stands, sustained merchantable volume in older trembling aspen stands is seriously limited by decay. Up to 35 percent of the standing volume may possess internal defects (Maini and Cayford 1968).

Wood Production and Foliage Relationships for Trembling Aspen

Investigations of trembling aspen wood production and crown foliage relationships in natural stands of any age are lacking.

STAND DEVELOPMENT PATTERNS IN WHITE SPRUCE PLANTATIONS

Stiell (1976) and Harvey (1981) have offered comprehensive reviews of the silvicultural techniques employed to secure natural and artificial regeneration of white spruce and their impact om stand development patterns. In general greatest mortality in white spruce plantations occurs within the first four years after planting (Stiell 1958; Froning 1972). One of the most important reasons for this early mortality is vegetative competition (McLeod 1964; Tucker et al. 1968; Sutton 1975; Eis and Craigdallie 1983). Stiell (1958) found that dense grass, and aspen and birch suckers and sprouts resulted in considerable mortality of newly planted white spruce. Site preparation to expose a mineral seedbed was considered a temporary solution to the encroachment of competing vegetation. The use of large transplant nursery stock also aided in the survival and success of the plantation.

MacKinnon (1974) in a survey of Ontario's crown land plantations determined that the fifth-year average survival of white spruce was 61 percent for bare-root stock and 33 percent for tubed seedlings. For plantations established with bare-root stock, 20 out of every 100 plantations had survival rates of 80 percent or more, and 42 out of every 100 plantations had survival rates of 70 percent or more. Mullin (1978), in establishing plantation performance averages for white spruce, indicated that a higher survival at year 20 might be expected by planting 2+2 stock, than after planting 3+0 nursery stock.

Percentage survival of planted white spruce established on former mixedwood sites and under varying levels of hardwood competition of similar or greater ages has not been extensively studied. Sutton (1987) reported that survival of white spruce underplanted on mixedwood sites near Chapleau and Manitouwadge, Ontario had an average survival of 55 percent after four growing seasons. In this respect they did not differ markedly from that reported by MacKinnon (1974).

Upon establishment the rate of stand development will be strongly influenced by the rate at which the spruce grow and occupy the available growing space. The growth rate of white spruce does not remain constant, however, and this variation must be considered when comparing stands of different ages.

Kozlowski and Ward (1957) reported that white spruce which were an average of 10.5 cm tall when outplanted as 3+0, grew 14.2 cm in the first growing season - a 135 percent increase. Average height gains in a 13 year-old plantation (15 year-old trees) in northern Wisconsin was 51 cm/year, which was less than a 10 percent increase in total height (Nienstaedt 1965).

Growth rates are affected by genetic and micro-site differences (Radsliff et al. 1983; Vyse 1981), and availability of resources necessary for photosynthesis and biomass production (e.g., sunlight, water, and nutrients). Drought, frost heaving, exposure, late season planting with physiologically active stock, or planting with poor or over-sized stock may either kill a seedling or cause a reduction in growth rate, especially in depressions or areas where there is no air drainage. The effects of these factors often can be observed in the variable initial height growth of planted white spruce (Stiell and Berry 1973; Vyse 1981; Thrower 1986). When a period of very slow initial height growth occurs the seedlings are said to be in "growth check". White spruce is very susceptible to this phenomenon.

Plantation white spruce will often exhibit slow juvenile height growth. White spruce trees reached breast height six to twelve years following planting at the Petawawa Forest Experiment Station (Stiell 1976). Hambly (1980) discovered that the annual height growth of planted white spruce in northern Ontario was more or less constant before breast height and then increased rapidly averaging 32 cm per year for the next 12 years. Stiell (1976) has reported that height growth for white spruce on the best sites at Petawawa began to decline between 25 and 35 years after planting from an average of 54 cm to 30 cm per year (Stiell and Berry 1973). Thrower (1984) also found that 31-year-old white spruce planted in the Prince and Jarvis Locations near Thunder Bay displayed an almost linear height growth once the trees had reached breast height. A similar linear height growth pattern was observed by Thrower (1986) in the development of growth intercept curves for plantation white spruce in the North Central Region, Ontario Ministry of Natural Resources.

Influence of Competitive Vegetation on Stand Development

Growing space created by harvesting and site preparation may be rapidly occupied by broad-leaved herbaceous and woody species and grasses. When the available growth resources are insufficient to support optimal growth of all plants present the plants are said to be in competition (Sutton 1969b). Competition is complex in nature, and the effects of one plant competing with another may be influenced by a variety of interactions between the two plants, the site, and the surrounding vegetation. In this thesis, the general term "competitive species" will refer to plants that are suspected of using growth resources at a rate or for a duration which may negatively impact on the survival, growth and development of the planted spruce.

The effects of competing vegetation on the growth and survival of white spruce varies with the age of the trees, site conditions, and site occupancy. Herbaceous plants and woody vegetation compete for different amounts of various resources, which in turn has different effects on the growth and survival of the spruce (Kimmins _et_ _al_. 1986).

The response of juvenile spruce to vegetation management in various trials throughout the boreal forest has been extremely variable. Positive growth response was reported by McLeod (1978) in Alberta, where two year-old white spruce planted on an outwash deep, dry to fresh moisture regime sandy loam soil grew better on vegetated than on non-vegetated plots. In a study of white spruce regenerated naturally under a mature overstory, Lees (1970) found that the height growth of seedlings was significantly reduced by vegetative competition; however, the mortality rate did not appear to be affected. Vyse (1981) reported opposite findings in terms of growth and survival. Heavy vegetative cover significantly reduced survival, but not the growth of young trees. This extremely variable response to the occupation of the site by non-crop species probably reflects a myriad of site - related differences between the studies including understorey micro-climate, differences in soil water balance and soil evapotranspiration patterns and differences in the performance potential of the seedlings being studied.

In established plantations, the type, amount and distribution of competitive species often will affect the growth of the spruce rather than its survival (Kozlowski and Ward 1957). Eis (1970) working in British Columbia reported that deciduous crowding without overtopping in white spruce plantations reduced height growth and diameter increments, but did not affect survival. Suppressed spruce trees surviving 30-50 years of suppression under mature aspen in Manitoba were still able to respond to release (Cayford 1957; Nienstaedt 1957).

White spruce, growing in plantations three to seven years-old under varying levels of competition, displayed a mean reduction of 39 percent in total height and a 57 percent reduction in leader length under severe competition (Oxenham 1983). Only under the highest amounts of competition did a significant increase in spruce mortality occur.

Of critical importance is the ability of the spruce crown to intercept sunlight. Shirley (1945) and Logan (1969) studied the growth of white spruce growing under artificial structures designed to provide various levels of natural light intensity. They both concluded that white spruce could be grown for an initial eight- to ten-year period in light intensities as low as 43 percent of full light without a significant reduction in height growth or incurring mortality.

At light intensities below 20 percent, severe reduction in height growth was found. Maximum height growth occurred at 45 percent to 75 percent of full light. The diameter and total seedling dry weight of white spruce was also reduced at light intensities lower than 100 percent, but the effect of this reduction on bolewood volume production was not determined. Studies of seedlings, transplants (Eis 1967, 1970) and 16 year-old plantations (Leaf and Keller 1956) have confirmed the applicability of Shirley's (1945) and Logan's (1969) findings to field situations.

The availability of moisture and nutrients and the ability to compete for them can also have significant impacts on seedling survival and growth rates. White spruce is one of the more nutrient demanding conifers (Stiell 1976) and soil fertility significantly affects its growth (Sutton 1975). Vegetative competition removes nutrients from the soil and will often cause self-grafting between those white spruce roots present in the rooting zone, causing further nutrient stress of the individual seedling (Eis 1977). Harding (1982) reported a decrease in white spruce site index for stands having increased available nutrient levels created by the increased presence and density of hardwoods on the site.

A positive effect of deciduous vegetation on nutrient availability is the fertilizing effect of the leaf litter (Wilde _et_ _al_. 1965). This effect is greatest in species that are able to "pump" nutrients up from soil layers deeper than white spruce roots normally reach (Thomas 1969).

There is no direct physical means by which root competition can be measured, but several studies have related root competition to white spruce growth by severing competing roots or comparing trees growing with different densities of surrounding vegetation (Shirley 1945; Eis 1970; Stiell 1976). The studies indicate that root competition may significantly reduce growth, seedling survival and, apparently, shade tolerance of the conifer component.

Response of White Spruce to Release

Release work involves freeing young spruce from other vegetation which overtops or crowds the spruce. Sutton (1975) studied weed control site preparation in two different situations: I. dense, lush grass on a fertile, moist sand; and II. stunted vegetation on a nearby infertile ("worked out") sand. On the former site , survival of white spruce outplants depended upon weed control; on the latter site, survival was independent of weed control, but growth was affected. After three years, released trees on the former site had a 20 to 33 percent height advantage over that of the controls. Trees released for a five year continuous period displayed a 36 percent advantage. However, the growth advantage of the released trees soon decreased when weeds were allowed to regrow.

Most researchers have found similar positive growth responses in white spruce following their release from hardwood competition (Armstrong 1963; Lees 1966; Sutton 1969b; Krishka and Towill 1989). Baskerville (1961) determined that conifer height growth response was greatest when the trees being studied were 0.9 to 1.2 m in height. Increased height growth was maintained by the conifer even though shrubs re-invaded the study area two to four years after release. Perala's (1982) review of growth benefit studies in the Upper Great Lakes has assembled evidence that red pine and white spruce, in general, can average 43 percent greater survival, 120 percent greater height growth and 814 percent greater weight growth when released from competition. It is important to realize that even small increases in height growth will greatly affect bole volume production; for example, a doubling in height growth will result in approximately a 7.3-times increment in weight.

Perala was also able to document that in general, conifers which suffered the most from suppression grew relatively the fastest after release; the more complete the release, and the greater the suppression, the larger the contrast in size and volume between released and suppressed conifers. Finally, it was also reported that conifers released from subordinate competition responded less than those released from over-topping competition.

The recuperative powers of young spruce are usually not affected by overtopping aspen competition. Given the opportunity, natural white spruce in an understorey position will respond favourably to release (Ontkean and Smithers 1959). Johnstone (1978) has reported that this response is, in part, related to the size of the spruce tree's crown at time of release. During the first five years following logging, the remaining residual white spruce trees experienced a delayed release response in volume and diameter increment, and a decline in height increment. Once the residual spruce's crown had expanded, significant increases in volume and height growth then occurred.

From the evidence presented, it seems imperative that if survival, height and diameter growth are to be good, some forms of intervention in the stand development pattern will have to be undertaken during the early successional stages of plantation development. A knowledge of stand successional patterns would greatly assist in optimizing the timing of release treatments and maximizing the associated growth response in planted white spruce.

METHODS

REGIONAL SETTING

The study was conducted in the Prince and Jarvis Locations, Crook and Blake Townships, Fort William Crown Management Unit, approximately 54 kilometres south of Thunder Bay, Ontario (48° 10' N., 89° 22' W., elevation 304 m) (Figure 1). The climate (Chapman and Thomas 1968) is modified continental characterized by a moderate level of rainfall averaging 73.84 cm / annum, warm summers and prolonged frost and snow cover during the winter. Mean annual temperature is 2.4°C with the yearly minimum occurring in January (-14.8°C) and the maximum occurring in July (17.5°C)

The underlying and exposed bedrock commonly includes sedimentary rocks such as sandstone, pelites, and conglomerates; granitic masses and formations containing a high iron content (Crown *et al*. 1978). This is overlain by Wisconsin age surficial deposits.

During the northward retreat of the Superior ice front, glacial meltwaters were ponded in the Superior Basin, forming a succession of lakes designated as Duluth, Algonquin and Nipissing in sequence, each having progressively lower water levels (Zoltai 1965; Geul 1970,1973).

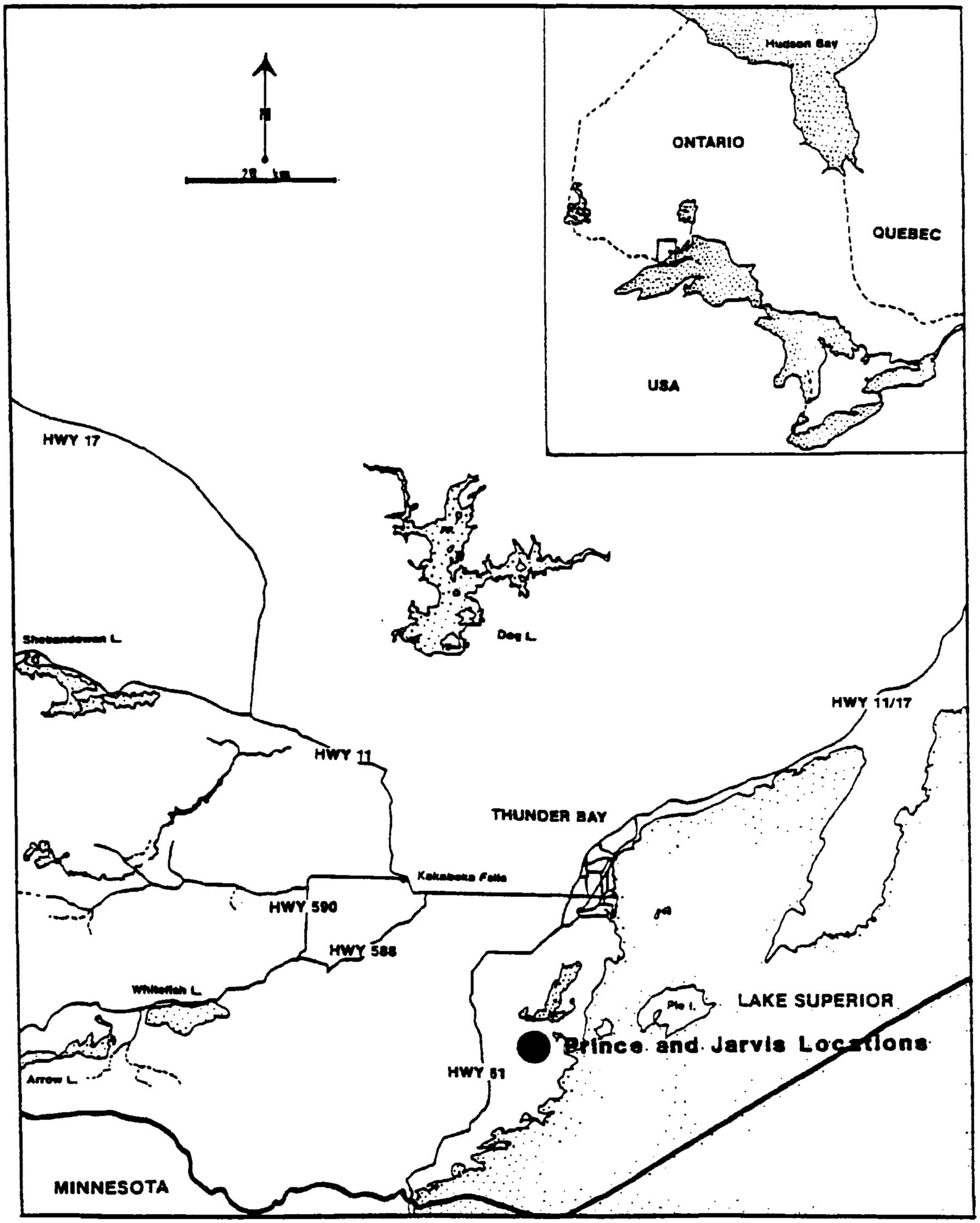


Figure 1. Location of Prince and Jarvis Locations.

These lakes fed by glacial meltwaters extended beyond the present Lake Superior shore and occupied valleys between the resistant diabase sills characteristic of the Prince and Jarvis locations (Burwasser 1977).

The deposits of the Prince and Jarvis Locations reflect a range of lake levels. For the most part, the lacustrine sediments are fine textured and were deposited in the lake basin or valley bottoms to form relatively thick, level lacustrine plains (Crown et al. 1978). The grey clay sediments were derived from gray shales similar to the shales observed on Mount McKay. Silt sediments were deposited in association with the clay.

Soils which developed on these lacustrine deposits have been classified by Crown et al. (1978) as belonging to the Jarvis River and Oskandaga soil series. The unifying feature of the two soil series is the calcareous red clay parent material underlying the somewhat lighter textured mineral surface soil horizons. The Jarvis River soils occur on the upper slope position and are moderately well-drained. In contrast, the Oskandaga soils commonly found on level toeslope areas are imperfectly drained. A complex of the two soils series exists in areas of Crooks and Blake Townships.

The present vegetation of the Prince and Jarvis Locations is quite variable as a result of recent fires and human intervention. Rowe (1972) describes Thunder Bay District as an ecotone between the Superior and Nipigon

Sections of the Boreal Forest and the Quetico Section of the Great Lakes-St. Lawrence Forest. Much of the natural forest is hardwood-softwood mixtures composed of trembling aspen, paper birch (Betula papyrifera Marsh.), balsam fir (Abies balsamea (L.) Mill.), black spruce, and white spruce.

Lumbering of the Prince-Jarvis Locations began in the early 1900's. White pine (Pinus strobus L.), found in pure stands along the numerous ridges, was the principal commercial species harvested in the early years. In 1947 Newaygo Timber Limited, a subsidiary of Consolidated Power and Paper Company, Wisconsin Rapids, Wisconsin, U.S.A. purchased the former mining locations from the Province of Ontario. The 24 square kilometres of land contained 90,000 cords of birch and poplar, and 4000 cords of spruce and balsam fir. The original plan was to cut 3000 cords of birch and poplar every year for 30 years. After this initial period of operation, cutting would shift from the lowland birch areas to the large central plateau where 1000 cords of spruce per year would be cut over the next 30 years. This plan was never followed inasmuch as the central plateau was never harvested. All timber was rafted to Wisconsin where the parent company, Consolidated Power and Paper, utilized it for the manufacture of super-calendared paper.

The reforestation programme of Newago Timber consisted of planting each cutover the year following the harvesting operation. No mechanical site preparation was ever used.

Approximately 250,000 white spruce seedlings were planted each year at a 1.8 x 1.8 m spacing. At an estimated rotation age of 60 years, Newaygo Timber estimated that the first white spruce plantations would yield 6000 cords of white spruce per year in perpetuity.

In 1960, the company closed the Prince-Jarvis operation and sold its camp and equipment. The overhead costs were too great in comparison with the income from wood products. From 1960 to 1969, Newaygo Timber and the Crown sold stumpage to several local 'pulp farmers' (independent cutters). In 1970 the land was returned to the Crown. Since then only small scale winter cuts have been undertaken: balsam fir, balsam poplar (Populus balsamifera L.), and trembling aspen have been cut for sale to local mills or waferboard plants. The Ontario Ministry of Natural Resources is responsible for plantation establishment on recent cutovers.

DESCRIPTION OF STUDY PLANTATIONS

White spruce was first planted in the Thunder Bay District about 1947. However, due to the widespread variability in site quality and conditions over which these plantations occur, sampling was restricted to plantations located upon lacustrine deposits. These soils are some of the most productive white spruce sites in the region (MacLean and Bedell 1955; MacLean 1960).

Four plantations (Figure 2) were selected to represent four recognizable stages in white spruce stand development:

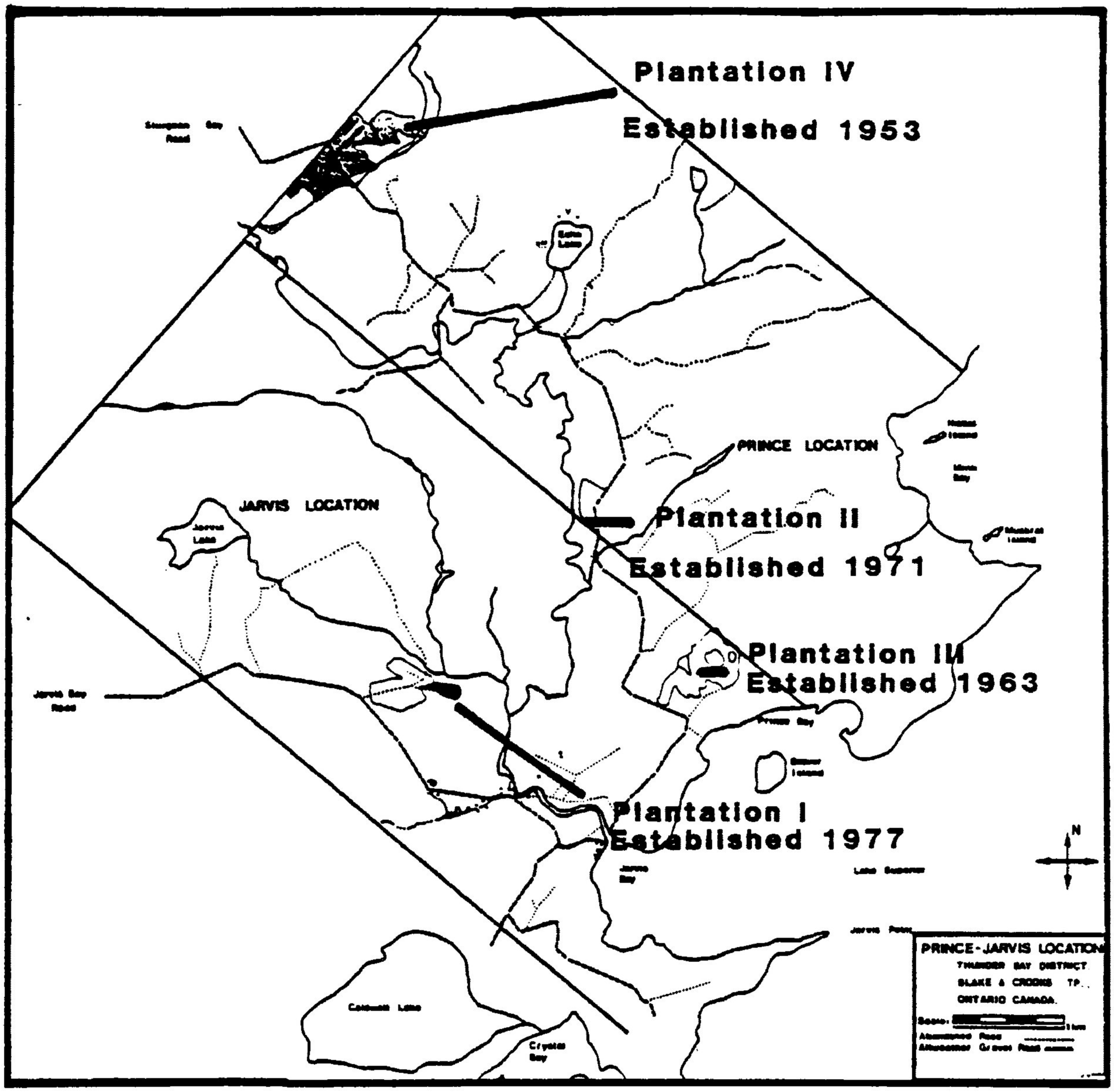


Figure 2. Four white spruce plantations were established for study in the Prince and Jarvis Locations.

(1) stand initiation (1 to 5 years old); (2) juvenile (5 to 10 years old); (3) sapling (11 to 20 years old), and (4) polewood (19 years and older).

To minimize site and stand variation, stands were selected if the met the following criteria:

(a) plantations were greater than 60 % average stocking to white spruce at five years of age;

(b) the hardwood component was even-aged;

(c) all plantations possessed similar species composition with no obvious discontinuities or lateral gradients of floristic composition;

(d) all plantations were at least 5 ha in area;

(e) uniform site quality with no obvious discontinuities or pronounced gradients;

(f) humus layer was less than 5 cm thick;

(g) reasonably accessible.

A summary of the four study plantations is presented in Table 1.

Plantation I

The original stand contained a large proportion of white and black spruces and a minor component of balsam fir. The area was logged in 1966 leaving numerous standing residual balsam poplar and trembling aspen stems. Site preparation using a modified V-blade plough in 1976 produced clear strips 2.5 to 3.0 m wide (Appendix A, Figure A5). The 'corridored' strips ran parallel to the elevational contours. In the spring of 1977 the area was planted with 3+0 white

Table 1. Summary of study areas.

Plantation number	Year planted	Location	Year harvested	Year of site preparation	Method of site preparation	Species planted	Year released	Herbicide and rate of application	Comments/ photo reference
I	1977	Jarvis Road Crooks Township UTM 16 230 328	Clearcut 1966	Summer 1975 - chemical Fall 1976 -mechanical	modified v-blade plough	white spruce (3-0 bareroot)	n/a	n/a	- numerous residual balsam poplar and balsam fir - L-slit planting -1.8 x 1.8m spacing - heavy herbaceous competition Appendix A, Figure A1
II	1971	Sturgeon Bay Road Crooks Township UTM 16 247 345	Clearcut 1966/1967	Fall 1971/Winter 1972 -mechanical	modified v-blade plough	white spruce (3-0 bareroot)	1974 1975	Simazine 2.5 kg ai/ha 2,4-D Ester 2.2 kg ai/ha	-1.8 x 1.8m spacing - heavy herbaceous competition Appendix A, Figure A2
III	1963	Sturgeon Bay Road Crooks Township UTM 16 252 333	Clearcut 1961/1962	n/a	mechanical skidding of logs with using yarding cables	white spruce (2-2 bareroot)	1970 1975	hand release 2,4-D Ester 2.2 kg ai/ha	-1.8 x 1.8m spacing - L-slit planting - pit planting technique - heavy woody shrub competition Appendix A, Figure A3
IV	1953	Sturgeon Bay Road Crooks Township UTM 16 224 381	Clearcut 1952	n/a	mechanical skidding of logs with using yarding cables	white spruce (2-2 bareroot)	1970 1975	hand release 2,4-D Ester 2.2 kg ai/ha	-1.8 x 1.8m spacing - former stand mostly white birch - pit planting technique - heavy woody shrub competition Appendix A, Figure A4

spruce seedlings at approximately 1.8 x 1.8 m spacing intervals in the spoilbank, spoilbank ledge and in the centre of the corridor.

Since corridoring, the area rapidly developed a dense cover of brush and trees, primarily trembling aspen, which are competing with the planted white spruce (Appendix A, Figures A6, A7). Grass, fireweed (*Epilobium angustifolium* L.), raspberries (*Rubus idaeus* var *strigosus* L.), rose (*Rosa acicularis* Lindl.) and large leaf aster (*Aster macrophyllus* L.) have overgrown many of the seedlings. Many of the white spruce planted in the centre of the corridor have exposed roots following frost-heaving. These same seedlings also experience periodic inundation in the spring or after extended rainy periods. Many seedlings, particularly those planted in the centre of the corridor exhibited nipped shoots and buds suggesting damage from the snowshoe hare (*Lepus americanus* Erxlebn.).

Soil conditions in the plantation varied according to micro-site position and the attendant severity of site preparation. Scarification by means of the V-blade plough exposed the Bt, and in a few areas, the parental C in the corridor micro-site (Appendix H, Tables H1, H2, H3). The litter mat, Ae(h) and portions of the Bt removed by ploughing was deposited along the edge of the plough's path. This deposition of material was characteristically two-tiered

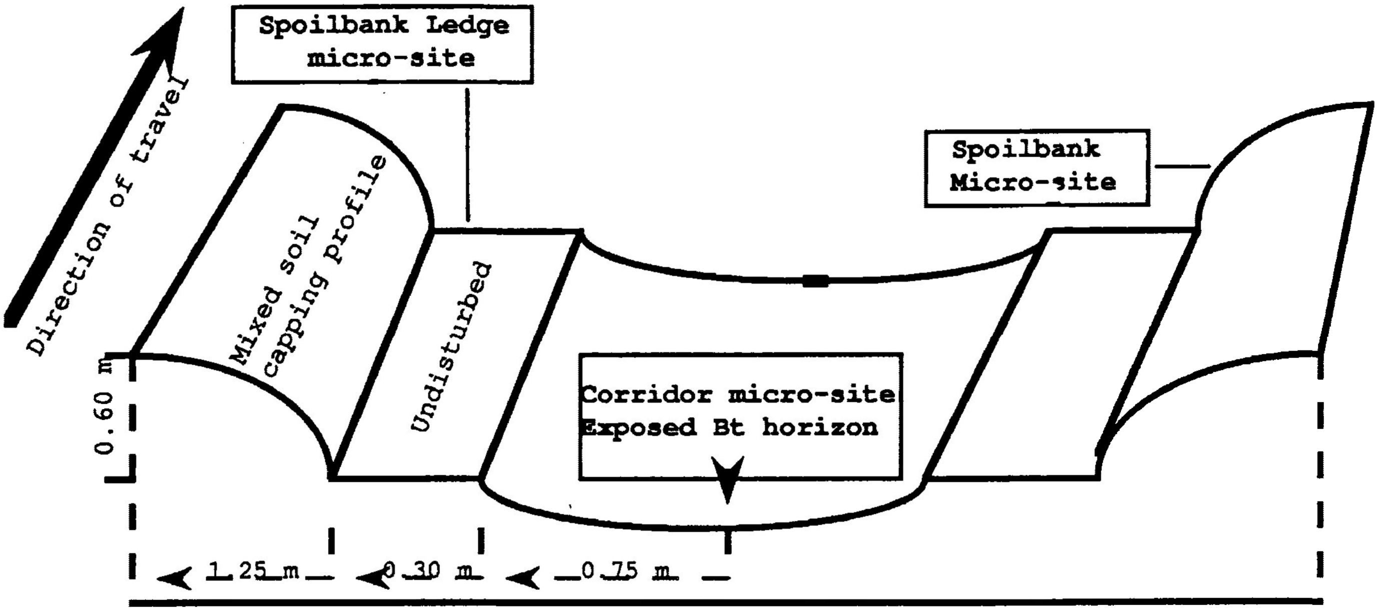


Figure 3. Schematic representation of scarified path made by the inner plough (central hollow) and outer plough and side arms of a C&H plough.

giving rise to a spoilbank ledge and spoilbank micro-site (Figure 3). Organic matter incorporation into the upper soil horizon (Ae) was greatest for the spoilbank ledge micro-site and least on the corridor (Appendix I, Table I1). The incorporation of organic matter into the Ae horizons was thought to be related to the observed lower bulk densities, increased water holding capacity and increased percentage pore space within the rooting zone depth that were observed on the spoilbank and spoilbank ledge micro-sites (Appendix I, Table I1). The bulk density of the Bt horizon soil was similar for all three micro-sites. The pH of the Ae horizon soils was somewhat higher in the corridor than on the spoilbank ledge or spoilbank. These differences reflect somewhat higher pH of the subsoil material in the corridor in contrast to the somewhat lower pH of surface soil found in the spoilbank ledge or spoilbank.

Plantation II

The area was clearcut for white spruce and trembling aspen in the winter of 1966-1967. Site preparation using a modified V-plough during the winter of 1971/1972 created clear strips 3.0 to 5.0 m wide. Scarification was less severe thus creating only two distinct micro-sites: spoilbank and corridor (Figure 3). The regeneration corridors extended through a clearcut area into a residual stand of trembling aspen and balsam poplar.

In the spring of 1971 the area was planted with 3+0 white spruce nursery stock at approximately 1.8 x 1.8 m spacing intervals on the spoilbank and corridor. An aerial herbicide treatment in 1975 reduced the crown projection of the aspen and balsam poplar but did not eradicate the remnant trees (Appendix A, Figures A8, A9, A10).

Since at spraying, the area has become covered with dense patches of medium-coarse grass (<u>Calamagrostis</u> <u>candense</u> (Michx.) Beauv., <u>Agrostis</u> <u>scabra</u> Willd., <u>Andropogon</u> <u>gerardii</u> Vitman) (Appendix A, Figure A8), raspberries, rose, large leaf aster, and aspen suckers (Appendix A, Figure A9). The area is gently rolling to hilly with southerly air drainage. Few seedlings displayed any signs of frost damage at the time of sampling. Many of the white spruce seedlings in the open areas had their leading shoot nipped by snowshoe hare.

Plantation II - age 10 years, was established on silty clay parental material. The Ae(h) and Bt horizons were clay loam, similar to that of plantation I. Unlike plantation I, the C&H ploughing was less severe, and some Ae was left on the corridor (Appendix H, Tables H4, H5). Apparently, at the time of corridoring there was a reduced depth of litter, a lack of slash, and fewer standing residual trees. Thus, more optimal conditions occurred for the use of the plough and, as a result, the scalping at the site was not as severe as that observed in plantation I.

The residual Ae horizon in the corridor micro-site possessed a greater of percentage organic matter than the spoilbank, possibly reflecting a larger accumulation and incorporation of hardwood leaf litter on this particular micro-site (Appendix I, Table I2). Bulk density of the soil in the rooting zone was also considerably less on the spoilbank than on the corridor. This was partly influenced by the greater depth of the Ae(h) horizon available for rooting on this micro-site when compared to that on the corridor.

Plantation III

The area was harvested in 1961-1962 by Newaygo Timber Company for white spruce and white birch. Site preparation was limited to natural scarification created by skidding the tree-length logs out to the roadside landings. In the spring of 1963, 2+2 white spruce transplants were pit-planted in the cutover.

During the winter of 1970, hand release treatment successfully eliminated the alder component of the stand (Appendix A, Figure A11). In 1975 the entire area was aerially-sprayed with 2,4-D to release the spruce from overstory competition by white birch and trembling aspen. In parts of the plantation, white birch and trembling aspen remain dominant (Appendix A, Figures A12, A13). Beneath the white spruce and trembling aspen canopy is a shrub stratum consisting of beaked hazel (Corylus cornuta Marsh.), willow

(Salix spp.), speckled alder (Alnus rugosa (Du Roi.) Spreng.), raspberry, and rose. The herbaceous stratum is formed, almost exclusively, by medium to wide-bladed grasses.

Appendix I contains results of soils analyses from the plots located in each of III and IV, respectively. The five plots in plantation III were established on sandy clay loams. Organic matter content was greater in the Ae(h) horizon than in the Bt horizon. Paralleling these trends, bulk density of the Ae(h) and Bt horizons was less in the mixedwood areas of the plantation than under the areas of pure spruce. Conversely the water holding capacity of the soil under the mixedwood was slightly less than that observed under the pure white spruce. Soil under the mixedwood condition had active and reserve pH measurements (Thrower and Schmidt 1985) that were less acidic than those from soil under the areas of pure white spruce. The accumulation of hardwood leaf litter and its quick decomposition and incorporation into the soil possibly provides a buffering effect in comparison to the steady accumulation and slow decomposition of acidic conifer needles.

Plantation IV

The area was clearcut of white birch and trembling aspen in 1952. Site preparation was limited to natural scarification created by skidding the logs out to the roadside. In the spring of 1953, 2+2 white spruce transplants were pit-planted in the cutover. A portion of the plantation south of the road soon became dominated by trembling aspen suckers; pit-planting was difficult in this area. The white spruce seedlings north of the roadway were planted on a white birch clearcut. Vegetative competition was very limited on these sites. Today the white spruce form an essentially pure stand north of the road (Appendix A, Figure A15), while to the south the white spruce are scattered and heavily suppressed by the overstory trembling aspen (Appendix A, Figures A16, A17).

During the winter of 1970, a selective hand release was partially successful in removing competing alder and trembling aspen. An aerial release treatment of 2,4-D applied during late summer, 1975, was unsuccessful in removing the aspen overstorey.

Plantation IV was located on a sandy clay loam (Appendix I; Table I4). Organic matter content was greater in the Ae(h) horizon than in the Bt horizon; bulk density of the Ae(h) and Bt horizons were less under the mixedwood portion of the plantation than under the pure white spruce.

SAMPLING PROCEDURES

Overview

The data acquisition phase consisted of three distinct sampling cycles. The first cycle involved a preliminary description of stand structure followed by a stratified random sampling of the planted white spruce in each plantation. The population was stratified according to micro-site position and the amount of overtopping or lateral hardwood competition. In the case of the two older plantations, the spruce population was stratified on the basis of its crown class and the amount of overtopping or lateral hardwood competition.

The number of planted white spruce sampled from each stratum was established following the principle of optimal allocation. Sufficient numbers of spruce were selected in each strata in plantations I and II to permit the estimation of the tree's total height (cm) to within a 10 percent standard error of the mean. Sampling in plantations III and IV was restricted to 15 plots per area by the Ontario Ministry of Natural Resources to minimize any damage to the remaining spruce from the destructive sampling. The number of spruce selected from each stratum are provided in Table 2.

The second cycle consisted of the collection of data related to the competitive stress placed on the randomly selected white spruce trees. The previously selected white spruce were used as crop tree centres for the establishment of fixed-area circular plots. Plot size varied with plantation age following Newbould (1967). Plot sizes were as follows:

Plantation age	Plot radius (m)	Plot area (m^2)
1 to 5 years	1.03	3.33
6 to 9 years	3.25	33.33
10 to 25 years	5.64	100.00
26 years +	9.77	300.00

Table 2. Micro-site/aspen competition situations in plantations I, II, III, IV,.

Plantation		Micro-site/aspen competition situation	Number of sample plots per situation	Number of white spruce sample trees
I.	(1977)	Corridor-low aspen (0-4 trees/m^2)	12	15
		Corridor-high aspen(> 4 trees/m^2)	3	
		Spoilbank-low aspen(0-4 trees/m^2)	8	15
		Spoilbank-high aspen (> 4 trees/m^2)	7	
		Spoilbank-low aspen(0-4 trees/m^2)	9	20
		Spoilbank-high aspen (> 4 trees/m^2)	11	
				50
II.	(1971)	Corridor-low aspen (0-2 trees/m^2)	7	14
		Corridor-high aspen(> 2 trees/m^2)	7	
		Spoilbank-low aspen(0-2 trees/m2)	9	16
		Spoilbank-high aspen (> 2 trees/m^2)	7	
				30
III.	(1963)	Low aspen (0-1 trees/m^2)	5	6
		High aspen (> 1 trees/m^2)	10	
				6
IV.	(1953)	Low aspen (0-1 trees/m^2)	5	6
		High aspen (> 1 trees/m^2)	10	
				6

All previously selected white spruce were then destructively sampled to permit an examination and comparison of patterns in biomass partitioning and accumulated dry matter production. Total height(m) and diameter at breast height (cm) (d.b.h.) for each of the dominant trembling aspen trees growing on the plot were also recorded; a sub-sample of this population representing each of the diameter and height classes for the species was destructively sampled at the same time that the spruce were removed. This facilitated an investigation of the possible influence of trembling aspen on the growth and dry matter production of the white spruce crop trees.

The third cycle involved studying stand level population structure, biomass partitioning and distribution among species. Floristic and stand structure information was collected from each plot. Stratified-clipping followed to obtain biomass information for all vegetation strata. The data were then examined on an individual plot basis with an emphasis on determining whether the presence and standing crop biomass of the non-crop lesser vegetation could be correlated with the observed crop tree growth and yield. These data were subsequently extrapolated to a stand basis.

Stand Structure

The population structure of the white spruce and trembling aspen occurring in each of the plantations was determined from a tally of each of the species occurring in the stratified random sample plots established in each plantation. Height, d.b.h. (outside bark) and root collar diameter at 0.10 m were recorded. Root collar diameter rather than d.b.h. was examined in plantations I and II aged four and ten years, respectively, since many of the white spruce seedlings had not yet reached breast height (1.35 metres).

Frequency distributions of root collar diameter or d.b.h. and height were then prepared for white spruce and trembling aspen. The mean, standard error of the mean, and variance of the following variables were also calculated:

1. Root collar diameter (where applicable)
2. Diameter at breast height (where applicable)
3. Total tree height
4. 1981 annual height increment
5. Annual height increments for plantation I (established in 1977)
   a. 1980 annual height increment
   b. 1979 annual height increment
   c. 1978 annual height increment.

The measurement of the past three year's of annual height increments was an attempt to trace the effect competition may have had on seedling height growth during recent growing seasons.

The observations were then subjected to Analysis of Variance using a completely randomized design with unequal replication (Snedecor and Cochran 1980). Micro-site and micro-site/aspen competition situations (Table 2) within a plantation were compared. All analyses were performed at the p = 0.05 level of significance; treatment means were compared using a Student-Neuman-Keul (S-N-K) test (Snedecor and Cochran 1980). The S-N-K test was applied because the error rate for each test is adjusted to reflect the size of the subset being tested and the number of strata (treatments). The S-N-K test has greater power than a t-test.

Floristics

Prior to destructive sampling of trees and vegetation for stem analyses and to obtain standing crop information, the floristics of a 2 x 2 m plot located at each randomly located plot centre were described. A nested 1 x 1 m plot was used to inventory all herbaceous species; shrub species were tallied within the full 2 x 2 m plot. Numbers of stems and visual estimates of percent ground cover (Table 3) for all species were recorded. Shrubs were defined as any plant with less than 10.2 cm d.b.h. but greater than 30.5 cm in height. Percent frequency, density, average cover, and relative importance values were calculated (Curtis 1959).

Table 3. The Daubenmire (1959)cover scale.

Cover class	Range of cover (%)	Class mid-points (%)
6	95-100	97.5
5	75-95	85.0
4	50-75	62.5
3	25-50	37.5
2	5-25	15.0
1	0-5	2.5

Bryophytes and lichens were not described.

The floristic data were then subjected to a standardized, non-centred polar ordination. The data were analyzed on a species by species and a plot by plot occurrence.

Individual Tree Biomass

Selection of Trees for Destructive Measurement of White Spruce Growth and Biomass

Five basal diameter classes for the white spruce occurring in each micro-site / aspen density situation were identified from the plot data previously collected in plantations I and II. The number of planted white spruce selected for sampling varied among plantations (Table 2). In plantations I and II a 100 percent sample of all plots was conducted. A minimum of one seedling per basal diameter class was sought. Time, budget constraints and sampling restrictions imposed by the Ontario Ministry of Natural Resources limited the number of trees removed from plantations III and IV. This resulted in a lack of replication within each of the sampling strata and disqualified statistical examination of differences in spruce biomass production and growth.

A stem position and crown projection map was also prepared for each plot. The mean inter-tree distance was subsequently computed using a formula given by Hiley (1967).

Tree biomass in plantations I and II was based on direct measurement of dry weight by components following the methodology of Bella and De Franceschi (1980). Fifty planted white spruce from plots located in plantation I were sampled. One hundred and eighty-one dominant aspen suckers occupying the plot area were also removed. In plantation II, thirty white spruce and thirty dominant trembling aspen from of the thirty plots were likewise harvested.

The determination of tree biomass in plantations III and IV followed the methods detailed by Alemdag (1981). Each felled tree was separated into stemwood, stem bark, branch wood (live branches), branch wood (dead branches), and twigs plus needles; respective fresh weights were obtained to the nearest 0.1 kg. Samples were taken from each component, (a) to establish ratios between ovendry mass (OM) and green mass (GM) of the samples; and (b) to determine stem-wood densities (WD).

Six white spruce representative of the suppressed, intermediate and dominant crown classes were removed for destructive sampling from each of plantations III and IV (Table 2). Three trees (one from each crown class) were selected from the mixedwood portion of the stand while the other three were chosen from blocks of pure white spruce. The three spruce trees sampled from the mixed spruce-aspen areas could not be assigned a true crown class because of suppression and were, therefore, selected on the basis of the degree of suppression - slightly, moderately and heavily suppressed.

Fifteen dominant and co-dominant associate trembling aspen were randomly selected from each of the two older plantations for destructive biomass measurement and stem analysis.

Community Standing Crop Biomass

The standing crop biomass for a given unit area is the dry weight of all the above-ground biomass of trees, shrubs and herbaceous plants present at the time of sampling. The standing crop biomass on the plots was measured directly using a stratified clipping method. The standing crop biomass of the white spruce and trembling aspen trees on a plot were estimated using the volume:dry weight relationship established previously. Standing crop biomass values (kg/m^2) was calculated by pooling and averaging the results from the individual plot data. The data base was then aggregated and stratified according to the micro-site/ trembling aspen situation. The information from the plots was then extrapolated to obtain estimates of standing crop (kg dry weight per hectare).

Stem analyses

Field sampling and stem analyses procedures followed Kavanagh (1983). Stem sections were removed every 5 cm along the bole for both the white spruce and trembling aspen in plantations I and II. Trees from plantations III and IV were sampled at 10 cm increments from base of the tree. Mean periodic sheath volume increments were calculated using Smalian's formula and the height-age and volume-age relationships were determined.

(a) **White spruce**. In plantation I (age 4), three seedlings exhibiting individual heights (m) and root collar diameters (cm) similar to the average condition previously measured for spruce growing on each of the micro-sites were removed for stem analysis.

Only two distinct micro-sites were identified in plantation II (age 10); three spruce were again removed from each situation following the procedure outlined above.

In plantations III and IV (aged 18 and 25 years, respectively) the six spruce previously removed for biomass determination were also used for stem analysis.

(b) **Trembling aspen** A trembling aspen tree of average height and diameter was selected for stem analysis. In plantations I and II, nine and six trembling aspen trees, respectively, were removed for stem analysis. In plantations III and IV the Ontario Ministry of Natural Resources was very concerned about possible damage to the white spruce crop trees from felling the trembling aspen and would permit the removal of only 3 aspen trees from each plantation.for stem analysis in addition to the fifteen previously removed for destructive biomass sampling.

STATISTICAL PROCEDURES

Development of Biomass Equations

Tree bole volume (dm^3) was estimated using the algorithm (Alemdag 1981):

Volume = $(\text{Diameter at breast height})^2 \times \text{Height}$

Regression equations were then computed relating tree bole volume (X) (dm^3) to the dependent variables Y1 . . . Y20 (Table 4). These regressions were computed for white spruce and trembling aspen in each of the four plantations using the conventional least squares method. A linear model was then fitted by logarithmic transformation (Zar 1968), and the transformed values were corrected for bias by the method outlined by Baskerville (1972).

Group regressions were used to determine if significant differences existed among the sets of regression equations developed for each of the two species in the four plantations. When differences between regression equations were not significant, data were then combined to produce a single equation that applied to the plantations contributing data (Tables 4,5,6).

The following models providing the best fit for estimating biomass components were calculated (Tables 4,5,6):

Table 4. Tree component weight regressions of ln W = a+b ln (d)[a] for white spruce in plantation I, age four years.

Component dry weights (kg)	Regression statistics				
	a	b	r[b]	SEE[c]	E[d]
Foliage dry weight	-4.0605	1.6508	0.473	0.52	0.2753
Branch wood and bark dry weight	-4.8616	2.0933	0.404	0.77	0.5862
Stemwood and bark dry weight	-4.4189	1.4880	0.499	0.45	0.2012
Total seedling dry weight	-3.2825	1.6134	0.511	0.21	0.2254

Root collar diameter (d) and height (h) in cm and m, respectively.

Has been adjusted as in Baskerville (1972).

Standard error of the estimate.

Standard error of the regression coefficient.

Table 5. Tree component weight regressions of W = a+b $(d^2h)_a$ for white spruce in plantation II, age ten years.

Component dry weights (kg)	Regression statistics				
	a	b	r	SEE^b	$E3_c$
Foliage dry weight	0.00539	0.07010	0.775	0.11	0.1286
Branch wood and bark dry weight	-0.02135	0.05803	0.632	0.13	0.1761
Stemwood and bark dry weight	0.00918	0.05352	0.794	0.002	0.0067
Total seedling dry weight	0.00674	0.18165	0.788	0.28	0.0797

[a] Root collar diameter (d) and height (h) in cm and m, respectively.

[b] Standard error of the estimate.

[c] Standard error of the regression coefficient.

Table 6. Tree component weight regressions of ln W = a+b ln (d^2h) for trembling aspen in plantation I, II, III, and IV. $_a$

Component dry weights (kg)	Regression statistics					
	a	b	r_b	SEE_c	E_d	n
Plantation I - 4 years						
Foliage	-1.85968	0.83918	0.8083	0.51	0.26088	187
Branch wood and bark	-2.53345	0.90469	0.7470	0.66	0.43226	187
Stemwood and bark	-0.82886	0.87446	0.8704	0.42	0.17778	187
Total tree above ground	-0.44366	0.88149	0.8774	0.41	0.16960	187

Table 6. (Continued)

Component dry weights (kg)	Regression statistics a	b	r_b	SEE_c	E_d	n
Plantation II - 10 years						
Foliage	-6.05615	0.79834	0.7935	0.0029	0.29726	30
Branchwood and bark	-4.73344	0.80803	0.8219	0.0080	0.29763	30
Stemwood and bark	-3.25906	0.83797	0.8219	0.0200	0.05521	30
Total tree above ground	-3.13114	0.86528	0.9580	0.0330	0.14041	30
Plantation III - 18 years						
Foliage	-7.37980	0.97968	0.9926	0.0030	0.01197	15
Branch wood and bark	-5.78504	1.00617	0.9915	0.4800	0.01442	15
Stemwood	-4.13311	0.98752	0.9990	0.6200	0.00119	15
Stembark	-5.53363	0.99396	0.9992	0.1700	0.00137	15
Bole (wood and bark)	-3.91271	0.98883	0.9995	0.6400	0.00088	15
Total above ground	-3.7424	0.99104	0.9994	0.5500	0.00096	15

Table 6. (Continued)

Component dry weights (kg)	Regression statistics a	b	r_b	SEE_c	E_d	n
Plantation IV - 28 years						
Foliage	-2.86218	0.87831	0.9219	0.0070	0.00489	15
Branch wood and bark	-6.08484	0.98778	0.9931	0.5900	0.00510	15
Stemwood	-4.17657	0.99428	0.9967	2.5700	0.00247	15
Stembark	-6.04953	1.00872	0.9896	0.9600	0.00804	15
Bole (stemwood and bark)	-4.03304	0.99629	0.9971	2.6100	0.00216	15
Total above ground	-2.86218	0.87831	0.9219	48.6600	0.4940	15

[a] Root collar diameter (d) and height (h) in cm, respectively.

[b] Has been adjusted as in Baskerville (1972).

[c] Standard error of the estimate.

[d] Standard error of the regression coefficient.

Standing Crop Density

Standing crop density was determined by dividing the total standing crop per unit area (kg/m^2) with the average stand height (m). This value reflects the apparent density of organic matter per unit volume of forest stand growing space (kg/m^3).

The plot data for each plantation were stratified on the basis of seedling micro-site position and/or aspen surrounding the white spruce crop trees where applicable. The standing crop relations using total aboveground dry weight estimates for each of these conditions were calculated and compared. The standing crop density of trembling aspen and white spruce in each of the situations and at each plantation age were also calculated.

Prediction of White Spruce Dry Matter Weight

Numerous studies have attempted to explain differences in observed conifer crop tree size using correlation with selected, measurable biological (e.g., amount of surrounding vegetation) and edaphic (e.g., soil conditions, soil nutrition) factors. Undoubtedly it is a combination of both above-ground and below-ground environmental conditions that controls the degree to which a crop tree to achieve its full genetic potential for growth. Multiple regression analysis was used in an attempt to explain variation in white spruce dry matter production as a function of a number of biological and edaphic factors.

The dependent variables used in the series of linear regression analyses included Y1, Y2, and Y3 (Table 7). The edaphic and biological factors examined as independent variables were X3, X4, X5, X6, X7, X8, X9, X10, X11, X14, X15, X16, X17, X18, X20, and X27 (Table 8).

Table 7. Dependent variable list for regression analysis

Y 1	Bole dry weight (kg)	- White spruce
Y 2	Stemwood dry weight (kg)	- White spruce
Y 3	Stembark dry weight (kg)	- White spruce
Y 4	Dead branch dry weight (kg)	- White spruce
Y 5	Live branch dry weight (kg)	- White spruce
Y 6	Foliage dry weight (kg)	- White spruce
Y 7	Total tree above ground dry weight (kg)	- White spruce
Y 8	Bole dry weight (kg)	- Trembling aspen
Y 9	Stemwood dry weight (kg)	- Trembling aspen
Y10	Stembark dry weight (kg)	- Trembling aspen
Y11	Dead branch dry weight (kg)	- Trembling aspen
Y12	Live branch dry weight (kg)	- Trembling aspen
Y13	Foliage dry weight (kg)	- Trembling aspen
Y14	Total tree above ground dry weight (kg)	- Trembling aspen
Y15	Root collar diameter (cm)	- White spruce
Y16	Diameter at breast height (cm)	- White spruce
Y17	Current annual height (cm)	- White spruce
Y18	Total height (m)	- White spruce
Y19	Number of frosted tip's and buds on the current year's growth of the white spruce crop trees.	
Y20	Calculated crop tree crown efficiency (m^3/kg).	

Table 8. Independent variable list for regression analysis

X 1	Volume estimate of white spruce crop tree (d^2h)
X 2	Volume estimate of trembling aspen crop trees (d^2h)
X 3	Plantation age (years)
X 4	Soil rooting depth (cm)
X 5	Soil organic matter - Ae horizon
X 6	Percent silt and clay (%) (Ae, B horizon)
X 7	Percent sand (%) (Ae, B horizon)
X 8	Percent stoniness (%) (B, C horizon)
X 9	Bulk density of Ae and B - horizons (g/100 cm^3)
X10	Water holding capacity of the soil (%) (Ae and B horizon bulked)
X11	pH of soil (Ae horizon)
X13	Trembling aspen density on plot
X14	Trembling aspen density /m^2
X15	Plot density including all species/plot
X16	Hiley's Inter-tree spacing factor (%)
X17	Height of dominant trembling aspen on the plot (m)
X18	Total dry weight of competing vegetation on the plot (kg/plot)
X19	Total dry weight of competing vegetation kg/m^2
X20	Total dry weight of trembling aspen on the plot (m)
X21	Total dry weight of trembling aspen (kg/m^2)
X22	Herb dry weight (kg/m^2)
X23	<u>Rosa</u> spp. dry weight (kg/m^2)
X24	<u>Rubus</u> spp. dry weight (kg/m^2)
X25	<u>Aster</u> <u>macrophyllus</u> dry weight (kg/m^2)
X26	Graminoids and sedges dry weight (kg/m^2)
X27	Percent cover of white spruce seedling from overtopping competing vegetation (%)
X28	Aspen foliage dry weight (kg/m^2)
X29	Aspen foliage dry weight (kg/plot)
X30	Basal area of trembling aspen (cm^2/plot)
X31	Basal area of trembling aspen (cm^2/m^2)
X32	Aspen density/plot
X33	Aspen density/m^2
X34	Total of tree dry weight (kg/m^2)
X35	Total of tree dry weight (kg/plot)
X36	Total of tree foliage dry weight (kg/m^2)
X37	Total of tree foliage dry weight (kg/plot)
X38	Height of white spruce crop trees (m)
X39	Crown length of white spruce crop tree (m)

Vegetation Competition

Conifer crop tree growth may be limited or arrested by graminoid, herbaceous, non-crop conifer and hardwood vegetation surrounding newly outplanted nursery stock. Lehela (1981) indicated that the nature (species) and abundance of non-desirable vegetation can often be correlated to the size, current year's growth and physical condition of conifer seedlings after outplanting.

Multiple regression analysis was used in an attempt to predict spruce crop tree dimensions and their biomass components. The dependent variables included Y1, Y2, Y3, Y5, Y6, Y15, Y16, Y17, and Y18 (Table 7). The independent variables used in the series of multiple linear regressions were X19, X21, X22, X23, X24, X25, and X26 (Table 8).

The cover of the aboveground portion of conifer seedlings by competing vegetation may be correlated with observed differences in the size and growth of the conifer crop species. The possible correlation and prediction of white spruce seedling size and growth using the percent cover of the seedling was examined using simple linear regression. The dependent variables that were tested consisted of Y1, Y2, Y3, Y5, Y6, Y7, Y15, Y16, Y17, and Y18 (Table 7).

Foliage Efficiency and Wood Production

The ability of the crown foliage to produce wood varies with tree age, stand density and distribution of the foliage within the crown. Crown efficiency of those trees removed for stem analysis was evaluated with respect to the current wood volume produced per unit foliage dry weight supported by the tree. The influence of tree age and surrounding trembling aspen density on a white spruce's crown efficiency was investigated using linear regression techniques. The dependent variable was Y20 - calculated crop tree crown efficiency (m^3/kg) (Table 7). The independent variable list consisted of X15, X16, X18, X20, X21, X29, X32, X33, X34, X35, X36, X37, and X38 (Table 8). Crown efficiencies per hectare were calculated as the ratio of total current annual wood production and foliage dry weight per hectare.

RESULTS

Results are presented separately for each of the four study plantations. Comparisons of results amongst each of the four plantations include trends in: (a) standing crop relations; and (b) the prediction of white spruce crop tree size and dry weight utilizing various biological and edaphic factors as independent variables.

PLANTATION I

Stand Composition and Structure

Trembling aspen sucker growth dominated Plantation I with an average density of 18,018 stems per hectare (Table 9). In contrast, white spruce density averaged 1,386 stems.

A comparison of the growth of dominants of both species indicated that the trembling aspen averaged 0.67 m taller in total height than the white spruce (Table 9). The mean root collar diameters of the trembling aspen and spruce differed insignificantly.

Examination of the 1978, 1979, 1980 and 1981 mean annual height increments for each of the two species revealed that the trembling aspen had put on consistently greater annual heights than the white spruce (Appendix B; Table B1). White spruce current annual height growth had also varied according to planting micro-site.

Frequency histograms of root collar diameter and total height are given for white spruce planted on each of the three

Table 9. Stand descriptions for plantations I, II, III, IV Prince-Jarvis Locations, Thunder Bay District (based upon measurements of dominant crop trees).

Parameter	Plantation			
	I	II	III	IV
WHITE SPRUCE				
1. Age (years)	4	10	18	28
2. Inter-tree spacing (m)	0.70	1.20	1.90	2.10
3. Density (stems/ha)	1386	1512	2050	2150
4. Avg. root collar diameter (cm)	1.62	3.31		
5. Avg. diameter breast height (cm)			10.55	13.07
6. dominant height (cm)	1.20	2.35	10.67	16.54
7. component basal area (m^2/ha)	.2856	.6282	17.7509	28.8014
8. M.A.I. height (m/year)	0.14	0.23	0.18	0.16
9. M.A.I. basal area (dcm^2/stem/year)		0.0019	0.0081	0.0104
10. M.A.I. volume (dcm^3/stem/year)	0.1736	0.0881	0.1558	0.2908
TREMBLING ASPEN				
11. Density (stems/ha)	18018	3900	2330	2075
12. Avg. root collar diameter (cm)	1.58	3.31		
13. Avg. diameter breast height (cm)			7.94	13.66
14. dominant height (m)	1.71	3.29	9.42	14.51
15. basal area (m^2/ha)	3.73	3.34	11.71	30.41
16. M.A.I. height (m/year)	0.57	0.42	0.42	0.47
17. M.A.I. basal area (dcm^2/stem/year)	0.0051	0.0036	0.0038	0.0054
18. M.A.I. volume (dcm^2/stem/year)	0.12282	0.1086	0.1384	0.1484

micro-sites - Corridor (Appendix C; Figure C1), Spoilbank Ledge (Appendix C; Figure C2), Spoilbank (Appendix C; Figure C3), and for trembling aspen (Appendix C; Figure C10). The histograms reveal great variability in observed root collar diameters and heights. The diagrams illustrate several other points: (1) There was a rather weak, but probably real, tendency for diameter distributions to be more uniform (i.e. broader and flatter) than the height distributions which had a well-defined normal distribution; (2) the distributions of root collar diameters were least variable on the corridor, and most variable on the spoilbank and spoilbank ledge; (3) seedling heights were most variable for the corridor micro-site and least variable on the spoilbank; (4) trembling aspen root collar diameter and height distributions (Appendix C; Figure C10) were highly variable compared with those of the white spruce.

Influence of Micro-site Conditions on White Spruce Growth

The influence of micro-site on the size and growth of the planted white spruce was found to be statistically significant (Figure 4; Appendix E (Tables E1 and E2)). Mean root collar diameters and heights of spruce growing on the spoilbank ledge were significantly larger ($\underline{P}$=0.01) than those of trees growing on the other micro-sites. Likewise, statistically significant differences in favour of the spoilbank existed between the mean root collar diameters and

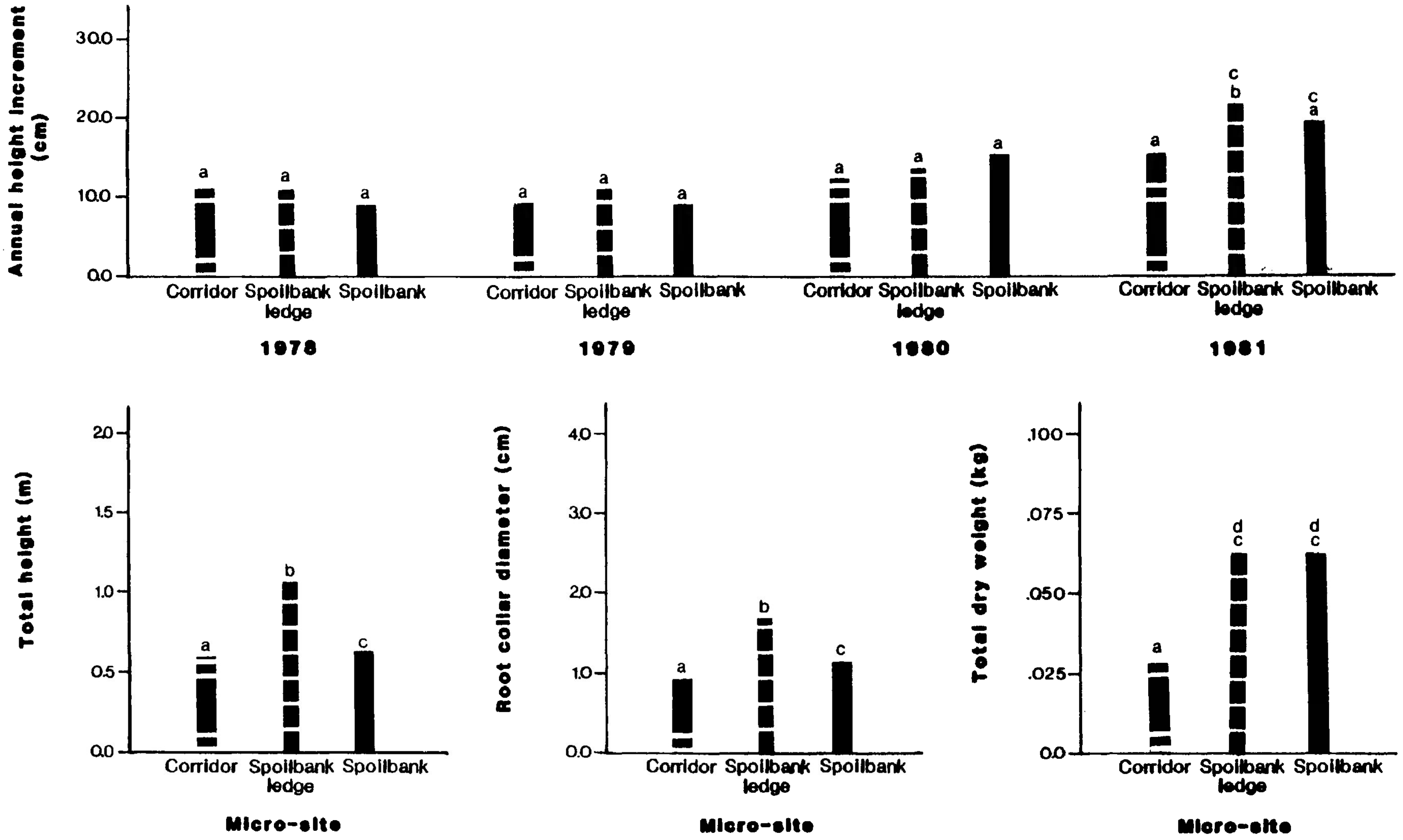


Figure 4. Comparison of white spruce tree growth between micro-site locations in Plantation I (age four years). (Refer to Appendix E, Table E1). Treatment means that are non-significant are assigned the same letter ($\underline{P}=0.05$).

heights of white spruce established on the spoilbank and corridor ($\underline{P}$=0.05).

White spruce planted on the spoilbank ledge also displayed a significantly larger mean 1981 current annual height increments when compared to trees planted on the corridor ($\underline{P}$=0.05) (Figure 4). No significant differences existed within the 1978, 1979, and 1980 mean periodic annual height increments, respectively.

Influence of Micro-site Conditions and Trembling Aspen Density on White Spruce Growth

To determine the influence of trembling aspen exerted an influence on the growth of the planted white spruce, the data from the destructively sampled spruce were stratified into micro-site/ trembling aspen density situations (Table 2). Appendix E (Table E3) provides a summary of the white spruce seedling growth data arranged by seedling micro-site/aspen density situation.

An increase in density of trembling aspen surrounding the white spruce seedlings sampled on the spoilbank and spoilbank ledge micro-sites was associated with decreased mean root collar diameters, decreased total heights, and decreased 1980 and 1979 current annual height increments. In contrast, the increased presence of trembling aspen in the corridor had no significant effect on the size and growth of white spruce seedlings located upon the same site (Figure 5).

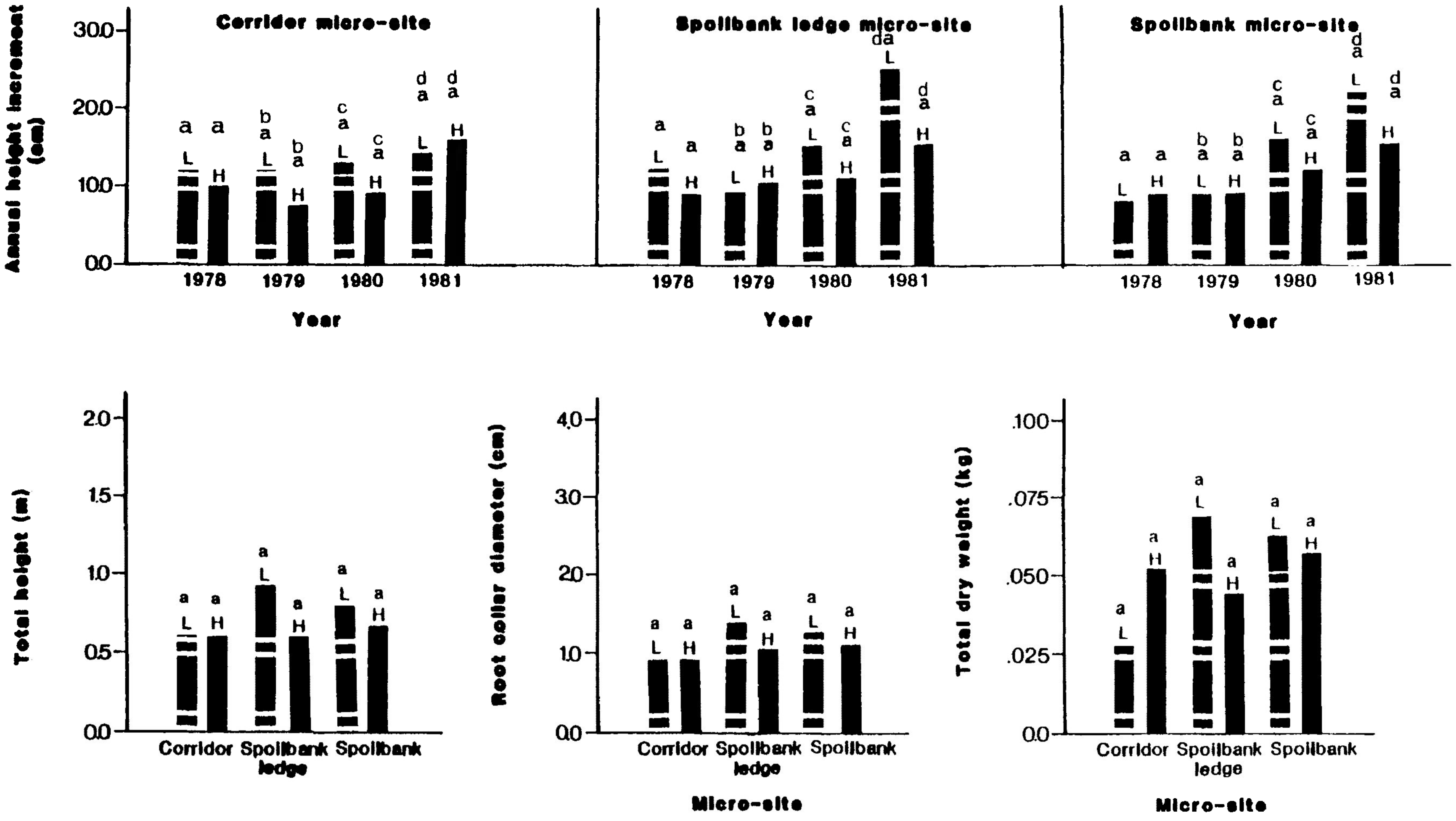


Figure 5. Comparison of white spruce tree growth between micro-site / trembling aspen competition situations in Plantation I (age four years). (Refer to Appendix E; Table E2). Treatment means that are non-significant are assigned the same letter (P=0.05).

L - low aspen density (0-4 stems / m2)
H - high aspen density (> 4 stems / m2)

A completely randomized one-way Analysis of Variance with unequal replication indicated no statistically significant differences between the seedling micro-site/ trembling aspen density situations with respect to average root collar diameter, total height, or 1981, 1980, 1979, 1978 periodic annual height increments (Appendix D; Tables D1, D2, D3, D4, D5, and D6).

Tree Stratum Standing Crop Relations

Biomass Partitioning in Individual White Spruce Trees

Differences in mean component dry weights of white spruce sampled from each of the three micro-sites were analyzed using unpaired *t*-tests (Appendix E; Table E1). Seedlings established on the spoilbank and spoilbank ledge were significantly larger and had greater average component dry weights than those growing in the corridor. No differences in mean dry weights for white spruce sampled from the spoilbank and spoilbank ledge were signiicant.

The influence of increased densities of trembling aspen on the dry matter distribution within the white spruce sampled from each of the micro-site conditions was then examined (Figure 6; Appendix E (Table E2)). White spruce seedlings established on the corridor and under high densities of trembling aspen, had insignificantly larger average component dry weights (foliage, branchwood and bark, stemwood and bark, total dry weight) than did the white spruce growing under low

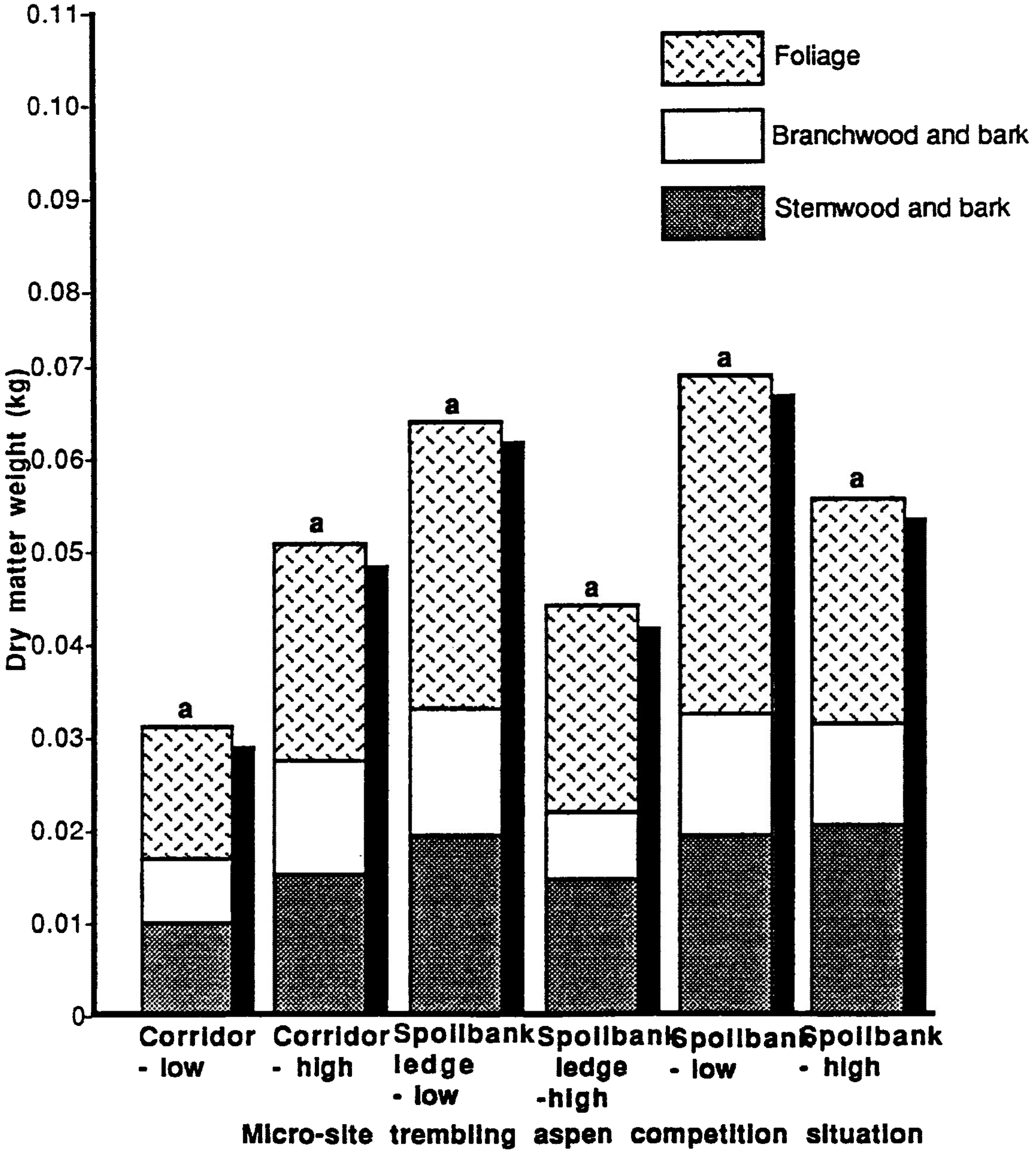


Figure 6. Dry matter partitioning for spruce crop trees sampled from the six micro-site / trembling aspen competition situations in Plantation I (age four years). (Refer to Appendix E; Table E4). Treatment means that are non-significant are assigned the same letter (P=0.05).

densities of trembling aspen on the same micro-site. In contrast, white spruce planted on the spoilbank ledge and spoilbank exhibited greater dry matter component weights under no or low trembling aspen densities than under high.

Completely randomized one-way Analysis of Variance using unequal replication for each of the dry weight components subsequently revealed no significant differences between the total dry weights for spruce from any of the six micro-site/trembling aspen density situations. Analysis of Variance Tables are presented in Appendix F (Tables F1, F2, F3, and F4).

Stem Analyses

(a) **White Spruce**. Nine of the fifty seedlings removed for destructive sampling were subjected to stem analyses. Appendix Q (Figures Q1 and Q7), show the trends in current annual volume increment (C.A.I.) versus mean annual volume increment (M.A.I.) for white spruce and trembling aspen. The M.A.I. and C.A.I. volumes for the representative white spruce seedlings increased with age, irrespective of micro-site position. No apparent reduction in volume increment was observed at age 3 years (time of outplanting). The volume increment then increased slowly from year of outplanting until a seedling age of 5 years. The mean annual volume increment for spruce on all micro-sites then increased rapidly in the third growing season after planting; differences in the mean annual volume increment of spruce between the three micro-sites became more apparent.

Four years after planting, the mean annual volume increment for the white spruce seedlings sampled on the spoilbank was increased over that for spruce removed from the corridor or spoilbank ledge positions. Examination of the current annual increment for four years after planting revealed differing responses in white spruce volume growth between the three micro-site positions. Spruce trees of average height and diameter selected from the spoilbank and spoilbank ledge displayed larger current annual volume increments than seedlings removed from the corridor. The larger C.A.I.'s on these two micro-sites is a notable trend especially since the relative densities of trembling aspen and broad-leaved species were also greater in these positions. Variation in the C.A.I. between replicates sampled from each of the micro-sites did exist.

(b) **Trembling aspen**. The volume/age relationships for a single stem of trembling aspen of dominant height sampled from the spoilbank is shown in Appendix Q (Figure Q7). The current and mean annual volume growth displayed a continuing increase with age. The magnitude of the increase and the absolute volume increment of the trembling aspen exceeded that described for the same-aged white spruce. Volume growth for trembling aspen increased rapidly after the first growing season (sucker age of 1 year).

Differences in observed volume increment and total tree volumes which have occurred between the white spruce seedlings and the trembling aspen may be related to differences in the initial height growth patterns between the two species (Appendix R; Figure R1). However, the small sample size associated with the stem analyses portion of the study does not allow statistical confirmation of this hypothesis. The trembling aspen had very rapid early height growth while the seven year-old white spruce displayed much slower early annual height growth.

Community Standing Crop Relations

Standing crop biomass values (kg/m^2) are presented in Tables 10 and 11. White spruce standing crop biomass was greater on the spoilbank micro-site under low trembling aspen densities (0.076 kg/m^2) than elsewhere. The lowest white spruce standing crop of 0.031 kg/m^2 occurred in the corridor under no or low trembling aspen densities. Standing crop biomass of white spruce declined progressively from the spoilbank/low aspen competition situation, spoilbank/high aspen density to the corridor/low aspen density situation. These trends paralleled differences in white spruce size and component dry weights previously described.

Table 10. White spruce and trembling aspen foliage/wood ratios standing crop (kg/m^2) and standing crop density (kg/m^2) arranged by micro-site position/aspen density situation in plantations I and II (aged four and ten years), respectively.

Micro-site/aspen density situation	Species	Mean height (m)	Percent total weight in foliage	Percent total weight in wood	Dry standing crop (kg/m^2)	Dry standing crop density (kg/m^2)
PLANTATION I - 4 YEARS						
1. Corridor - low	white spruce	0.59	48.0	34.0	0.031	0.053
	* trembling aspen	1.67	16.7	61.3	0.100	0.060
2. Corridor - high	white spruce	0.60	44.0	30.0	0.050	0.083
	* trembling aspen	1.67	16.7	61.3	1.520	0.910
3. Spoilbank ledge - low	white spruce	0.82	46.0	26.0	0.076	0.093
	* trembling aspen	1.67	16.7	61.3	0.335	0.201
4. Spoilbank ledge - high	white spruce	0.68	46.0	34.0	0.039	0.057
	* trembling aspen	1.67	16.7	61.3	1.553	0.930
5. Spoilbank - low	white spruce	0.76	49.0	29.0	0.064	0.084
	* trembling aspen	1.67	16.7	61.3	0.246	0.147
6. Spoilbank - high	white spruce	0.67	48.0	38.0	0.055	0.082
	* trembling aspen	1.67	16.7	61.3	0.852	0.510
PLANTATION II - 10 YEARS						
1. Corridor - low	white spruce	1.10	44.9	29.0	0.269	0.267
	* trembling aspen	3.29	4.3	76.8	0.309	0.094
2. Corridor - high	white spruce	1.38	39.3	35.4	0.1081	0.078
	* trembling aspen	3.29	4.3	76.8	0.612	0.186
3. Spoilbank - low	white spruce	1.65	37.7	30.6	0.339	0.206
	* trembling aspen	3.29	4.3	76.8	0.316	0.096
4. Spoilbank - high	white spruce	1.20	43.7	30.0	0.086	0.072
	* trembling aspen	3.29	4.3	76.8	1.400	0.426

* trembling aspen appeared highly uniform in size and therefore was not stratified by micro-site. The trembling aspen values represent the average for all trees combined.

Table 11. Standing crop (kg/m^2) of competing vegetation arranged by micro-site position/aspen density in plantations I and II (aged four and ten years),

	Micro-site aspen density situation	Vegetation component	Plantation I-4 years Mean dry standing crop (kg/m^2)	Plantation II-10 years Mean dry standing crop (kg/m^2)
			(n=12 plots)	(n=8 plots)
	Corridor - low	Trembling aspen	0.100	0.309
		Herbaceous species	0.054	0.091
		Graminoid and sedges	0.129	0.350
		Aster macrophyllus	0.017	0.014
		Rubus strigosus	0.016	0.022
		Rosa acicularis	0.008	0.027
			(n=3 plots)	(n=7 plots)
2.	Corridor - high	Trembling aspen	0.152	0.612
		Herbaceous species	0.046	0.068
		Graminoid and sedges	0.354	0.212
		Aster macrophyllus	0.022	0.025
		Rubus strigosus	0.009	0.033
		Rosa acicularis	0.005	0.058
			(n=8 plots)	
3.	Spoilbank ledge - low	Trembling aspen	0.335	
		Herbaceous species	0.033	
		Graminoid and sedges	0.098	
		Aster macrophyllus	0.062	
		Rubus strigosus	0.063	
		Rosa acicularis	0.012	
			(n=7 plots)	
4.	Spoilbank ledge - high	Trembling aspen	1.553	
		Herbaceous species	0.041	
		Graminoid and sedges	0.159	
		Aster macrophyllus	0.052	
		Rubus strigosus	0.034	
		Rosa acicularis	0.019	
			(n=9 plots)	(n=8 plots)
5.	Spoilbank - low	Trembling aspen	0.246	0.316
		Herbaceous species	0.034	0.039
		Graminoid and sedges	0.134	0.487
		Aster macrophyllus	0.027	0.019
		Rubus strigosus	0.077	0.039
		Rosa acicularis	0.043	0.023
			(n=11 plots)	(n=7 plots)
6.	Spoilbank - high	Trembling aspen	0.852	1.400
		Herbaceous species	0.027	0.023
		Graminoid and sedges	0.151	0.237
		Aster macrophyllus	0.039	0.022
		Rubus strigosus	0.043	0.022
		Rosa acicularis	0.110	0.028

Trembling aspen biomass always exceeded white spruce biomass (Table 10), irrespective of the micro-site/trembling aspen density situation (Table 11). The largest aspen standing crop of 1.553 kg/m^2 occurred under the spoilbank ledge/high aspen density situation; the standing trembling aspen crop on the corridor/high aspen competition condition was also large (1.52 kg/m^2). The spoilbank location supported fewer stems of trembling aspen, consequently the standing crop biomass was less.

Competing herbs, graminoids, woody shrubs and trembling aspen accounted for a large percentage of the above-ground biomass on the three micro-sites (Table 11).

(a) The corridor had a particularly well-defined presence of graminoids accompanying increased aspen densities.

(b) The spoilbank ledge micro-site had large populations of Aster macrophyllus, Rubus strigosus and Rosa acicularis and a diversity of other herbaceous species (Table 11). Under high aspen densities, graminoid and sedge biomass was greatest (0.159 kg/m^2), although this value was less than that encountered for the same species on the corridor micro-site (0.354 kg/m^2). Aster macrophyllus accounted for 0.052 kg/m^2 of the biomass on the spoilbank ledge with an average mean standing crop of 0.034 kg/m^2 and 0.019 kg/m^2, for Rubus strigosus and Rosa acicularis, respectively. These species also contributed to the standing crop under no or low aspen densities.

In general, the largest standing crops of Aster macrophyllus and Rubus strigosus were observed under low aspen densities while total biomass for Rosa acicularis and the graminoids was greatest on sites dominated by trembling aspen.

(c) The spoilbank micro-site supported fewer herbs but more woody brush and tree species (Table 11). Graminoids, Rubus strigosus and Rosa acicularis dominated the spoilbank understory both in density and standing crop biomass. Under higher aspen densities, graminoids and sedges contributed more biomass on the site (0.151 kg/m^2) than Rubus strigosus and Rosa acicularis.

The average standing crop biomass for each of these competing species exceeded that of the white spruce crop trees (0.086 kg/m^2) (Table 10).

Standing crop biomass of broad-leaved and woody vegetation on the micro-site were closely related to the dominance of the trembling aspen. Under high densities of trembling aspen, graminoids, and Rosa acicularis displayed increased standing crop values; the opposite occurred for Rubus strigosus. Standing crop biomass of Aster macrophyllus and the herbaceous species (principally Epilobium angustifolium) were less than those of graminoids, or woody shrubs on the spoilbank.

Foliage Efficiency and Wood Production

Mean percentage dry weight for bolewood and foliage components of the white spruce and trembling aspen were calculated (Table 10). White spruce crop trees consistently had a greater percentage of their total dry weight in foliage than did trembling aspen. At age 4 years, foliage on an average spruce crop tree composed 46.8 percent of the total aboveground dry weight; in contrast, foliage of a 4-year trembling aspen tree constituted only 11.2 percent of the total aboveground dry weight.

An inverse relationship existed for bolewood dry weights. In trembling aspen, 64.6 percent of the total above-ground biomass resided in the bole, whereas, white spruce bolewood averaged 31.1 percent of the total dry weight.

The foliage and bolewood component dry weights of the white spruce crop trees did not vary significantly with micro-site and associated trembling aspen densities (Table 10). White spruce foliage composed a relatively constant percentage (44 to 49 percent) of the total tree biomass, irrespective of micro-site position or the associated density of trembling aspen. The ratio of foliage dry weight:total tree dry weight also remained relatively constant for trembling aspen.

Total height was highly variable for white spruce in plantation I (Table 10). This resulted in white spruce located under high densities of trembling aspen displaying a greater percentage of their total above-ground biomass in bolewood as compared to seedlings occurring under no or low densities of trembling aspen.

Foliage Efficiency for Wood Production

The ability of the foliage to produce wood was defined as the ratio of current annual wood volume to total foliage dry weight of the tree. Abnormal climatic conditions during the previous growing season (e.g., drought, excess precipitation) could influence the calculation of foliage efficiency. This possible influence was minimized using a mean current wood volume derived from the current and each of the preceding four year's wood volumes (dcm^3). Foliage efficiencies for a representative spruce tree sampled from each of the micro-site/aspen density situations are presented in Table 12.

Planted white spruce growing on the spoilbank ledge and under no or low trembling aspen densities displayed a foliage efficiency of 0.4249 dcm^3/kg dry weight foliage; spruce seedlings on the corridor under no or low aspen densities had a foliage efficiency of 0.2642 dcm^3/kg dry weight. Under high trembling aspen densities the micro-site/ foliage efficiency relationship was reversed. The representative spruce sampled from the corridor had a greater foliage efficiency (0.2927 dcm^3/kg dry weight foliage) than the white spruce sampled from

Table 12. White spruce crop tree crown foliage efficiency for wood production in plantations I, II, III, and IV as arranged by seedling micro-site position / trembling aspen density or by crop tree crown class / aspen density levels in each plantation.

Plantation	Crop tree situation. (Micro-site or crown	Average crown foliage efficiency (dm^3/kg foliage dry weight)	
I.	Corridor - low level	0.2642	(n=1)
	Corridor - high level	0.2927	(n=1)
	Spoilbank ledge - low level	0.4249	(n=1)
	Spoilbank ledge - high level	0.2078	(n=1)
	Spoilbank - low level	0.3422	(n=1)
	Spoilbank - high level	0.2851	(n=1)
II.	Corridor - low level	0.2862	(n=3)
	Corridor - high level	0.4845	(n=1)
	Spoilbank - low level	0.5993	(n=2)
	Spoilbank - high level	0.5015	(n=3)
III.	Pure white spruce		
	Dominant	2.0737	(n=1)
	Intermediate	1.6375	(n=1)
	Suppressed	1.8018	(n=1)
	Mixedwood condition		
	Lightly suppressed	0.1987	(n=1)
	Moderately suppressed	0.3162	(n=1)
	Heavily suppressed	0.1333	(n=1)
IV.			
	Pure white spruce		
	Dominant	1.0455	(n=1)
	Intermediate	0.6781	(n=1)
	Suppressed	1.5848	(n=1)
	Mixedwood condition		
	Lightly suppressed	0.6245	(n=1)
	Moderately suppressed	0.4071	(n=1)
	Heavily suppressed	1.2162	(n=1)

the spoilbank (0.2851 dcm^3/kg dry weight foliage), or for the tree removed from the spoilbank ledge (0.2078 dcm^3/kg dry weight foliage).

Stand Floristics

(a) Plot relationships. Appendix J contains a species list for plantation I.

Relationships for the lesser vegetation in each plantation were analyzed using non-centred polar ordination (Appendix O). Preliminary plot groupings on the ordination diagram suggests the importance of micro-site and the presence and abundance of trembling aspen in determining floristic composition and distributions. In Appendix O (Figure O1), the various lines indicate clusters of plots which represent the various micro-site/trembling aspen density situations.

The spoilbank, spoilbank ledge and corridor micro-sites were all similar in species composition, although those plots with higher trembling aspen densities tended to be clumped together in the centre of the ordination.

Major environmental variables can often be correlated with the distribution of plots in an ordination. The distribution of micro-sites along the vertical axis were correlated with an increased presence of an Aeh horizon and increased organic matter. On the horizontal axis, the presence of micro-sites associated with trembling aspen densities were corrrelated with an increased water holding capacity of the soil resulting from an increased depth of H and Ah horizons.

(b) Species relationships. The ordination diagram detailing species relationships is presented in Appendix P (Figure P1). Micro-site/plant associations separated out well when aspen density (vertical axis) was plotted against degree of site disturbance (horizontal axis). For the 64 species of lesser vegetation, the major division in the micro-site plant communities was based on the presence of graminoids, sedges and *Rubus strigosus*. The corridor community consisted of *Carex*-*Populus*-*Salix* and was mostly found where the Ae(h) horizon and litter mat had been removed by scalping. Plants growing on this very disturbed micro-site were also exposed to full sunlight.

A *Populus*-*Epilobium*-*Aster*-*Rubus*-*Rosa*-*Calamagrostis* association dominated the spoilbank ledge and was associated with an intact Ae(h) (Appendix P; Figure P1). A loosely piled litter mat deposited from the corridor area enhanced moisture and possibly nutrient relations. A wide range of light conditions also existed on this micro-site. Species distributed towards the top of the vertical axis were exposed to more sunlight and were more common under herbaceous species rather than in shadier conditions under tall shrubs and trembling aspen. The spoilbank ledge micro-site displayed the greatest diversity of understory plant species.

The spoilbank plant community of Populus-Corylus-Rubus-Rosa-Lonicera was relatively herb-poor and was associated with a buried undisturbed soil profile; additions of surface soil and organic material from the corridor also occurred. Woody shrubs and aspen dominated this micro-site. This micro-site was the most favourable for tree growth presumably because of greater organic content, deeper surface soils, greater content of macro-pores and a well-developed Ae(h) horizon.

PLANTATION II

Stand Composition and Structure

The trembling aspen density in plantation II was 3900 stems per hectare compared with 1512 stems per hectare for planted white spruce (Table 9). Of the two species, trembling aspen displayed consistently greater mean total height and mean annual height increments (Appendix B; Table B2). Histograms of white spruce root collar diameter and height for trees on the corridor and spoilbank micro-sites (Appendix C; Figures C4 and C5) revealed an increase in the range of size classes compared to that observed for plantation I. The corridor root collar diameter histogram was nearly normal with slight positive skewing to the smaller diameter classes. In contrast, the root collar diameter histogram for white spruce located on the spoilbank was not normal. These observations agree with the trends observed in plantation I - root collar distributions are least variable on the corridor and most variable on the spoilbank.

Trends in white spruce height distribution on the two micro-site conditions were opposite to those observed for the root collar diameters. Heights of planted white spruce growing on the corridor were highly variable compared with those of spruce established on the spoilbank. These findings agree with the pattern of height distribution for white spruce observed in plantation I.

Influence of Micro-site Conditions on White Spruce Growth

The influence of micro-site on the size and growth of the planted white spruce was found to be statistically significant (Figure 7; Appendix E (Tables E3 and E4)). Mean height and root collar diameters of spruce growing on the spoilbank were significantly larger than those of trees growing on the corridor (P=0.05). The mean height of the spruce sampled on the spoilbank was 1.72 m. In contrast, the mean height of white spruce sampled from the corridor was 1.38 m. Average root collar diameters were 2.27 cm and 2.89 cm for spruce growing on the spoilbank and corridor micro-sites, respectively. No statistically significant differences were observed within the 1981, 1980, 1979, or 1978 periodic annual height increments of the planted spruce when stratified by micro-site position.

Influence of Micro-site Conditions and Trembling Aspen Density on White Spruce Growth

The growth of the planted white spruce appeared to be affected by the combination of micro-site and trembling aspen densities (Appendix E; Table E4). White spruce seedlings planted in the corridor displayed larger diameters and heights under high aspen densities (> 2 stems/m^2) than under the low densities (< 2 stems/m^2) (Figure 8). White spruce seedlings sampled under high trembling aspen densities also displayed greater periodic annual height increments in 1981, 1980, 1979,

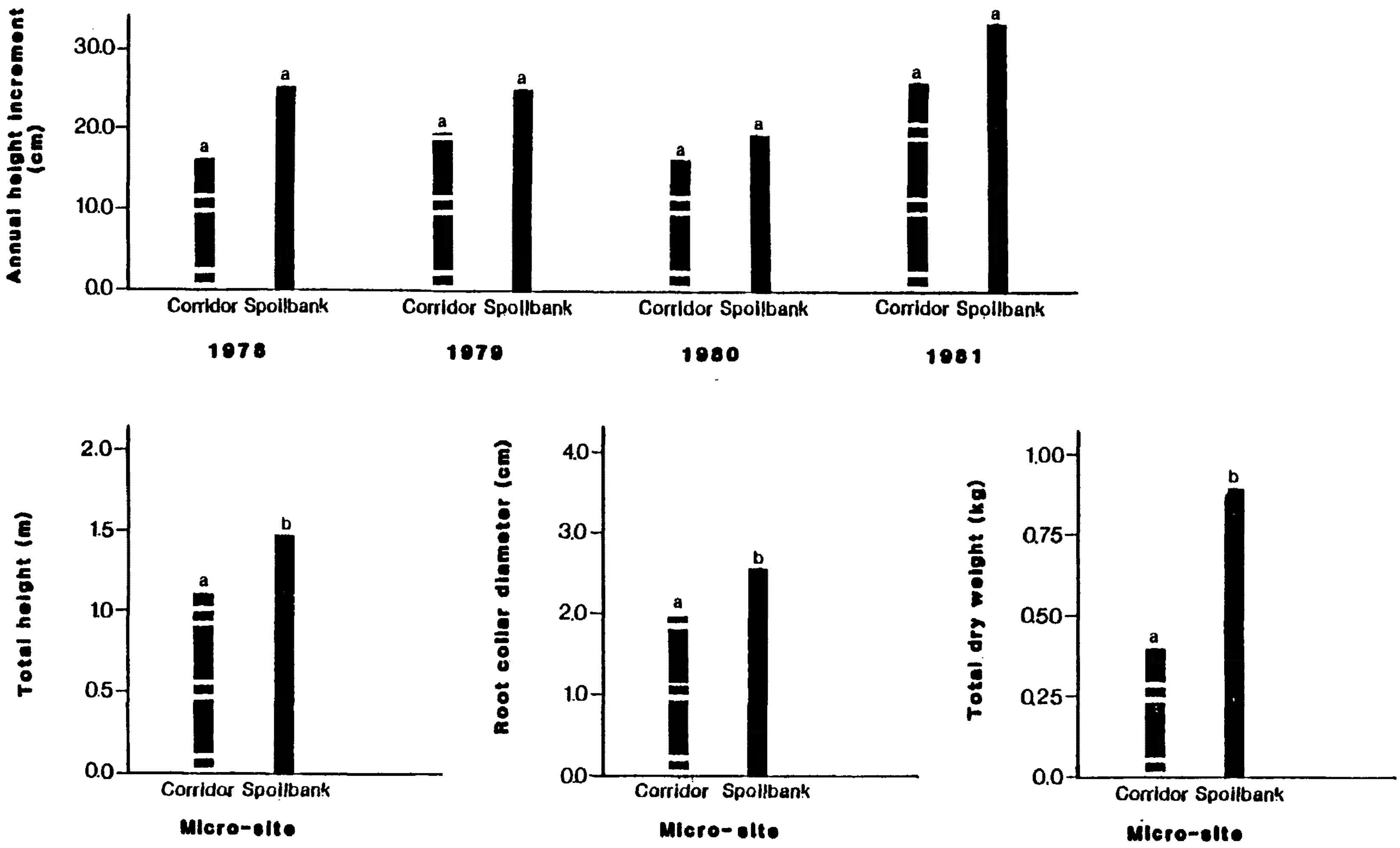


Figure 7. Comparison of white spruce tree growth between micro-site locations in Plantation II (age ten years). (Refer to Appendix E; Table E3). Treatment means that are non-significant are assigned the same letter (P=0.05).

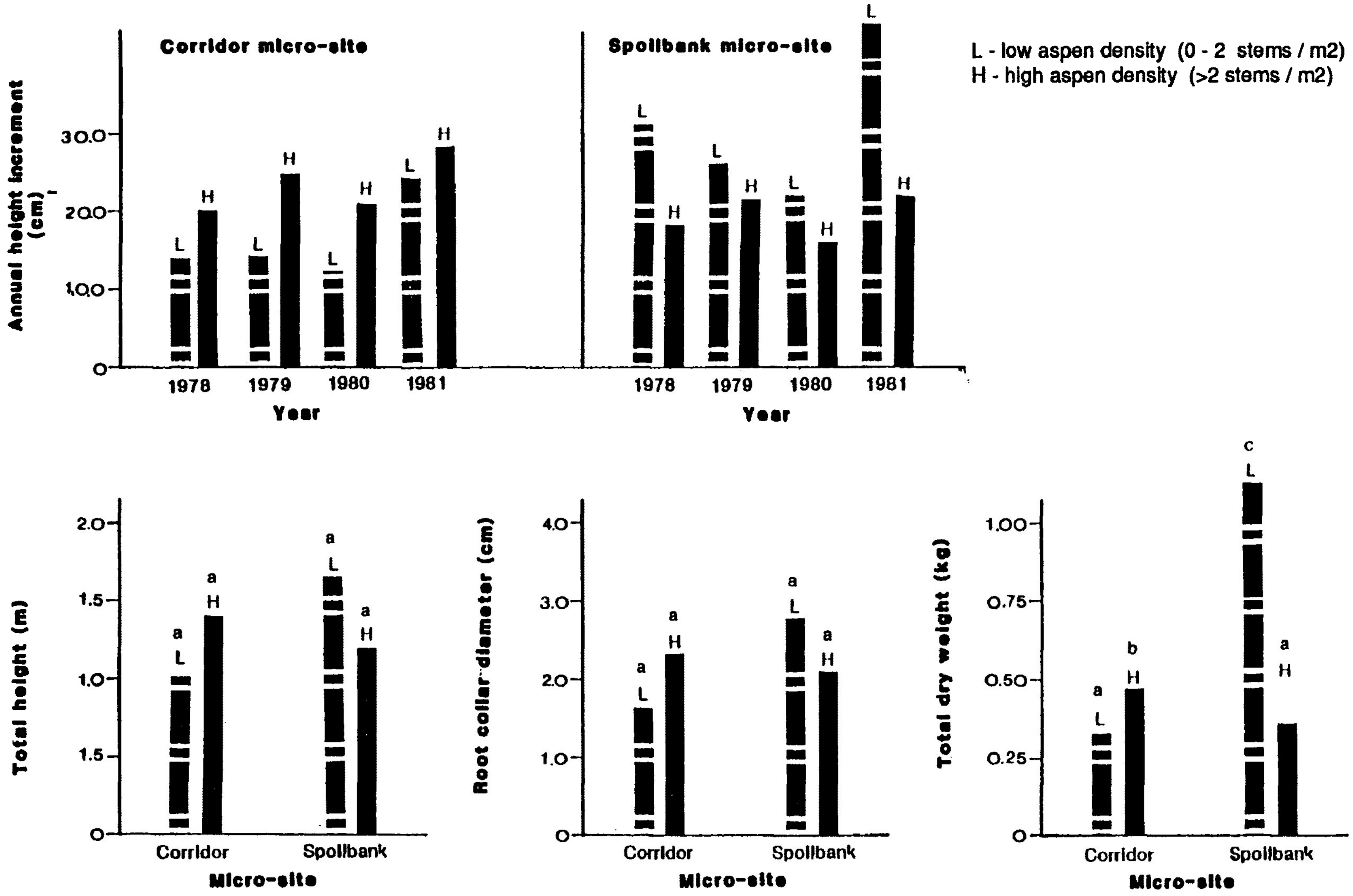


Figure 8. Comparison of white spruce tree growth between micro-site/trembling aspen competition situations in Plantation II (age ten years). (Refer to Appendix E; Table E4). Treatment means that are non-significant are assigned the same letter (P=0.05).

and 1978 than white spruce existing under low densities.

Figures 5 and 8 show that white spruce growing on the spoilbank in plantation I and II under low aspen densities were consistently larger than those spruce growing on the corridor micro-site.

A one-way completely randomized Analysis of Variance with Unequal Replication (Appendix B; Tables B6, B7, B8, B9, B10, B11, B12) indicated statistically significant differences existed for only the seedlings located on the spoilbank ledge under varying densities of trembling aspen. Thus the observed size differences for spruce growing on the corridor under different levels of aspen density were non-significant.

Tree Stratum Standing Crop Relations

Biomass Partitioning in Individual White Spruce Trees

White spruce growing on the two micro-sites (Appendix E; Table E3) generally showed significant differences in biomass partitioning. The trends were similar to those observed for spruce in plantation I (Appendix E; Table E1). No significant (*P*=0.05) differences in mean foliage, branch or total dry weights were observed between the corridor and the spoilbank populations.

Further stratification of the data according to the aspen density on the plot revealed patterns of growth and dry matter accretion similar to those observed in plantation I -

age 4 years from establishment (Appendix E; Table E4). Important differences with the previously established trend (Figure 9) included: (1) spoilbank seedlings were larger and heavier than spruce sampled from the corridor; (2) the mean total dry weight and size of spruce sampled from the corridor was greatest under high trembling aspen densities; and (3) the mean total dry weight and size of spruce sampled from the spoilbank was greatest under no or low trembling aspen densities. These differences, as previously described, were statistically significant (Appendix F; Tables F5, F6, F7, F8).

Other significant differences in biomass partitioning were also observed. The mean foliage and branch dry weights for crop trees grown on the spoilbank/low aspen density situations was significantly greater than that observed in the other situations. The mean stem and total tree dry weights for each of the micro-site/aspen density combinations were also determined to be significantly different from each other, respectively (Figure 9).

Stem Analyses

(a) White spruce. Volume growth for the white spruce (Appendix Q; Figure Q2) was similar to patterns observed for white spruce in plantation I (Appendix Q; Figure Q1). Early volume growth was minimal for the first 1.5 years following planting irrespective of micro-site, and then the mean and current annual increments increased sharply. Spruce sampled

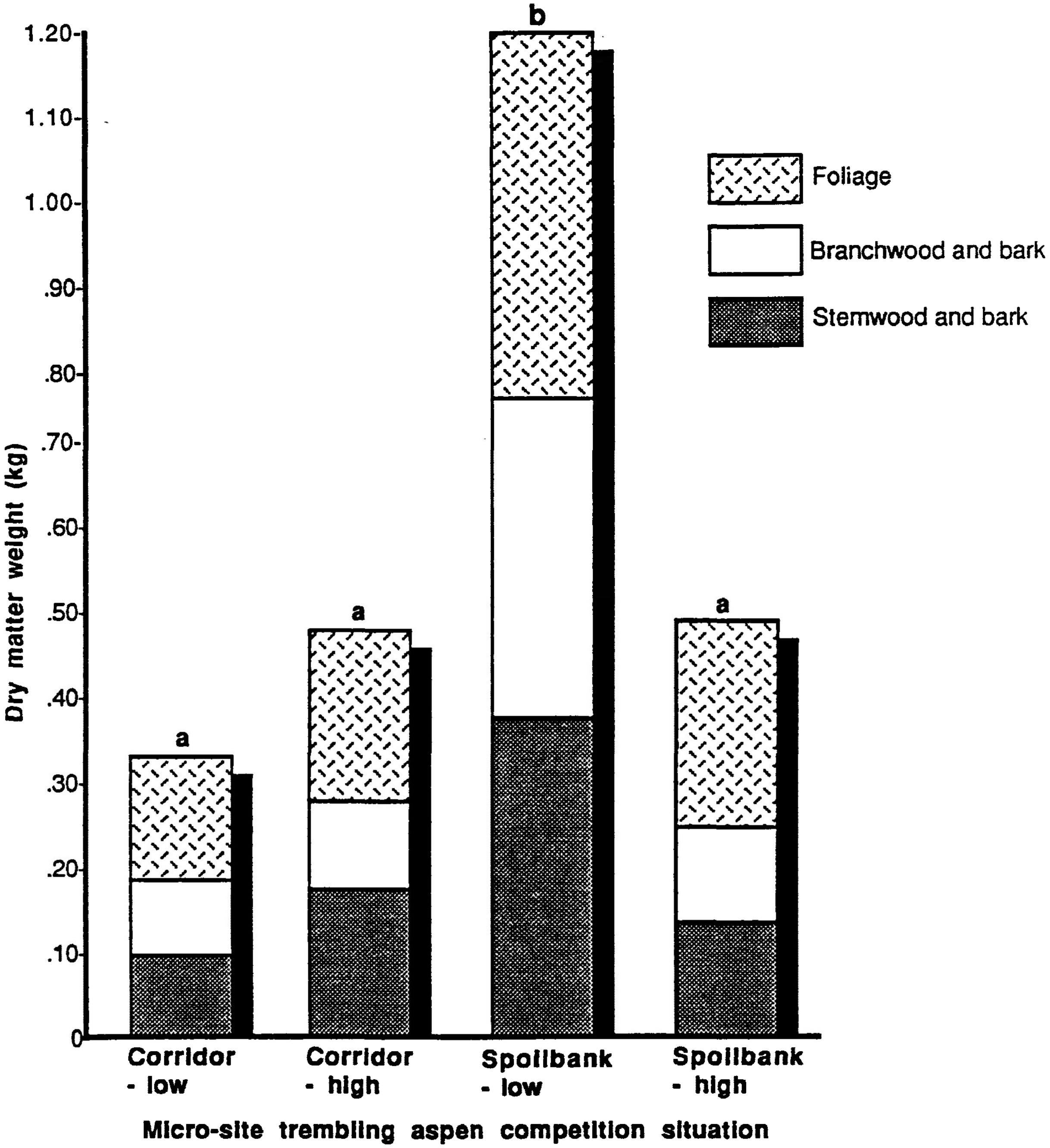


Figure 9. Dry matter partitioning for spruce crop trees sampled from the four micro-site / trembling aspen competition situations in Plantation II (age ten years). (Refer to Appendix E; Table E4). Treatment means that are non-significant are assigned the same letter (P=0.05).

from the spoilbank had greater mean and current annual increments than those of spruce in the corridor. The sharp increase in current annual increment for white spruce on the spoilbank five years after planting followed the herbicide release of plantation II in the previous year. This inflection point was also detected in the height versus age curves for the sample tree (Appendix R; Figure R2).

(b) Trembling aspen. The cumulative volume growth of the dominant trembling aspen sucker was greater than that for the white spruce. The M.A.I. and C.A.I. curves for aspen showed a continual increase with age (Appendix Q; Figure Q8 for aspen; Figure Q2 for white spruce). The observed differences in volume increment and total tree volume between the two species is, in part, attributable to the sustained, vigorous height growth of aspen each year since the planting (Appendix R; Figure R2).

Community Standing Crop Relations

Since planting, the mean white spruce standing crop biomass had increased to 0.171 kg/m^2 from 0.022 kg/m^2 found in plantation I (Table 17). In contrast, the mean trembling aspen standing crop biomass observed in plantation II was less (0.546 kg/m^2) than in plantation I (0.603 kg/m^2). The increase in white spruce crop tree biomass from plantation I to plantation II was concentrated on approximately the same number of seedlings. In contrast, the decline in trembling aspen densities between plantations I and II (Table 9) had contributed to the observed reduction in aspen standing crop biomass.

Micro-site position also influenced the standing crop biomass of both the spruce and trembling aspen in plantation II (Table 10). White spruce standing crop biomass was greatest on the spoilbank under low trembling aspen densities. At age 10 years the mean white spruce biomass on the spoilbank microsite was 0.339 kg/m^2, in contrast to the 0.064 kg/m^2 observed in plantation I. The mean white spruce standing crop on the corridor was slightly less, 0.269 kg/m^2. Increased densities of trembling aspen on the spoilbank were associated with greatly reduced white spruce standing crop biomass (0.086 kg/m^2).

The standing crop (kg/m^2) of competing vegetation occurring under the four micro-site/aspen density situations in plantation II is presented in Table 11. Generally, the standing crop biomass for each class of competing vegetation occurring on the corridor was greater in plantation II than that observed for plantation I. Under low trembling aspen densities, graminoid biomass increased on the corridor from plantation I (0.129 kg/m^2) to plantation II (0.350 kg/m^2). Under high trembling aspen densities on corridors less standing crop of graminoid biomass was observed in comparison to plantation I. Most notable in the corridor micro-site of plantation II was the increased standing crops attributed to the woody shrub species - Rubus strigosus and Rosa acicularis, under all levels of trembling aspen competition.

An increased abundance of herbaceous species on the corridor micro-site in plantation II, in comparison to that found in plantation I, represented an 80 percent increase in standing crop on this micro-site. Conversely on the spoilbank of plantation II, the standing crop biomass for all classes of lesser competing vegetation excepting graminoids was less than in plantation I. Graminoid biomass on the spoilbank of plantation II was greater than that observed on the spoilbank in plantation I.

Crown Efficiency and Wood Production

Stratification of the data (Table 10) indicated that 37.7 to 44.9 percent of the total spruce crop tree above ground dry weight was contained in the foliage irrespective of seedling micro-site position and/or the density of trembling aspen. Similarly, bolewood accounted 29.7 to 35.4 percent of the total spruce seedling dry weight. Seedling micro-site and the level of trembling aspen competition surrounding the plot appeared to have little or no influence on dry matter of stemwood.

Foliage Efficiency for Wood Production

The white spruce sampled from the spoilbank had larger average foliage efficiencies irrespective of trembling aspen density than those spruce sampled from the corridor (Table 12). Overall, white spruce planted on the spoilbank and under no or low trembling aspen densities seemed to have the best foliage efficiencies based upon a limited sample size.

Stand Floristics

(a) Plot relationships. The ordination of floristic information by plot is contained in Appendix O (Figure O2). The more defined cluster patterns indicate a better definition of the micro-site/trembling aspen density situations than that observed in plantation I. Distribution of micro-sites along the vertical axis was correlated with increasing amounts of soil organic matter, increased depth of the Aeh horizon, and the increased abundance of trembling aspen and woody shrubs. An increased abundance of graminoids and *Rubus strigosus* shown on the horizontal axis seems associated with increased soil moisture conditions.

(b) Species relationships. Appendix P (Figure P2) presents the arrangement of species in plantation II. Generally species diversity increased on the corridor micro-site with the addition of herb species such as *Trientalis borealis*, *Aster macrophyllus*, *Solidago canadensis*, *Rosa acicularis* and *Rubus idaeus*. Site conditions on the corridor were probably being improved through the addition of hardwood leaf litter. These additions possibly contributed to the observed increase in the organic content and reduced bulk density of the rooting zone; macro-soil porosity and water-holding capacity also were increased.

The spoilbank micro-site had communities of *Salix*-*Alnus*-*Petasites*-*Equisetum* and *Populus*-*Corylus*-*Aralia*-*Cornus*-*Maianthemum*; the occurrence of these species was likely associated with the cover of trembling aspen and a reduction in the light intensity on the forest floor; the presence of aspen had also increased the organic matter content of the Ah(e). The spoilbank micro-site had a larger diversity of herbaceous species than the corridor.

PLANTATION III

Stand Composition and Structure

White spruce density in plantation III was 2050 stems per hectare (Table 9); the trembling aspen density of 2330 stems was similar to that of the spruce.

Differences in total height and d.b.h. existed between the spruce and trembling aspen. Throughout the mixed portion of the plantation, the aspen (height of 9.42 m) overtopped the spruce (height 3.32 m) (Appendix B; Table B3). White spruce in the pure stand averaged greater heights (8.89 m) and larger d.b.h. (10.56 cm) than their counterparts in the mixed stand condition (Appendix B; Table B3).

Histograms of d.b.h. and height distribution for white spruce growing in a pure stand and mixedwood condition, respectively, are given in Appendix C (Figures C6 and C7). Height and d.b.h. for the trembling aspen is given in Appendix C (Figure C12). The d.b.h. distribution for white spruce mixed with aspen showed extreme positive skewing towards the smaller diameter classes and a limited range of 2 to 8 cm. In contrast, the d.b.h. distribution for spruce growing as a pure stand ranged from 2 to 20 cm.

In the pure spruce the d.b.h. distribution closely approximated a normal distribution. Two modal classes (8 to 10 cm and 12 to 14 cm) existed within this distribution; the 12 to 14 cm modal class reflecting individuals in the dominant or co-dominant crown class and the 8 to 10 cm modal class associated with spruce in suppressed and intermediate crown classes.

Heights of spruce mixed with aspen had a normal distribution and a limited range of height from 0.1 to 7.0 metres (Appendix C; Figure C7). In contrast, white spruce in pure stand conditions displayed a wide range of heights from 0.1 to 12 metres with a skewing towards the larger classes. The height distribution was slightly bi-modal with peaks in the 5 to 6 metre and 10 to 11 metre classes; this bi-modal distribution further supports the idea that in this pure, well-stocked area crown closure by age 18 years had resulted in stratification of the spruce into several crown classes.

Tree Stratum Standing Crop Relations

Biomass Partitioning in Individual White Spruce Trees

The reduced size of white spruce occurring under mixed stand conditions was reflected in corresponding decreased component dry weights in comparison to those for trees growing in pure stand conditions (Appendix E; Table E5 and Figure 10). The total dry weight for dominant white spruce growing in a pure stand was twice that of lightly suppressed white spruce mixed with aspen. In similar fashion the total dry weights of co-dominant and suppressed white spruce occurring in the pure stand were approximately five times greater than the heavily suppressed white spruce mixed with trembling aspen.

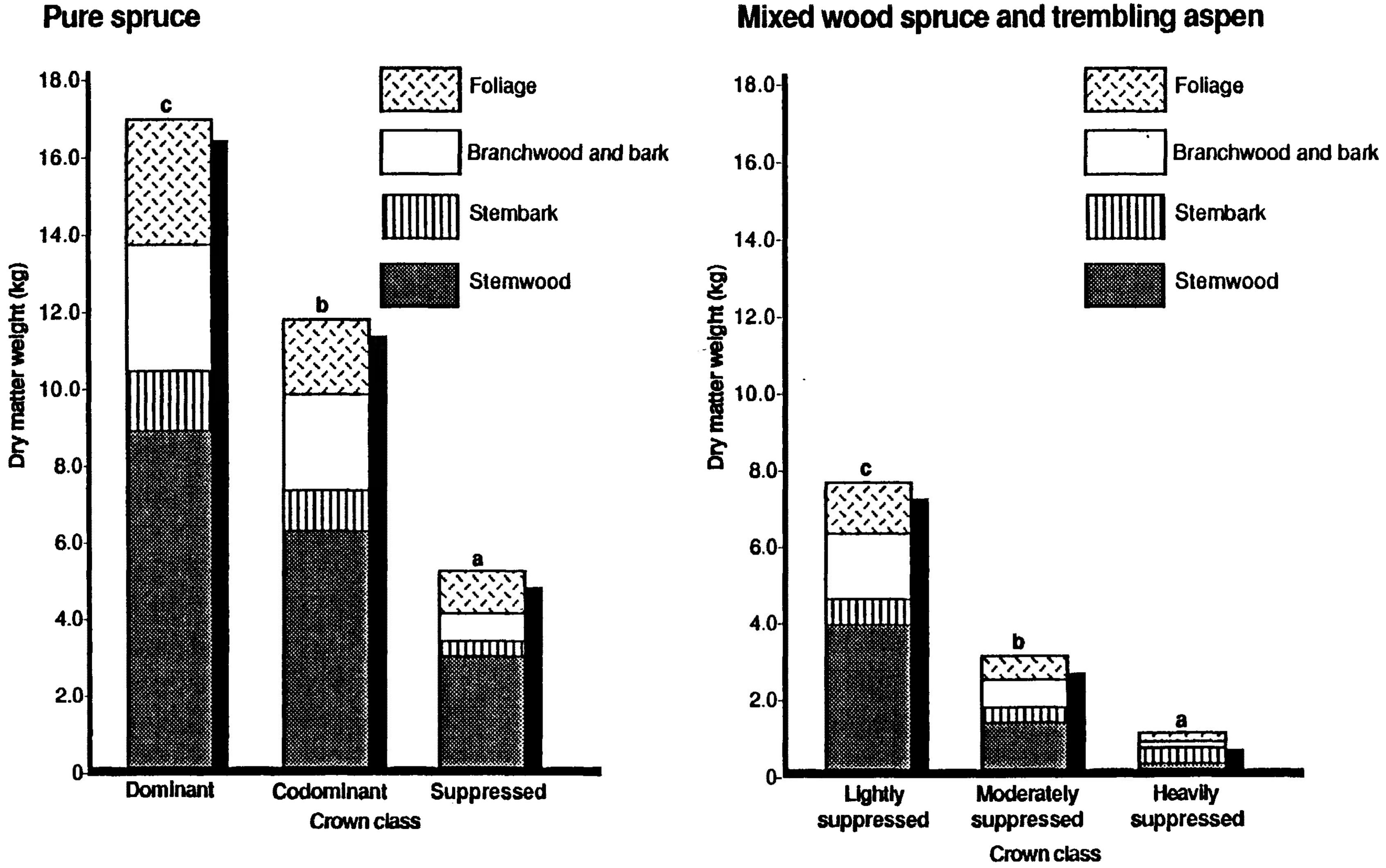


Figure 10. Dry matter partitioning for spruce crop trees from the suppressed, codominant and dominant crown classes in Plantation III (age 18 years). (Refer to Appendix E; Table E5). Treatment means that are non-significant are assigned the same letter ($P=0.01$).

Stem Analyses

(a) White spruce. The mean annual volume increment for dominant and intermediate white spruce in the pure stand increased linearly from age eleven years to age 18 (Appendix Q; Figure Q4). Dominant spruce had the larger mean annual volume increment (0.92 dcm^3/year) at age 18 years than that of a tree from the intermediate crown class (0.43 dcm^3/year). Mean annual volume increment remained relatively constant between age 0 and 9 years for sample trees from both crown classes indicating a longer period of initial slow growth in plantation IV than that observed in plantation I (Appendix Q; Figure Q1). Similar trends existed for the current annual increment of each spruce tree. A small decline in the current annual increment for dominant and intermediate crown classes had recently occurred. This may reflect the onset of complete crown closure and canopy-crowding.

White spruce mixed with trembling aspen (Appendix Q; Figure Q3) had a reduced mean annual increment in comparison with that described previously (Appendix Q; Figure Q4). At age 18 years, the mean annual increment for spruce in the pure stand was 0.85 dcm^3/year compared with 0.14 dcm^3/year for spruce in the mixed stand. The current annual increment of white spruce growing with trembling aspen fluctuated through time instead of steadily increasing with age. The C.A.I.-M.A.I. curves for the lightly suppressed spruce mixed with aspen were falling or stationary. This suggests that canopy coverage by the trembling aspen was complete and beginning to influence even dominant white spruce growth as early as 16 years since planting.

Community Standing Crop Relations

Standing crop (kg/m^2) biomass values for white spruce in both the pure and mixedwood stand conditions are presented in Table 13. In pure white spruce stands the standing crop biomass ranged from 2.111 kg/m^2 to 2.886 kg/m^2 depending upon crown class (Table 13). In contrast, the presence of trembling aspen reduced the white spruce standing crop to between 0.349 kg/m^2 to 0.645 kg/m^2 irrespective of crown class. Standing crop biomass for the suppressed spruce in the pure stand was greater than for the dominant white spruce in the mixedwood condition. This is because most of the spruce in the pure stand were in the suppressed crown class.

Table 14 outlines standing crop estimates for competing vegetation arranged according to the crown class of white spruce and stand condition. A very sparse understory occurs under pure, older, well-stocked white spruce stands. This sparse understory had only small amounts of standing biomass composed of herbs, graminoids, Aster macrophyllus, Rubus strigosus, Rosa acicularis and other woody shrubs. Herbaceous species and Aster macrophyllus standing crop biomass in plantations III and IV was similar to that observed

Table 13. White spruce and trembling aspen foliage/wood ratios standing crop (kg/m^2) and standing crop density (kg/m^3) for pure white spruce and mixed spruce and aspen areas arranged by degree of suppression in plantation III, aged 18 years.

White spruce crown position	Species	Mean height (m)	Percent total weight in foliage	Percent total weight in wood	Dry standing crop (kg/m^2)	Dry standing crop density (kg/m^2)
Mixed Spruce and Aspen						
1. Heavily suppressed n = 3 plots	white spruce	1.96	12.95	21.39	0.645	0.329
	trembling aspen	9.42	2.50	66.40	0.380	0.040
2. Moderately suppressed n = 3 plots	white spruce	3.80	17.22	50.37	0.598	0.157
	trembling aspen	9.42	2.50	66.40	5.890	0.626
3. Lightly suppressed n = 3 plots	white spruce	5.02	17.51	52.87	0.349	0.069
	trembling aspen	9.42	2.50	66.40	7.250	0.769
Pure Spruce						
1. Suppressed n = 2 plots	white spruce	4.40	20.29	47.56	2.511	0.571
2. Intermediate n = 2 plots	white spruce	5.40	16.96	52.44	2.111	0.391
3. Dominant and co-dominants n = 2 plots	white spruce	6.40	16.93	53.48	2.886	0.451

Table 14. Standing crop (kg/m^2) of competing vegetation arranged by white spruce sample crop tree crown position in plantations III and IV, aged 18 and 28 years, respectively.

Crown position	Vegetation component	Plantation III Pure spruce mean dry standing crop (kg/m^2) (n=2 plots each)	Plantation III Mixedwood spruce & aspen mean dry standing crop (kg/m^2) (n=3 plots each)	Plantation IV Pure spruce mean dry standing crop (kg/m^2) (n=2 plots each)	Plantation IV Mixedwood spruce & aspen mean dry standing crop (kg/m^2) (n=3 plots each)
Suppressed	Trembling aspen	0.000	0.380	0.000	7.590
	Herbaceous species	0.042	0.546	0.036	0.767
	Graminoid and sedges	0.001	0.345	0.000	0.287
	Aster macrophyllus	0.022	0.006	0.019	0.003
	Rubus strigosus	0.000	0.175	0.000	0.154
	Rosa acicularis	0.004	0.001	0.003	0.003
	Shrubs	0.000	0.221	0.000	0.030
Intermediate	Trembling aspen	0.000	5.890	0.000	22.200
	Herbaceous species	0.021	0.641	0.018	0.476
	Graminoid and sedges	0.000	0.190	0.001	0.221
	Aster macrophyllus	0.024	0.004	0.021	0.001
	Rubus strigosis	0.000	0.185	0.000	0.146
	Rosa acicularis	0.003	0.002	0.001	0.001
	Shrubs	0.000	0.652	0.000	0.014
Dominant	Trembling aspen	0.000	7.250	0.000	16.090
	Herbaceous species	0.011	0.432	0.011	0.342
	Graminoid and sedges	0.001	0.176	0.000	0.164
	Aster macrophyllus	0.019	0.004	0.021	0.001
	Rubus strigosus	0.000	0.145	0.000	0.091
	Rosa acicularis	0.002	0.001	0.000	0.000
	Shrubs	0.000	0.347	0.000	0.013

in plantations I (age 4 years) and plantation II (10 years)(Table 14). At 18 years, stand establishment and crown closure of white spruce was almost complete and this is reflected in a decreased abundance of shade intolerant, pioneer-stage woody shrubs.

The area mixed with aspen had a greatly increased standing crop of herbaceous species, graminoids, Rubus strigosus and other woody shrubs such as Cornus stolonifera, Acer spicatum and Alnus rugosa (Table 14). Comparisons with plantation II revealed that crop biomass of the herbaceous species was twenty fold greater. Increased numbers of herbaceous species in the mixed stand of plantation III was associated with a 50 percent decrease in the standing crop of graminoids. Rubus strigosus in the mixed stand also showed a twenty fold increase in standing crop biomass in comparison with plantation II. The contribution of Rosa acicularis to stand biomass was minimal.

Plantation III had several more shade tolerant woody shrub species - Cornus stolonifera, Acer spicatum and Alnus rugosa, which collectively contributed to a large standing crop biomass of 0.221 kg/m^2 to 0.347 kg/m^2 (Table 14). The magnitude of contribution of these shrubs to stand biomass was associated with the white spruce crown position - greater standing crops of these tolerant shrubs occurred under the dominant spruce crown class. In comparison standing crops of herbs, graminoids, and Rubus strigosus was much greater under suppressed white spruce. This may be related to sharp variations in canopy height which allowed the penetration of direct sunlight to the forest floor.

Foliage Efficiency and Wood Production

Differences in dry matter partitioning between various spruce crown classes are given in Figure 10 and Table 13. White spruce suppressed by aspen had reduced percentages of total tree dry weight attributable to foliage in comparison to trees in those of intermediate and dominant crown classes in the same mixed stand (Table 13). No major differences in foliage and wood ratios between the intermediate and dominant crown classes of the two stand conditions were noted.

Foliage Efficiency for Wood Production

Presence of aspen was associated with a reduction in the observed white spruce crown foliage efficiencies (Table 12). The dominant white spruce sampled from the pure spruce stand had a foliage efficiency of 2.0737 dcm/kg dry weight compared to 0.1987 dcm/kg dry weight for the lightly suppressed spruce in the mixed stand.The dominant white spruce sampled in the pure stand condition had greater crown foliage efficiencies than those of the representative intermediate and suppressed spruce sampled from the same.

Stand Floristics

(a) Plot relationships. The ordination diagram (Appendix O; Figure O3) presents the ordination of plots in respect to the occurrence of aspen. Plots dominated by aspen are located in the left portion of the ordination diagram. The distribution of plots along the vertical axis was correlated with a decrease in crown closure; also a decreased depth of the needle mat resulting from decreased numbers of spruce in the canopy.

(b) Species relationships. An *Aralia*-*Aster*-*Cornus*-*Maianthemum* community occurred beneath the closed canopy of pure spruce (Appendix P; Figure P3). These herbaceous species were less abundant and their distribution was confined to canopy gaps where light intensity was greater.

Corylus-*Prunus*-*Alnus* were found as common constituents of the mixedwood stand condition and were often associated with herbaceous species which occurred in the pure stand condition. The depth of the Ah(e) increased with the increasing presence of trembling aspen in the overstory. The vertical axis was thought to reflect increasing light intensity under the various stand conditions.

PLANTATION IV

Stand Composition and Structure

White spruce density was 2150 stems per hectare (Table 9). The density of trembling aspen in the mixture was 2075 stems.

Differences in total height and d.b.h. existed between the spruce and trembling aspen components. As in plantation III, the aspen (average height of 14.51 m) overtopped the spruce (average height of 7.03 m) throughout the mixedwood stand condition (Appendix B; Table B4). Presence of aspen also resulted in decreased white spruce diameters.

Histograms of d.b.h. and height for all crown classes of white spruce growing in the pure and mixedwood stands, respectively, are given in Appendix C (Figures C8 and C9). Height and d.b.h. for all trembling aspen in plantation IV also is given in Appendix C (Figure C13).

Differences in white spruce heights and diameters were also observed between the pure and mixedwood stand conditions (Appendix B; Table B4 and Appendix E; Table E5). Dominant white spruce growing with aspen were shorter (15.7 m) than spruce in a pure stand (16.5 m) (Appendix E; Table E6).

Appendix E (Table E6) summarizes white spruce growth as stratified by crown class for the two stand conditions. Spruce trees growing in a mixture with trembling aspen were significantly smaller than those from the pure stand. Heights of white spruce in the mixedwood condition were also highly variable. Appendix B (Figures B8 and B9) show the distributions of d.b.h. and height for white spruce in the mixed and pure stands. The d.b.h. distribution for white spruce in the mixed stand approximated a normal distribution with a mean in the 12 to 15 cm class. In contrast, the diameter distribution for white spruce in the pure stand was bi-modal with peaks in the 12 to 15 cm and 18 to 21 cm classes. This latter distribution approximated a normal curve with skewing towards the larger diameter classes. Height distributions for both the mixed and pure areas resembled normal curves; the distribution for spruce in the mixed area had a positive skewing towards the smaller heights.

Tree Stratum Standing Crop Relations

Biomass Partitioning in Individual White Spruce Trees

Variations in white spruce component dry weights (Figure 11 and Appendix E; Table E6) are similar to relations given for plantation III (Figure 10 and Appendix E; Table E5). Dominant spruce trees in the pure stand were 469 percent greater in total dry weight than the lightly suppressed spruce in the mixed stand. Suppressed spruce in the pure stand also had 16 times greater dry weight than heavily suppressed trees in the mixed stand. Foliage dry weights of spruce also differed between the three major crown classes, and for spruce in the pure and mixed stands (Figure 11).

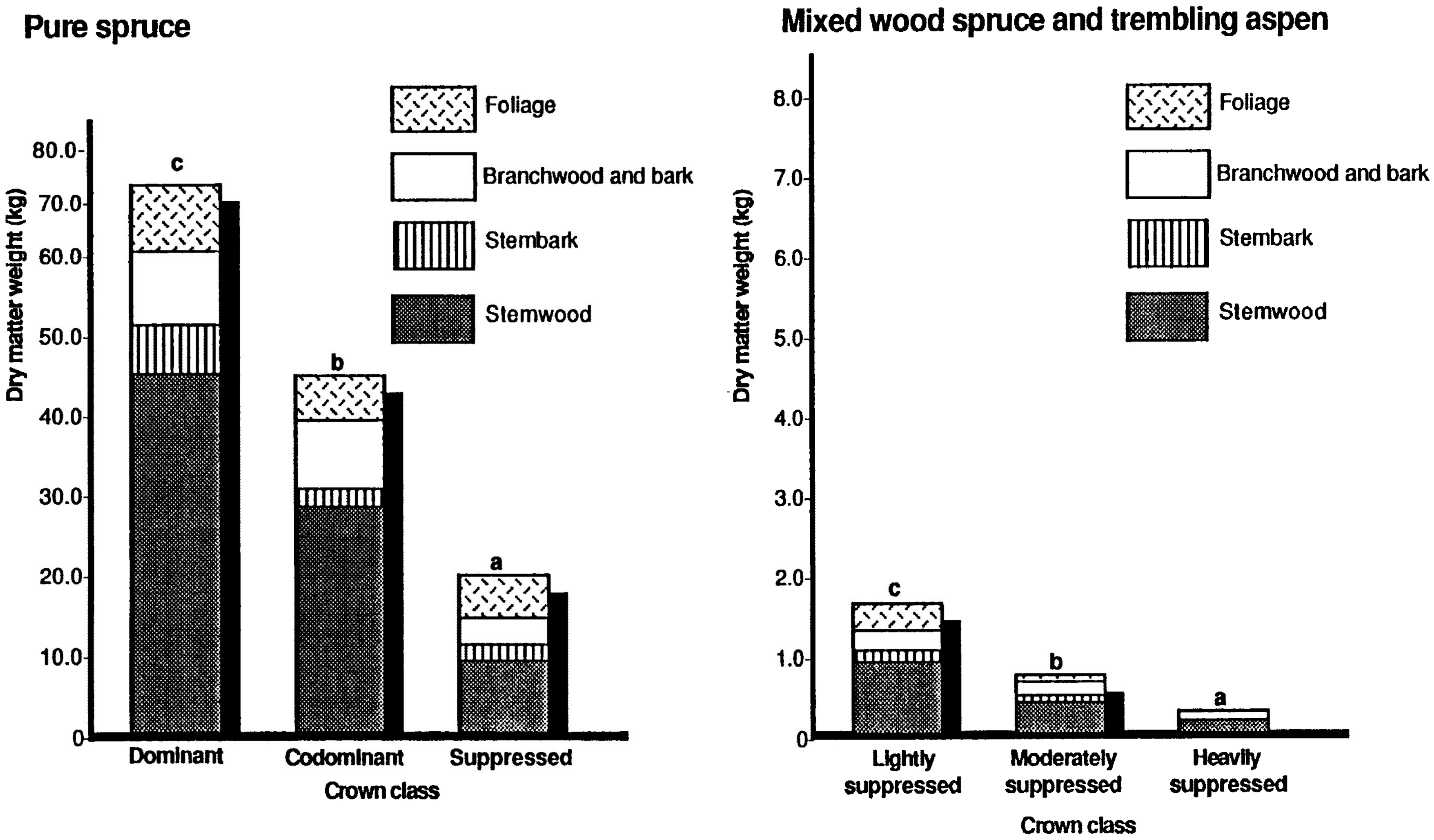


Figure 11. Dry matter partitioning for spruce crop trees from the suppressed, codominant and dominant crown classes in Plantation IV (age 28 years). (Refer to Appendix E; Table E6). Treatment means that are non-significant are assigned the same letter (*P*=0.01).

Stem Analyses

(a) White spruce. Stem analyses (Appendix Q; Figures Q5 and Q6) showed white spruce volume growth patterns similar to those observed for plantation III. Trends in volume increment included: (1) a slow period of volume growth for the first 7 years following planting in both the pure spruce and mixed areas; (2) slow initial growth resulting in gradually increasing mean and current volume increments for dominant and intermediate crop trees from age 11 to 28 years; (3) a greater current and mean annual increment for dominant rather than intermediate crown classes; (4) greatly reduced current and mean annual volume increments for spruce growing with trembling aspen (0.057 dcm^3/year M.A.I.) compared to dominant trees from the pure spruce area (4.59 dcm^3/year); (5) a reduction in the current annual increment beginning at 20 years for suppressed spruce mixed with trembling aspen; mean annual increment also leveled suggesting that canopy coverage was complete and that aspen was beginning to influence spruce volume as early as 16 years since planting.

Community Standing Crop Relations

White spruce in the pure stand had a similar standing crop biomass ranging from 3.247 kg/m^2 to 3.622 kg/m^2 irrespective of crown position (Table 15). Comparing plantation III (Table 13) with plantation IV (Table 15) we find that the standing crop biomass of the white spruce in the pure stand component increased approximately 50 percent from age 18 to 28 years; tree height almost doubled. Spruce growing in the mixed stand had an 86 percent reduction in standing crop (0.452 kg/m^2 to 0.498 kg/m^2) (Table 15) in contrast to spruce from the pure portion of the stand.

Complete canopy coverage and understory shading in the pure spruce area resulted in very few competing understory species. Herbaceous species and _Aster macrophyllus_ had a standing crop biomass of less than 0.036 kg/m^2 and represented less than one percent of the total standing crop weight of the stand (Table 14).

In contrast, the mixed stand had a large standing crop of understory herbaceous species, graminoids, and _Rubus strigosus_, irrespective of the crop tree crown class (Table 14). Standing crop biomass for these understory species were similar to those observed in Plantation III (Table 14), except that graminoids had reduced standing crop values. The standing crop biomass of woody shrub competitors was minimal

Table 15. White spruce and trembling aspen foliage/wood ratios standing crop (kg/m^2) and standing crop density (kg/m^3) for pure white spruce and mixed spruce and aspen areas arranged by degree of suppression in plantation IV, aged 28 years.

White spruce crown position	Species	Mean height (m)	Percent total weight in foliage	Percent total weight in wood	Dry standing crop (kg/m^2)	Dry standing crop density (kg/m^2)
Mixed Spruce and Aspen						
1. Suppressed	white spruce	2.60	14.83	30.27	0.452	0.174
n = 3 plots	trembling aspen	14.51	2.78	71.04	7.590	0.523
2. Intermediate	white spruce	5.10	14.80	52.60	0.499	0.098
n = 3 plots	trembling aspen	14.51	2.78	71.04	22.290	1.536
3. Dominant and	white spruce	6.10	14.00	58.28	0.498	0.082
co-dominant n = 3 plots	trembling aspen	14.51	2.78	71.04	16.090	1.109
Pure Spruce						
1. Suppressed n = 2 plots	white spruce	10.40	15.15	55.13	3.247	0.312
2. Intermediate n = 2 plots	white spruce	9.70	12.77	60.20	3.616	0.373
3. Dominant n = 2 plots	white spruce	11.06	12.16	63.11	3.622	0.328

on this site reflecting some possible differences in original stand floristics between plantation III and IV.

Foliage Efficiency and Wood Production

Foliage and wood ratios for white spruce and trembling aspen for plantation IV are given in Figure 11 and Table 15 and are similar to plantation III.

Foliage Efficiency for Wood Production

Foliage efficiency for white spruce in plantation IV was less than for spruce in plantation III (Table 12). As in plantation III, spruce growing in a mixed stand had reduced efficiencies when compared to spruce growing in a pure stand.

ALL PLANTATIONS

Trends in Standing Crop Relations

Comparisons among the four plantations showed a range of total standing biomass values from 9016 kg/ha at age 4 years to 40,290 kg/ha at age 28 years (Table 16). White spruce biomass accounted for 3.5 percent of the total stand biomass in the youngest stand. In contrast, the trembling aspen accounted for 68.8 percent. Graminoids were also important and contributed 16.2 percent (1467 kg/ha) of the total standing biomass.

In the 28 year-old plantation, 49.4 percent of the total standing crop biomass was contributed by the planted white spruce. The trembling aspen component in plantation IV

Table 16. Standing crop (kg/m^2) relations listed by stand age for parts of plantations having mixed white spruce and aspen.

Plantation Age	Vegetation component	Mean dry standing crop (kg/ha)	Percent of total standing crop
Plantation I	a) All vegetation	9016 kg/ha	
Age 4 years	b) Trembling aspen	6206 kg/ha	68.8
	c) White spruce	220 kg/ha	3.5
	d) Herbaceous species	39 kg/ha	0.6
	e) Graminoid & sedge species	1467 kg/ha	23.6
	f) *Aster macrophyllus*	374 kg/ha	6.0
	g) *Rubus strigosus*	459 kg/ha	7.4
	h) *Rosa acicularis*	250 kg/ha	4.0
Plantation II	a) All vegetation	10067 kg/ha	
age 10 years	b) Trembling aspen	6450 kg/ha	64.1
	c) White spruce	1705 kg/ha	16.9
	d) Herbaceous species	557 kg/ha	5.5
	e) Graminoid & sedge species	981 kg/ha	9.7
	f) *Aster macrophyllus*	198 kg/ha	2.0
	g) *Rubus strigosus*	32 kg/ha	0.3
	h) *Rosa acicularis*	92 kg/ha	0.9
Plantation III	a) All vegetation	22750 kg/ha	
Age 18 years	b) Trembling aspen	2253 kg/ha	9.9
	c) White spruce	15164 kg/ha	66.7
	d) Herbaceous species	2821 kg/ha	12.4
	e) Graminoid and sedge species	2370 kg/ha	10.4
	f) *Aster macrophyllus*	132 kg/ha	0.6
	g) *Rubus strigosus*	8 kg/ha	<0.1
	h) *Rosa acicularis*	2 kg/ha	<0.1
Plantation IV	a) All vegetation	40290 kg/ha	
Age 28 years	b) Trembling aspen	15293 kg/ha	38.0
	c) White spruce	19890 kg/ha	49.4
	d) Herbaceous species	2750 kg/ha	6.8
	e) Graminoid and sedge species	2240 kg/ha	5.6
	f) *Aster macrophyllus*	110 kg/ha	0.3
	g) *Rubus strigosus*	6 kg/ha	<0.1
	h) *Rosa acicularis*	1 kg/ha	<0.1

accounted for only 38.0 percent of the total stand biomass (Table 16). Graminoid species were less important, contributing only 5.6 percent of the total biomass. Herbaceous species and woody shrubs accounted for the remaining 7.5 percent of the total standing crop in the oldest plantation.

Several trends in dry matter accretion over time were observed: (1) a gradual increase in white spruce biomass which paralleled a general decrease in the trembling aspen standing crops in plantations I to III; (2) a progressive decrease in standing dry matter for graminoids, Aster macrophyllus, Rubus strigosus and Rosa acicularis; and (3) an almost constant level of herbaceous dry matter accretion in plantations II, III and IV.

Standing Crop Density

Standing crop densities for white spruce and trembling aspen under varying micro-site, spruce-trembling aspen mixtures and crown class situations are given in Tables 10,15 and are summarized in Table 17. For 18 and 28-year-old pure, well-stocked white spruce stands, the standing crop density was 0.17 kg/m^3; in contrast, the white spruce standing crop density of plantation I, age 5 years was 0.29 kg/m^3 (Table 17).

Generally, the standing crop density for the tree strata was decreased from 0.27 kg/m^3 at age 5 years to 0.10

Table 17. White spruce and trembling aspen foliage/wood ratios standing crop (kg/m^2) and standing crop density (kg/m^3) for mixed areas of the four plantations.

Plantation age		Species	Stems per ha	Mean height (m)	Dominant height (m)	Percent total weight in foliage	Percent total weight in wood	Dry standing crop (kg/m^2)	Dry standing crop density (kg/m^3)
Pure Spruce									
1.	Plantation I Age 4 years	white spruce	1860	0.76	---	46.8	31.1	0.022	0.29
		trembling aspen	130000	1.67	---	11.2	64.6	0.6026	0.37
		tree strata[a]	148600	1.21		N/A	N/A	0.3213	0.27
2.	Plantation II Age 10 years	white spruce	1954	1.55	---	40.1	31.3	0.1705	0.11
		trembling aspen	50000	3.29	---	5.3	78.3	0.5460	0.20
		tree strata[a]	52954	2.42		N/A	N/A	0.4077	0.17
3.	Plantation III Age 18 years	white spruce	1000	8.89	---	17.4	51.5	1.5164	0.17
		trembling aspen	1050	9.42	---	2.5	66.4	0.2253	0.024
		tree strata[a]	2050	9.15		N/A	N/A	0.8708	0.10
4.	Plantation IV Age 28 years	white spruce	550	11.84	---	13.0	60.2	1.9890	0.17
		trembling aspen	1610	14.51	---	2.7	85.7	1.5293	0.11
		tree strata[a]	2160	13.18		N/A	N/A	1.7590	0.14

[a] Tree strata includes both stems of white spruce and trembling aspen.

kg/m^3 at age 18 years (Table 17). This decline was followed by an increase to 0.14 kg/m^3 observed in the 28-year-old plantation. The increase in standing density for plantation IV was not density induced (Table 9) and may reflect a slowing in the height growth of either the white spruce or trembling aspen components (Appendix R).

Prediction of White Spruce Component Dry Weight from Edaphic and Biological Factors

Two sets of regression equations were constructed for predicting white spruce total and component dry weights. One equation was based on combined data from the two youngest plantations (Appendix L), the other on combined data from all plantations (Appendix K). The micro-site and floristic compositions of the two youngest stands necessitated separate analyses.

Equations were developed using bole dry weight (kg), foliage dry weight (kg) and total tree above-ground dry weight (kg) as the dependent variables.

Analyses for plantations I and II (Appendix L):

1) Stem Dry Weight = 0.36715+0 (Depth)-0.22969 (OM)
(SDW) -0.01239 (WHC)-0.002649 (Pot Veg)
+0.03766 (Age)+0.002593 (Com Veg)

r^2=0.73
(Appendix L; Table L1)

2) Foliage Dry Weight = 0.4025+0.1116 (Depth)-0.02740 (OM)
(FDW) -0.01423 (WHC)-0.01872 (Pot Veg)
+0.04918 (Age)+0.002012 (Com Veg)
r^2=0.65
(Appendix L; Table L2)

3) Total Tree Dry Weight (TDW) = 7.89241+0.001712 (Cover)
+0.02590 (Depth)-0.10736 (OM)
+0.002783 (Aspen)-0.06128 (WHC)
-0.008068 (Pot Veg)+0.02147 (IT)
-0.03298 (Pot Ht)+0.07581 (Age)
+0.00291 (Plt Den)+0.008693 (Com Veg)
r^2=0.72
(Appendix L; Table L3)

Standard residual analyses indicated no outliers or heteroscadasticity in the data set.

The partial correlation values for each of the equations developed for plantation I and II (combined) (Appendix L; Tables L1, L2, L3) are a measure of the correlation between the independent variable and the dependent variable after the influence of other variables has been removed. The most influential factors in the prediction of stem and foliage dry weight analyses were: (a) depth of rooting zone with a partial correlation coefficient of 0.525; (b) age with a partial correlation coefficient of 0.477; and (c) competing vegetation (kg/^{2}) with a partial correlation coefficient of 0.291.

For total dry weight the most influential factors were: (a) depth of the rooting zone with a partial correlation coefficient coefficient of 0.459; (b) cover of the seedling by competing vegetation with a partial correlation coefficient of 0.129; and (c) inter-tree spacing factor with a partial correlation coefficient of 0.039.

Analyses for plantation I, II, III, IV (Appendix K):

1) Stem Dry Weight (SDW) = 28.85494+0.32107 (% Sand)
-20.94525 (Bulk Density)+0.61684
(% OM)-0.16347 (Pot Height)
-0.66413 (Depth)+0.62835 (WHC)
-14.90578 (pH)+1.09625 (Age)
$r^2=0.84$
(Appendix K; Table K1)

2) Foliage Dry Weight (FDW) = 6.06639+0.05652 (% Sand)
-3.24509 (Bulk Density)+0.07452
(% OM)-0.05663 (Pot Height)
-0.09418 (Depth)+0.08945 (WHC)
-2.71349 (pH)+0.21473 (Age)
$r^2=0.85$
(Appendix K; Table K2)

3) Total Tree Dry Weight (TDW) = 8.53917-0.00949 (Cover)
+0.12586 (Plot Density)+0.54446
(Aspen Biomass)-0.15096 (WHC)
+0.16077 (% Sand)+0.18912 (% LM)
-0.05374 (Inter-tree spacing)
-3.80315 (pH)-1.05310 (Pot Ht)
+0.60783 (Age)
$r^2=0.73$
(Appendix K; Table K3)

For predicting bole and foliage dry weight, the most influential factors were: (a) age; (b) water holding capacity (WHC); (c) percentage sand; and (d) percentage organic matter in the rooting zone depth. In contrast, the most influential factors for predicting total tree dry weight were: (a) trembling aspen plot density; (b) biomass of all competing vegetation; and (c) age of the stand.

Prediction of White Spruce Size and Component Dry Weights from Dry Weights of Vegetation Located Around the Crop Trees

Multiple regressions involving the total data set from the four plantations were developed to predict the size and component dry weights of white spruce from the presence and abundance of competing vegetation located around white spruce. No predictive relationships were found for branchwood and bark dry weight, for total tree dry weight, or for current annual height based on initial regression analyses. Accordingly, these dependent variables were dropped from the analyses.

Appendix M presents predictive equations involving the following dependent variables: (1) root collar diameter (RCD); (2) height (H); (3) foliage dry weight (FDW); and (4) branch wood and bark dry weight (BDW).

1) $$\text{White Spruce Root Collar Diameter (RCD)} = 1.14638+3.32209\,(\text{Spruce})+0.28405\,(\text{Aspen})+1.48365\,(\text{Shrubs})+0.51797\,(\underline{\text{Aster}})-2.98179\,(\underline{\text{Rosa}})-0.11956\,(\underline{\text{Rubus}})+0.19167\,(\text{Gram})-1.87081\,(\text{Herb})$$

$r^2=0.86$
(Appendix M; Table M1)

These eight factors explained 86 percent of the variability in observed root collar diameters. Standard residual analyses indicated no outliers, heteroscadasticity or multi-collinearity of the data set.

Examination of the partial correlation coefficients for the eight significant variables indicated that other spruce biomass on the plot surrounding the crop tree significantly influenced root collar diameter. Trembling aspen biomass, shrub biomass, and *Aster macrophyllus* biomass had partial correlation coefficients of 0.535, 0.293 and

0.012, respectively, and were of secondary influence in predicting root collar diameter.

2) White Spruce Height (Ht) (m) = 0.59063+2.47074 (Spruce)+0.19096 (Trembling Aspen)+0.84193 (Shrubs)

r^2=0.91
(Appendix M; Table M2)

These three factors explained 91 percent of the variability in observed white spruce height. Standard residual analyses indicated no outliers or multi- collinearity among the elements of the data set. Slight heteroscadasticity of the data was detected. Spruce biomass with a partial correlation coefficient of 0.944 had the strongest association with crop tree height. Trembling aspen biomass and shrub biomass possessed smaller partial coefficients of 0.665 and 0.282 respectively.

3) White Spruce Foliage Dry Weight (FDW) = 0.02583+1.37375 (Spruce)+0.06448 (Trembling Aspen)+0.23304 (Shrubs) +0.4221 (*Aster*)-0.71272 (*Rosa*) +0.31214 (*Rubus*)-0.13315 (Gram) -1.16513 (Herb)

r^2=0.77
(Appendix M; Table M3)

These six factors explained 77 percent of the observed variation in white spruce foliage dry weight. Large partial coefficients were observed for the first three independent variables spruce (0.858), trembling aspen biomass (0.261) and shrubs (0.090). These factors are the same as those indicated as being important in the prediction of crop tree height and root collar diameter. Removal of the remaining three independent variables for Aster, Rosa, Rubus, graminoids and herbs from this equation resulted in a reduced correlation coefficient.

4) $$\text{White Spruce Branch Wood and Bark Dry Weight (kg) (BDW)} = 0.10908+1.97128\,(\text{Spruce}) -1.82848\,(\text{Shrub})+0.15478\,(\text{Trembling Aspen})$$

$r^2=0.76$
(Appendix M; Table M4)

These three factors explained 76 percent of the observed variation in white spruce branch wood and bark dry weight.

Spruce biomass on the plot was most highly correlated with the dependent variable and possessed a partial correlation coefficient of 0.871.

Prediction of White Spruce Size and Component Dry Weight Utilizing Percentage Cover by Competing Vegetation

The mean percent cover values of competing vegetation on the plot are presented in Tables 18 and 19.

General trends observed in plantations I and II (Table 18) were: (1) greater coverage of the planted spruce by competing vegetation at age 10; (2) greater cover by competing vegetation on the spoilbank rather than the corridor. In plantation I, the greatest shading of spruce by competing vegetation occurred on the portion of the spoilbank

Table 18. Mean per cent cover of competing vegetation arranged by micro-sites and trembling aspen competition for plantations I and II.

	Micro-site/trembling aspen situation	Competing vegetation mean per cent cover
Plantation I - aged 4 years		
	Corridor - low level	58.1
	Corridor - high level	71.0
	Spoilbank ledge - low level	63.4
	Spoilbank ledge - high level	87.4
	Spoilbank - low level	61.0
	Spoilbank - high level	76.6
Plantation II - aged 10 years		
	Corridor - low level	85.9
	Corridor - high level	87.7
	Spoilbank - low level	80.1
	Spoilbank - high level	96.3

Table 19. Mean per cent cover of competing vegetation arranged by white spruce crown cover class and presence/absence of trembling aspen for plantations III and IV.

Crop tree crown class	Competing vegetation mean per cent cover
Plantation III - aged 18 years	
Pure spruce	
Suppressed	0.0
Intermediate	0.0
Dominant	0.0
Mixed trembling aspen and spruce	
Heavily suppressed	87.5
Moderately suppressed	65.0
Lightly suppressed	34.5
Plantation IV - aged 28 years	
Pure spruce	
Suppressed	0.0
Intermediate	0.0
Dominant	0.0
Mixed trembling aspen and spruce	
Heavily suppressed	74.5
Moderately suppressed	81.5
Lightly suppressed	77.6

ledge where a high density of trembling aspen existed.

In plantations III and IV (Table 19) heavily suppressed white spruce in the aspen mixedwood were subjected to 87.5 (plantation III) and 74.5 (plantation IV) percent coverage by competing vegetation. Regression analyses presented no significant relationships between white spruce crop tree dimensions or component dry weights and associated cover by competing vegetation.

Samples of hemispherical photographs used to calculate the percentage coverage by competing vegetation for each plot are given in Appendix G. The photographs illustrate a qualitative description of the nature, distribution and amount of competition to be found in each plantation.

Prediction of Crown Foliage Efficiency for White Spruce Crop Trees

The influence of tree age, competing vegetation and surrounding trembling aspen density on a white spruce's crown foliar efficiency for wood production was investigated using multiple linear regression techniques. The following predictive equation was derived:

Mean Annual Cubic = 0.13430+0.13100 (Spruce Height)
Decimeters -0.02547 (Total Dry Weight Aspen/m^2
Volume +0.01275 (Inter-tree spacing)
(Wood Produced per -0.001862 (Total Tree Folige Dry
Kilogram Foliage) Weight/Plot)+0.01433 (Plot Density)
+0.19774 (Total Dry Weight of Trees per Plot)+0.17915
(Aspen Density/Plot)+0.13430 (Total Dry Weight of
Competing Vegetation/m^2)
r^2=0.86
(Appendix N; Table N1)

Examination of the partial correlation coefficients of the independent variables revealed that crown foliage efficiency values were most highly correlated with the total dry weight of trees in the plot (partial correlation coefficient = 0.376) followed by spruce crop tree height (m) (partial correlation coefficient = 0.168) and the trembling aspen density on the plot (partial correlation coefficient = 0.129). Residual analysis revealed no outliers or influential points. All assumptions for linear regression were satisfied based on examination of residuals for heteroscadasticity, independency and normality of the data.

DISCUSSION

The overall objective was to determine relationships in young white spruce plantations (trees 4 to 28 years-old) related to their biomass production, structure and dynamics. However, the need for caution must be stressed since differences in soils, vegetation, time between harvesting and planting, intensity of utilization, site preparation techniques, planting stock (including handling differences) and weather would each influence how the spruce grow and respond differently to varying levels of competition.

The discussion is presented in three sections. The first section deals with the differences in successional status between the 4 to 28 year-old white spruce plantations established on former mixedwood cutovers. The second section considers the influence of trembling aspen competition on the growth and dry matter production of planted white spruce, and the third section deals with management recommendations based on this study.

SUCCESSIONAL CHANGES IN STAND STRUCTURE

The four plantations had much variation in spruce and aspen densities, site preparation, disturbance, and differences most certainly existed in the floristic composition of each site at the time of planting. Nevertheless, these four plantations were on similar lacustrine soils, possessing similar topography and site quality. Based upon the differences in stand structure and composition, a general pattern of succession is suggested which involves four discrete stages: (1) stand initiation; (2) stem exclusion; (3) full site occupancy, and (4) competition induced mortality and understory reinitiation.

Stand Initiation Stage (Plantations I and II)

The stand initiation stage spans the period from time of planting to when the conifer crop is considered established and 'Free to Grow' (OMNR 1986). Duration of the initiation stage varies widely for different plantations (Sutton 1982; McMinn 1984).

Stand Composition and Structure

Seventy-seven percent of the planted white spruce in plantation I had survived the four years since planting (Table 9). This survival was better than average fifth year survival reported for white spruce in the North Central Region, Ontario Ministry of Natural Resources (68.8 percent based on plantation records from 1957 to 1981) (MacKinnon 1974; Rudolph 1984).

Plantation II displayed a similar survival rate of 74 percent. Stiell (1958) surveyed pulpwood plantations in Ontario and Quebec and found that most of the mortality encountered in white spruce plantation establishment occurred within 5 years of planting. Vyse (1981) working on the drier sites of the British Columbia interior also concluded that the majority of mortality often occurred within two years of planting. Heavy shrub competition was largely responsible for mortality on the British Columbia sites.

In the stand initiation stage (plantations I and II), the density of trembling aspen suckers exceeded the number of planted white spruce seedlings on both sites (Table 9). It can be hypothesized that the reduced density of aspen in Plantation II (3900 stems/ha) is the result of interspecific competition among young aspen suckers when compared to aspen densities of 18018 stems/ha in the younger plantation I. The trembling aspen densities were generally less than those commonly observed for mixedwood cutovers across Manitoba, Saskatchewan and Alberta (Peterson et al. 1982).

The growth and development of pure trembling aspen stands from root suckers has been described by Graham et al. (1963) and Pollard (1971) as consisting of alternating periods of slow and rapid growth; the first period of slow growth and initial population mortality occurring in or about the fifth year. Pollard (1971) considered that extensive mortality of the smaller aspen suckers coincided with canopy closure and heavy shading in the understory.

Regardless of the conditions that have led to the present aspen densities, these numbers of stems in plantation II (Table 9) will still be sufficient to form a normally stocked, Site Class II aspen stand (Plonski 1974). This early ability of aspen to dominate plantations emphasizes the importance of early stand tending and crop release to manipulate growing space in favour of the planted white spruce.

In plantations I and II the average height of the dominant aspen was much greater than that of the dominant spruce (Appendix B; Tables B1 and B2). Aspen in plantation I had consistently larger current annual height increments in each of the four years after the spruce were planted than those of the outplants (Appendix B; Table B1). The magnitude of the difference in total height between spruce and aspen in plantation I progressively increased from time of planting. This difference in height growth between the white spruce and aspen resulted in a two-tiered canopy early in the stand initiation stage (Appendix A; Figure A8, A9 and A10).

White spruce in plantation I displayed small current annual height increments in each of the three years after planting irrespective of micro-site position and the presence of broad-leaved vegetation (Figures 4 and 5) and did not exhibit classical "post-planting check". Instead the outplants seemed to be in an establishment phase during which time the root systems were developing and expanding while, in contrast, tops were not yet showing much growth. The increased 1981 current annual height increment for the spruce, and emerging growth differences between spruce on the various micro-sites, suggests that after four years the spruce were no longer exhibiting classical 'post-planting check'.

This observation is in agreement with the findings of Sutton (1978) who noted that planted white spruce seedlings can have an establishment period during which height and volume growth is minimal. According to Hambly (1980), the current annual height increment of planted white spruce in northern Ontario increases very slowly to a maximum at an age of 14 years. White spruce plantations in British Columbia, pass through two or three seasons of slow height ("check") growth before beginning an accelerated growth pattern (Vyse 1981).

White spruce in the latter phase of the stand initiation stage (Plantation II) displayed significant differences in total heights between the corridor and spoilbank micro-sites (Figure 7). No statistically significant differences had been observed within the 1981, 1980, 1979, or 1978 spruce current annual height increments (Figure 7 and Appendix E (Tables E3 and E4). This would suggest that observed differences in the total height growth of young white spruce trees can be best attributed to differences in early height growth (including differences in initial nursery stock size). Years to reach breast height for white spruce varies considerably depending on site quality, presence and abundance of vegetative competition and nursery stock quality (Thrower 1986).

Trembling aspen in plantations I and II assumed dominant and co-dominant positions with the white spruce or developed as dominants in gaps created by spruce mortality (Appendix A; Figures A7, A9 and A10).

Influence of Micro-site Conditions on White Spruce Growth and Stand Development

Growth of the planted spruce in plantation I was closely related to micro-site. Figures 4 and 5 show that spruce planted on the spoilbank had root collar diameters and total heights significantly larger than the spruce planted on the spoilbank ledge and corridor (also Appendix E; Tables E1 and E2). Similarly, white spruce occurring on the spoilbank ledge had larger root collar diameters and total heights than seedlings from the corridor (Figures 4 and 5).

Turcotte (1976) and Thauvette (1982) observed similar relationships for white spruce planted in a C & H plough and shear-bladed site, respectively, in the Thunder Bay District. Each observed that white spruce planted beside windrows had better height growth and increased root collar diameters than did spruce planted between windrows. These growth differences were attributed to the resultant soil conditions created by the mechanical site treatment. Soil and air temperature, light intensity, soil nutrients, soil texture and structure, frost-heaving, flooding, and soil water were all found to be factors affecting seedling survival and growth. Sutton (1969) has stated that survival and early growth of white spruce depends on early inception of root growth. This is most likely to occur with a combination of healthy, physiologically-active planting stock and favourable soil conditions.

Evidence from soil profile examinations (Appendix H; Tables H1, H2 and H3) from the corridor, spoilbank ledge and spoilbank micro-sites in plantation I, respectively, confirm that excessive site preparation had created less than favourable micro-sites for planting. On the corridor the LFH, Ae and Bt layers were completely removed exposing the slightly ameliorated silty clay C horizon. The spoilbank ledge had little disturbance to the Ae and Bt horizon and was characterized by mixing of the LFH and Ae horizons. The presence of partially decomposed organic matter in the Ae horizons in the spoilbank and spoilbank ledges was thought to have resulted from this mixing.

The soil disturbance resulting from site preparation was not as evident in plantation II (Appendix M). The Ae horizon in the corridor remained intact and some mixing of the LFH and mineral soil had occurred. The soil profile on the spoilbank also remained undisturbed except for additions of slash and litter.

Stiell (1976) reported that white spruce, like most species, makes best growth on moist well-drained loamy to dry loam soils with fresh to very fresh moisture regimes (MR 1 to MR 3, classification of Hills, 1952). Compact, fine-textured subsurface layers are not readily penetrated by seedling roots

(Minore et al. 1969). In plantations I and II, therefore, removal of surface organic matter and the upper mineral horizons in the corridors has resulted in seedlings being planted in an unsatisfactory rooting medium (Appendix A; Figures A5 and A8).

Extensive massive soil cracking was also observed in the corridor in plantations I and II. Root-balling and uni-directional root distribution were frequently observed in the planting slits of this micro-site. Field staff planting white spruce on heavy silts and clays have always noted smaller root lengths and widespread natural pruning of the roots by shrinkage of the clay during the summer was also widespread. Sutton (1978) also noted root systems took much longer to develop due to drastic and repeated root pruning by frost and drought in clay. Seedlings may also be frost-heaved when planted in exposed, fine-textured mineral soils such as those exposed by severe V- plough scarification (Crossley 1952; Weetman 1965).

Cracking of the soil surrounding the root collars persisted until year 10 in plantation II and suggests that: (1) blading on finer-textured soils may not provide benefit seedling establishment even though competing vegetation is effectively removed, (2) excessive site preparation will have a long term influence on seedling growth and development.

White spruce planted on the spoilbank and spoilbank ledge had more favourable growing conditions than spruce planted on the corridors. Incorporation of organic matter into the Ae horizon of the rooting zone decreased the bulk density of the soil and increased macro pore space and soil aeration (Appendix I; Table E1).

Thrower (1984) found that the depth of Ah(e) horizon remaining after site disturbance on the lacustrine soils of the Prince and Jarvis locations was closely correlated to the height growth of planted white spruce. Studies in British Columbia have also shown that planted white spruce and lodgepole pine have an improvement of up to twenty-five percent in height growth over five years on sites where site preparation has mixed the organic matter into the upper mineral soil (McMinn 1974, 1976, 1976b). Seedlings planted on these favourable micro-sites were considered to be permanently established after only three growing seasons.

Seedlings established on the spoilbank ledge had an uneven distribution of lateral and secondary roots. On this micro-site more extensive root development occurred on the spoilbank side while fewer roots extended towards the corridor. These observations suggest that the wind-firmness of the plantation at older ages (and implicitly larger size trees) may be reduced by the combination of initial micro-site soil conditions and planting method. Marek (1984) has reported similar relations for jack pine growing in corridored plantations.

The complete removal of the LFH, Ae and portions of the Bt horizon in the corridor may also affect the supply of available nutrients to the white spruce seedling (Appendix H; Tables H1 and H5). In undisturbed soils, the nutrients are usually concentrated in the surface soil layer (Sutton 1978). Thus removal of these surface soils during site preparation, such as on the corridor micro-sites, means that seedling roots have to extend out of the corridors and into the windrows before reaching nutrient-rich soils.

Seedlings suffering from nutrient deficiencies created by removal of nutrient-rich mineral soils will usually also suffer from moisture stress. Lack of nutrients available to the root system often interferes with normal root metabolism and processes such as water uptake (Sutton 1978). Stem growth then decreases because of insufficient moisture and nutrient absorption. In fine-textured soils, removal of the surface layers to expose mineral soil may leave seedlings without access to an adequate supply of nitrogen (McMinn 1984). Nitrogen deficiencies may in turn contribute to a reduction in current annual shoot growth.

Excessive site modification through site preparation has undoubtedly contributed to the differences in root collar diameters and heights of white spruce growing in plantations I and II. Thrower's (1984) analyses of 31 year-old white spruce planted on scalped areas indicated little increase in growth, thus little site quality improvement, in the 32 years since blading.

Influence of competing vegetation on white spruce growth and stand development

Spruce growing under low trembling aspen density had greater total heights and root collar diameters than seedlings located in areas of high aspen density (Appendix E; Tables E2 and E4) (Figures 5 and 8).

Trends in current annual height growth of white spruce on the corridor micro-site in plantation I suggested that the presence of trembling aspen for the two years following planting did not adversely affect height growth (Figure 5).Possibly the presence of aspen during these first two years may have provided a beneficial micro-environment for spruce planted on the corridor micro-site. By deduction, this would suggest that the aspen did not affect survival or height growth of the spruce until three or four years following planting.

Eis (1970) found that shading affected root and stem growth in opposite ways. Stem growth was greater than root growth in less than 50 percent of full sunlight.In contrast, trees growing in full sunlight showed more root growth than stem growth. Posner (1984) determined that 4 to 6 year-old white spruce that were shaded by woody shrub competition were taller and had larger caliper than those growing in the open. According to Sutton (1978) plants already on a planting site may be beneficial in providing a "nursing" effect to newly established seedlings. The variation in the growth responses of planted white spruce under varying shade conditions as reported in the literature and in this study would strongly support the argument that neither site nor existing vegetation conditions exclusively determine successful establishment or early growth for planted spruce. Rather a combination of species, the performance potential of the nursery stock, quality of planting, competition, and site factors determine the rate of early tree growth.

Development of Understory Flora

When an area is clearcut and planted with conifer seedlings there is a large increase in the abundance and diversity of the ground flora in response to the sudden opening of the canopy, the associated temperature change, and modification of soil moisture and nutrient relations. Understory species found in white spruce plantations I and II (Appendix J) were similar to those found by Jeglum (1980) and Savinsky (1981) when black spruce growing on shallow soils near Nipigon, Ontario were clearcut.

A total of 54 vascular plant species were found in plantations I and II (Appendix J). Perennial forbs were the most numerous, followed by shrubs, annual forbs and graminoids. Eleven species of non-vascular plants (ferns, lichens, mosses) occurred in plantation I and twelve species in plantation II. The greatest variety of shrubs, perennial graminoids and forbs, and annual forbs were observed between

10 and 18 years after planting (Appendix J). Annual forb species declined sharply in number between plantation I and II, although this may only reflect differences in pre-cut stand conditions. Total numbers of species found under the 'managed' stands was approximately 22 percent of the total number of understory taxa reported for unmanaged boreal natural stands by Carleton and Maycock (1981).

Within each plantation the distribution and abundance of the lower vegetation varied with micro-site and the density of spruce and aspen tree cover. Variation in vegetation on the micro-sites was considered to be related to: (a) differing soil and temperature conditions; and (b) heterogeneity of vegetation prior to logging; this may be significant if many plants with underground rhizomes and root suckers remain undisturbed after site preparation.

In England small-seeded plants that survived well in the soil beneath Norway spruce (*Picea abies* Karst.) plantations included: *Carex* spp., *Galium* spp., *Aster* spp., *Juncus* spp., *Luzula* spp. (Hill 1978). Also the grasses *Agrostis* spp., *Oryzopsis* spp., and *Bromus* spp. were reported to contribute large numbers of long-lived propagules to the seed bank of a site (Hill 1978).

In addition to plants whose seeds survive on the site, certain plants with airborne seeds are capable of rapidly colonizing the prepared cutover. Hill (1978) reported that in many parts of North America and the Soviet Union, *Epilobium* spp., Calamagrostis spp., and members of the Compositae colonize cutovers in this manner. Such seeds have an advantage at time of establishment in contrast to seeds buried in the litter that may be ploughed under by site preparation or that may be eaten.

Species present that have extensive underground root systems or rhizomes included: Rubus idaeus, Alnus spp., Betula papyrifera, Corylus cornuta, Prunus spp., Rosa acicularis, Populus tremuloides, Salix spp., Equisetum sylvaticum, Aster macrophyllus, Clintonia borealis, and Maianthemum canadense.

Distribution of lesser vegetation on the spoilbank, spoilbank ledge, and corridor, micro-sites of plantations I and II was apparently related to differences in light intensity, depth of litter layer, and soil moisture.

Gordon (1981) determined that light and moisture may not be limiting factors in the development of understory vegetation in young black spruce plantations until the onset of stand closure and the beginning of the stem exclusion stage. As the stand closes and evapotranspiration increases, moisture and light are probably the major factors in "distributing" ground vegetation.

Many of the early successional herbaceous species are better adapted to rapid early growth and survival than the newly planted white spruce. Other vegetation in a plantation compete with spruce for soil moisture and nutrients; if the competitors are larger than spruce then less light and moisture is available for the spruce (Sutton 1969b). The degree to which the growth of the spruce will suffer depends on the density and relative size of the competitors. Young planted spruce are often adversely affected by grass, particularly the root mat build-up on compact soils. Waldron (1963) has shown that Calamagrostis spp. is a greater hindrance to the survival of white spruce seedlings than are herbs. However, some meadow plants, such as Solidago spp. appear to offer protection to young seedlings.

Controlling root competition by elimination of the surrounding lesser vegetation increases tolerant conifer height growth (Perala 1982). All authors except Sutton (1975), directly attribute improved conifer growth following elimination of lesser vegetation to measured or inferred increases in soil moisture resulting from lowered evapotranspiration. Sutton (1975) found that controlling root competition increased available soil moisture. However, he concluded that increased height growth of white spruce was primarily related to improved nutrition, and secondarily related to increased available water.

Stem Exclusion Stage - Plantation III

As trees grow larger, greater utilization of the growing space is achieved and competition occurs with other individuals. This characterizes the stem exclusion stage. Competition in plantation III occured mostly between the planted spruce and the trembling aspen.

Stand Composition and Structure

In plantation III - age 18 years, the density of planted white spruce was similar to that in plantation II - age 10 years. It was 2050 stems per hectare (Table 9) with a basal area of 17.75m^2 per hectare. This basal area is similar to that for Site Class I black spruce of the same age in Ontario (Plonski 1981).

In contrast, the aspen density in plantation III was considerably less (2330 stems/ha) than that in Plantation II (3900 stems/ha). This aspen component had a corresponding basal area of 11.72m^2 per hectare (Table 9). A 30 percent reduction in aspen density between stands of similar ages in the B18a mixedwood forest is not unusual and often parallels the onset of crown closure (Maini and Cayford 1968). This reduced aspen density in Plantation III may reflect competition induced mortality as well as possible initial differences in stand composition. Maximum densities for 20-year-old sucker origin stands in the prairie provinces have been reported as high as 25,000 stems per hectare (Peterson et al. 1982).

Competition often results in accelerated size differentiation among individuals in the population (Ford 1975, 1982). The diameter and height distributions for the pure white spruce in plantation III were normal (Appendix C; Figure C6). In contrast, planted white spruce growing in a mixed stand with trembling aspen exhibited a skewed diameter distribution (Appendix C; Figure C7). White spruce in the pure stand had d.b.h.'s ranging from 2 to 20 cm while white spruce in the mixed stand condition had d.b.h.'s ranging from 2 to 8 cm. Petawawa white spruce plantations had a d.b.h. spread of 25 cm and an average d.b.h. of 12.7 cm (Stiell and Berry 1973). Assman (1970) and Ford (1975) reported similar wide ranges in diameter for mixed stands of Norway spruce in Europe.

This wide range in diameter can be explained as follows: as competition proceeds, an increasingly large percentage of spruce falls behind the largest individuals, resulting in an increasingly skewed rather than normal distribution. The differentiation into distinct crown classes then parallels the differentiation into broader diameter distributions (Hamilton 1969). As stand development proceeds further and the weakest (smallest) trees of a crop are removed, either by natural elimination or thinning, then the left-hand "tail" of the distribution curve is reduced leaving an approximately normal distribution.

Height distributions for white spruce in the pure portion of the stand (Appendix C; Figure C6) revealed a similar wide range from 0.1 to 12 m and negative skewing towards the larger classes. The height distribution was also slightly bi-modal. The bi-modality of the data in plantation III strongly suggests that crown closure and differentiation of the planted white spruce into several crown classes had occurred well prior to the age at which measurements were taken (age 18 years). The spruce in the mixedwood condition had a normal height distribution. Heights ranged from 0.1 to 0.7 m (Appendix C; Figure C7).

Influence of Micro-site Conditions on White Spruce Growth and Stand Development

Plantation III had not been subjected to severe site preparation and did not display micro-site specific differences in the growth of planted spruce. The tallest white spruce in the pure stand condition were located on soils having lower bulk densities; tallest trees were also in areas possessing an Ah or Aeh. White spruce produces numerous secondary and lateral roots within 40 cm of the soil surface; thus the ability of the surface soil and litter layer to supply moisture and nutrients will greatly enhance growth of spruce.

Thrower (1984) studied a white spruce plantation adjacent to plantation III and concluded that height growth was closely related to depth of the Ah horizon; he attributed better growth on soils with deeper Ah horizons to increased moisture and nutrient availability. Similar results have been described for planted white spruce in the southern part of its range (McClain and Armson, 1975; Nienstaedt 1982).

Influence of Competing Vegetation on White Spruce Growth and Stand Development

Regression analyses indicated that total dry weight of planted white spruce was correlated with aspen density and biomass. Height growth of spruce, as well as branchwood and bark dry weight and bole dry weights of the planted spruce, were also found to be inversely related to the biomass of spruce, trembling aspen and shrubs on the sample plots. This would seem to suggest that the size attained by the spruce up to and during the stem exclusion stage is closely related to the amount of available growing space in the canopy. As the density and dominance of trembling aspen become greater, the planted spruce become overtopped by the expanding aspen crowns. Thus, the within-stand environment is altered causing large deviations in spruce growth and in the height attained by the planted white spruce.

Development of the Understory Flora

Understory development in the stem exclusion stage was thought to be directly related to the density of trembling aspen and to its resulting influence on the light intensity in the understory (Table 19). Portions of the stand dominated by trembling aspen had as much as 87 percent canopy coverage while, in contrast, the areas of pure spruce had no total coverage (Table 19). The sparse understory found under the dense canopy of the pure spruce stand was evidence of the mortality of shade-intolerant species (Table 17, Appendix J). In contrast, a well developed shrub and herbaceous understory present existed under the mixed stand (Appendix P; Figure P3). Species dominance in the mixed stand varied considerably and included *Rubus idaeus*, *Rubus pubescens*, *Populus balsamifera*, *Corylus cornuta*, *Ribes glandulosum*, *Acer spicatum* and *Prunus virginiana* (Appendix P; Figure P3). This pattern of understory development is consistent with that observed by Kabzems et *al*. (1976) on silty loam lacustrine deposits in Saskatchewan and by Ellis and Mattice (1974) for cutover sites at "the experimental lakes area" northwest of Kenora, Ontario.

The understory of the mixedwood areas of plantations III and IV will continue to develop, but rapid shifts in species abundance should be expected as intolerant species are eliminated. More tolerant "climax" species such as *Acer spicatum* and *Corylus cornuta* should continue to increase in size, density, and relative abundance. These tolerants will persist as members of the community until further disturbance occurs.

Significant development of a bryophyte flora was noted in the understory of the pure white spruce. Feathermosses and in particular Pleurozium schreberi were common on those sites. Dicranum fuscesens, Dicranum scoparium, Plagiothecium spp. and Lophocolea spp. also accounted for a large coverage of the ground floor. Moss species were fewer under the mixed stand.

Full Site Occupancy Stage - Plantation IV

Full site occupancy occurs when the above-ground growing space is fully occupied by tree crowns. Mortality of overtopped conifer trees may still occur depending upon individual tree tolerance and the frequency of minor disturbance creating gaps in the canopy. This stage also coincides with the re-introduction of intolerant tree, shrub and herbaceous species into the understory.

Stand Composition and Structure

Density of white spruce in plantation IV beneath a canopy of trembling aspen was 206 stems/ha in contrast to 2150 stems/ha in the block of pure spruce (Table 9). The living spruce appeared to occupy an intermediate crown class within the trembling aspen canopy; only a few scattered spruce were in the codominant or dominant crown class.

Differences in white spruce height existed between the block of pure spruce and the mixedwood area (Appendix B; Table

B4 and Appendix E; Table E6). These patterns of height growth confirm those observed by Cayford (1957) who studied the effects of aspen on the growth of planted white spruce in Saskatchewan.

White spruce d.b.h. was greatest in the pure stand (Appendix B; Table B4), (Appendix E; Table E6). The range of stem diameters for spruce increased with mean d.b.h., for both pure and mixed stands (Appendix C; Figures C8 and C9). This conforms with the findings of Stiell and Berry (1973), who studied the development of unthinned white spruce plantations to age 50 at the Petawawa Forest Experiment Station.

ALL STAGES OF STAND DEVELOPMENT

TRENDS IN DRY MATTER ACCRETION AND DISTRIBUTION

White spruce biomass in plantations I and II (stand initiation stage) was greatest on the spoilbank ledge and spoilbank micro-sites, respectively (Figures 6 and 9). These spoilbank micro-sites also supported the largest standing crop of trembling aspen (Tables 11 and 14). Standing crop biomass for trembling aspen declined from plantations I to III (Table 16), even though aspen continued to dominate the tree strata. The observed decline is inferred to be the result of different original stand densities for aspen on each of the sites.

The biomass of tall shrubs increased from plantation I to plantation IV (Table 16). In particular, Alnus rugosa and Acer spicatum attained small tree size early in the development of the stands. Under mixedwood conditions *Corylus cornuta* dominated the tall shrub stratum of plantations III and IV.

The average standing crop per unit area of low shrub species also increased rapidly during the stand initiation stage (plantations I and II) and then plateaued upon canopy closure (plantations III and IV). *Rubus strigosus* and *Rosa acicularis* dominated the low shrub stratum of plantations I, II and III and then declined in plantation IV.

The standing crop per hectare of herbaceous species increased from plantations I and II (the stem exclusion stage) to plantation IV (the full site occupancy stage) (Table 17). This increase may reflect the gradual thinning and opening of the aspen canopy and the creation of more favourable understory light conditions in the mixed stand condition.

Ohmann and Grigal (1979) studying early revegetation and nutrient dynamics following a forest fire in northern Minnesota observed similar trends in standing crop biomass for herbaceous and *Aster* species. On moist sites they observed that the proportion of the total stand biomass attributable to herbaceous species was less than that on drier sites. However, more species attained larger individual standing crops on the moist sites (e.g. *Aralia hispida* L., *Clintonia borealis* (Ait.) Raf., *Lycopodium* spp., *Streptopus roseus* Michx., *Trientalis borealis* Raf., *Aralia nudicaulis* L. and *Epilobium angustifolium* L.).

The continued presence of graminoids in plantations I, II, III and IV is indicative of the very moist, fertile fine-textured soils. Control of the graminoid species is required to provide a more suitable micro-site and growing conditions for the planted spruce. Graminoid species quickly overtop planted spruce; physical "smothering" of planted seedlings by dense grass has been documented by Stiell (1976). White spruce root development may also be indirectly reduced by dense sod on compact soils. Root competition for available nutrients and moisture between planted spruce and graminoid species is considered to be the primary causal relationship to the reduction in root growth (Sutton 1969).

Stand Biomass

Total stand biomass per unit area increased from plantations I to IV (Table 17) and varied considerably within each plantation reflecting differences in stocking and overstory species basal area. No attempt was made to adjust the observed total biomass per unit area to a biomass per unit area for a normally stocked stand.

During the stand initiation stage (plantation I and II), the total above-ground biomass ranged from 9.0 to 10.0 tonnes/ha (Table 16). Outcalt and White (1981a,b) have reported standing crops of 2.6 to 4.2 tonnes/ha for whole-tree logged mixedwood cutovers in northern Minnesota two years after site preparation. MacLean and Wein (1976) working in a

5-year-old fire-origin jack pine mixedwood documented an above-ground biomass of 1 to 2 tonnes/ha, and contrasted it to pure hardwood stands of similar age and stand history which had stand biomass of 8 to 10 tonnes/ha.

Total above-ground biomass at time of full site occupancy (plantation IV) was 40.3 tonnes/ha) based on an average of the pure and mixed stands (Table 16). Pastor and Bockheim (1981) have reported a total stand biomass of 197 tonnes/ha for a 60-year-old aspen - mixed hardwood - stand in northern Wisconsin. Only 39 percent of the standing crop in study plantation IV (age 28 years) was aspen.

A 40-year-old normally stocked stand of aspen in Minnesota yielded 207.6 tonnes/ha of above-ground biomass (Bray and Dudkiewicz 1967) while fully stocked spruce stands of the same age in northern Minnesota contained only 150 tonnes per hectare of dry matter (Alban et al. 1978). More recently, Gordon (1982) examined fully-stocked, mature, spruce-aspen mixed stands in northern Ontario and determined the above-ground standing crop to be 135.9 tonnes/ha at an average age of 105 years.

A substantial amount of biomass variation in mixed stands is due to variation in the stocking, stand density, site quality, and species composition. Gordon (1982) attributed observed differences in standing biomass on northern Ontario boreal mixedwood sites to basic differences in site quality. More standing crop biomass was predicted expected on mixedwood sites where organic matter was rapidly incorporated and rapid nutrient cycling occurred.

Stand age is also important in determining the standing crop biomass of a forest. Gordon (1982) indicated that boreal mixedwoods follow a successional pattern of differential longevity where aging effects occur at different times for each of the species in the mixture. As one species begins to die out, another species experiences crown release and subsequently an increase in diameter increment. In this fashion, the productivity of the mixed forest is sustained beyond the life span of some of its component species. The trembling aspen-white spruce mixedwood can be considered an example of successional pattern associated with differential longevity of the constituent species. Unfortunately the softwood volume obtained from mixed stands will not be as great as from pure plantations being managed exclusively for softwood fibre.

Within-Tree Partitioning of Dry Matter

Variation in stand biomass is closely related to the rate at which stemwood production occurs during the life of a stand. In contrast, foliage biomass is related to specific stages of stand development and yearly foliage production. In this study the foliage biomass measured for selected white spruce sample trees represented three to five years of foliage production.

Increased aspen density corresponded with a general reduction in white spruce growth. A reduction in white spruce foliage and stemwood dry matter accretion was also noted (Tables 10, 13, and 15). Peterson et al. (1982), observed similar trends for pure trembling aspen and white spruce stands, respectively, on the prairies.

The percentage of total dry weight as foliage and branchwood in the planted spruce became stabilized shortly after crown closure associated with the stem exclusion stage (Table 13). Dominant white spruce had 17.4 percent of total aboveground dry weight as foliage while dominant aspen only had 2.0 percent of their total aboveground dry weight as foliage (Table 16).

TREMBLING ASPEN COMPETITION IN RELATION TO GROWTH AND DRY MATTER PRODUCTION OF WHITE SPRUCE

Foliage and Wood Production in Individual White Spruce

Total current annual wood production for young, planted spruce was found to be directly related to tree foliage dry weight (Tables 10, 13, and 15). The larger the tree, the more foliage it carried. Exceptions occurred where variable sized spruce located in plantations I and II (stand initiation stage) supported similar amount of foliage (Table 10). Current annual wood production for spruce occurring in a mixed stand was greatest for trees surrounded by the fewest numbers of aspen suckers (Table 10). Spruce foliage efficiency in older mixed stands (plantations III and IV) was less than that of spruce growing in a pure stand.

Dominant white spruce growing without any aspen nearby showed greater foliage efficiencies than those of the suppressed and intermediate crown class spruce (Table 12). This increased foliage efficiency may be related to a larger crown surface area exposed to sunlight and not necessarily due to a larger total foliage dry weight.

The results of this study with white spruce are different from those that Phillion (1980) reported with jack pine; dominant jack pine in pure stands were less efficient wood producers per unit dry weight foliage than suppressed, intermediate and codominant trees. Weetman and Harland (1964) have suggested that this trend is due to a greater amount of branch wood production associated with dominant pine trees.

Greater spruce foliage efficiency also was observed to coincide with increasing stand age (Table 12). Assman (1970) noted that Norway spruce crown foliage efficiency reached a maximum during the phase of full vigor (40 to 60 years age). This phase coincides with the age at which large crowns occur. For Assman's study spruce d.b.h. was 20 to 25 cm and mean heights ranged from 12 to 20 m, dependent upon site quality. Phillion (1980) could find no relationship between foliage efficiency and stand age in 17- and 32-year-old jack pine stands.

These results lead to the following question: how should white spruce be grown to maximize total current annual wood production? Our goal should be to manipulate stand structure and growing space so that most of the crowns are fully exposed to direct sunlight without increasing spacing to the point where branch production is favoured over bolewood production.

Assman (1970) noted that, as a general rule, the needles of Norway spruce fully exposed to light will have the highest gross and net assimilation rates while shaded foliage will have the lowest assimilation rates. Gordon (1982) has suggested that white spruce in boreal mixedwoods have adapted to a somewhat wider spacing thus favouring maximum crown surface and at the same time avoiding premature needle loss. Pure white spruce stands in Alaska seldom have more than 75 percent crown closure giving some credence to this idea of optimum white spruce crown efficiencies at wider spacings.

Obtaining maximum exposure of spruce foliage in plantations firstly requires removal of the overtopping aspen, thus ensuring that sufficient sunlight reaches the suppressed spruce. Exposure of spruce foliage may then be optimized by spacing and thinning regimes that favour well formed dominant and codominant trees. In both pure and mixed stands, loosening of the crown contact between the spruce and its neighbours should be slight and temporary, allowing the spruce to rapidly and, most importantly, completely utilize the additional growing space.

Foliage and Wood Production in Stands

Foliage efficiencies of 1.58 dcm^3 wood/kg dry foliage in the 18-year-old, and 1.38 dcm^3 wood/kg dry foliage in the 28-year-old pure white spruce stands, are comparable to the average of 1.0 dcm^3 wood/kg dry foliage for coniferous forests in North America (Zavitkovski 1976). These values are also greater than the 0.60 and 0.63 dcm^3 wood/kg dry foliage documented for jack pine stands in northwestern Ontario (Phillion 1980) and the 0.60 dcm^3 wood/kg dry foliage for 45-year-old balsam fir in New Brunswick (Baskerville 1965b). The crown efficiency of 1.38 dcm^3 wood/kg dry foliage for white spruce in plantation III compared favourably with 0.81 dcm^3/kg dry foliage for 26-year-old white spruce growing at a 1.8m x 1.8m spacing, and the 1.47 dcm^3/kg for 26-year-old red pine growing at a 1.8m x 1.8m spacing on sandy loam at the Thunder Bay Forest Station (Schaerer 1978).

In contrast, the foliage efficiencies for the white spruce growing at wide spacings in the mixed stands of plantations III and IV were substantially less, 0.26 dcm^3/kg and 1.40 dcm^3/kg, respectively. Schaerer (1978) working in white spruce spacing trials at the Thunder Bay Forest Station concluded that the production of stemwood per unit foliage was less at wider spacings, irrespective of species. Similarly, balsam fir and red pine produced more stemwood per unit foliage at close rather than wide spacings in eastern Canada

(Baskerville 1965b).

Volume Growth of Individual Spruce Trees

White spruce M.A.I. and C.A.I. curves were often erratic. However, certain trends were discernible. The M.A.I. and P.A.I. for representative spruce on each of the micro-sites in plantations I and II (stand initiation stage) increased with age (Appendix Q; Figures Q1 and Q2). Spruce M.A.I. increased slowly from time of plantation establishment (seedling age 3 years) until a seedling age of 5 years. This period of slow volume growth probably paralleled the period of seedling establishment and root system re-development and growth.

Three years after planting, the M.A.I. and C.A.I. for spruce growing on the spoilbank and spoilbank ledge micro-sites were increasing more rapidly than those on the corridor (Appendix Q; Figures Q1 and Q2). This trend probably reflects more suitable soil moisture and nutrient conditions on the spoilbank and spoilbank ledge. The M.A.I. for spoilbank-grown dominant spruce free of aspen competition in plantation II - age 10 years, suddenly increased six years after planting. This sharp increase might be reflecting the observed onset of a period of rapid height and diameter growth promoted by the self-thinning of the aspen surrounding the spruce.

Dominant white spruce growing in the mixed stand during the stem exclusion and full site occupancy stages (Appendix Q; Figures Q3 and Q4) had a lower M.A.I. than dominant spruce in the pure stand (Appendix Q; Figures Q5 and Q6). These results differ from Harvey's (1982) findings that the volume of white spruce is not affected by the density of aspen surrounding the crop tree. This study also did not support Harvey's (1982) claim that fast growing spruce trees were usually found with slow growing aspen trees.

Stem analyses indicated that aspen competition was limiting spruce volume growth in plantation II, thus release is possibly required for spruce between age 4 and 10 years after planting. Release at older ages also would be beneficial for overtopped white spruce as evidenced by periodic fluctuations in the C.A.I. of these trees throughout the period of crown closure (Appendix Q; Figures Q3 and Q5).

MANAGEMENT CONCERNS

Three areas of silvicultural concern are identified in this study: (1) need for proper species-site selection; (2) need for proper methods of site preparation matched to site conditions; and (3) the need for early release of planted white spruce.

1. Site selection. Lacustrine clays and silty clay loams of this study area are excellent sites for white spruce growth. Plantations III and IV are similar to the Site Index 18m and 21m classes developed by Stiell and Berry (1967). Growth and yield information from several other districts and studies (Figure 12) also indicate that the plantations in Prince and Jarvis Locations are among the most productive white spruce stands in the province. Hambly (1980) studying white spruce plantations growing in northern Ontario found no differences in height growth between white spruce growing on sands, silts and clays. Her study, however, was restricted to a limited range of plantation age (1 to 15 years), and included other than free-growing dominants in the data base.

In deciding where the "new" forest of tomorrow will be created, forest managers must be able to identify the most productive sites so that investments in intensive management will yield the maximum economic return. The most productive species for each site cannot be based only on the occurrence of the species in the natural "old" forest - although that is still a consideration.

Lacustrine soils in the Thunder Bay District are excellent sites for white spruce, black spruce and jack pine, and, therefore, should be reserved for planting of both white and black spruces for short-rotation saw timber production. This study has indirectly indicated that saw timber-sized material could be produced through release here and thinning

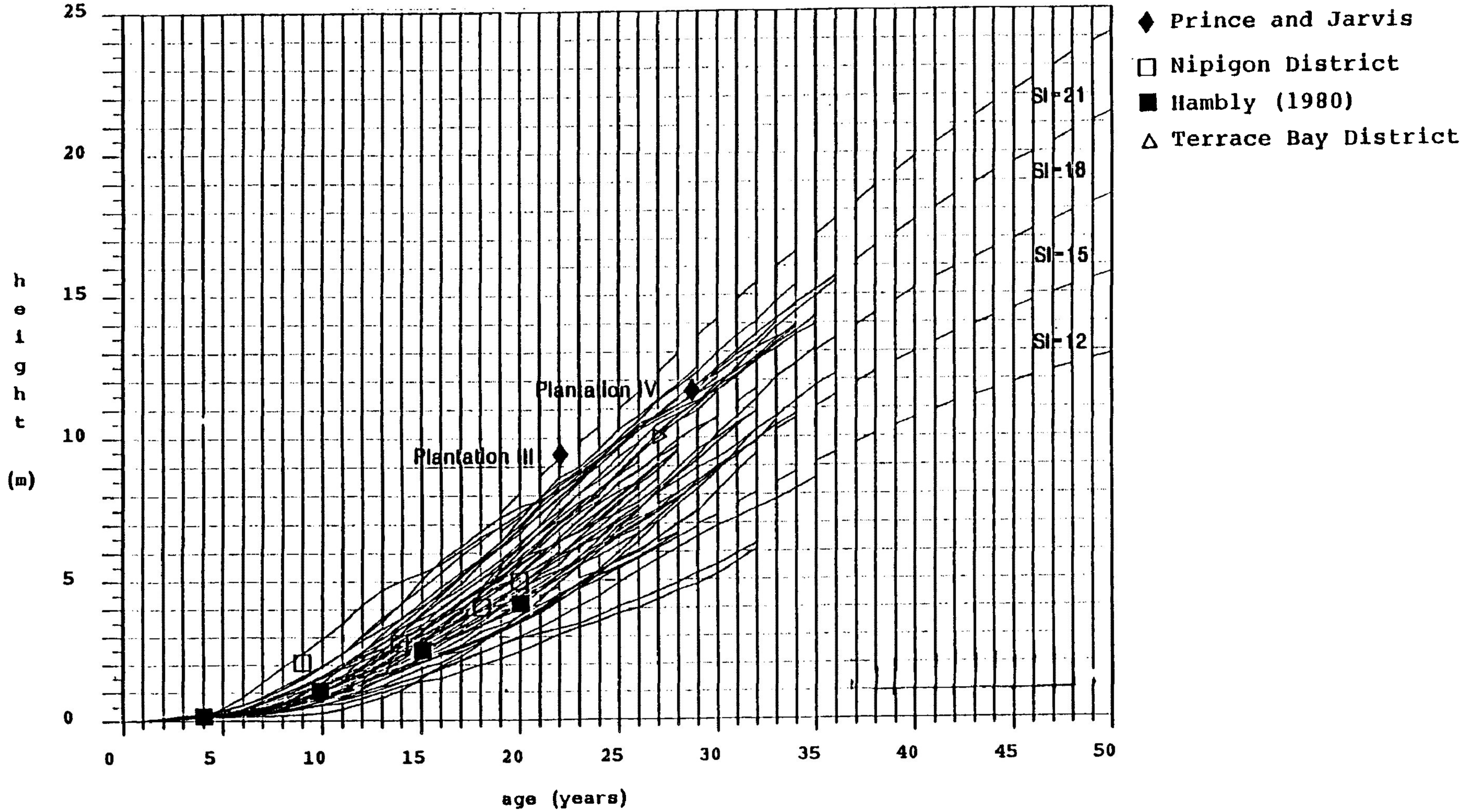


Figure 12. Comparison of height/age (average) relationships for white spruce growing in the pure stand in plantations III and IV with height/age curves developed by Thrower (1986) and average height/age relations for plantation white spruce in other parts of the North Central Region, OMNR.

of white spruce plantations approximately 40 years after planting.

2.Site preparation. Modified C & H and V- ploughs are commonly used for site preparation of areas that have been invaded by heavy brush competition or are covered by large amounts of logging debris. Plantations I and II are examples of common but improper application of a V- plough. In the corridors severe scarification frequently removed surface soils leaving exposed subsoils that were less than favourable micro-site conditions for planting.

While scalping to mineral soil has been an accepted site preparation option on moist to fresh, moderately to well-drained fine-textured soils, this study indicates that growth of planted white spruce is optimal on a micro-site that has the surface organic layers mixed in with the A horizon or where a buried organic horizon is created. The ideal micro-site for planting bareroot stock should consist of a thin layer of surficial organic material (preferably fibric or humic - not litter) in contact with, or mixed into, the A horizon. Thus, the organic matter is available to seedling roots.

The presence of this organic matter may be important in the physical development and establishment of the seedling's root system and ultimately the nutrition of the plant. A thin layer of well-decomposed organic material will protect soil surfaces from wind/rain erosion, will retain moisture in the underlying mineral soil, and also will moderate and ameliorate soil warming (McMinn 1974). In addition, the presence and incorporation of organic matter into the rooting zone horizon of compact, fine-textured layers will favour soil structure, macropore space, and will facilitate adequate aeration and permit extensive root system development. McMinn (1974) has also suggested that this ideal micro-site condition favours a decrease in the susceptibility of planting stock to frost heaving, especially on clay soils. Scraping off surface organic matter to increase soil temperature will be counter-productive when the exposed soil suffers seasonal flooding and becomes poorly aerated.

In order to secure these desired micro-site conditions, scarification involving angle-blading or the use of V- ploughs should be limited to frozen soils. The use of blades or ploughs on frozen soils having a shallow snow depth would minimize any scalping or compaction of surface soils while achieving the goal of slash rearrangement and mineral soil exposure.

Lacustrine soils that are fertile and well-drained are ideal spruce sites. The forest manager should consider site preparation alternatives, other than the V- plough since increased volumes resulting from complete stocking and the good growth such as found in the pure spruce stands might more than outweigh increased site preparation and subsequent plantation release costs.

Abitibi-Price Incorporated, Thunder Bay Woodlands Division, uses a single application of 2 kg ai/hectare 2,4-D for chemical site preparation on lacustrine silts and clays. Herbicides are used in late June to kill hardwood brush and sucker-growth aspen, then slash and dead brush is flattened using a Marden chopper. The Marden chopper is also effective in mixing some mineral soil with the litter layers. The final step is use of a two-rowed Bracke patch scarifier to create 2000 plantable spots per hectare. The planting chances created by the Bracke provide a more suitable micro-site than that resulting from the use of a C & H or V- plough.

Canadian Pacific Forest Products has had excellent success in creating the optimum micro-site condition described previously using a hydraulic powered disc trenching unit on their Dog River-Mattawin Forest, west of Thunder Bay. Plantation establishment is followed by an aerial release treatment using 1.6 kg ai glyphosate two years later.

3. Early release. Results of this study indicate that an early release would be most beneficial and effective in the stand initiation stage as represented by plantation I and II (Appendix Q; Figures Q1, Q2, Q3, Q4). Vegetation other than the spruce may remain as a covering nurse crop during the first few years after planting, but should be reduced no later than the fourth year following planting to prevent serious loss of volume and height growth.

Experience on former upland mixedwood sites in the North Central Region has demonstrated three approaches to chemical weed control that are consistently successful: (1) ground application of glyphosphate at 2.2 kg ai/hectare where the site is flat to gently-rolling, and essentially free from large surface stones and where grasses, Corylus, aspen or Rubus spp. are a problem; (2) two consecutive seasons of aerial application of 2,4-D at 1.8 kg ai/hectare in low ester form where Alnus spp. and Acer spicatum are a problem; and (3) aerial application of glyphosphate at 2.2 kg ai/hectare in situations where eradication of scattered hardwood residuals is required in addition to control broad-leaved ground vegetation (Rudolph 1984). Glyphosphate is used selectively on those sites where competition from Corylus cornuta, Rubus idaeus, Rosa acicularis, graminoids, and aspen sucker growth, exists while 2,4-D is favoured for general broad-leaved competition control. The concept of two consecutive aerial applications of 2,4-D is cost competitive with a single aerial application of glyphosphate and has been equally effective in eliminating aspen sucker growth and woody shrub species.

Chemical site preparation for fine textured soils prior to planting also has potential in eliminating the need for an early release treatment. Several recent trials using Pronone (registered trademark for granular hexazinone) on fine textured soils in the Nipigon and Thunder Bay Districts have shown great promise for controlling a wide range of competing species. Unfortunately this chemical is presently only licensed for experimental ground application. Ground application of liquid Velpar L (registered trademark for liquid hexazinone)at a rate of 9 to 11 litres of product/ha in conjunction with Bracke mechanical site preparation is finding more and more acceptance for treatment of mixedwood sites west of Thunder Bay.

Not only does early release control shading of the planted trees but it also reduces root competition for nutrients and soil moisture thus favouring more extensive root growth of the planted conifers (Sutton 1975). Early release has been shown to favour survival and growth for most of the boreal conifer species. Subsequent additional releases may also be needed rather than viewing release as a "once only" operation in plantation management (Perala 1982).

SUMMARY AND CONCLUSIONS

Four white spruce plantations, ages 4, 10, 18 and 28 years, were studied to evaluate the influence of trembling aspen on stand structure, and growth and dry matter production of planted white spruce.

STAND STRUCTURE AND COMPOSITION

Stand structure and composition of the four plantations varied with age and the occurence of trembling aspen within each stand. The density of planted white spruce varied between the four case studies; within each plantation the densities of planted white spruce was always less under trembling aspen. White spruce heights and diameters in the absence of trembling aspen displayed normal distributions. The onset of crown closure and crown class differentiation characterized by plantations II and IV (ages 18 and 28 years) was reflected in the development of a bi-modal height distribution. White spruce growing beneath an aspen overstory had generally smaller average diameters and heights which were normally distributed.

Micro-site position and the presence of overtopping aspen significantly influenced the growth of the planted white spruce in plantations I and II (ages 4 and 10 years). Both planted white spruce and second-growth aspen produce optimum growth and biomass production on micro-sites with deep surface horizons (Ah horizon) where mixing of organic matter with the surface mineral soil horizons has occurred.

Total standing crop increases with stand age; partitioning of the dry matter within the community is concentrated on woody shrub and tree species in later stages of stand development. Variation in biomass production and standing crop relations for white spruce changed with increasing age and varied with:

(1) stocking levels of the white spruce and aspen;
(2) soil micro-site position; and
(3) presence and abundance of associated herbaceous vegetation.

Species present at the various stages of plantation development were similar to those observed for post-burn forest succession although the relative abundance and spatial organization of species differed.

INFLUENCE OF TREMBLING ASPEN DENSITY ON ABOVE-GROUND DRY MATTER PRODUCTION AND ACCUMULATION IN PLANTED WHITE SPRUCE

Spruce foliage efficiencies for wood production increased with stand age, decreasing aspen densities and increasing dominance (crown class).

Planted white spruce consistently carried a greater proportion of its dry matter as foliage than did trembling aspen; the presence of overtopping or lateral competing vegetation was related to a decline in spruce growth as well as the proportion of spruce dry matter occurring as foliage. Foliage and stemwood biomass of planted white spruce were significantly reduced under high aspen densities and where the standing crop biomass of graminoids, herbs and shrubs was greatest.

Stand development patterns indicate the need for early plantation release. Release from aspen is needed in the stand initiation stage (3-5 years following planting) to prevent loss of potential white spruce height and volume growth.

INFLUENCE OF STAND AGE, SITE CONDITIONS AND SURROUNDING VEGETATION ON WHITE SPRUCE GROWTH AND WOOD PRODUCTION

Total biomass production in white spruce plantations located on lacustrine silts and clays equals or exceeds total biomass production described for mature boreal ecosystems and other second-growth stands on former mixedwood sites. Moderately to well-drained lacustrine silty clay and clay loam sites support excellent growth of white spruce and should be managed under a "Prime Site" approach.

Foliage, stemwood and total tree dry weights for white spruce could be explained using multiple regression models incorporating the variables: depth of Ae(h); water holding capacity of the rooting zone; biomass (kg/m^2) of trembling aspen; biomass (kg/m^2) of graminoids, herbs and low shrubs and the percent cover by overtopping vegetation.

LITERATURE CITED

Alban, D. H., D. A. Perala and B. E. Schlaegel. 1978. Biomass and nutrient distribution in aspen, pine, and spruce stands on the same soil type in Minnesota. Can. J. For. Res. 8:209-299.

Alemdag, J. S. 1980. Aboveground-mass equations for six hardwood species from natural stands of the research forest at Petawawa. Environ. Can., Can. For. Serv., PNFI, Petawawa, Ont., Info. Rept. PI-X-6, 9 pp.

Armson, K. A. 1975. Establishment and development of black spruce, pp.45-46,In: J.W. Fraser, J.K. Jeglum and D.E. Ketcheson, cochairmen. Black Spruce Symposium, Environ. Can., Can. For. Serv., GLFRC, Sault Ste. Marie, Ont., COJFRC Symp. Proc. O-P-4.

Armstrong, R. H. 1963. The history and mechanics of forest planting and aerial spraying. Pulp and Pap. Mag. Can., 64: 268-270.

Assman, E. 1970. The Principles of Forest Yield Study. Pergamon Press, Oxford, U.K. 506 pp.

Bartos, D.L. and R.S. Johnston. 1978. Biomass and nutrient content of quaking aspen at two sites in the western United States. For. Sci. 24:273-280

Baskerville, G. L. 1961. Response of young fir and spruce to release from shrub competition. Can. Dept. For., Tech. Note 98, 14 pp.

Baskerville, G. L. 1965b. Estimation of dry weight tree components and total standing crop in conifer stands. Ecology 46:867-869.

Baskerville, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2:49-53.

Bella, I. E. 1968. Estimating aerial component weights of young aspen trees. Can. Dept. For. Rur. Dev., Info. Rept. M5-X-12, 36 pp.

Bella, I. E. and J. M. Jarvis. 1967. High total productivity of a young aspen stand in Manitoba. Pulp. Pap. Mag. Can. 68:432-437.

Bella, I.E. and J. P. de Francheschi. 1980. Biomass productivity of young aspen stands in Western Canada. Environ. Can., Can. For. Serv.,NOFRC, Edmonton, Alta. Info. Rept. NOR-X-219, 23 pp.

Berry, A. B. 1968. How plantation white spruce responds to crown thinning. Can.For.Ind. 88:20-22.

Berry, A. B. 1987. Plantation white spruce variable density volume and biomass yield tables to age 60 at the Petawawa National Forestry Institute. Environ. Can., Can. For. Serv., PNFI, Petawawa, Ont., Info. Rept. PI-X-71, 21 pp.

Bray, J. R. and L. A. Dudkiewicz. 1963. The composition, biomass and productivity of two Populus forests. Bull. Torr.Bot. Club. 90:298-308.

Burwasser, G. J. 1977. Quaternary geology of the City of Thunder Bay and vicinity. Ont. Min. Nat. Resourc., Geol. Surv. Rept. GR164, 70 pp.

Canadian Soil Survey Committee. 1978. The Canadian System of Soil Classification, Agric. Can., Res. Br., Publ. 1646, 164 pp.

Carleton, T. J. and P. F. Maycock. 1981. Understory-canopy affinities in boreal forest vegetation. Can. J. Bot. 59:1709-1716.

Cayford, J. H. 1957. Influence of the aspen overstory on white spruce growth in Saskatchewan. Can. Dept. North. Affairs Nat. Resourc., For. Br., Tech. Note 58, 12 pp.

Chapman, L. J. and M. K. Thomas. 1968. The climate of northern Ontario, Climatological Studies No. 6, Can. Dept.Transport. 58 pp.

Crossley, D. I. 1952. White spruce reproduction resulting from various methods of forest soil scarification. Can. Dept. Resourc. Dev., For. Br., Silv. Res. Note 102, 18 pp.

Crow, T. R. 1978. Biomass and production in three contiguous forests in Northern Wisconsin. Ecology 59:265-273.

Crown, P. H., D. W. Hoffman and C. J. Acton. 1978. Soils of the Thunder Bay Map Sheet, 52A, Thunder Bay District, Ontario. Rept. 48 - Ont. Soil Surv., Ont. Inst.Ped., Univ. Guelph, Guelph, Ont. 191 pp. + maps.

Curry, G. E. 1961. Stem height and root growth of spruce in plantations near Longlac, Ontario, and the application of the results to planting practice. M.Sc.F. thesis, Univ. Toronto, Toronto. 98 pp.

Curtis, J. T. 1959. The Vegetation of Wisconsin, Univ. Wisc.Press, Madison, Wisc. 657 pp.

Cushon, G. 1980. A non-destructive method of estimating the distribution of foliage dry weight and changes in foliage dry weight in coniferous tree crowns. B.Sc.F. thesis, Lakehead University, Thunder Bay. 26 pp.

Daubenmire, R. F. 1959. Plants and Environment, 2nd ed. John Wiley and Sons, Inc., New York. 422 pp.

Doucet, R., J. V. Berglund and C. E. Farnsworth. 1976. Dry matter production in 40-year old Pinus banksiana stands in Quebec. Can. J. For. Res. 6:357-367.

Einspahr, D. W. and M. K. Benson. 1968. Management of aspen on 10 to 20 year rotations. J. For. 66:557-560.

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

Eis, S. 1970. Root-growth relationships of juvenile white spruce, alpine, fir, and lodgepole pine on three soils in the interior of British Columbia. Dept.Fish. For., Can. For. Serv., Publ. 1276. 10 pp.

Eis, S. 1977. Root forms in habitats with heavy shrub competition. Environ. Can., Can. For. Serv., PFRC, Victoria, BC., Bi-mon. Res. Notes 33:27-29.

Eis, S. and D. Craigdallie. 1983. Regeneration and growth of white spruce and alpine fir in the interior of British Columbia. Can. J. For. Res. 13:339-343.

Ellis, R. C. and C. R. Mattice. 1974. Stand development following pulpwood harvesting at the Experimental Lakes Area in Northwestern Ontario. Can. For. Serv., GLFRC, Sault Ste. Marie, Ont., Info. Rept. O-X-207. 43 pp.

Ford, E. D. 1975. Competition and stand structure in some even-aged plant monocultures. J. Ecol. 63:311-33.

Ford, E. D. 1982. High productivity in a pole-stage Sitka spruce stand and its relation to canopy structure, Forestry 55:1-17.

Froning, K. 1972. An appraisal of recent plantations in forests of the Prairie Provinces. Dept. Environ., Can. For. Serv., NFRC, Edmonton, Alta., Info. Rept. NOR-X-31, 45 pp.

Geul, J. J. C. 1970. Geology of Devon and Pardee Townships and the Stuart Location. Ont. Dept. Mines Geol. Rept. 87, 52 pp.

Geul, J. J. C. 1973. Geology of Crooks Township, Jarvis and Prince Locations and Offshore Islands, District of Thunder Bay, Ontario. Ont. Div. Mines, Geol. Report 102, 46 pp.

Gordon, A.G., 1982. Nutrient cycling dynamics in different spruce and mixedwood ecosystems in Ontario and the effects of nutrient removal through harvesting. Pages 97-118 _In_: Wein,R.W., R.W. Riewe and I.R. Methven, editors. Resources and Dynamics of the Boreal Zone, Ass. Can. Univ. Nor. Studies, Ottawa, Ont.

Gordon, A.M. and L. Morrow. 1979. Growth of young plantation black spruce (Picea mariana (Mill.) B.S.P.) in the Lake Nipigon - Beardmore area. File Rept., Ont. Min. Nat. Resourc., Nipigon Dist., Nipigon Ont.,16 pp.

Gordon, A.M. 1981. Dynamics and community structure of ground flora in managed stands of black spruce (_Picea mariana_ (Mill.) B.S.P.) and jack pine (_Pinus banksiana_ Lamb.) near Lake Nipigon, Ontario. Draft Report, Ont. Min. Nat. Resourc., Nipigon Dist., Nipigon, Ont. 65 pp.

Graham, S. A., R. P. Harrison Jr. and C. E. Westell Jr. 1963. Aspens. Univ. Mich. Press, Ann Arbor Mich.,264 pp.

Haig, R.A. 1959. Reforestation by planting 1918-1930, Riding and Duck Mountains, Manitoba and Saskatchewan, Can. Dept. Nor. Affairs Nat. Resourc., For. Br., Mimeo 59-3, 12pp.

Hambly, E. S. L. 1980. Growth of young black and white spruce in Northern Ontario. Ont. Min. Nat. Resourc., For. Resourc. Group, Man. Plan. Sect., Tor. Ont. 52 pp.

Hamilton, G. J. 1969. The dependence of volume increment of individual trees on dominance, crown dimensions and competition. Forestry 42:133-144.

Harding, R. B. 1982. Site quality evaluation for white spruce plantations in Northern Minnesota. Ph.D. dissertation, Univ. Minn., Coll. For., St. Paul Mn., 135 pp.

Harvey, E. M. 1981. Post logging succession and vegetation management with hexazinone herbicide in *Picea glauca* (Moench) Voss - *Populus tremuloides* Michx. Forest. M.Sc.F. thesis, Lakehead University, Thunder Bay Ont. 247 pp.

Hiley, W. E. 1967. Woodland Management. Faber and Faber, London. 463 pp.

Hills, G. A. 1952. The Classification and Evaluation of Sites for Forestry. Ont. Dept. Land and For., Res. Rept. 24, Toronto, Ont., 41 pp.

Hill, M. O.1978. The development of flora in even-aged plantations. p. 175-192. *In*: Ford, E. D., D. C. Malcolm and J. A. Atterson, (editors). The Ecology of Even-aged Forest Plantations. Proc. of Div. I Meeting, I.U.F.R.O., Edinburgh, Scotland. 582 pp.

Jeglum, J. K. 1980. Stripcutting in shallow soil upland black spruce near Nipigon, Ontario. I. Study establishment and site conditions. Environ. Can., Can. For. Ser., GLFRC, Sault Ste. Marie Ont.,Info. Rept. O-X-315, 73 p.

Johnson, H.J. 1973. An evaluation of scarification and direct seeding in Alberta. Environ. Canada, Can. For. Serv., NFRC, Edmonton, Alta., Info. Rept. NOR-X-71, 23 pp.

Johnson, H.J. 1986. The release of white spruce from trembling aspen overstoreys - a review of available information and silvicultural guidelines. Man. Dept. Nat. Resourc., For. Resourc. Dev. Agmt., Winnipeg, Man.,109 pp.

Johnstone, W. D. 1978. Growth of fir and spruce advance growth and logging residuals following logging in west-central Alberta. Environ. Canada, Can. For. Serv., NFRC, Edmonton, Alta.,Info. Rept. NOR-X-203, 16 pp.

Johnstone, W. D. and E. B. Peterson. 1980. Above-ground component weights in Alberta *Populus* stands. Environ. Canada, Can. For. Serv., NFRC, Edmonton, Alta.,Info. Rept. NOR-X-226,18 pp.

Kabzems, A. 1971. The growth and yield of well stocked white spruce in the mixedwood section of Saskatchewan. Sask.Dept. Nat. Resourc., Prince Albert, Sask., Tech. Bull. 5, 75 pp.

Kabzems, A., A. L. Kodowan, and W. C. Harris. 1976. Mixedwood Section in an Ecological Perspective. Sask. Dept. Tour. Ren. Resour., For. Br., Tech. Bull. 8, 118 pp.

Kavanagh, J. 1983. Stem analysis: sampling techniques and data processing. M.Sc.F. thesis, Lakehead University, Thunder Bay, Ont. 86 pp.

Kimmins, J.P. 1974. Studies of biomass distribution and tree form in old virgin forests in the mountains of south coastal British Columbia. Univ. of British Columbia, Vancouver, B.C., 12 pp.

Kimmins, J.P., S. Watts and D. Lavendar. 1986. Effects of non-commercial vegetation on the physiology of young conifers. Dept. For. Sci., Faculty For., Univ. British Columbia, Vancouver, B.C., 25 pp.

Kira, T. and T. Shidei. 1967. Primary production and turnover of organic matter in different forest ecosystems of the western Pacific. Jap. J. Ecol. 17:70-78.

Kozlowski, T. T. and R. C. Ward. 1957. Seasonal height growth of conifers. For. Sci. 3:61-66.

Krishka, C.S. and W.D. Towill. 1989. Spruce height and volume growth response to an aerial release treatment using 2,4-D on three plantations near Manitouwadge, Ontario. Ont. Min. Nat. Resourc., Northwest. Ont. For. Tech. Dev. Unit, Thunder Bay, Ont. Tech. Rept. 8, 21 pp.

Leaf, A. L. and T. Keller. 1956. Tentative technique for determining the influence of soil on the growth of forest plantations. Am. Soc. Agron.,J. Soil Sci. 20:110-112.

Lees, J. C. 1966. Release of white spruce from aspen competition in Alberta's spruce-aspen forest. Can. Dept. For., Publ. 1163, 8 pp.

Lees, J. C. 1970. Natural regeneration of white spruce under spruce-aspen shelterwood, B-18a forest section, Alberta. Can. Dep. Fish. For., Can. For. Serv., Publ. 1274, 16 pp.

Lehela, A. 1981. Benefits of herbicide control of unwanted vegetation in the Boreal mixedwood forest. Pages 234-238 In: R.D. Whitney and K.M. McClain, cochairmen. Boreal Mixedwood Symp. Environ. Can., Can. For. Serv., GLFRC, Sault Ste.Marie, Ont. COJFRC Symp. Proc. O-P-9.

Logan, K. T. 1969. Growth of tree seedlings as affected by light intensity IV. Black spruce, white spruce, balsam fir, and eastern white cedar. Can. Dept. Fish. For., Can.For.Serv., Publ. 1256, 12 pp.

Love, D.V. and J. R. M. Williams. 1968. The economics of plantation forestry in southern Ontario. Can. Dept. Reg. Econ. Expansion., Can. Land Inv. Rept. 5, 46 pp.

MacKinnon, G. E. 1974. Survival and growth of tree plantations on crown lands in Ontario. Ont. Min. Nat. Resourc., For. Resourc. Group, Toronto, Ont. 17 pp.

MacLean, D. W. 1960. Some aspects of the Aspen-Birch-Spruce-Fir type in Ontario. Can. Dept. For., For. Res. Div., Tech. Note 94, 23 pp.

MacLean, D. W. and G. H. D. Bedell. 1955. Northern Clay Belt growth and yield survey, Can. Dept. Nor. Affairs Nat. Resourc., For. Br., Tech. Note 20, 31 pp.

MacLean, D. A. and R. W. Wein. 1976. Biomass of jack pine and mixed hardwood stands in northeastern New Brunswick. Can. J. For. Res. 6:441-447.

Maini, J. S. and J. H. Cayford. 1968. Growth and Utilization of Poplars in Canada. Can. Dept. For. Rur.Dev., For. Br., Publ. 1205, 257 pp.

Marek, G. T. 1984. Evaluation of three silvicultural treatments in North Central Region, Ont. Min. Nat. Resourc., For. Resourc. Group, Thunder Bay Ont., 57 pp.

McClain, K. 1980. Definition and distribution of the Boreal Mixedwood Forest in Ontario.Pages 5-9 In: R. D. Whitney and K. M. McClain, cochairmen. Boreal Mixedwood Symp. Environ. Can., Can. For. Serv., GLFRC, Sault Ste. Marie, Ont. COJFRC Symp. Proc. O-P-9

McClain, K. M. and K. A. Armson. 1975. Growth responses of pine and spruce seedlings to regimes of soil moisture and fertility. A. Soc. Agron., J. Soil Sci. 30:140-144.

McLeod, A. J. 1978. Reforestation in Alberta. Agric. and For. Bull., Univ. Alta., Edmonton, Alta. 1:8-13.

McLeod, J. W. 1964. Planting white spruce on wet bush land. Can. Dept. For., For. Res. Br., Publ. 1067, 4 pp.

McMinn, R. G. 1974. Effect of four site treatments on survival and growth of white spruce and lodgepole pine seedlings. Environ. Can.,Can. For. Serv., PFRC, Victoria B.C., Bi-mon. Res. Notes 30:19-20.

McMinn, R. G. 1976. Is there a better method of mechanical site preparation for spruce-balsam sites? B.C. For. Serv.,Victoria B.C., Reforestation Notes 3:6-7.

McMinn, R. G. 1976b. Site preparation: Biological expectations, Pages 1-8 In: E. Markus, Chairman, Plantation Establishment Symposium. Environ. Can., Can. For. Serv., GLFRC, Sault Ste. Marie, Ont., COJFRC Symp. Proc. O-P-5.

McMinn, R. G. 1984. Mechanical Site treatment prescription should be based on specific site knowledge. Pages 21-27 In: Proc. Mechanization of Silviculture, Can. Pulp Pap. Assoc., Woodlands Sect., Montreal, P.Q.

Minore, D., C. E. Smith and R. F. Wollard. 1969. Effects of high soil density or seedling root growth of several Northwestern tree species. U.S. Dept. Agric. For. Serv., Pac. Northwest. For. and Range Exp. Stn., Portland, Oreg.,Res. Note PNW-112, 16 pp.

Moller, C. M. 1947. The effect of thinning, age and site on foliage, increment and loss of dry matter. J.For. 45:393-404.

Morrison, I. K. and K. A. Armson. 1968. The rhizometer, a device for measuring roots of tree seedling. For. Chron. 44:21-23.

Mullin, R. E. 1978. Plantation performance averages for white spruce. Ont. Min. Nat. Resourc., Toronto, Ont.,For. Res. Note 15, 2 pp.

Newbould, P.J. 1967. Methods for estimating primary production of forests. Intl. Biolog. Progr. Handb. No. 2, 62 pp.

Nie, N. H., C.H. Hull, J.G. Jenkins, K. Steinbrenner and D.H. Bent. 1980. SCSS: Statistical Package for the Social sciences. McGraw-Hill Inc. 675 pp.

Nienstaedt, H. 1957. Silvical characteristics of white spruce (Picea glauca). U.S. Dept. Agric. For. Serv., Lake States For. Exp. Stn., St. Paul Mn., Pap.55, 23 pp.

Neinstaedt, H. 1965. White spruce (Picea glauca (Moench Voss). Pages 318-327 In: H.A. Fowells, editor. Silvics of Forest Trees of the United States. USDA For. Serv. Agric. Hndbk. No. 271.

Nienstaedt, H. 1982. White spruce in the Lake States. Pages 142-162 In: G.D. Mroz and J.F. Berner, editors. Proceedings of a Conference on Artificial Regeneration of Conifers in the Upper Great Lakes Region, Mich. Tech. Univ., Houghton, Mich.

Ohmann, L. F. and D. F. Grigal. 1979. Early revegetation and nutrient dynamics following the 1971 Little Sioux Forest Fire in Northeastern Minnesota, For. Sci. Monogr. 21, 80 pp.

OMNR. 1986. Timber Management Planning Manual for Ontario, Ont. Min. Nat. Resourc., Toronto, Ont., 218 pp.

Ontkean, G. and L. A. Smithers. 1959. Growth of Alberta white spruce after release from aspen competition, Can. Dept. North. Aff. Nat. Resourc., For. Br., For. Res.Div., Mimeo 59-1, 17 pp.

Outcalt, K. W. and E. H. White. 1981a. Phytosociological changes in understory vegetation following timber harvest in northern Minnesota. Can. J. For. Res. 11:175-183.

Outcalt, K. W. and E. H. White. 1981b. Understory biomass and nutrients 2 years after timber harvest in northern Minnesota. Can. J. For. Res. 11:305-308.

Ovington, J. D. 1962. Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1:103-192.

Oxenham, R. 1983. A study on the effect of competing vegetation and browsing on early plantation performance. Nova Scotia Dept.Lands For., Tech. Note 5, 10 pp.

Pastor, John and J. D. Bockheim. 1981. Biomass and production of an aspen-mixed hardwood - spodosol ecosystem in northern Wisconsin. Can. J. For. Res. 11:132-138.

Payandeh, B. and J. E. Field. 1986. Yield functions and tables for mixedwood stands of Northwestern Ontario, Environ. Can., Can. For. Serv., GLFRC, Sault Ste. Marie, .Ont., Info. Rept. 0-X-375, 7 pp.

Peet, R. K. 1981. Changes in biomass and production during secondary forest succession. Pages 324-338 In: D. C. West, H. H. Shugart and D. B. Botkin, editors. Forest Succession: Concepts and Application, Springer-Verlag, New York.

Perala, D. A. 1973. Stand equations for estimating aerial biomass, net productivity and stem survival of young aspen suckers on good sites. Can. J. For. Res. 3:288-292.

Perala, D. A. 1982. Early release - current technology and conifer response. Pages 396-410 In: G.D. Mroz and J.F. Berner, editors. Artificial Regeneration of Conifers in the Upper Great Lakes Region Conference. Mich. Tech. Univ., Houghton, Mich.

Peterson, E. B., Y. H. Chan and J. B. Cragg. 1970. Aboveground standing crop, leaf area, and caloric value in an aspen clone near Calgary, Alberta. Can. J. Bot. 48:1459-1469.

Peterson, E. B., V. M. Levson, and R. D. Kabzems. 1982. Upper limits of standing crop density for woody species in the prairie provinces. Environ. Can., Can. For. Serv., NFRC, Edmonton, Alta., Info. Rept. NOR-X-243, 55 pp.

Phillion, B. J. 1980. Foliage and wood production in 17 and 32 year-old Pinus banksiana Lamb. of Northwestern Ontario. M.Sc.F. thesis, Lakehead Univ., Thunder Bay, Ont., 104 pp.

Plonski, N. L. 1981. Normal yield tables (metric) for major forest species of Ontario. Ont. Min. Nat. Resourc., For. Resourc. Group, Toronto, Ont., 40 pp.

Pollard, D. F. W. 1971. Mortality and annual changes in distribution of above-ground biomass an an aspen sucker stand. Can. J. For. Res. 1:262-266.

Popovich, S. 1972a. Total cubic volume table for white spruce plantations, Drummondville, Quebec. Dept. Environ., Can. For. Serv., LFRC, Ste. Foy, P.Q., Info. Rept. Q-X-28, 36 pp..

Popovich, S. 1972b. Volume tables for plantation white spruce, Grand'Mere, Quebec. Dept. Environ., Can. For. Serv., LFRC, Ste. Foy, P.Q., Info. Rept. Q-X-29, 38 pp.

Posner, S. D. 1984. Effect of deciduous shrubs on young white spruce, and implications of shrub control on the supply of moose forage in Northeastern Minnesota. M.Sc. thesis, Univ. Minn., St. Paul, Mn., 129 pp.

Radsliff, W., C. A. Mohn, and W. Cromwell. 1983. Variation among white spruce provenances in Minnesota test plantings. Mn For. Res. Note 283, 4 pp.

Rauscher, M. 1984. Growth and yield of white spruce plantations in the Lake States (A literature review), U.S.D.A. For. Serv., North Central For. Expt. Sta., St. Paul, Mn., Res. Pap. NC-253, 46pp.

Rowe, J. S. 1972. Forest Regions of Canada. Can. For. Serv., Ottawa, Ont., Publ. 1300, 172 pp.

Rudolph, J.T. 1984. Silvicultural information system summary of plantation survival in North Central Region, Ontario Ministry of Natural Resources, Internal File Rept., Ont. Min. Nat. Resourc., Thunder Bay, Ont. (unpublished).

Rudolph, P.O. 1950. Forest plantations in the Lake States. U.S.D.A. For. Serv., North Central For. Exp. Stn., St. Paul, Mn., Tech. Bull. 1010, 24pp.

Savinsky, H. M. 1981. Nutrient budget evaluation of four pulpwood stands harvested by full-tree logging. M.Sc.F. thesis, Fac. For., Univ. Tor. Toronto, Ont., 85 pp.

Schaerer, C. 1978. A non-destructive method of measuring and correlating foliage dry weight and productivity of white spruce in a spacing trial. B.Sc.F. thesis, Lakehead Univ.,Thunder Bay, Ont., 31 pp.

Schlaegel, B.E. 1975. Yields of four 40-year-old conifers and aspen in adjacent stands. Can. J. For. Res. 5: 278-280.

Shirley, H. L. 1945. Light as an ecological factor and its measurement. Bot. Rev. aa:497-532.

Snedecor, G. W. and W. G. Cochran. 1980. Statistical Methods (7th Ed.). Iowa State Univ.Press, Aimes, Iowa, 593 pp.

Stanek, W. and D. State. 1978. Equations predicting primary productivity (biomass) of trees, shrubs and lesser vegetation based on current literature. Environ. Can., Can. For. Serv., PFRC, Victoria, B.C., Info. Rept. BC-X-183, 58 pp.

Stiell, W. I. 1958. Pulpwood plantations in Ontario and Quebec. Can. Pulp Pap. Assoc., Woodl. Sect., Index No. 1770 (F-2), 42 pp.

Stiell, W. M. 1967. Thinning 34 year-old white spruce plantations from below-10 year results. Can. Dept. Fish. For., Can. For. Ser., Publ. 1258, 16 pp.

Stiell, W. M. 1969. Crown development in white spruce plantations. Can. Dept. Fish For., Can. For. Serv., Publ. 1249, 12 pp.

Stiell, W. I. 1976. White spruce: Artificial regeneration in Canada. Can. Dept. Env., Can. For. Ser., For. Mgt. Inst., Petawawa Ont., Info. Rept. FMR-X-85, 275 pp.

Stiell, W. M. and A. B. Berry. 1967. White spruce plantation growth and yield at the Petawawa Forest Experiment Station. Can. Dept. For. Rur. Dev., For. Br., Publ. 1200, 15 pp.

Stiell, W. M. and A. B. Berry. 1973. Development of unthinned white spruce plantations at age 50 at Petawawa Forest Experiment Station. Can. Dept. Environ.,Can. For. Serv., Publ. 1317, 18 pp.

Sutton, R. F. 1969. Silvics of White Spruce (Picea glauca (Moench) Voss). Can. Dept. Fish. For., For. Br., Publ. 1250, 57 pp.

Sutton, R. F. 1969b. Chemical control of competition in plantations. For. Chron. 45: 252.

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

Sutton, R. F. 1978. Root development in young outplants, particularly white spruce. Pages 172-185 In: E. Van Eerden and James M. Kinghorn, editors. Root Form of Planted Trees Symp. Environ. Can., Can. For. Serv., PFRC, Victoria, B.C., Joint Rept. 8.

Sutton, R. F. 1982. Plantation establishment with bareroot stock: Some critical factors, Pages 304-321, In: G.D. Mroz and J.F. Berner, editors. Artificial Regeneration of Conifers in the Upper Great Lakes Region, Mich.Tech. Univ., Houghton, Mich.

Sutton, R.F. 1987. Plantation establishment in boreal Ontario: A study of spring planting and mechanization. Environ. Can.,Can. For. Serv.,GLFRC, Sault Ste. Marie, Ont., Info. Rept. 0-X-383, 26 pp.

Thauvette, C. C. 1982. Microsite in relation to establishment and growth of white spruce. B.Sc.F. thesis, Lakehead Univ., Thunder Bay, Ont., 83 pp.

Thomas, W. A. 1969. Accumulation and cycling of calcium by dogwood trees. Ecol. Monogr. 39:101-120.

Thrower, J. S. 1984. Scalping of surface soil adversely affects the growth of white spruce planted on a lacustrine soil near Thunder Bay, Ontario. B.Sc.F. thesis, Lakehead Univ., Thunder Bay,Ont.,48 pp.

Thrower, J. S. and M. Schmidt. 1985. Soils Laboratory Manual, Lakehead Univ., School For., Thunder Bay, Ont., 88 pp.

Thrower, J. S. 1986. Estimating site quality from early height growth of white spruce and red pine plantations in the Thunder Bay Area. M.Sc.F. thesis, Lakehead Univ., Thunder Bay, Ont., 143 pp.

Tucker, R. E. and J. M. Jarvis, and R. M. Waldron. 1968. Early survival and growth of white spruce plantations in Riding Mountain National Park, Manitoba. Can. Dep. For. Rur. Dev., For. Br., Publ. 1239, 6 pp.

Turcotte, Alain, J. P. 1976. Effect of severe windrow scarification on white spruce two years after planting. B.Sc.F. thesis, Lakehead Univ., Thunder Bay,Ont.,36 pp.

Vyse, A. 1981. Growth of young spruce plantations in interior British Columbia. For. Chron. 47:174-180.

Waldron, R. M. 1963. Planting white spruce in cut-over and undisturbed white spruce-aspen stands in Manitoba. Can. Dept. For., For. Resourc. Br., Manitoba - Saskatchewan, Dist. Rept., 63-M5-9, 16 pp.

Wambach, R. F. and G. Cooley. 1969. Compatability of mechanization with silviculture. J. For. 67:104-108.

Weetman, G. F. and R. Harland. 1964. Foliage and wood production in unthinned black spruce in northern Quebec. For. Sci. 10:80-88.

Weetman, G. F. 1965. The need to study silvicultural effects of mechanized logging systems in eastern Canada. For. Chron. 4:252-256.

Weingartner, D. J. and J. T. Basham.(Ed.). 1979. Forest Management and Research Needs in the Boreal Mixedwood Forest of Ontario. File Rept. prepared by Spruce -Fir-Aspen For. Res.Comm., Can. Ont. Joint For. Res. Comm., 90 pp.

Wilde, S.A., R.B. Corey, J.G. Iyer and G.K. Voigt. 1972. Soil and Plant Analysis for Tree Culture (2nd ed.),Oxford and IBH Publishing Co., New Delhi, India, 224pp.

Wilde, S. A., J. G. Iyer, Christian Tanzer, W. L. Trautman and K. G. Watterson. 1965. Growth of Wisconsin coniferous plantations in relation to soils. Univ. Wis. Res. Bull. 262, 18 pp.

Willcocks, A. J. 1973. Growth studies on a twenty-eight years old plantation at Moonbeam, Ontario. Ont. Min. Nat. Resourc., Kapuskasing For. Dist., Kapuskasing, Ont.,23 pp.

Young, H. E. and D. M. Carpenter. 1967. Weight, nutrient element and productivity studies of seedlings and saplings of eight tree species in natural ecosystems. Maine Agron. Exp. Sta., Univ. Maine (Orono), Tech. Bull. 28, 39 pp.

Zar, J. H. 1968. Calculation and miscalculation of the allometric equation as a model in biological data. Biosc.18:1118-1120.

Zavitkovski, J. 1971. Dry weight and leaf area of aspen trees in northern Wisconsin. p.193-205. In: Forest Biomass Studies. Univ. of Maine, Orono, Maine.

Zavitkovski, J. 1976. Ground vegetation biomass, production and efficiency of energy utilization in some northern Wisconsin forest ecosystems. Ecology 57:694-706.

Zoltai, S. C. 1965. Glacial features of the Quetico-Nipigon area, Ontario. Can. J. Earth Sci. 2:247-269.

Appendix A. Photographs of plantations I, II, III, IV, and specific examples of micro-site/trembling aspen competition situations in each plantation

Figure A1:. White spruce in Plantation I was established in 1977. Modified V-blade scarification was used followed by planting of 3+0 stock.

Figure A2: White spruce in Study Plantation II were established in 1971. Modified V-blade scarification was used followed by planting of 3+0 stock.

Figure A3: White spruce in Plantation III were established in 1963.

FIgure A4: White spruce in Plantation IV were established in 1953.

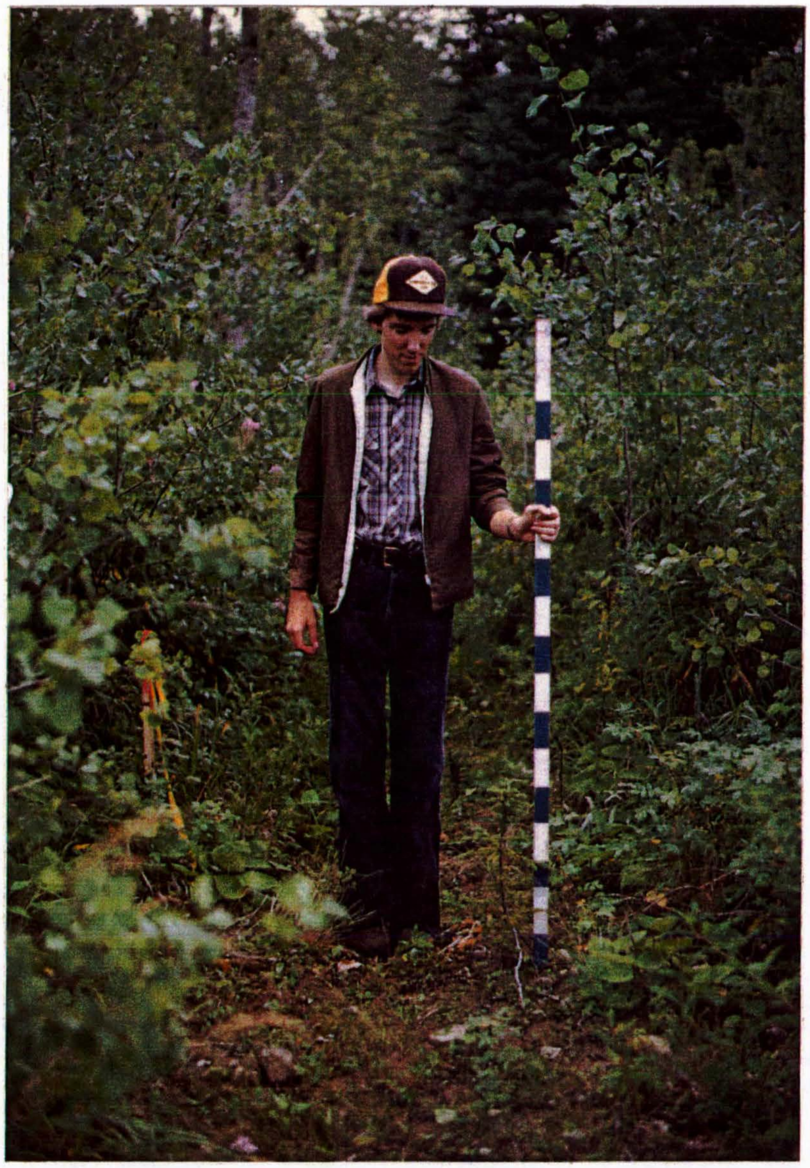


Figure A5: Trembling aspen in Plantation I were established in 1977. Competition is greatly reduced in the corridor where a hollow micro-site was created by V-blading.

Figure A6: White spruce in Plantation I were established in 1977. Seedlings situated on the spoil bank micro-site are subjected to overtopping and heavy inter-species competition from aspen sucker growth.

Figure A7: White spruce in Plantation I were established in 1977. Seedlings situated on the spoilbank ledge micro-site are subjected to overtopping and heavy inter-species competition from grasses, sedges and raspberries.

Figure A8: White spruce in Plantation II were established in 1971. This is a low density trembling aspen area. Heavy competition from grasses and sedges exists.

Figure A9: White spruce in Plantation II were established in 1971. This is a medium density trembling aspen area where aspen has overtopped all the spruce trees. Heavy competition from grasses and sedges exists.

Figure A10: White spruce in Plantation II were established in 1971. This is a heavy density trembling aspen area where aspen has overtopped all the spruce trees. Competition from grasses and sedges is light.

Figure A11: White spruce in Plantation III were established in 1963. This is a high density trembling aspen area.

Figure A12: White spruce in Plantation IV were established in 1953. Trembling aspen competition is present.

Figure A13: White spruce in Plantation IV were established in 1953. Trembling aspen competition is absent. Ground flora and rooting habit of the spruce is conspicuous.

Figure A14: White spruce in Plantation IV were established in 1953. Trembling aspen competition present. The large spruce is 0.98 metres in height at 28 years old.

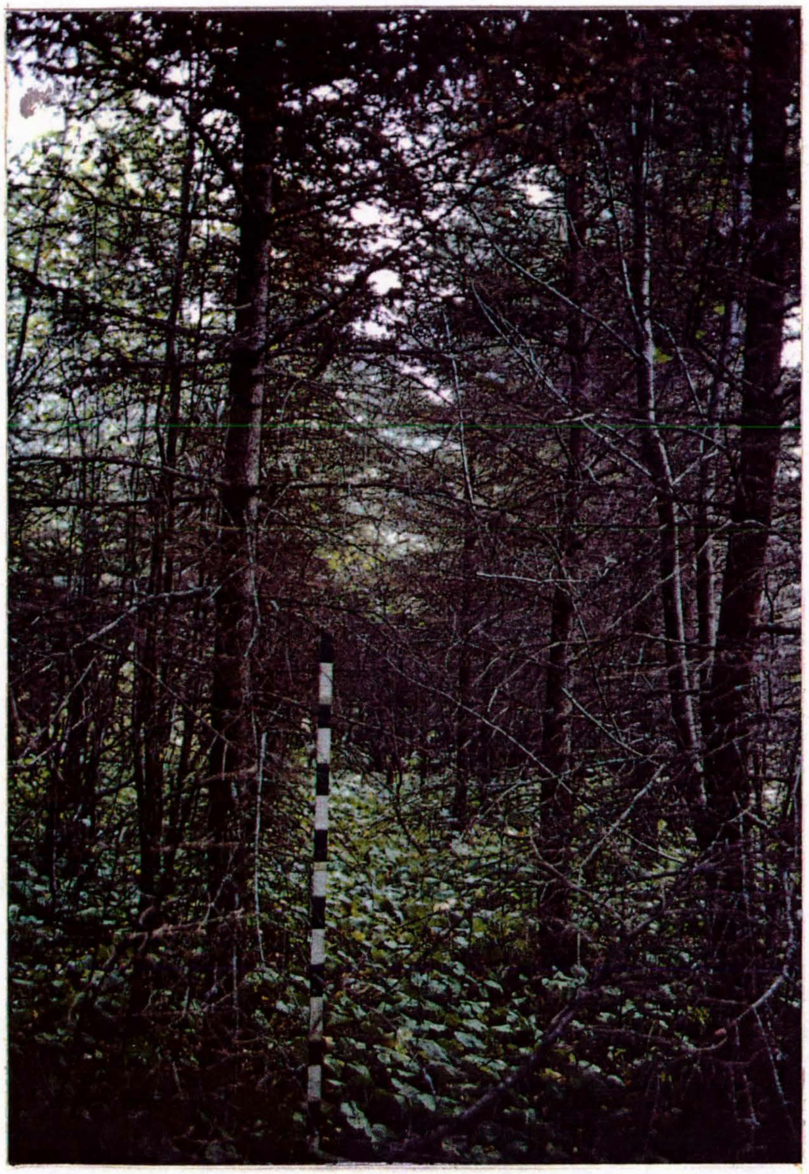


Figure A15: White spruce in Plantation IV were established in 1953. No trembling aspen competition is present.

Figure A16: White spruce in Plantation IV were established in 1953. Severe trembling aspen competition is present. The measured spruce in 0.98 metres in height at 28 years old.

Figure A17: White spruce in Plantation IV were established in 1953. Severe trembling aspen competition is present. The spruce in the foreground is 1.1 metres in height at 28 years old.

Appendix B. Summary statistics for stand components in plantations I, II, III, IV

Table B1: Summary statistics for stand components in plantation I.

Species	Micro-Site location	Parameter	Mean	Range	Standard Deviation	N
White spruce[1]	Corridor	Root collar diameter (cm)	0.92	0.66 - 1.31	0.3352	45
		Average height (m)	0.59	0.27 - 1.28	0.2938	45
		Free-to-Grow height (m)[2]	1.21			20
		1981 Height increment (m)	0.15	0.02 - 0.30	0.0777	15
		1980 Height increment (m)	0.11	0.01 - 0.33	0.0776	15
		1979 Height increment (m)	0.10	0.01 - 0.42	0.1043	15
		1978 Height increment (m)	0.12	0.01 - 0.40	0.1023	15
	Spoilbank ledge	Root collar diameter (cm)	1.62	0.78 - 1.58	0.5919	56
		Average height (m)	1.04	0.41 - 1.17	0.4681	56
		Free-to-Grow height (m)	1.67			25
		1981 Height increment (m)	0.22	0.10 - 0.39	0.0857	15
		1980 Height increment (m)	0.18	0.02 - 0.25	0.1774	15
		1979 Height increment (m)	0.12	0.02 - 0.18	0.0970	15
		1978 Height increment (m)	0.13	0.03 - 0.18	0.1403	15

1. All trees irrespective of the presence/absence of trembling aspen on the site.

2. Free-to-Grow height is the average height of those trees in the population whose total height is at least one metre, and is judged to be essentially free from competing vegetation of other species.

Table B1: (Continued)

Species	Micro-Site location	Parameter	Mean	Range	Standard Deviation	N
	Spoilbank	Root collar diameter (cm)	1.15	0.53 - 1.76	0.4286	60
		Average height (m)	0.66	0.39 - 1.33	0.1371	60
		Free-to-Grow height (m)	1.20			10
		1981 Height increment (m)	0.19	0.06 - 0.37	0.0884	20
		1980 Height increment (m)	0.14	0.03 - 0.28	0.0649	20
		1979 Height increment (m)	0.09	0.01 - 0.23	0.0602	20
		1978 Height increment (m)	0.08	0.00 - 0.16	0.0396	20
Trembling aspen	All positions	Root collar diameter (cm)	1.58	0.87 - 1.94	0.7311	181
		Average height (m)	1.67	0.78 - 2.43	0.6346	181
		Dominant height (m)	2.78			67
		1981 Height increment (m)	0.68	0.21 - 0.96	0.0426	181
		1980 Height increment (m)	0.73	0.17 - 0.94	0.0324	181
		1979 Height increment (m)	0.40	0.08 - 0.73	0.0251	181
		1978 Height increment (m)	0.40	0.09 - 0.59	0.2913	181

Table B2: Summary statistics for stand components in plantation II.

Species	Micro-Site location	Parameter	Mean	Range	Standard Deviation	N
White spruce[1]	Corridor	Root collar diameter (cm)	2.27	0.30 - 4.81	1.4	23
		Average height (m)	1.38	0.57 - 2.56	0.50	23
		Free-to-Grow height (m)[2]	1.76			6
		1981 Height increment (m)	0.24	0.11 - 0.41	0.08	23
		1980 Height increment (m)	0.15	0.09 - 0.34	0.07	23
		1979 Height increment (m)	0.19	0.10 - 0.33	0.07	23
		1978 Height increment (m)	0.14	0.03 - 0.30	0.08	23
	Spoilbank ledge	Root collar diameter (cm)	2.89	0.44 - 5.82	1.25	28
		Average height (m)	1.72	0.74 - 3.24	0.56	28
		Free-to-Grow Height (m)	2.35			8
		1981 Height increment (m)	0.32	0.09 - 0.52	0.14	28
		1980 Height increment (m)	0.20	0.10 - 0.29	0.17	28
		1979 Height increment (m)	0.22	0.10 - 0.36	0.06	28
		1978 Height increment (m)	0.22	0.06 - 0.39	0.10	28

1. All trees irrespective of the presence/absence of trembling aspen on the site.

2. Free-to-Grow height is the average height of those trees in the population whose total height is at least one metre, and is judged to be essentially free from competing vegetation of other species.

Table B2: (Continued)

Species	Micro-Site location	Parameter	Mean	Range	Standard Deviation	N
Trembling Aspen	All Positions	Root collar diameter (cm)	3.31	1.11 - 4.21	1.834	382
		Average height (m)	3.29	2.64 - 3.87	1.654	382
		Dominant height (m)	9.65			30
		1981 Height increment (m)	0.26	0.08 - 0.56	14.22	30
		1980 Height increment (m)	0.17	0.09 - 0.39	9.54	30
		1979 Height increment (m)	0.20	0.12 - 0.53	9.67	30
		1978 Height increment (m)	0.14	0.05 - 0.33	8.05	30

Table B3: Summary statistics for stand components in plantation III.

Species	Micro-Site location	Parameter	Mean	Range	Standard Deviation	N
White spruce[1]	Pure spruce	Diameter (breast height)(cm)	10.56	5.60 - 20.6	4.535	145
		Height (m)	8.89	3.20 - 4.70	2.995	145
		Dominant height (m)	10.67			25
	Mixed aspen and spruce	Diameter (breast height)(cm)	3.32	6.40 - 23.5	1.317	178
		Height (m)	3.32	1.90 - 3.6	1.158	178
		Dominant height (m)	4.86			20
Trembling aspen		Diameter (breast height)(cm)	7.94	4.76 - 10.34	3.690	210
		(Height(m)	9.42	7.64 - 9.85	4.760	210
		Dominant height (m)	16.48			40

[1] All crown classes of white spruce included.

Table B4: Summary statistics for stand components in plantation IV.

Species	Micro-Site location	Parameter	Mean	Range	Standard Deviation	N
White spruce[1]	Pure spruce	Diameter (breast height)(cm)	13.07	4.0 - 20.2	4.744	414
		Height (m)	7.03	2.2 - 13.4	1.919	414
		Dominant height (m)	16.54			25
	Mixed aspen and spruce	Diameter (breast height)(cm)	11.63	2.0 - 14.3	3.714	158
		Height (m)	11.84	2.90 - 15.40	3.362	158
		Dominant height (m)	15.67			25
Trembling aspen		Diameter (breast height)(cm)	13.66	6.35 - 28.35	4.869	488
		Height (m)	14.51	10.22 - 21.25	5.044	488
		Dominant height (m)	14.80			25

1. All crown classes of white spruce included.

Appendix C. Diameter and height distributions for populations of white spruce and trembling aspen in plantations I, II, III, IV.

Plantation I - 4 years

White spruce - Corridor micro-site

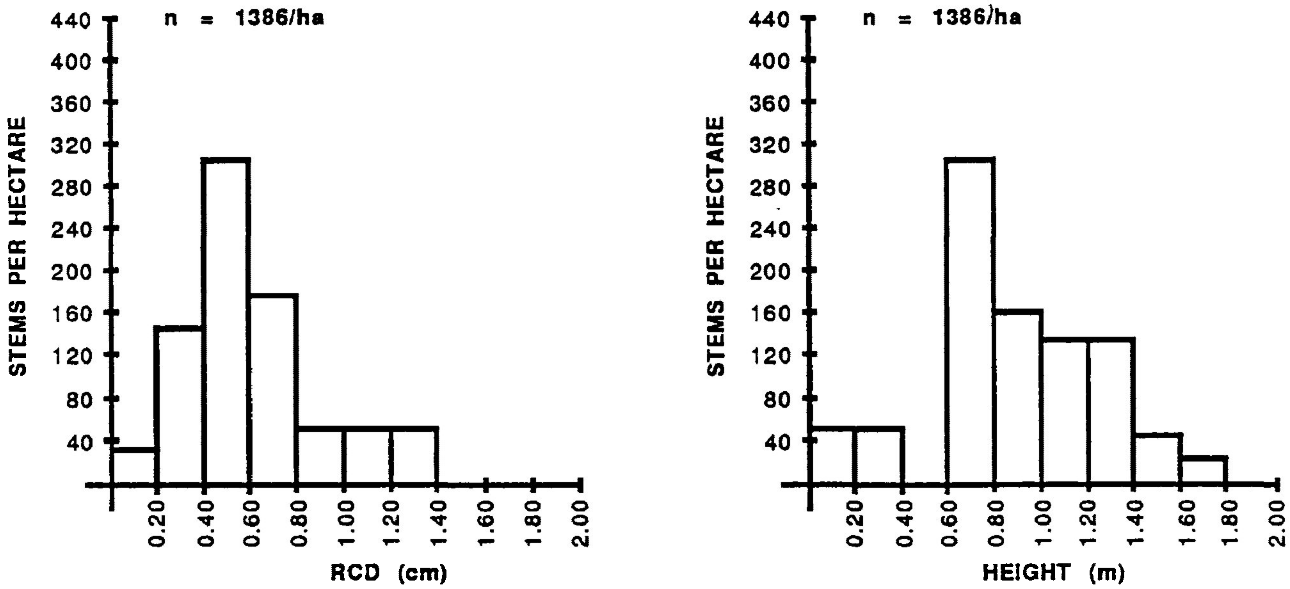


Figure C1: Root collar diameter (cm) and height (m) distribution for white spruce.

Plantation I - 4 years

White spruce - Spoilbank ledge micro-site

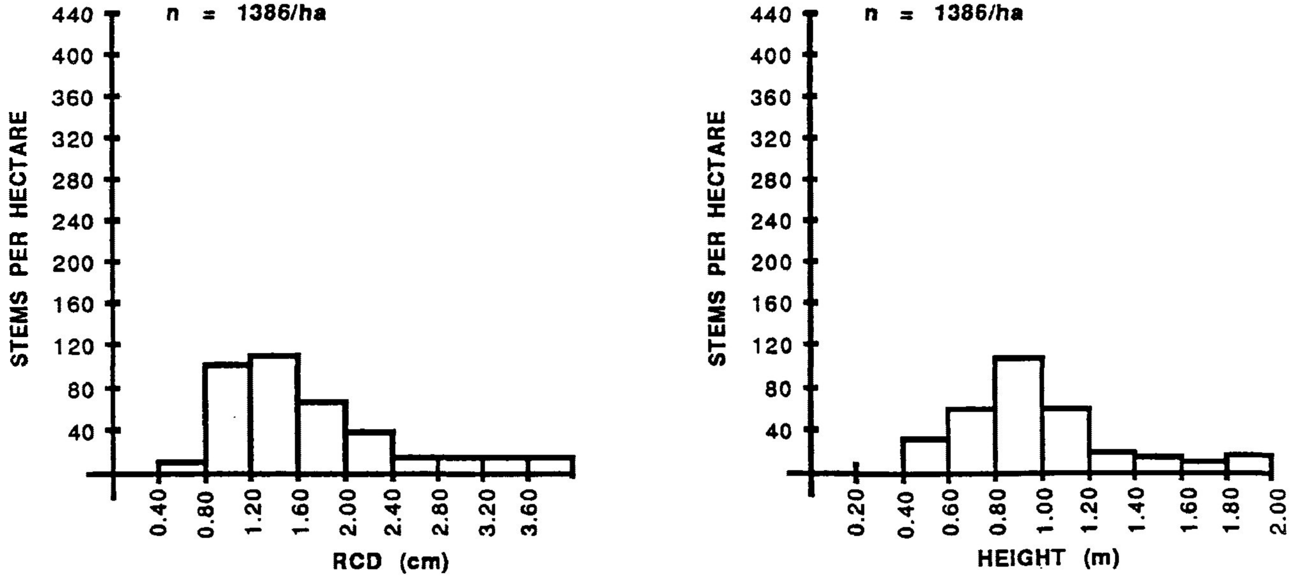
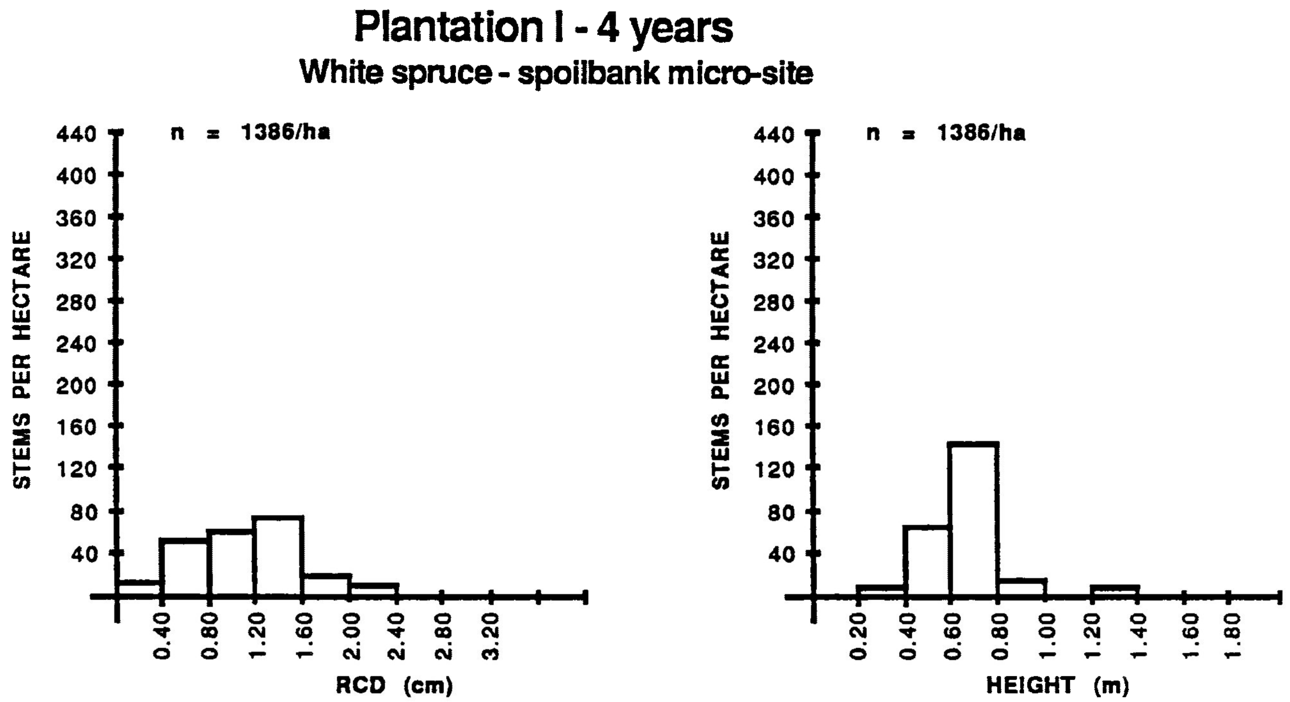


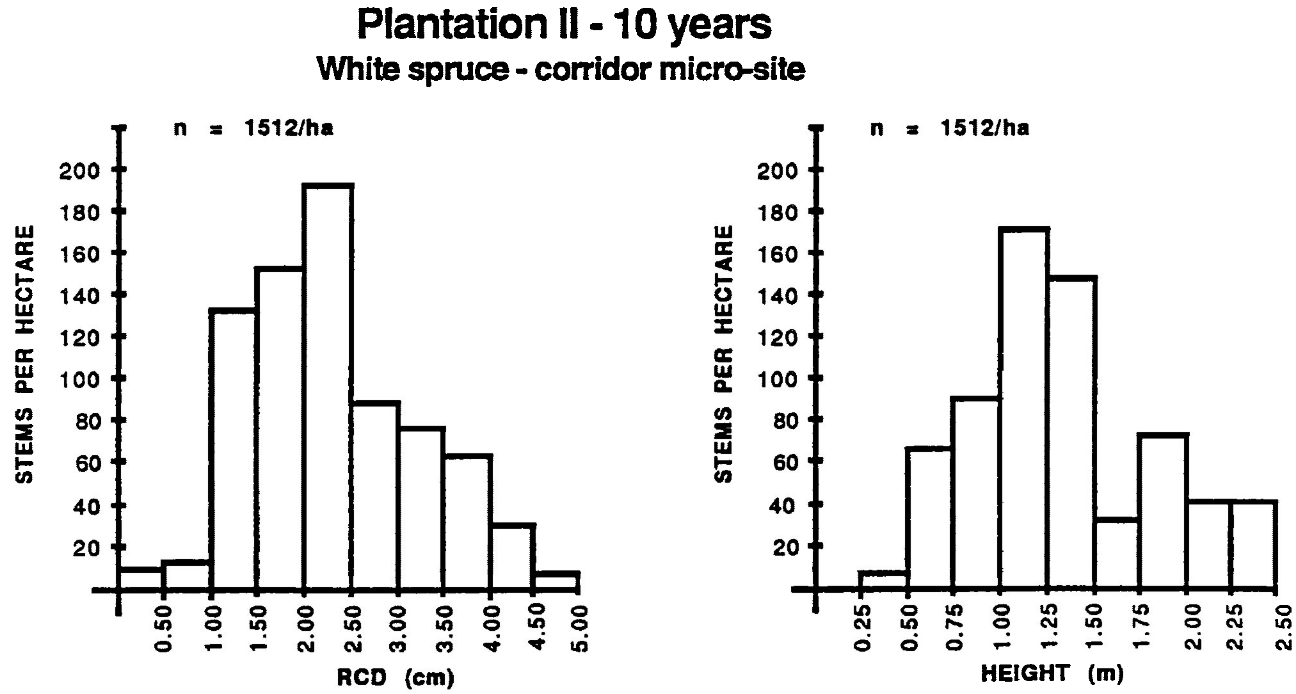
Figure C2: Root collar diameter (cm) and height (m) distribution for white spruce.



Plantation I - 4 years

White spruce - spoilbank micro-site

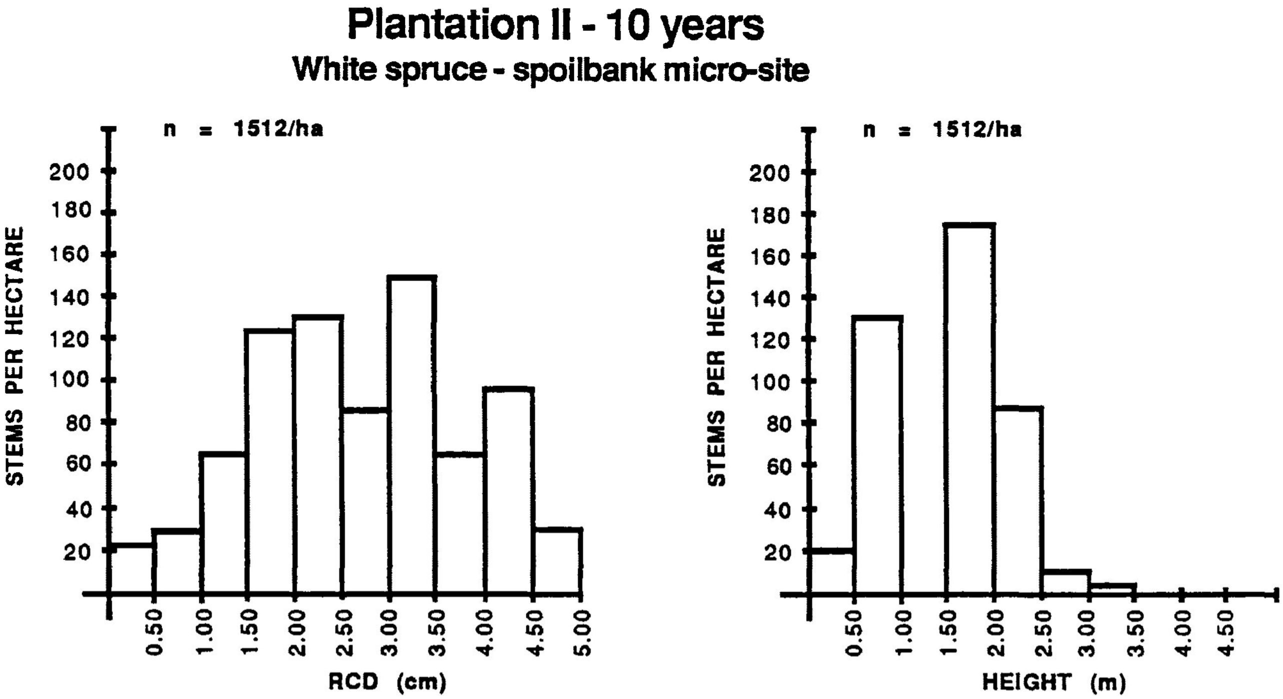
Figure C3: Root collar diameter (cm) and height (m) distribution for white spruce.



Plantation II - 10 years

White spruce - corridor micro-site

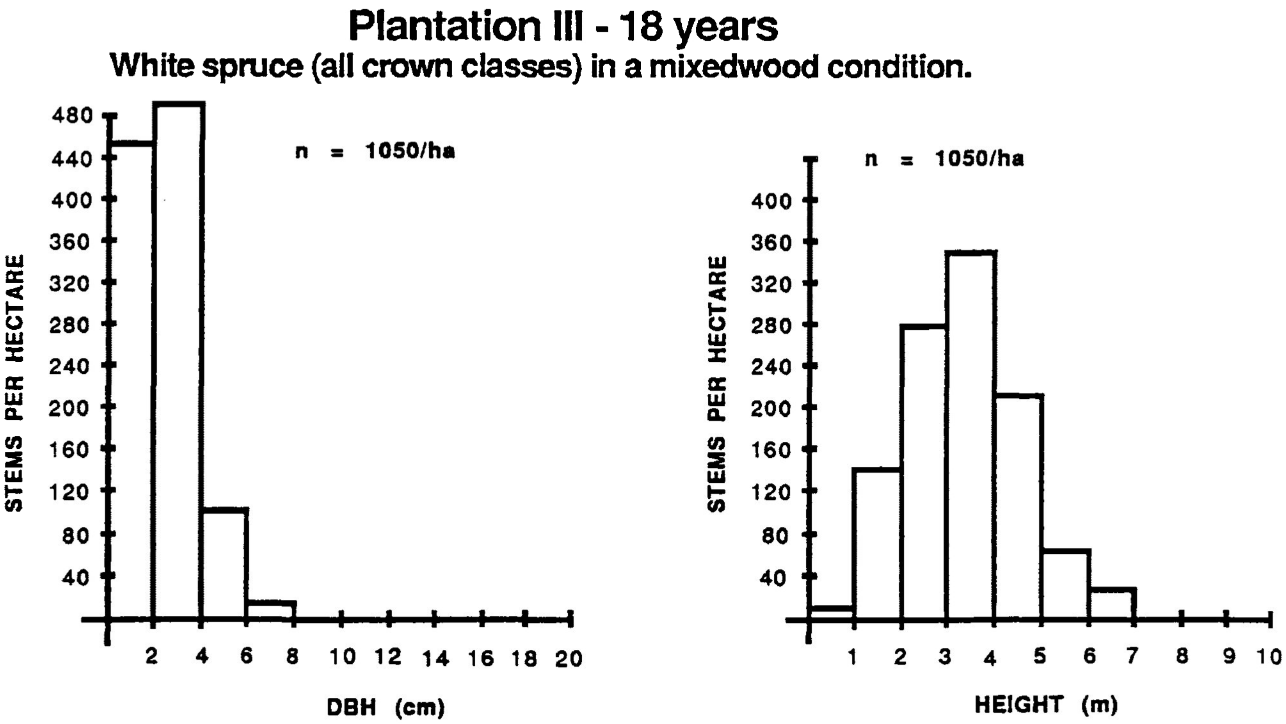
Figure C4: Root collar diameter (cm) and height (m) distribution for white spruce.



Plantation II - 10 years

White spruce - spoilbank micro-site

Figure C5: Root collar diameter (cm) and height (m) distribution for white spruce.



Plantation III - 18 years

White spruce (all crown classes) in a mixedwood condition.

Figure C6: Diameter at breast height (cm) and height (m) distribution for white spruce.

Plantation III - 18 years

White spruce (all crown classes) in a pure stand condition.

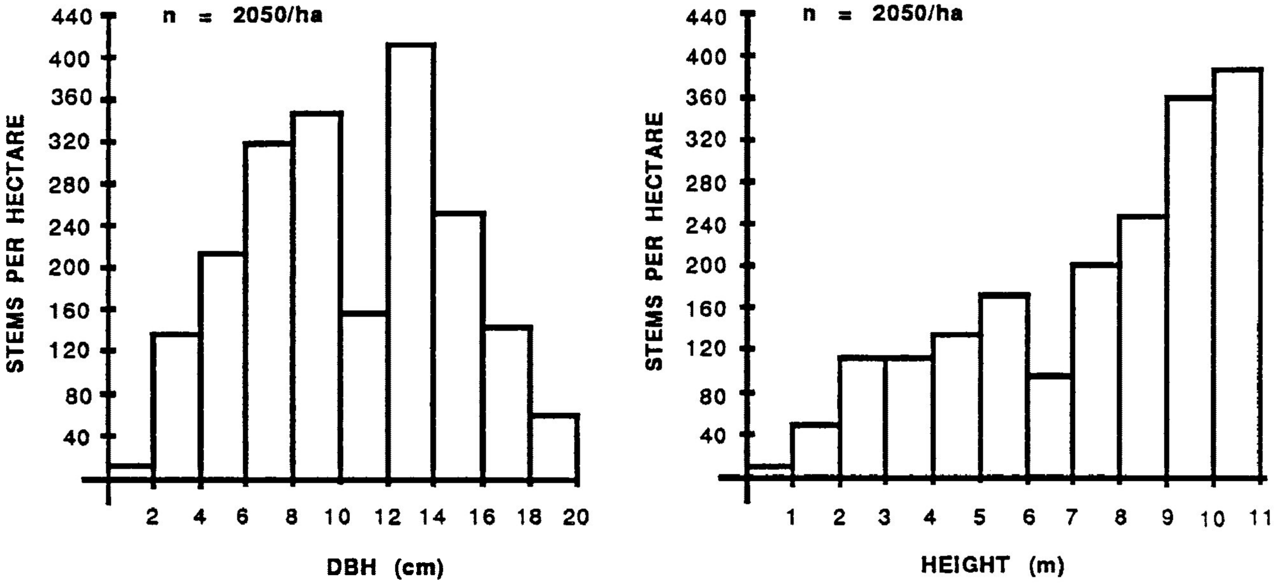


Figure C7: Diameter at breast height (cm) and height (m) distribution for white spruce.

Plantation IV - 28 years

White spruce (all crown classes) in a mixedwood condition.

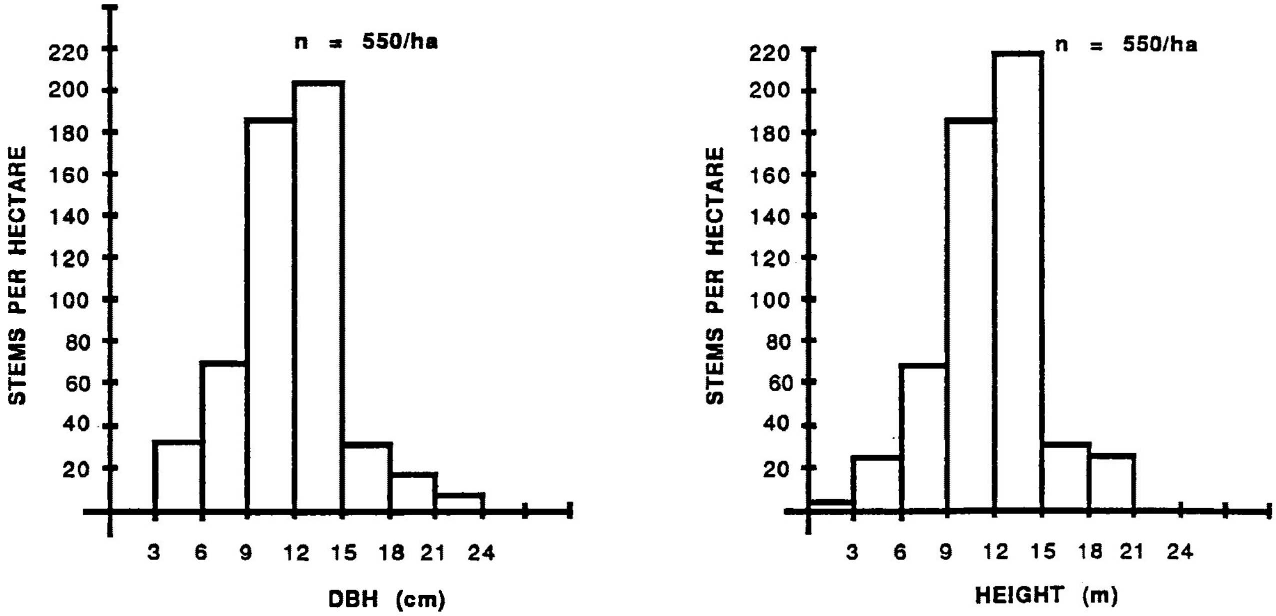
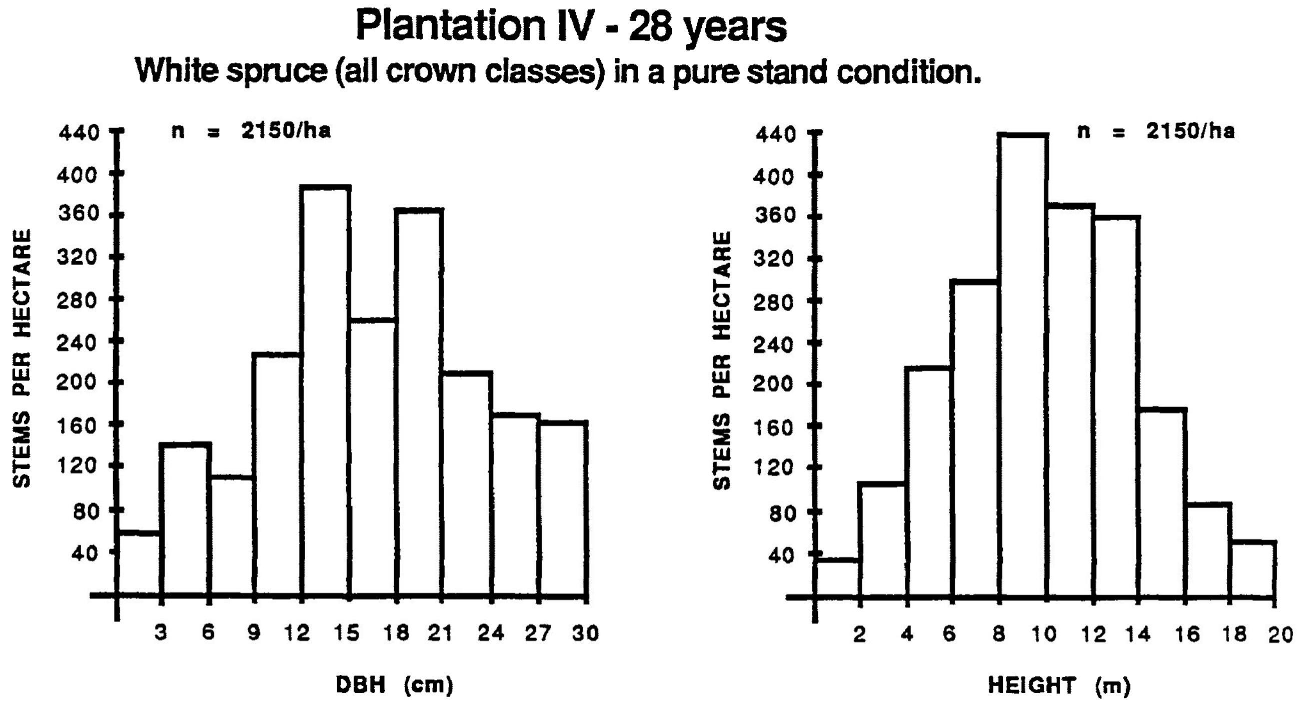
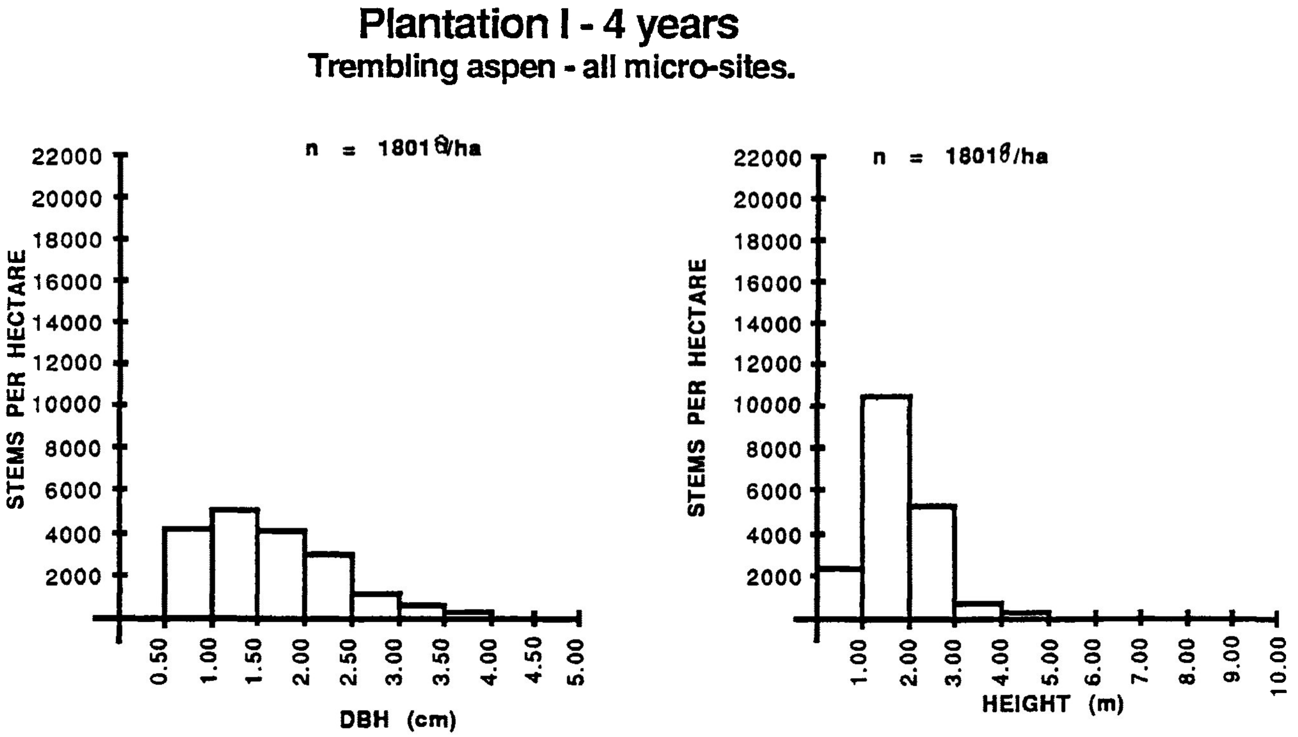


Figure C8: Diameter at breast height (cm) and height (m) distribution for white spruce.


Plantation IV - 28 years

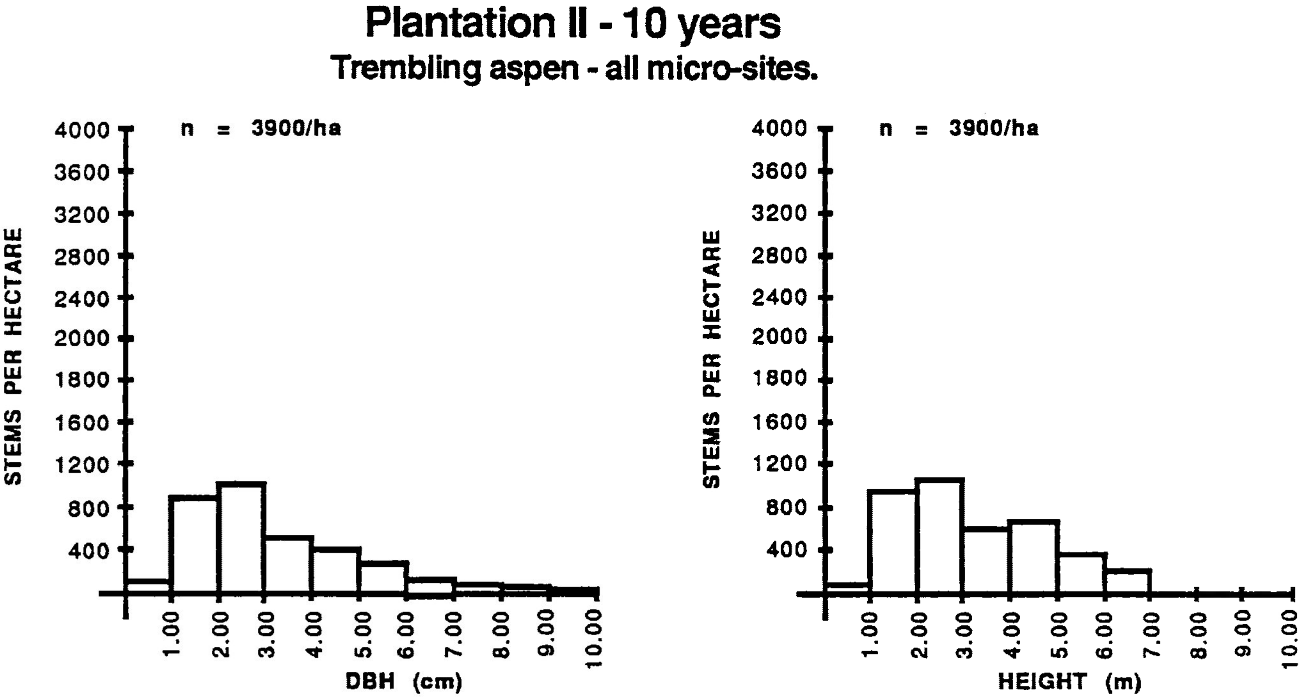
White spruce (all crown classes) in a pure stand condition.

Figure C9: Diameter at breast height (cm) and height (m) distributions for white spruce.


Plantation I - 4 years

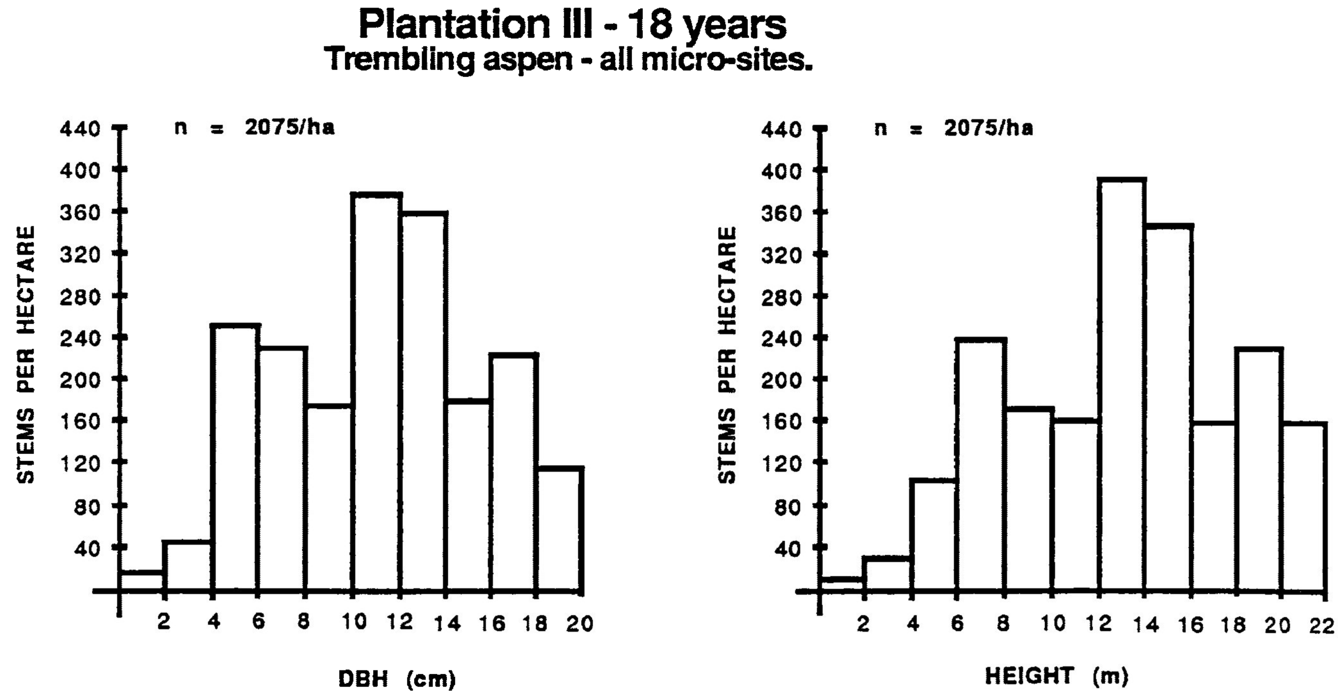
Trembling aspen - all micro-sites.

Figure C10: Root collar diameter (cm) and height (m) distributions for trembling aspen..



Plantation II - 10 years
Trembling aspen - all micro-sites.

Figure C11: Root collar diameter (cm) and height (m) distribution for white spruce.



Plantation III - 18 years
Trembling aspen - all micro-sites.

Figure C12: Diameter at breast height (cm) and height (m) distributions for trembling aspen.

Plantation IV - 28 years

Trembling aspen - all micro-sites.

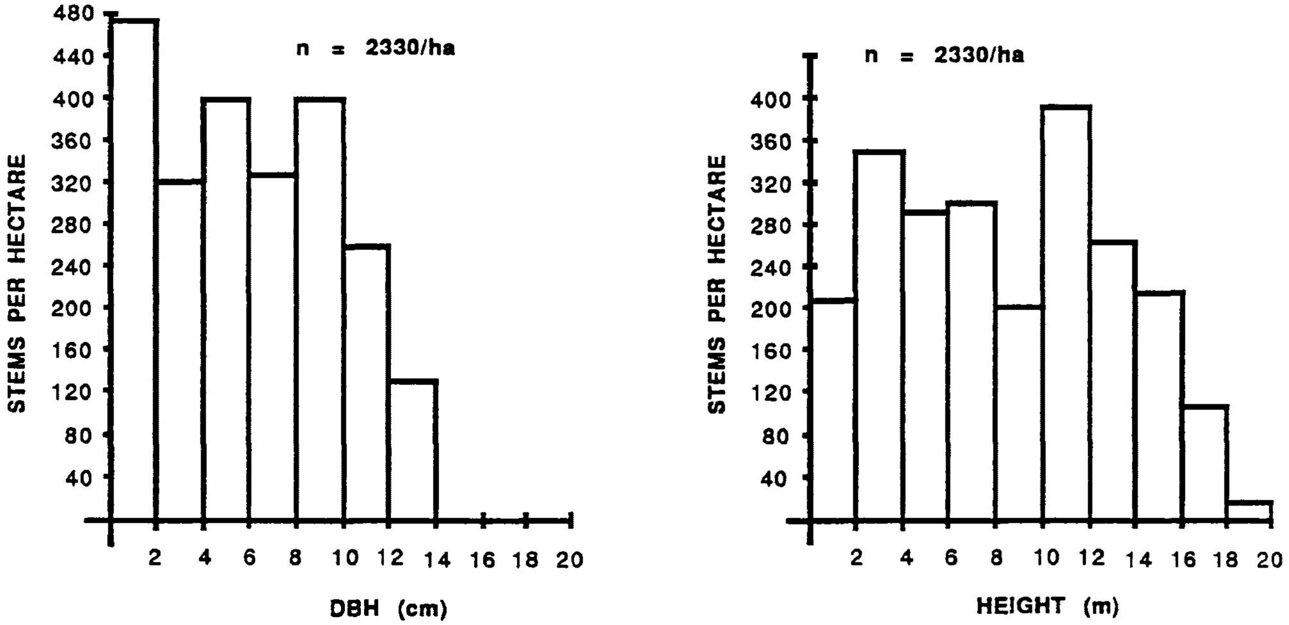


Figure C13: Diameter at breast height (cm) and height (m) distributions for trembling aspen.

Appendix D. Analysis of variance tables for selected white spruce crop trees (all crown classes) in diameter and height growth - plantations I and II, established 1977 and 1971 respectively.

Table D1. Completely randomized one-way analysis of variance table for root collar diameters (cm) of selected white spruce in plantation I - established 1977. (6 micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*	
Treatment (t-1)	5	1.89	0.38	1.90	N.S.
Error t(r-1)	44	8.77	0.20		
Total tr-1	49	10.66			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table D2. Completely randomized one-way analysis of variance table for heights (m) of selected white spruce in plantation I established 1977. (6 micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*	
Treatment	5	1.00	0.20	1.33	N.S.
Error	44	6.51	0.15		
Total	49	7.51			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table D3. Completely randomized one-way analysis of variance table for 1981 height increment (cm) of selected white spruce in plantation I - established 1977. (6 micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*	
Treatment	5	0.11	0.02	2.00	N.S.
Error	44	0.26	0.0.1		
Total	49	0.37			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table D4. Completely randomized one-way analysis of variance table for 1980 height increment (cm) of selected white spruce in plantation I - established 1977. (6 micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*	
Treatment	5	0.05	0.01	2.94	N.S.
Error	44	0.15	0.0034		
Total	49	0.20			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

S-N-K Test for Difference Between Treatment Means

$\underline{X_1 \quad X_2 \quad X_3 \quad X_4 \quad X_6} \quad X_5$ P = 0.05

Table D5. Completely randomized one-way analysis of variance table for 1979 height increment (cm) of selected white spruce in plantation I - established 1977. (6 micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*	
Treatment	5	0.001	.00002	0.002	N.S.
Error	44	0.239	0.01		
Total	49	0.24			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table D6. Completely randomized one-way analysis of variance table for 1978 height increments (cm) of selected white spruce in plantation I - established 1977. (6 micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatment	5	0.01	.00200	0.44	N.S.
Error	44	0.20	.00454		
Total	49	10.66			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table D7. Completely randomized one-way analysis of variance table for root collar diameters (cm) of selected white spruce in plantation II - established 1971. (6 micro-site/ aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatment	3	5.8855	1.9618	1.4522	N.S.
Error	26	35.1245	1.3509		
Total	29	41.01			

F (3,26) = 4.64 at the P = 0.01 level

F (3,26) = 2.98 at the P = 0.05 level

Table D8. Completely randomized one-way analysis of variance table for height (m) of selected white spruce crop trees in plantation II - established 1977. (Four micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatment	3	1.7994	0.5998	1.7456	N.S.
Error	26	8.9346	0.3436		
Total	29	10.734			

F (3,26)= 4.64 at the P = 0.01 level

F (3,26)= 2.98 at the P = 0.05 level

Table D9. Completely randomized one-way analysis of variance table for 1981 height increment (cm) of selected white spruce in plantation II - established 1971. (Four micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatment	3	0.2481	0.0827	7.974	**
Error	26	0.2697	0.01037		
Total	29	0.5178			

F (3,26) = 4.64 at the P = 0.01 level

F (3,26) = 2.98 at the P = 0.05 level

S.N.K. Test for Differences in Treatment Means

Spoilbank High Aspen	Corridor Low Aspen	Corridor High Aspen	Spoilbank Low Aspen

P = 0.01

Table D10. Completely randomized one-way analysis of variance table for 1980 height increment (cm) of selected white spruce in plantation II - established 1971. (Four, micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatment	3	0.1972	0.06573	2.81498	N.S.
Error	26	0.6073	0.02335		
Total	29	0.8045			

F (3,26) = 4.64 at the P = 0.01 level

F (3,26) = 2.98 at the P = 0.05 level

Table D11. Completely randomized one-way analysis of variance table for height increment (cm) of selected white spruce in plantation II - established 1971. (Four micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*
Treatment	3	0.0628	0.0209	6.147**
Error	26	0.0902	0.0034	
Total	29	0.1530		

F (3,26) = 4.64 at the *P* = 0.01 level

F (3,26) = 2.98 at the *P* = 0.05 level

S.N.K. Test for difference between treatment of means

The Corridor-low aspen treatment has heights significantly different from the spoilbank-low aspen treatment at = 0.01.

The Corridor-high aspen treatment has heights significantly different from the corridor-low aspen treatment at *P* = 0.01.

Table D12. Completely randomized one-way analysis of variance table for 1978 height increment (cm) of selected white spruce in plantation II - established 1971. (Four, micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*
Treatment	3	0.13	0.0433	8.66**
Error	26	0.13	0.005	
Total	29	0.26		

F (3,26) = 4.64 at the *P* = 0.01 level

F (3,26) = 2.98 at the *P* = 0.05 level

S.N.K. Test for difference between treatment means

Corridor-low aspen is significantly different from spoilbank-low aspen at the *P* = 0.01 level.

Appendix E. Summary of white spruce seedling growth based upon analyses of destructively sampled crop trees removed from plantations I, II, III and IV.

Table E1. Summary of white spruce crop tree growth arranged by seedling micro-site position in plantation I established 1977.

	Means arranged by seedling micro-site position		
Variable	Corridor	Spoilbank ledge	Spoilbank
Root collar diameter (cm)	0.915(46)	1.621(55)	1.153(60)
	P =0.01		
			P =0.01
Total height (m)	0.594(46)	1.043(55)	0.063(60)
	P =0.01		
			P =0.01
1981 Height increment (m)	0.14(15)	0.21(15)	0.19(20)
		P =0.05	
1980 Height increment (m)	0.12(15)	0.13(15)	0.14(20)
1979 Height increment (m)	0.091(15)	0.102(15)	0.094(20)
1978 Height increment (m)	0.115(15)	0.103(15)	0.084(20)
Foliage dry weight (g)	16.41(15)	25.53(15)	29.57(20)
			P =0.05
Branch dry weight (g)	7.23(15)	12.39(15)	13.37(20)
			P =0.05
Stem dry weight (g)	11.33	18.31	20.52
		P =0.05	
			P =0.05
Total dry weight (g)	34.79	55.60	61.13
		P =0.01	
			P =0.05

*Unpaired T-tests were used to detect statistically significant differences between the treatment means at the *P* =0.01 and *P* =0.05 levels of significance.
Number of trees are shown in parentheses.

Table E2. Summary of white spruce seedling growth based upon analyses of destructively sampled crop trees removed from plots located in each of the micro-site/aspen competition situations in plantation I (established 1977).

		Corridor low	Corridor high	Spoilbank ledge low	Spoilbank ledge high	Spoilbank low	Spoilbank high
1981 Height increment	(cm)	13.66±2.37(a)	15.33±1.20	25.75±3.13	15.57±1.55	22.77±3.12	15.55±2.07
1980 Height increment	(cm)	12.58±2.68	9.33±1.85	15.38±2.76	11.00±1.07	15.67±1.07	12.09±1.56
1979 Height increment	(cm)	9.66±3.11	7.00±2.52	9.87±1.71	10.57±1.60	8.77±2.35	9.91±1.52
1978 Height increment	(cm)	11.83±3.12	10.00±4.58	12.00±1.86	8.75±1.03	7.88±1.34	8.73±1.18
Total tree height	(m)	0.58±0.09	0.60±0.08	0.82±0.07	0.68±0.10	0.76±0.09	0.67±0.05
Dominant tree height	(m)	1.11±0.07	1.28±0.09	1.76±0.03	1.54±0.08	1.31±0.08	1.13±0.06
Root collar diameter	(cm)	0.92±0.06	0.94±0.20	1.32±0.11	1.06±0.06	1.26±0.12	1.09±0.11
Foliage dry weight	(g)	14.85±2.70	22.64±0.53	30.74±10.19	19.58±2.31	33.12±8.05	26.66±6.56
Branch wood and bark dry weight	(g)	5.74±0.80	13.21±4.01	15.75±6.15	8.54±1.33	15.10±3.68	11.96±3.20
Stemwood and bark	(g)	10.39±1.52	15.12±1.76	17.25±6.10	14.31±1.80	19.40±4.76	21.43±4.22
Total dry weight	(g)	30.74±4.93	50.99±2.91	66.98±22.10	42.60±3.26	67.79±16.17	55.67±12.03
Number of seedlings destructively sampled		N=12	N=3	N=8	N=7	N=9	N=11

(a) Standard error of the mean

Table E3. Means of white spruce crop tree growth for seedling micro-site position in plantation II established 1971.

	Micro-site position		
Variable	Corridor (n=14)	Spoilbank (n=16)	
Root collar diameter (cm)	1.97	2.49	P=0.05
Total height (m)	1.19	1.46	P=0.01
1981 Height increment (m)	0.26	0.33	
1980 Height increment (m)	0.16	0.19	
1979 Height increment (m)	0.19	0.24	
1978 Height increment (m)	0.16	0.24	
Foliage dry weight (g)	165.36	342.23	
Branch dry weight (g)	100.51	267.50	
Stem dry weight (g)	131.02	267.32	P=0.05
Total dry weight (g)	396.88	878.04	

*Unpaired T-tests were used to detect statistically significant differences between the treatment means at the P=0.01 and P=0.05 levels of significance.

Number of trees are shown in parentheses.

Table E4. Summary of white spruce seedling growth based upon analyses of destructively sampled crop trees removed from plots located in each of the micro-site/aspen competition situations in plantation II (established 1971).

Parameter		Corridor-low	Corridor-high	Spoilbank-low	Spoilbank-high
1981 Height increment	(m)	0.24+0.043(a)	0.28+0.028	0.44+0.086	0.22+0.042
1980 Height increment	(m)	0.12+0.015	0.21+0.029	0.22+0.019	0.15+0.017
1979 Height increment	(m)	0.14+0.021	0.24+0.023	0.26+0.021	0.21+0.017
1978 Height increment	(m)	0.12+0.035	0.20+0.022	0.31+0.022	0.18+0.027
Total tree height	(m)	1.01+0.169	1.38+0.184	1.65+0.237	1.20+0.232
Root collar diameter	(m)	1.64+0.348	2.30+0.279	2.83+0.491	2.06+0.359
Foliage dry weight	(g)	149.27+44.66	181.44+54.38	452.14+97.89	203.18+71.54
Branch wood and bark dry weight	(g)	84.20+27.90	116.81+31.70	380.50+113.26	122.21+41.64
Stemwood and bark	(g)	98.80+34.03	163.24+35.31	366.69+71.22	139.56+45.12
Total dry weight	(g)	322.27+102.76	461.49+119.12	1199.33+255.22	464.96+146.124
Number of seedlings destructively sampled		N=7	N=7	N=9	N=7

(a) Standard error of the mean

Table E5. Summary of white spruce sample crop tree growth in plantation III established 1963.

Crown position and presence of trembling aspen	Diameter breast height (cm)	Height (m)	Stemwood dry weight (kg)	Stembark dry weight (kg)	Branch dry weight (kg)	Foliage dry weight (kg)	Total dry weight (kg)	Number of trees sampled
Pure Spruce								
1. Suppressed	5.24	4.40	2.299	0.421	1.118	0.977	4.815	1
2. Codominant	8.04	5.40	6.125	0.977	2.597	1.981	11.680	1
3. Dominant	9.38	6.40	8.983	1.329	3.611	2.875	16.798	1
Mixedwood Spruce and Aspen								
1. Heavily suppressed	2.10	1.96	0.218	0.542	0.127	0.132	1.019	
2. Moderately suppressed	4.50	3.80	1.448	0.280	0.652	0.495	2.875	1
3. Lightly suppressed	6.81	5.02	4.039	0.682	1.581	1.338	7.640	1

Table E6. Summary of white spruce sample crop tree growth in plantation IV established 1953.

Crown position and presence of trembling aspen	Diameter breast height (cm)	Height (m)	Stemwood dry weight (kg)	Stembark dry weight (kg)	Branch dry weight (kg)	Foliage dry weight (kg)	Total dry weight (kg)	Number of trees sampled
<u>Pure Spruce</u>								
1. Suppressed	10.13	9.73	10.895	1.618	4.255	2.994	19.762	1
2. Codominant	14.22	10.39	27.259	3.446	8.790	5.784	45.279	1
3. Dominant	17.61	11.06	45.956	5.435	12.575	8.854	72.821	1
<u>Mixedwood Spruce and Aspen</u>								
1. Heavily suppressed	2.60	2.55	0.392	0.568	0.143	0.192	1.295	
2. Moderately suppressed	6.40	5.11	3.475	0.558	1.595	0.978	6.606	1
3. Lightly suppressed	9.40	6.10	9.032	1.269	3.027	2.169	15.497	1

Appendix F. Analysis of variance tables for white spruce crop tree (all crown classes) by weights components - plantations I and II, established 1977 and 1971 respectively.

Table F1. Completely randomized one-way analysis of variance table for white spruce crop tree foliage dry weight (gm) in plantation I - established 1977. (Six micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatments (t-1)=	5	2327.70	465.54	1,250	N.S.
Error t(r-1)=	44	16406.01	372.86		
Total	49	18733.71			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table F2. Completely randomized one-way analysis of variance table for white spruce crop tree branch dry weight (gm) in plantation I - established 1977. (Six micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatment	5	728.217	145.643	1.433	N.S.
Error	44	4472.728	101.653		
Total	49	5200.945			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table F3. Completely randomized one-way analysis of variance table for white spruce crop tree stem dry weight (gm) in plantation I - established 1977. (Six micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatment	5	1037.826	207.565	1.4873	N.S.
Error	44	6140.682	139.561		
Total	49	7178.508			

F (5,44 = 3.51 at the P = 0.01 level

F (5,44 = 2.45 at the P = 0.05 level

Table F4. Completely randomized one-way analysis of variance table for white spruce crop tree total dry weight in plantation I - established 1977. (Six micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F	
Treatments	5	10218.757	2043.751	1.162	N.S.
Error	44	77381.038	1758.660		
Total		87599.795			

F (5,44) = 3.51 at the P = 0.01 level

F (5,44) = 2.45 at the P = 0.05 level

Table F5. Completely randomized one-way analysis of variance table for white spruce crop tree foliage dry weight (gm) in plantation II - established 1971. (Four micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F
Treatment	3	483897.991	161299.330	3.767*
Error	26	1113083.221	42810.893	
Total	29	1596981.212		

F (3,26) = 4.64 at the P = 0.01 level

F (3,26) = 2.98 at the P = 0.05 level

S.N.K. Test for Difference Between Treatment Means

Corridor -low aspen	Corridor -high aspen	Spoilbank -high aspen	Spoilbank - low aspen

P = 0.05

Table F6. Completely randomized one-way analysis of variance table for white spruce crop tree branch dry weight (gm) in plantation II - established 1971. (Four micro-site aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F
Treatments	3	451385.243	150461.747	4.398*
Error	26	889447.78	34209.53	
Total	29	1340833.023		

$F\ (3,26) = 4.64$ at the $P = 0.01$ level

$F\ (3,26) = 2.98$ at the $P = 0.05$ level

S.N.K. Test for Difference Between Treatment Means

Corridor -low aspen	Corridor -high aspen	Spoilbank -high aspen	Spoilbank - low aspen	
———	———	———	$P = 0.05$	

Table F7. Completely randomized one-way analysis of variance table for white spruce crop tree stem dry weight (gm) in plantation II - established 1971. (Four micro-site/aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	F
Treatment	3	492770.403	164256.80	6.700**
Error	26	637326.797	24512.569	
Total	29	1130097.2		

$F\ (3,26) = 4.64$ at the $P = 0.01$ level

$F\ (3,26) = 2.98$ at the $P = 0.05$ level

S.N.K. Test for Difference Between Treatment Means

Corridor -low aspen	Corridor -high aspen	Spoilbank -high aspen	Spoilbank -low aspen	
———	———	———	$P = 0.01$	
	———	———	———	$P = 0.01$
		———	———	$P = 0.01$

Table F8. Completely randomized one-way analysis of variance table for white spruce crop tree total dry weight (gm) in plantation II - established 1971. (Four micro-site aspen competition situations).

A.N.O.V.A.

Source	df	SS	MS	*F*
Treatments	3	3910279.9	1303426.63	5.113**
Error	26	6627503.88	254903.99	
Total	29	10537783.78		

F (3,26) = 4.64 at the P = 0.01 level

F (3,26) = 2.98 at the P = 0.05 level

S.N.K. Test for Difference Between Treatment Means

Corridor -low aspen	Corridor -high aspen	Spoilbank -high aspen	Spoilbank - low aspen	
———	———	———		P = 0.01
	———	———	———	P = 0.01

Appendix G. Hemispherical photographs of representative white spruce for different micro-sites and different aspen densities in plantations I, II, III, and IV.

Quantifying vegetation competition surrounding crop trees

Stand development and the associated dynamics of forest succession is, in part, based on the ability of the species to develop and maintain themselves within a given environment. Competition between plants occurs when two plants make demands upon a site factor in excess of the ability of that factor to satisfy the needs of both plants.

Crown competition for light amongst the spruce crop tree and the associated vegetation was quantified on the basis of percentage cover (shading) of the crop tree. Hemispherical photographs were used to examine the degree of cover of the crop tree being studied in relation to the percentage cover of its crown by adjacent spruce and aspen trees. These photographs were taken vertically at the centre of each plot using a Canon F 135 mm camera fitted with a Canon 7.5 mm f/5.6 fish-eye lens. The lens has a fixed focus (from 70 mm to infinity) and has built in filters. Preliminary trials showed that a skylight filter gave adequate results based on the need for clear images. Kodak Plus-X film ASA 125 was used.

Photographs were taken on lightly overcast days while other plot work was being completed. Exposure settings were calculated on the basis of instantaneous light meter readings. The camera was fitted to a tripod and was levelled with a spirit level. To record the orientation of the photograph, a stick was placed due north in a manner that allowed it to show prominently in the photograph. A sign stand that displayed the plot number was also included in the photograph.

The photographs produced were circular and enlarged to a standardized diameter (approximately 19 cm) to produce clear features on the plot photograph. These photographs were then photo-copied onto transparent acetate overhead projector sheets. The acetate sheet was subsequently masked with black paper so that only the plot photograph was visible. The masked plot photo was then placed in a rhizometer (Morrison and Armson 1968). The area of the plot photo that displayed darkened images as a result of the presence of competing vegetation was calculated. This area of cover was expressed as a percentage of the total area of the plot photograph. It was then equated to the percent cover of the crop tree crown by other plants, shrubs and trees.

The photographs showed considerable image distortion towards the outer edge of the picture (parallax). Relative measures such as percent cover will not be totally accurate depending upon the size of the objects (trees, shrubs, competition) close to the plot centre.

Figure G1: Plantation I established 1977. Plot #8. Corridor/low levels of trembling aspen competition.

Figure G2: Plantation I established 1977. Plot #23. Corridor/medium levels of trembling aspen competition.

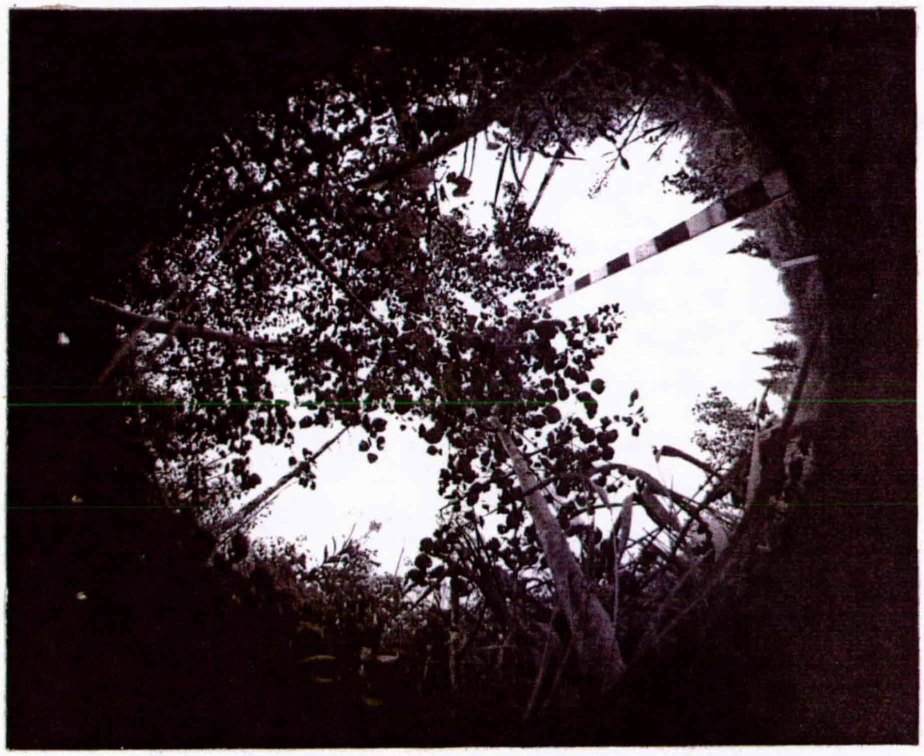


Figure G3: Plantation I established 1977. Plot #12. Corridor/high levels of trembling aspen competition.

Figure G4: Plantation I established 1977. Plot #37. Spoilbank ledge/low levels of trembling aspen competition.

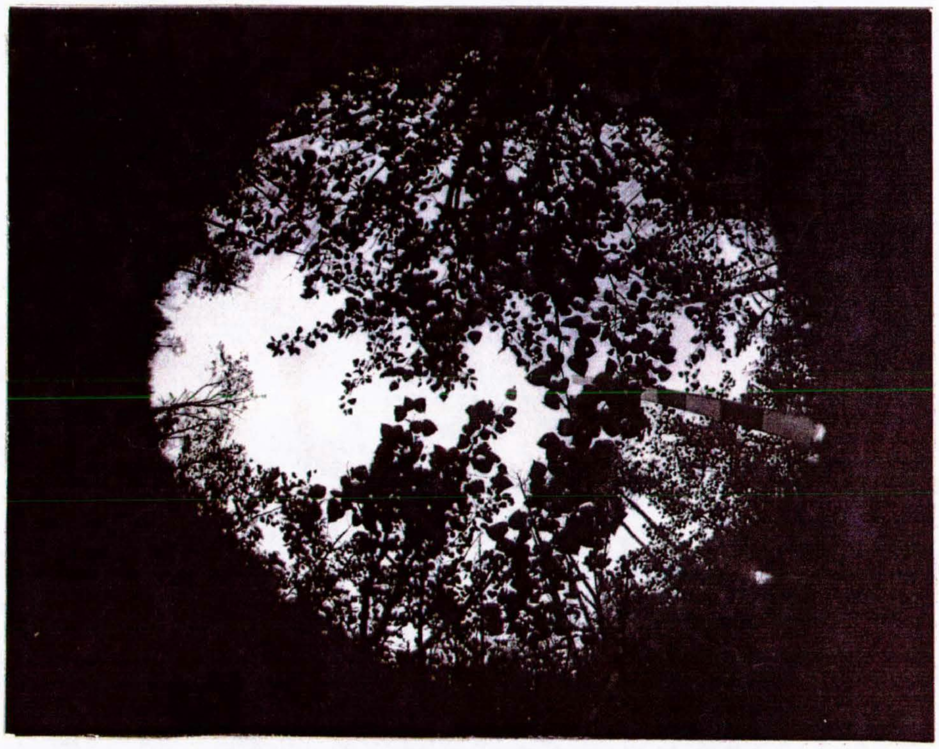


Figure G5: Plantation I established 1977. Plot #14. Spoilbank ledge/medium levels of trembling aspen competition.

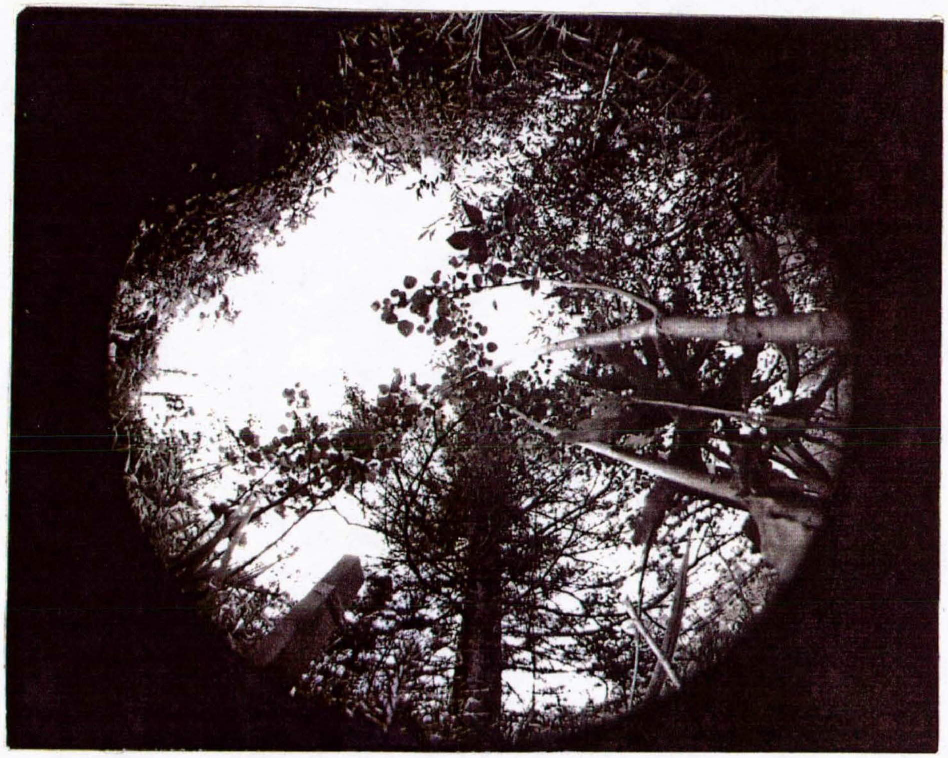


Figure G6: Plantation I established 1977. Plot #5. Spoilbank ledge/high levels of trembling aspen competition.

Figure G7: Plantation I established 1977. Plot #31. Spoilbank/low levels of trembling aspen competition.

Figure G8: Plantation I established 1977. Plot #25. Spoilbank/medium levels of trembling aspen competition.

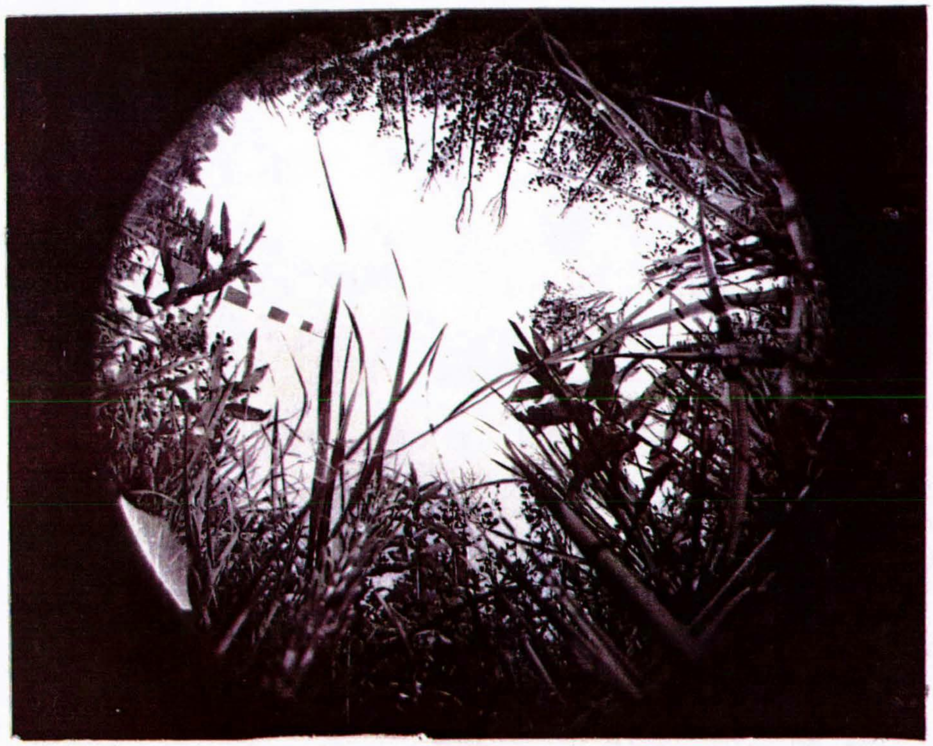


Figure G9: Plantation I established 1977. Plot #45. Spoilbank/high levels of trembling aspen competition.

Figure G10: Plantation II established 1971. Plot #1. Corridor/low level of trembling aspen competition.

Figure G11: Plantation II established 1971. Plot #21. Corridor/high level of trembling aspen competition.

Figure G12: Plantation II established 1971. Plot #18. Spoilbank/low level of trembling aspen competition.

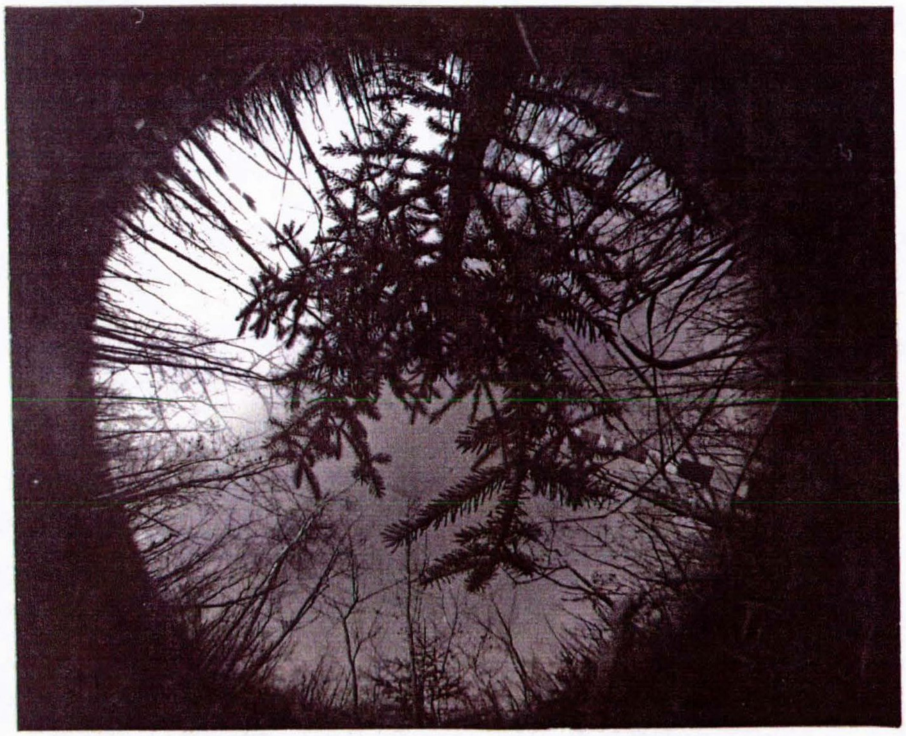


Figure G13: Plantation II established 1971. Plot #29. Spoilbank/high levels of trembling aspen competition.

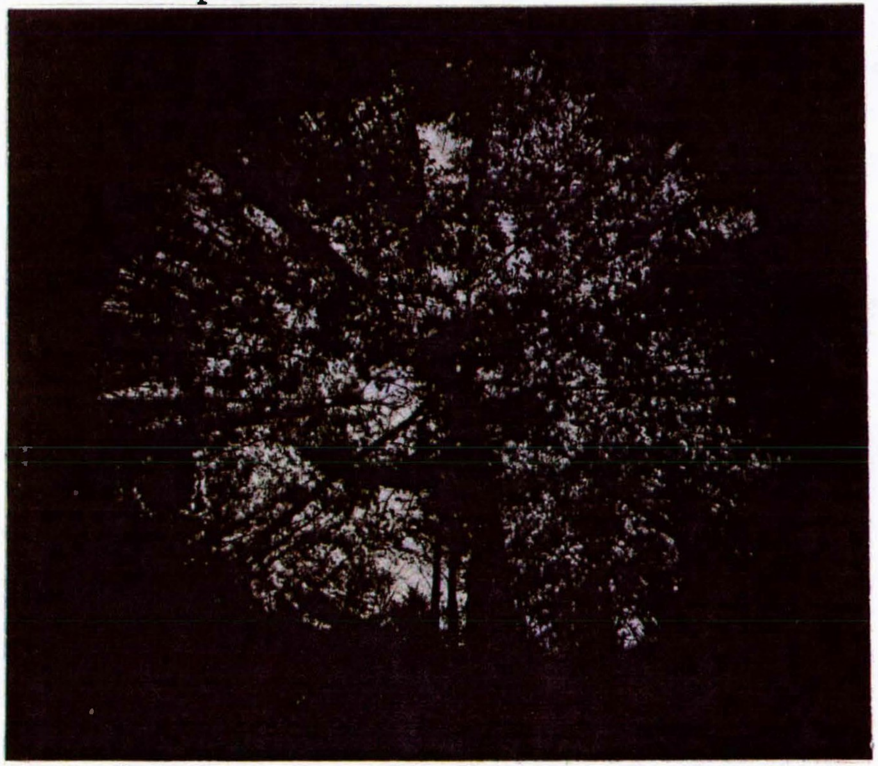


Figure G14: Plantation III established 1963. Plot #17b. Suppressed crop tree under trembling aspen competition.

Figure G15: Plantation III established 1963. Plot #12b. Intermediate crop tree under trembling aspen competition.

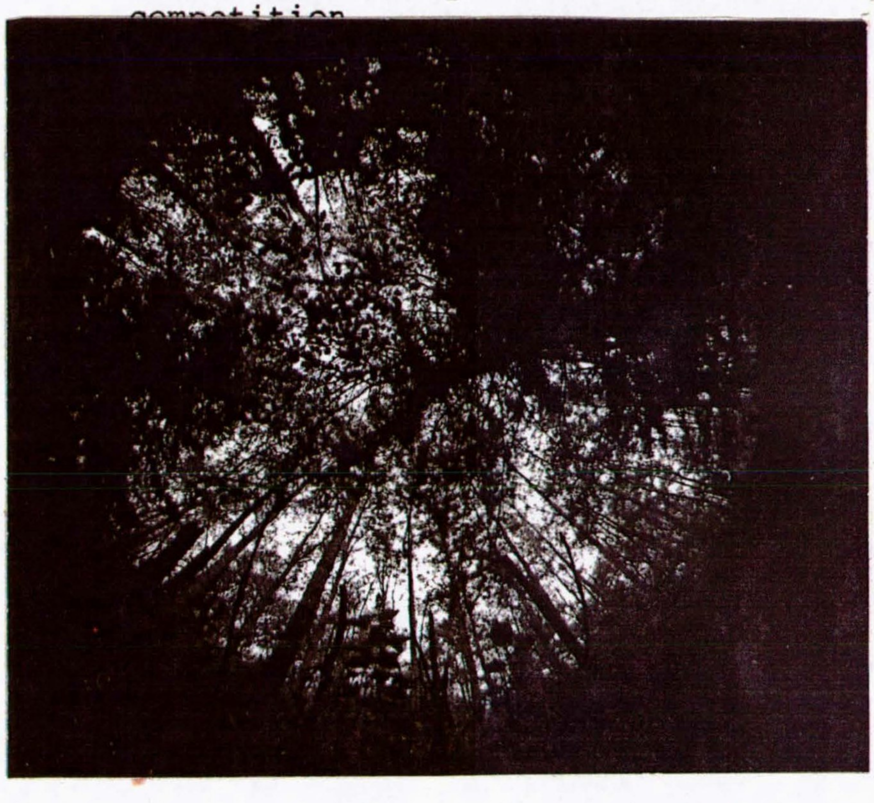


Figure G16: Plantation III established 1963. Plot #20b. Dominant crop tree under trembling aspen competition.

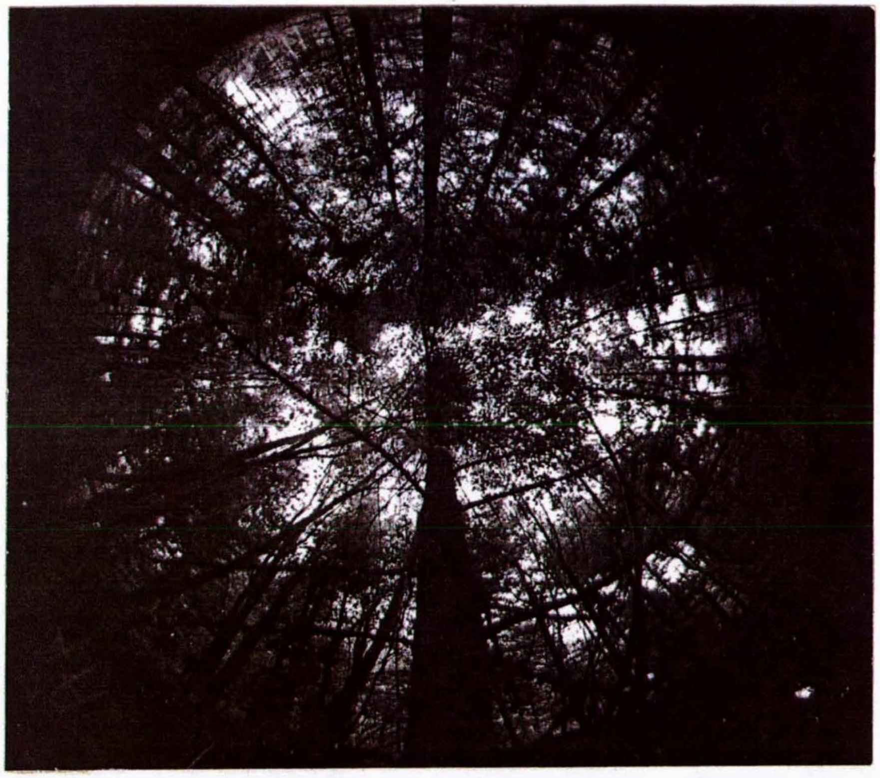


Figure G17: Plantation III established 1963. Plot #4a. Suppressed crop tree in pure white spruce stand.

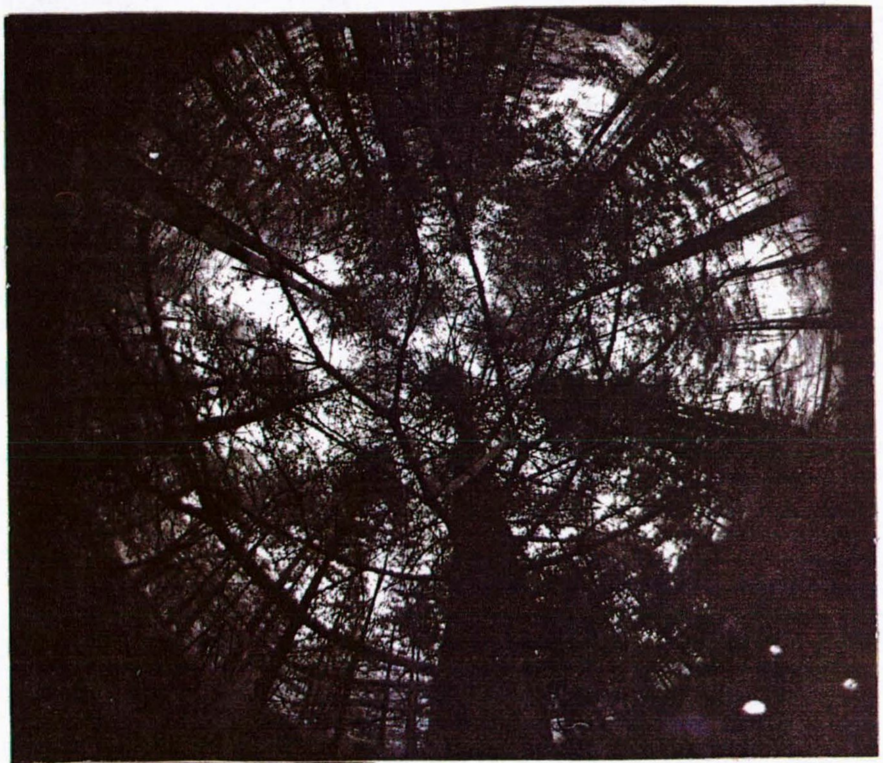


Figure G18: Plantation III established 1963. Plot #3a. Intermediate crop tree in pure white spruce stand.

Figure G19: Plantation III established 1963. Plot #5a. Dominant crop tree in pure white spruce stand.

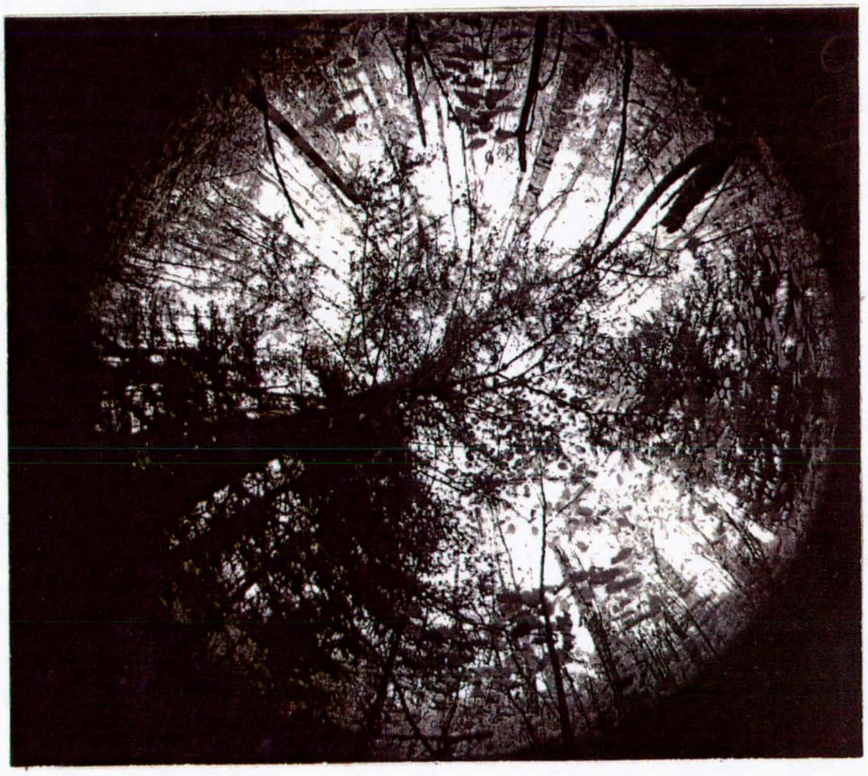


Figure G20: Plantation IV established 1953. Plot #13. Suppressed crop tree under trembling aspen competition.

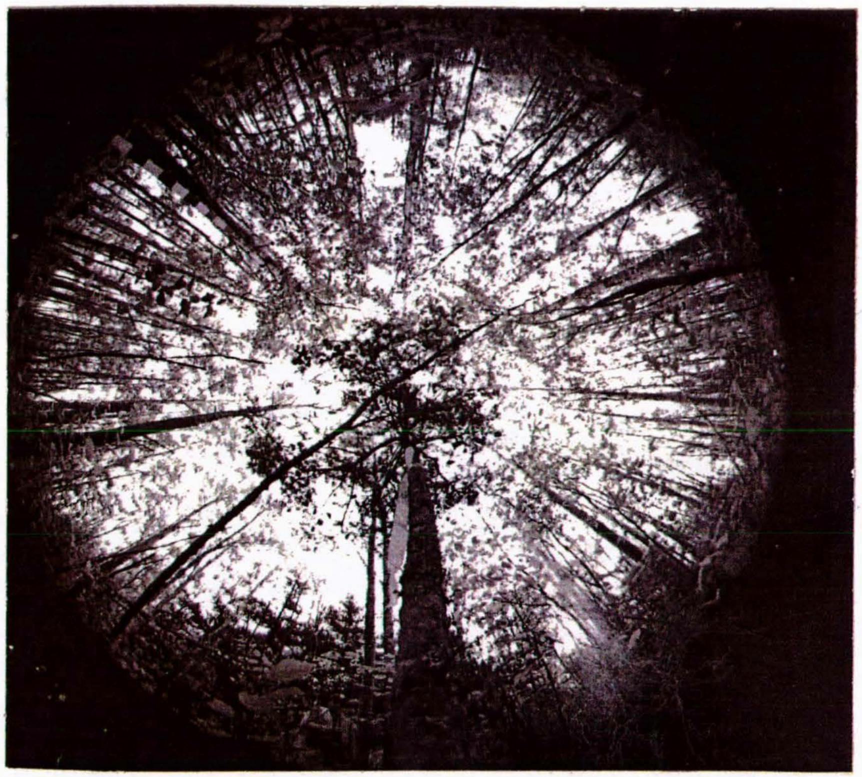


Figure G21: Plantation IV established 1953. Plot #16. Intermediate crop tree under trembling aspen competition.

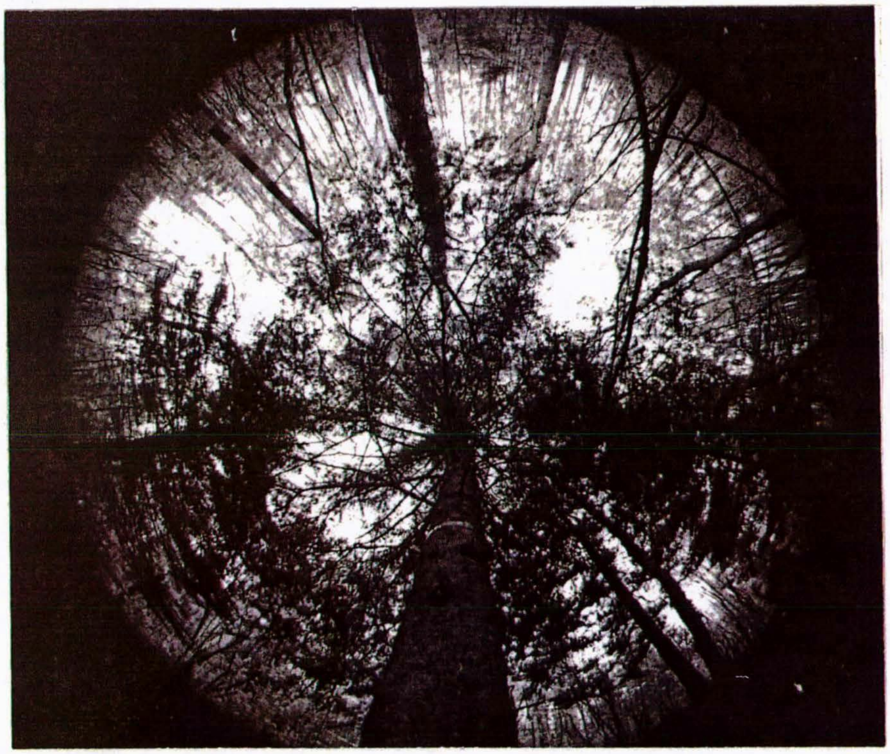


Figure G22: Plantation IV established 1953. Plot #15. Dominant crop tree under trembling aspen competition.

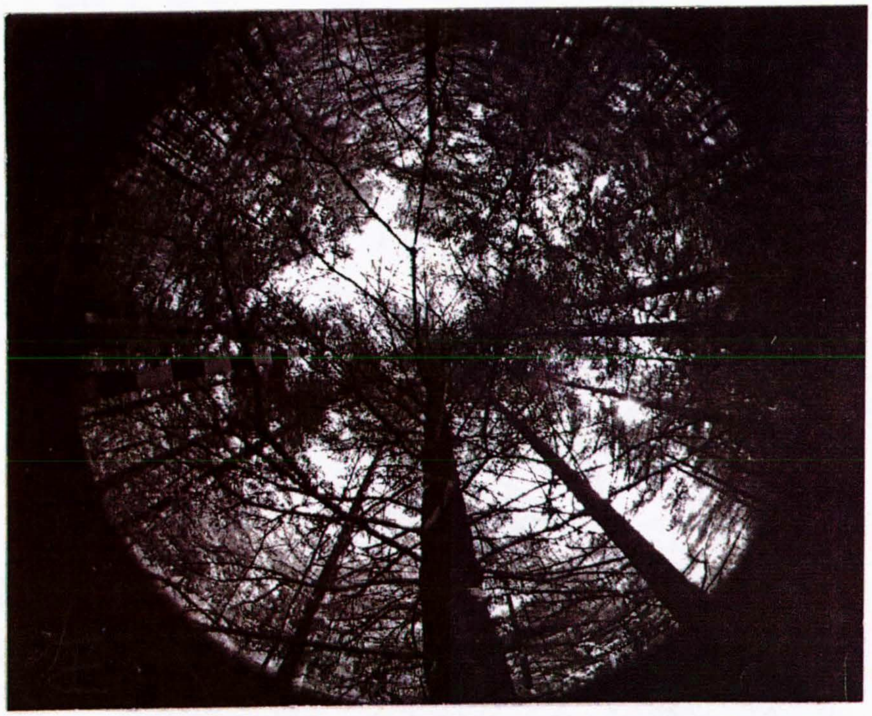


Figure G23: Plantation IV established 1953. Plot #1. Suppressed crop tree in pure white spruce stand.

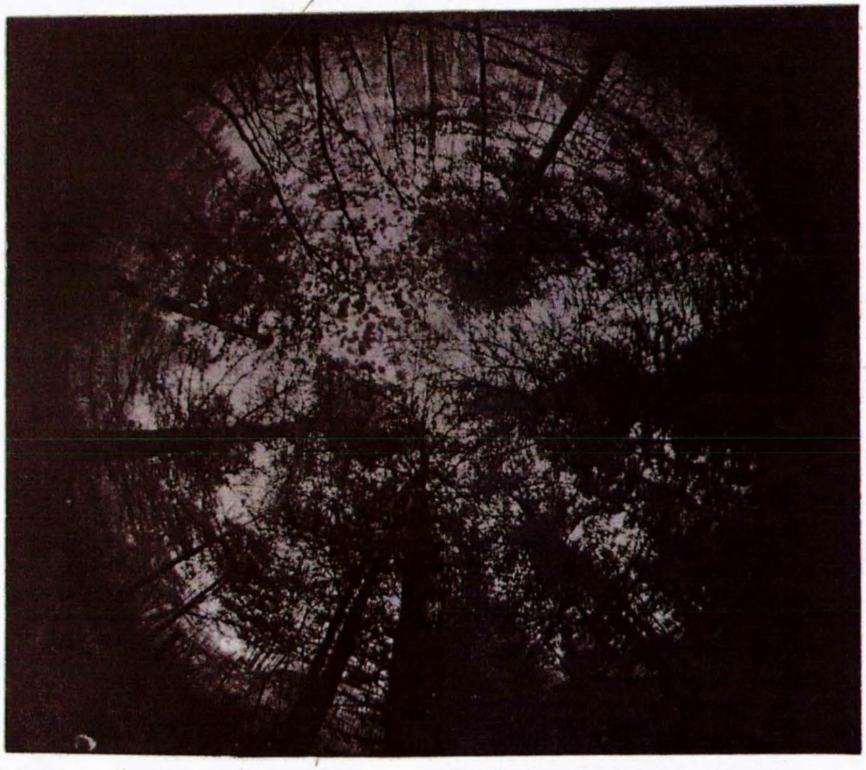


Figure G24: Plantation IV established 1953. Plot #6. Intermediate crop tree in pure white spruce stand.

Figure G25: Plantation IV established 1953. Plot #5a.
Dominant crop tree in pure white spruce stand.

Appendix H. Soil profile descriptions from plantations I, II, III, IV, arranged by seedling micro-site and/or presence of trembling aspen in the overstory.

Soil Profile Descriptions.

A profile pit was dug in every third sample plot and a soil profile was drawn. The depth of each soil horizon was measured, as well as the total rooting depth. Soil samples for determining bulk density, stone content, pH, organic matter and soil texture were taken in the centre of each major horizon. All soil profiles were described according to the guidelines outlined in the Canadian System of Soil Classification (1978).

Table H1. Soil profile description for corridor micro-site position in plantation I, established 1977.

Horizon	Depth (cm)	Description
Lf	1.0 - 0	Discontinuous deciduous leaf litter overlying mineral soil; few roots; abrupt smooth boundary.
AB	0 - 4.5	Light grey (2.5 YR/Y; medium sandy clay; friable; plentiful trembling aspen root suckers; discontinuous; clear wavy boundary; patches of LFH intermixed into this layer.
Bt	4.5 -14.5	Weak reddish-brown (7.5 YR 4/4 wet) clay; fine to medium angular blocky; plastic when wet; very hard when dry; many fine spruce roots in the top of the horizon.
Ck	14.5^+	Red clay (5 YR 4/3) with no silt varves; clay is massive and has blocky structure; hard when dry; contains small specks of red sandstone and few 1-2 cm pebbles.

Table H2. Soil profile description for spoilbank ledge micro-site position in plantation I, established 1977.

Horizon	Depth (cm)	Description
Lfh	1.5 - 0	Deciduous leaf litter (L); large numbers of small rootlets; decomposed amorphous organic matter (h); smooth boundary to underlying mineral soil.
Ae(discontinous)	0 - 5	Weak red (10 R 5/3) silty clay; course angular blocky; plastic when wet; friable and porous when dry; many large rounded rocks 20-30 cm diameter.
AB	5 - 23	Pale red (7.5 YR 5/4) silty clay loam; weak fine platy; friable; few small 0-2 cm diameter subangular blocky rocks.
Bt	23 - 35	Pale red (7.5 YR 5/4 silty clay; fine to medium angular blocky; plastic when wet; very hard when dry; coarse sand present in discontinuous bands.
Ck	35^+	Weak red (10 YR 4/4) clay and pale red (10 YR 6/3) varves; clay layers have pseudo-blocky structure; silt layers have fine platy structure; hard.

Table H3. Soil profile description for spoilbank micro-site position in plantation I, established 1977.

Horizon	Depth (cm)	Description
LFH	2 - 0	Deciduous leaf litter (L); large numbers of small rootlets; semi-decomposed amorphous organic matter (F); decomposed amorphous organic matter (H).
Aeh	0 - 11	Weak red (10 R 2/1) silty clay loam; course angular blocky; plastic when wet; hard when dry; many fine roolets and trembling aspen roots present; buried slash and decaying wood. Spoilbank was created by material from the corridor being piled on top of the original soil profile. A two-tiered condition was created with tier I - recently added organic and soil material; tier II - the underlying LFH layers present before corridoring.
AB	11 - 21	Pale red brown (5 YR 4/6) silty clay loam; weak fine platy; friable.
Bt	21 - 35	Deep red (7.5 YR 4/6 clay; fine to medium angular blocky; plastic when wet; hard when dry; coarse sand, fine gravel present.
ck	35^+	Reddish grey (10 YR 6/3) clay; blocky structure; hard. Weak red (10 YR 6/3) silt varies.

Table H4. Soil profile description for spoilbank micro-site position in plantation II, established 1971.

Horizon	Depth (cm)	Description
LFH	2 - 0	Deciduous leaf litter (L); semi-decomposed amorphous organic matter (F); decomposed amorphous organic matter (H).
Aeh	0 - 8	Very weak red (10 YR 2/1) silty clay loam; upper level pseudo-blocky to friable; remainder coarse angular blocky; plastic when wet, hard when dry; fine rootlets present.
AB	8 - 11	Reddish grey clay (10 YR 5/3) containing a large percentage by volume of decomposed slash and wood (10 YR 25 4/6); very friable.
BM	11 - 15	Charcoal layer (10 YR 2/1).
Bt_1	15 - 35	Reddish grey clay (10 YR 5/3)containing large rounded rocks; medium angular blocky; plastic when wet, hard when dry; coarse sand/fine gravel present; few faint mottles present.
Ck	35^+	Reddish grey clay (10 YR 5/3); massive to blocky structure; hard.

Table H5. Soil profile description for corridor micro-site position in plantation II, established 1971.

Horizon	Depth (cm)	Description
LFH	2 - 0	Root mat; Deciduous leaf litter (L) and partially decomposed litter (F); decomposed amorphous organic matter (H) overlying mineral soil; discontinous.
Aeh	0 - 7	Weak reddish-grey (10 YR 5/1) friable when dry silty clay; plastic when wet; trembling aspen roots present.
Btf	7 - 30	Weak red (7.5 YR 4/2) silty clay; coarse angular blocky; plastic when wet, hard when dry.
Ckg	30^+	Pale red (10 YR 6/1) clay; pseudo-blocky structure; faint mottles (7.5 YR 5/6); indistinct horizons; few gravel and small pebbles in clay. Ground water present at this depth (non-permanent).

Table H6. Soil profile description for areas of plantation III and IV containing trembling aspen-component, established 1963 and 1953 respectively.

Horizon	Depth (cm)	Description
LFH	2 - 0	Root mat; Deciduous leaf litter (L) and partially decomposed litter (F); decomposed amorphous organic matter (H) overlying mineral soil; discontinous.
Aeh	0 - 4.5	Grey-brown (10 YR 2/1) silty clay; granular, friable; many fine roots present 1-2 mm diameter and scattered larger lateral roots; horizon boundary wavy to indistinct.
AB	4.5 - 8	Indistinct horizon of varying thickness.
Btg	8 - 42	Deep brown (10 YR 5/4) silty clay; fine angular blocky; plastic when wet, hard when dry; a few low contrast mottles, 2-4 mm diameter 10 YR 6/2; small stone 2-4 cm diameter present; few vion stains. Water table present at 30 cm.
Cg	42 - 76	Purplish-grey (10 YR 4/4) silty clay; fine angular blocky; plastic when wet, hard when dry. Intermittent gleying and clay streaking.
Ckg	76^+	

Table H7. Soil profile description for plantation III and IV containing trembling aspen-component, established 1963 and 1953 respectively.

Horizon	Depth (cm)	Description
LFH	8 - 0	Root matter; conifer leaf litter (L) and very poorly developed partially decomposed litter (F); thick layer of decomposed amorphous organic matter (H) overlying mineral oil; continuous.
Aeh	0 - 4	Dark brown (7.5 YR 3/2) silty clay; granular, friable; many fine roots present and scattered larger lateral roots.
AB	4 - 8	Indistinct AB; wavy boundaries; reddish brown (2.5 YR 4/4) silty clay loam; fine angular blocky; plastic when wet, hard when dry; friable in upper portions.
Bt	8 - 42	Reddish to yellow (2.5 YR 4/4 - 10 YR 4/3) clay loam; fine angular blocky; plastic when wet, hard when dry; few small stones (red sandstone).
Ckg	42^+	Purplish-grey clay loam; coarse angular blocky; plastic when wet; hard when dry; calcareous.

Appendix I. Physical and chemical soil properties for soils sampled in plantations I, II, III, IV, arranged by seedling micro-site position and/or presence of trembling aspen in the overstory.

Soils Analyses

Bulk Density.

Bulk density refers to the weight of oven-dry material per unit volume. It is closely correlated with porosity, infiltration capacity, and degree of aeration. The field sampling procedure, laboratory methods and calculations followed Wilde *et al.* (1972) and Thrower and Schmidt (1985).

Water Holding Capacity.

The water holding capacity of a soil is usually expressed as field capacity. This refers to the percent by volume of the soil that is occupied by water that has not drained away by gravity 24 hours after the soil has been saturated. Low water holding capacity soils are prone to drought while soils with a high capacity suffer from poor aeration due to water logging. The field and laboratory methods follow Wilde *et al.* (1972) and Thrower and Schmidt (1985).

Soil Texture.

Soil texture influences the water holding capacity and nutrient status of the soil. A modified Bouyocous hydrometer method was used in which 50 gram soil samples were required due to their obviously fine texture. Methodology and calculations followed Thrower and Schmidt (1985).

Soil Organic Matter Content.

The presence of organic matter in the soil is of vital importance when considering its physical, biological and chemical parameters. The wet combustion method was used for determining organic matter content. This method determines the organic matter content through the quantitative measurement of the carbon oxidization of the organics in the soil when an oxidizing agent is added. Procedures followed that of Wilde *et al*. (1972) and Thrower and Schmidt (1985).

Table I1: Physical and chemical soil properties for soils sampled from plantation I, established 1977, by seedling micro-site position.

Parameter	Micro-site position Corridor	 Spoilbank ledge	 Spoilbank
% Sand - Ae	12.50	9.14	13.31
% Silt - Ae	11.11	13.76	12.31
% Clay - Ae	76.39	77.10	74.38
% Sand - Bt	11.00	10.23	10.82
% Silt - Bt	10.34	14.82	10.36
% Clay - Bt	78.66	64.72	78.82
% Organic matter - Ae	6.66	17.05	13.18
% Organic matter - Bt	5.53	8.48	12.78
Bulk density - Ae	1.667	1.617	1.410
Bulk density - Bt	1.944	1.966	2.211
Water holding - Ae	34.20	42.10	39.20
capacity - Bt	29.80	36.00	29.90
Active pH - Ae	4.90	4.80	4.70
Active pH - Bt	5.00	4.80	4.90
Reserve pH - Ae	4.10	4.10	3.90
Reserve pH - Bt	5.50	4.20	4.10
% Pore space - Bt	58.70	64.40	59.10
Active pH - C	5.10	5.40	5.10
Number of samples	3	4	3

Table I2: Physical and chemical soil properties for soils sampled from plantation 11, established 1971, by seedling micro-site position.

Parameter	Micro-site position Corridor	 Spoilbank
% Sand - Ae	11.89	12.55
% Silt - Ae	17.25	22.78
% Clay - Ae	70.86	64.67
% Sand - Bt	14.87	10.54
% Silt - Bt	14.80	17.03
% Clay - Bt	70.33	72.43
% Organic matter - Ae	4.68	9.43
% Organic matter - Bt	5.03	3.87
Bulk density - Ae	1.276	0.927
Bulk density - Bt	1.409	0.968
Water holding - Ae	44.30	41.40
capacity - Bt	39.70	37.20
Active pH - Ae	4.50	4.60
Active pH - Bt	5.70	4.60
Reserve pH - Ae	4.40	4.60
Reserve pH - Bt	4.30	3.80
Active pH - C	5.70	5.20
Reserve pH - C	4.80	4.30
Number of samples	5	4

Table I3 Physical and chemical soil properties for soils sampled from plantation 111, established 1963, by white spruce crop tree crown classes and presence/absence of trembling aspen.

Parameter	All crown classes Mixed wood spruce & aspen	Pure spruce
% Sand - Ae	11.00	10.19
% Silt - Ae	10.35	8.25
% Clay - Ae	78.65	81.56
% Sand - Bt	11.76	15.06
% Silt - Bt	12.83	9.60
% Clay - Bt	75.43	75.34
% Organic matter - Ae	13.19	11.75
% Organic matter - Bt	4.96	4.28
Bulk density - Ae	1.400	1.635
Bulk density - Bt	1.993	1.997
Water holding - Ae	25.40	23.20
capacity - Bt	22.70	19.50
Active pH - Ae	5.20	4.40
Active pH - Bt	5.10	4.00
Reserve pH - Ae	5.20	4.30
Reserve pH - Bt	5.10	3.10
Active pH - C	5.50	4.60
Reserve pH - C	5.40	4.80
Number of samples	3	2

Table I4: Physical and chemical soil properties for soils sampled from plantation 1V, established 1953, by white spruce crop tree crown classes and presence/absence of trembling aspen.

	All crown classes	
Parameter	Mixed wood spruce & aspen	Pure spruce
% Sand - Ae	15.40	17.92
% Silt - Ae	25.77	27.29
% Clay - Ae	59.09	54.79
% Sand - Bt	25.75	28.35
% Silt - Bt	19.62	18.42
% Clay - Bt	54.63	52.23
% Organic matter - Ae	15.12	14.61
% Organic matter - Bt	5.29	4.36
Bulk density - Ae	1.655	1.523
Bulk density - Bt	1.986	2.060
Water holding - Ae	32.10	36.90
capacity - Bt	22.70	25.30
Active pH - Ae	5.00	4.90
Active pH - Bt	5.10	5.40
Reserve pH - Ae	4.50	4.20
Reserve pH - Bt	4.00	4.20
Active pH - C	5.30	5.60
Reserve pH - C	4.30	4.40
Number of samples	5	5

Appendix J. Species list for plantations I, II, III, IV

Appendix J

Species list for plantations (I, II, III, IV)

(*Denotes presence in all plantations)

Grasses

Bromus ciliatus L (I, III)
Calamagrostis canadensis Michx. (Nutt.) *
Carex spp. *
Oryzopsis pungens (Torr.) Hitch. (I, II)
Scirpus cyperinus (L.) Knuth (I, II)

Ferns, Lichens, Mosses

Athyrium felix-femina (L.) Roth (II, III, IV)
Aulacomium palustre (Hedw.) Schwaegr. (I, II, III)
Brachythecium curtum (Lindb.) Limpr. (I)
Brachythecium oxycladon (Bred.) Jaeg. & Saverb. *
Dicranum fuscescens Turn. *
Dicranum polysetum Sw. (I, II, III)
Dryopteris spinulosa (O. F. Muell) (II, III, IV)
Equisetum pratense Ehrh. (II)
Equisetum sylvaticum L. (II, III, IV)
Hylocomium splendens (Hedw.) BSG. *
Lycopodium annotinum L. (IV)
Lycopodium clavatum L. (I)
Lycopodium obscurum L. (I, III, IV)
Pleurozium schreberi (BSG) Mitt. *
Polytrichum commune Hedw. *
Polytrichum juniperum Hedw. *
Pteridium aquilinum (L.) Kuhn (III, IV)
Ptilium crista-castrensis (Hedw.) De Not (I, II, III)

Herbs

Achillea millefolium L. *
Actaea rubra (Ait.) Willd. (II, IV)
Anaphalis margaritacea var. occidentalis Greene (I, II, III)
Anemone quinquefolia L. *
Aster ciliolatus Lindl. (I)
Aster laevis L. (I, II, III)
Aster macrophyllus L. *
Aster praealtus Lindl. *
Aster umebellatus Mill. (I, II, III)
Cerastium vulgatum L. *
Cirsuim arvense L. *
Clintonia borealis (Ait.) Raf. *
Coptis groenlandica (Oeder) Fern. *
Cornus canadensis L. (I, II)

Appendix J (cont.)

Epilobium angustifolium L. *
Erigeron spp. *
Fragraria virginana Duchesne (I, II, III)
Galium triflorum Michx. *
Lathyrus ochroleucus Hook. (II, III)
Maianthemum canadense Desf. *
Melampyrum lineare Desr. *
Mentha arvense L. *
Mertensia paniculata (Ait.) G. Don (II, III, IV)
Mitella nuda L. *
Petasites palmatus (Ait.) Gray *
Plantago major L. (I, II, III)
Polygonium persicara Michx. (III, IV)
Smilacina stellata (L.) Desf. *
Solidago canadensis L. (I, II, III)
Solidago hispida Muhl. (I, II, III)
Solidago uliginosa Nutt. (I)
Streptopus roseus Michx. (II, III, IV)
Taraxacum officinale Weber (I, II, III)
Trientalis borealis Raf. *
Trifolium repens L. (I, II, III)
Viccia americana Muhl. (I)
Viola canadensis L. *
Viola incognita Brainerd (I)

Shrubs and Seedlings

Abies balsamea (L.) Mill. *
Acer spicatum Lam. (I, III, IV)
Alnus rugosa (II, III, IV)
Amelanchier spp. (III, IV)
Alnus crispa (Ait.) Pursh (IV)
Betula papyrifera Marsh. *
Corylus cornuta Marsh. *
Diervilla lonicera Mill. *
Lonicera canadensis Bartr. *
Picea glauca (Moench.) Voss *
Picea mariana (Mill.) BSP. (I, III, IV)
Populus tremuloides Michx. *
Prunus pensylvanica L. (II, III, IV)
Prunus virginana L. (II, III, IV)
Ribes glandulosum Grauer *
Rosa acicularis Lindl. (I, II, III)
Rubus idaeous L. *
Rubus pubescens Raf. *
Salix bebbiana Sarg. (I, II)
Salix discolour Mohl. (I, II, IV)
Vaccinium angustifolium Ait. (I)
Vaccinium myrtylloides Michx. (I, II, III)
Viburnium edule (Michx.) Raf. (II)
Viburnium trilobum Marsh (II, III)

Appendix K. SCSS (Nie *et al*. 1980) computer output for regression analysis associated with the prediction of white spruce crop tree biomass from edaphic and biological factors (data from plantations I, II, III, IV).

Table K1. Regression analyses for white spruce stemwood dry weight (kg) as related to several edaphic and biological variables for plantations I, II, III and IV (combined).

(a) Regression equation: White spruce stemwood dry weight (kg) = 28.85494 + 0.32107 (Sand) - 20.94525 (Bulk Density) + 0.61684 (OM) - 0.16347 (Potht) - 0.61643 (Depth) + 0.62835 (WHC) - 14.90578 (pH) + 1.09625 (Age)

(b) Regression statistics: Multiple R = 0.91776 R Square = 0.84228 Adjusted R Square = 0.82690

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	8	3160.838	395.10480
Residual	82	591.859	7.21779
Total	90		

(d) Variables in equation:

Variable-in		Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
(Sand)	Percentage of sand in soil (%)	0.32107	0.31156	0.479
(BD)	Bulk density (gm/cm^3)	-20.94525	-1.11709	-0.721
(OM)	Percentage of organic matter in Ae (%)	0.61684	0.19175	0.316
(Potht)	Height of dominant trembling aspen (m)	-0.16347	-0.11213	-0.184
(Depth)	Depth of rooting zone (cm)	-0.66413	-0.66926	-0.648
(WHC)	Water holding capacity (%)	0.62835	0.51340	0.581
(pH)	pH	-14.90375	-0.43261	-0.377
(Age)	Age (years)	1.09625	1.17568	0.813

Table K2. Regression analyses for white spruce foliage dry weight (kg) as related to several edaphic and biological variables for plantations I, II, III and IV (combined).

(a) Regression equation: White spruce foliage dry weight (kg) = 6.06639 + 0.05652 (Sand) - 20.94525 (Bulk Density) + 0.61684 (OM) - 0.16347 (Potht) - 0.66143 (Depth) + 0.62835 (WHC) - 14.90578 (pH) + 1.09625 (Age)

(b) Regression statistics: Multiple R = 0.92491 R Square = 0.85546 Adjusted R Square = 0.84136

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	8	105.865	13.23313
Residual	82	17.887	0.21814
Total	90		

(d) Variables in equation:

Variable-in	Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
(Sand) Percentage of sand in soil (%)	0.56520	0.30201	0.483
(BD) Bulk density (gm/cm^3)	-3.24509	-0.95307	-0.679
(OM) Percentage of organic matter in Ae (%)	0.07452	0.12756	0.225
(Potht) Height of dominant trembling aspen (m)	-0.05663	-0.21390	-0.350
(Depth) Depth of rooting zone (cm)	-0.09418	-0.52264	-0.570
(WHC) Water holding capacity (%)	0.08945	0.40245	0.505
(pH) pH	-2.71349	-0.43368	-0.392
(Age) Age (years)	0.21473	1.26811	0.844

Table K3. Regression analysis for white spruce total tree dry weight (kg) as related to several edaphic and biological factors in plantations I, II, III and IV (combined).

(a) Regression equation:

White spruce total tree dry weight (kg) = 8.53917 + 9.492 x 10^{-3} (Cover) + 0.12586 (Pltden) + 0.54446 (Aspen) - 0.15096 (WHC) + 0.16077 (Sand) + 0.18912 (OM) - 0.05374 (IT) + 1.821 x 10^{-3} (ComVeg) - 3.45547 (BD) - 3.80315 (pH) - 1.0531 (Potht) + 0.60783 (Age)

(b) Regression statistics: Multiple R = 0.85554 R Square = 0.73195 Adjusted R Square = 0.69017

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	12	2022.692	168.5577
Residual	17	740.745	9.6200
Total	29		

(d) Variables in equation:

Variable-in		Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
(Cover)	Percentage cover of crop tree by competing vegetation (%)	-9.492 x 10^{-3}	-0.04442	-0.060
(Pltden)	Plot density	0.12586	0.44013	0.287
(Aspen)	Density of trembling aspen in plot	0.54446	0.08738	0.120
(WHC)	Water holding capacity of soil (%)	-0.15096	-0.13908	-0.115
(Sand)	Percentage sand in soil (bulked)(%)	0.16077	0.18077	0.226
(OM)	Percentage organic matter in Ae horizon (%)	0.18912	0.06468	0.079
(IT)	Inter-tree spacing	-0.05374	7.36 x 10^{-3}	-0.009
(ComVeg)	Biomass of competing vegetation (kg)	1.821 x 10^{-3}	0.35095	0.328
(BD)	Bulk density of soil (gm/cm3)	-3.45547	-0.21328	-0.212
(pH)	pH	-3.80315	-0.12861	-0.109
(Potht)	Height of dominant trembling aspen (m)	-1.05310	-0.83971	-0.585
(Age)	Age (years)	0.60783	0.72024	0.403

Appendix L. SCSS (Nie <u>et</u> <u>al</u>. 1980) computer output for regression analysis associated with the prediction of white spruce crop tree biomass from edaphic and biological factors (data from plantations I, II,III and IV).

Table L1. Regression analysis for white spruce stemwood dry weight (kg) as related to several edaphic and biological factors in plantations I and II (combined).

(a) Regression equation:

White spruce stemwood dry weight (kg) $= 0.36715 + 8.008 \times 10^{-3}$ (Depth) $- 0.022969$ (OM)
$- 0.01239$ (WHC) $- 0.002649$ (POtveg) $+ 0.03766$ (Age)
$+ 0.002593$ (ComVeg)

(b) Regression statistics: Multiple R = 0.85492 R Square = 0.73089 Adjusted R Square = 0.70877

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	6	1.151	0.19191
Residual	73	0.424	0.00581
Total	79		

(d) Variables in equation:

	Variable-in	Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
(Depth)	Depth of rooting zone (cm)	8.008×10^{-3}	0.38575	0.525
(OM)	Percentage organic matter in Ae horizon (%)	-0.02269	-0.25597	-0.406
(WHC)	Water holding capacity (%)	-0.01239	-0.31079	-0.368
(POtveg)	Biomass of competing trembling aspen on plot (kg)	-2.649×10^{-3}	-0.29355	-0.249
(Age)	Age (years)	0.03766	0.64957	0.477
(ComVeg)	Biomass of competing vegetation on plot (kg)	2.593×10^{-3}	0.50110	0.291

Table L2. Regression analysis for white spruce foliage dry weight (kg) as related to several edaphic and biological factors in plantations I and II (combined).

(a) Regression equation: White spruce foliage dry weight (kg) = 0.4025 + 0.1116 (Depth) - 0.02740 (OM) - 0.01423 (WHC) - 0.01872 (PotVeg) + 0.04918 (Age) + 0.002012 (ComVeg)

(b) Regression statistics: Multiple R = 0.80712 R Square = 0.65145 Adjusted R Square = 0.6228

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	6	1.732	0.28868
Residual	73	0.927	0.01269
Total	79		

(d) Variables in equation:

Variable-in		Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
(Depth)	Depth of rooting zone (cm)	0.0116	0.41379	0.556
(OM)	Percentage organic matter in Ae horizon (%)	-0.02740	-0.23788	-0.352
(WHC)	Water holding capacity (%)	-0.01423	-0.27485	-0.293
(POtveg)	Biomass of competing trembling aspen on plot (kg)	-0.01872	-0.15754	-0.201
(Age)	Age (years)	0.04918	0.65305	0.428
(ComVeg)	Biomass of competing vegetation on plot (kg)	2.012×10^{-3}	0.29932	0.226

Table L3. Regression analysis for white spruce tree dry weight (kg) as related to several edaphic and biological factors in plantations I and II (combined).

(a) Regression equation: White spruce total dry weight (kg) = 7.89241 + 0.001712 (Cover) + 0.02590 (Depth) - 0.10736 (OM) + 0.002783 (Aspen) - 0.06128 (WHC) - 0.008068 (PotVeg) + 0.02147 (IT) - 0.03298 (Potht) + 0.07581 (Age) + 0.00291 (Pltden) + 0.008693 (ComVeg)

(b) Regression statistics: Multiple R = 0.8479 R Square = 0.72 Adjusted R Square = 0.67

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	12	12.516	1.04296
Residual	67	4.894	0.07305
Total	79		

(d) Variables in equation:

Variable-in		Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
(Cover)	Percentage cover of crop tree by competing vegetation (%)	1.712×10^{-3}	-0.7965	0.129
(Depth)	Depth of rooting zone (cm)	0.02590	0.37529	0.459
(OM)	Percentage organic matter in Ae horizon (%)	-0.10736	-0.36427	-0.354
(Aspen)	Trembling aspen density in plot	2.783×10^{-3}	5.447×10^{-3}	0.007
(WHC)	Water holding capacity of soil (%)	-0.06128	-0.46242	-0.335
(PotVeg)	Biomass of competing aspen on plot (kg)	-8.06×10^{-3}	-0.26896	-0.171
(IT)	Inter-tree spacing	0.02147	0.03451	0.039
(Potht)	Height of dominant trembling aspen (m)	-0.03298	-0.10849	-0.122
(Age)	Age of white spruce (years)	0.07581	0.39337	0.203
(Pltden)	Plot density of all stems	2.911×10^{-3}	0.07967	0.057
(ComVeg)	Biomass of competing vegetation (kg)	8.693×10^{-3}	0.50529	0.280

Appendix M. SCSS (Nie *et al*. 1980) computer output for regression analysis associated with the prediction of white spruce crop tree size (Rcd, Dbh, Ht) and component dry weights from dry weights of competing vegetation located around the crop trees.

Table M1. Regression analysis of white spruce tree root collar diameter (cm) as related to the dry weight of surrounding competing vegetation (all plantations combined).

(a) Regression equation: White spruce root collar diameter (cm) = 1.14638 + 3.32209 (Spruce) + 0.28405 (Trembling aspen) + 1.48365 (Shrubs) + 0.51797 (*Aster*) - 2.98179 (*Rosa*) - 0.11956 (*Rubus*) + 0.19167 (Graminoids) - 1.87081 (Herbs)

(b) Regression statistics: Multiple R = 0.92563 R Square = 0.85679 Adjusted R Square = 0.84299

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	8	629.864	78.73297
Residual	83	105.277	1.26840
Total	91		

(d) Variables in equation:

Variable-in	Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
White spruce biomass	3.32209	0.88250	0.907
Trembling aspen biomass	0.28405	0.30354	0.535
Shrub biomass	1.48365	0.11907	0.293
Aster biomass	0.51797	5.217×10^{-3}	0.012
Rosa biomass	-2.98179	-0.03195	-0.081
Rubus biomass	-0.11956	-2.341×10^{-3}	0.005
Graminoid biomass	-0.19167	0.01085	0.026
Herb biomass	-1.14638	-0.08829	-0.166

Table M2. Regression analysis of white spruce tree height (m) as related to the dry weight of surrounding competing vegetation (all plantations combined).

(a) Regression equation: White spruce height (m) = 0.59063 + 2.47074 (Spruce) + 0.19096 (Trembling aspen) + 0.84193 (Shrubs)

(b) Regression statistics: Multiple R = 0.94906 R Square = 0.90071 Adjusted R Square = 0.89732

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	3	349.138	116.38613
Residual	88	38.491	0.43739
Total	91		

(d) Variables in equation:

Variable-in	Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
White spruce biomass	2.47074	0.90385	0.944
Trembling aspen biomass	0.19096	0.28101	0.665
Shrub biomass	0.84193	0.09305	0.282

Table M3. Regression analysis of white spruce foliage dry weight (kg) as related to dry weight of surrounding competing vegetation (all plantations combined).

(a) Regression equation:

White spruce foliage dry weight (kg) = 0.02583 + 1.37375 (Spruce) + 0.06448 (Trembling aspen)
+ 0.23304 (Shrubs) + 0.4221 (*Aster*) - 0.71272 (*Rosa*)
- 0.31214 (*Rubus*) - 0.13315 (Graminoids)
- 1.16513 (Herbs)

(b) Regression statistics: Multiple R = 0.87781 R Square = 0.77055 Adjusted R Square = 0.74944

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	8	100.089	12.51117
Residual	83	29.804	0.35908
Total	91		

(d) Variables in equation:

Variable-in	Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
White spruce biomass	1.37375	0.86817	0.858
Trembling aspen biomass	0.64480	0.16392	0.261
Shrub biomass	0.23304	0.04449	0.090
Aster biomass	0.42210	1.011 x 10^{-3}	0.002
Rosa biomass	-0.71272	-0.01817	-0.036
Rubus biomass	0.31214	0.14540	0.026
Graminoid biomass	-0.13315	-0.01793	-0.033
Herb biomass	-1.16513	-0.13081	-1.930

Table M4. Regression analysis of white spruce branchwood and bark dry weight (kg) as related to dry weight of surrounding competing vegetation (all plantations combined).

(a) Regression equation: White spruce branchwood and bark dry weight (kg) = -0.10908 + 1.97128 (Spruce) - 1.82848 (Shrubs) + 0.15478 (Aspen)

(b) Regression statistics: Multiple R = 0.87190 R Square = 0.76021 Adjusted R Square = 0.75194

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	3	202.887	67.628
Residual	87	63.996	0.736
Total	90		

(d) Variables in equation:

Variable-in	Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
White spruce biomass	1.97128	0.86877	0.871
Shrub biomass	-1.82848	-0.13594	-0.221
Trembling aspen biomass	0.15478	0.18788	0.299

Appendix N. SCSS (Nie *et al*. 1980) computer output for regression analysis associated with the prediction of crown foliage efficiency of white spruce crop trees.

Table N1. Regression analysis of white spruce crown foliage efficiency (mean annual dcm^3/kg foliage) as related to several edaphic and biological factors.

(a) Regression equation: Mean annual dcm^3 wood/kg foliage = 0.13430 + 0.13100 (Spruce height) - 0.02547 (total dry weight aspen/m^2) + 0.01275 (inter-tree spacing) - 0.001862 (total tree foliage dry weight/plot) + 0.01433 (Plot density) + 0.19774 (total dry weight of trees/plot) + 0.17915 (Aspen density/plot) + 0.13430 (total dry weight competing vegetation/plot)

(b) Regression statistics: Multiple R = 0.92804 R Square = 0.86125 Adjusted R Square = 0.80283

(c) Regression A.N.O.V.A.:

Term	Degrees of Freedom	Sum of Squares	Mean Square
Regression	8	7.958	0.99475
Residual	19	1.282	0.06747
Total	27		

(d) Variables in equation:

Variable-in	Unstandardized regression coefficients	Standardized regression coefficients	Partial regression coefficients
Spruce height	0.13100	0.70778	0.111
Trembling aspen biomass/m^2	-0.02547	-0.15332	-0.058
Inter-tree spacing	0.01275	0.02049	0.045
Total tree foliage biomass/plot	-1.862×10^{-3}	-0.99204	-0.700
Plot density	-0.01433	-0.60597	-0.306
Total tree biomass/plot	0.19774	1.66084	0.710
Trembling aspen density/plot	0.17915	0.60871	0.328
Total biomass competing vegetation/plot	-0.07237	-0.50917	-0.210

Appendix O. Polar ordinations for sample plots situated in plantations I, II, III, IV.

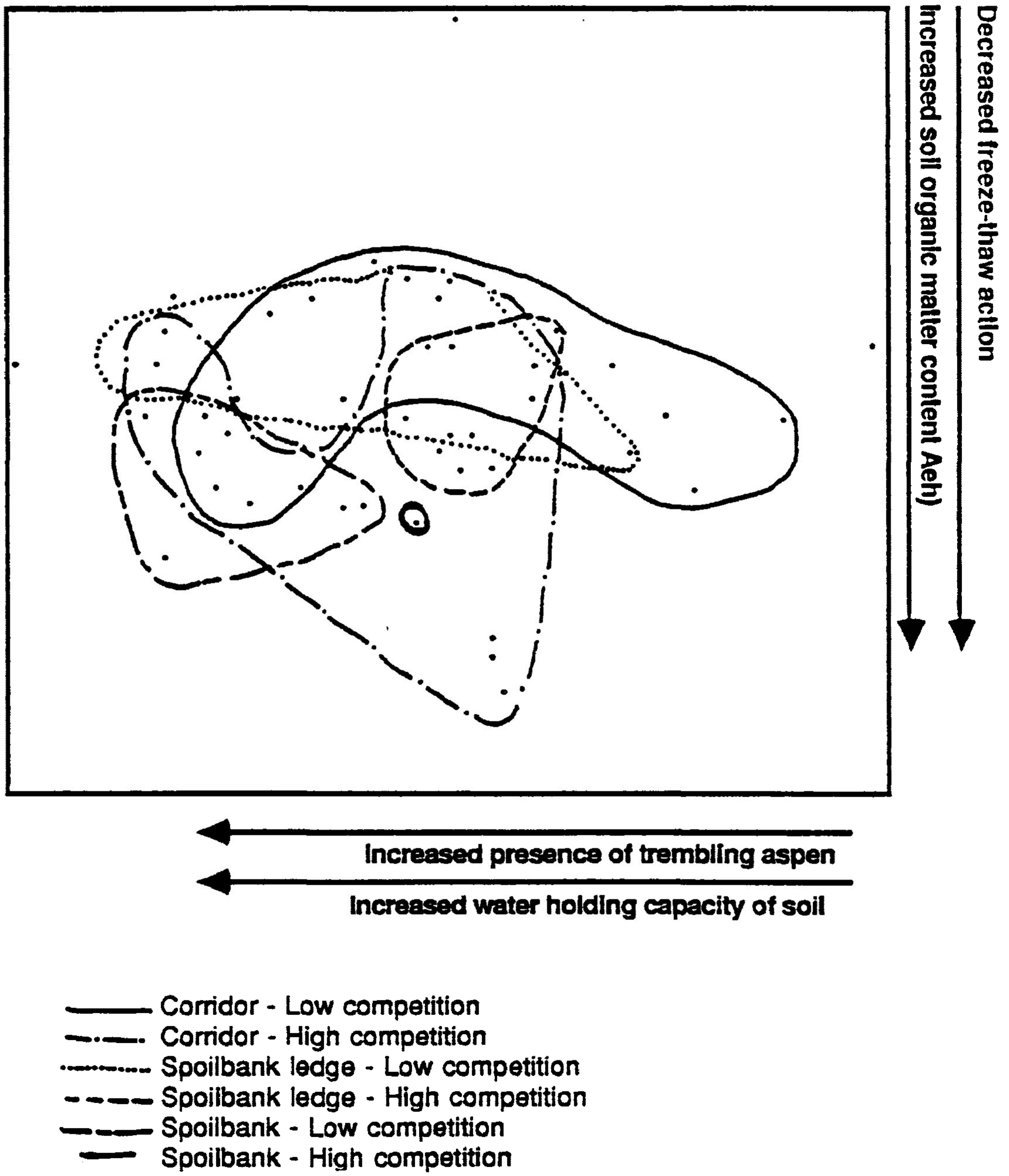


Figure 01. Polar ordination (centred and relativized) for sample plots in plantation I (age 4 years). Boundaries indicate clusters of plots from similar micro-sites / trembling aspen density situations.

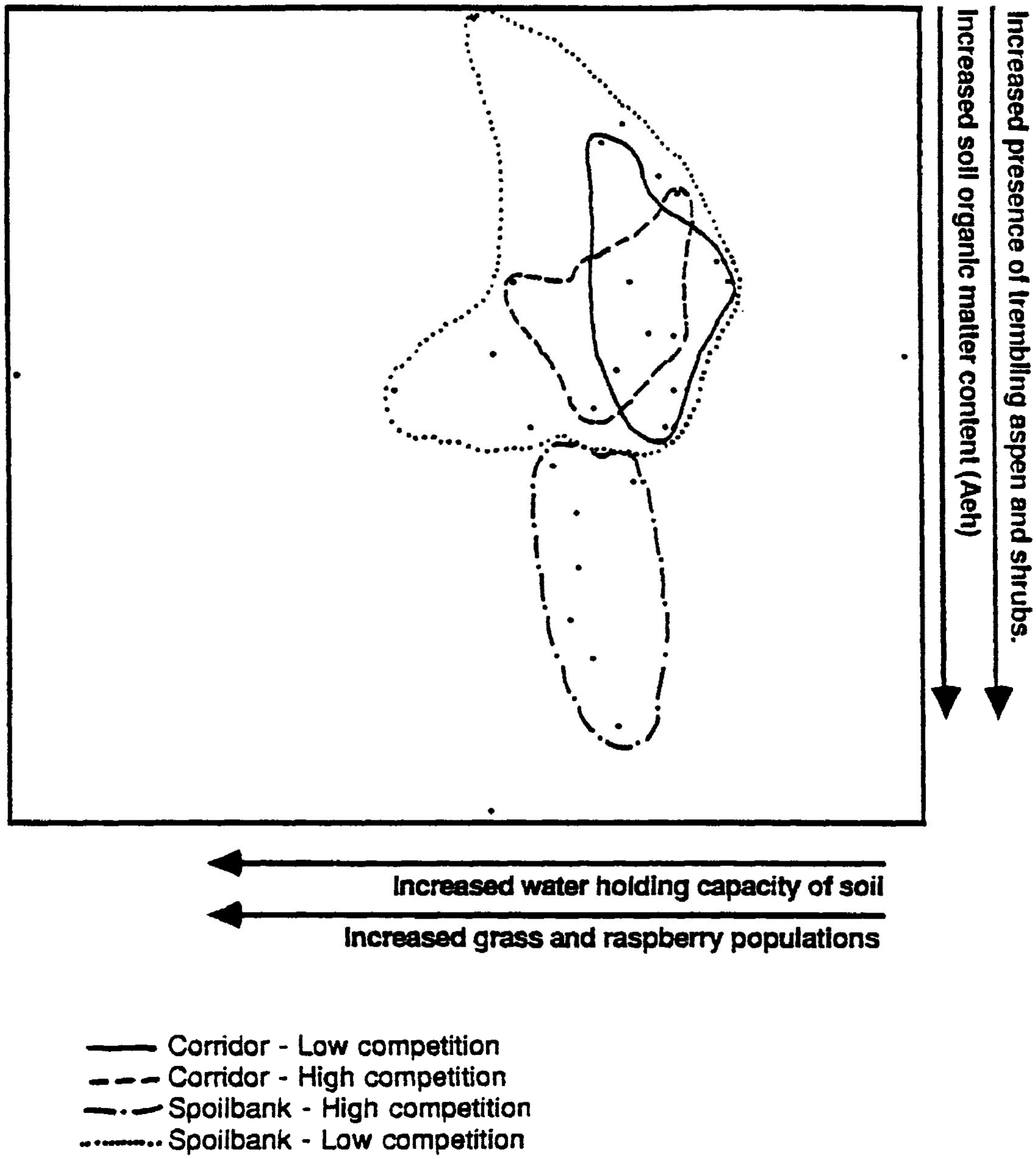


Figure 02. Polar ordination (centred and relativized) for sample plots in plantation II (age 10 years). Boundaries indicate clusters of plots from similar micro-site / trembling aspen density situations.

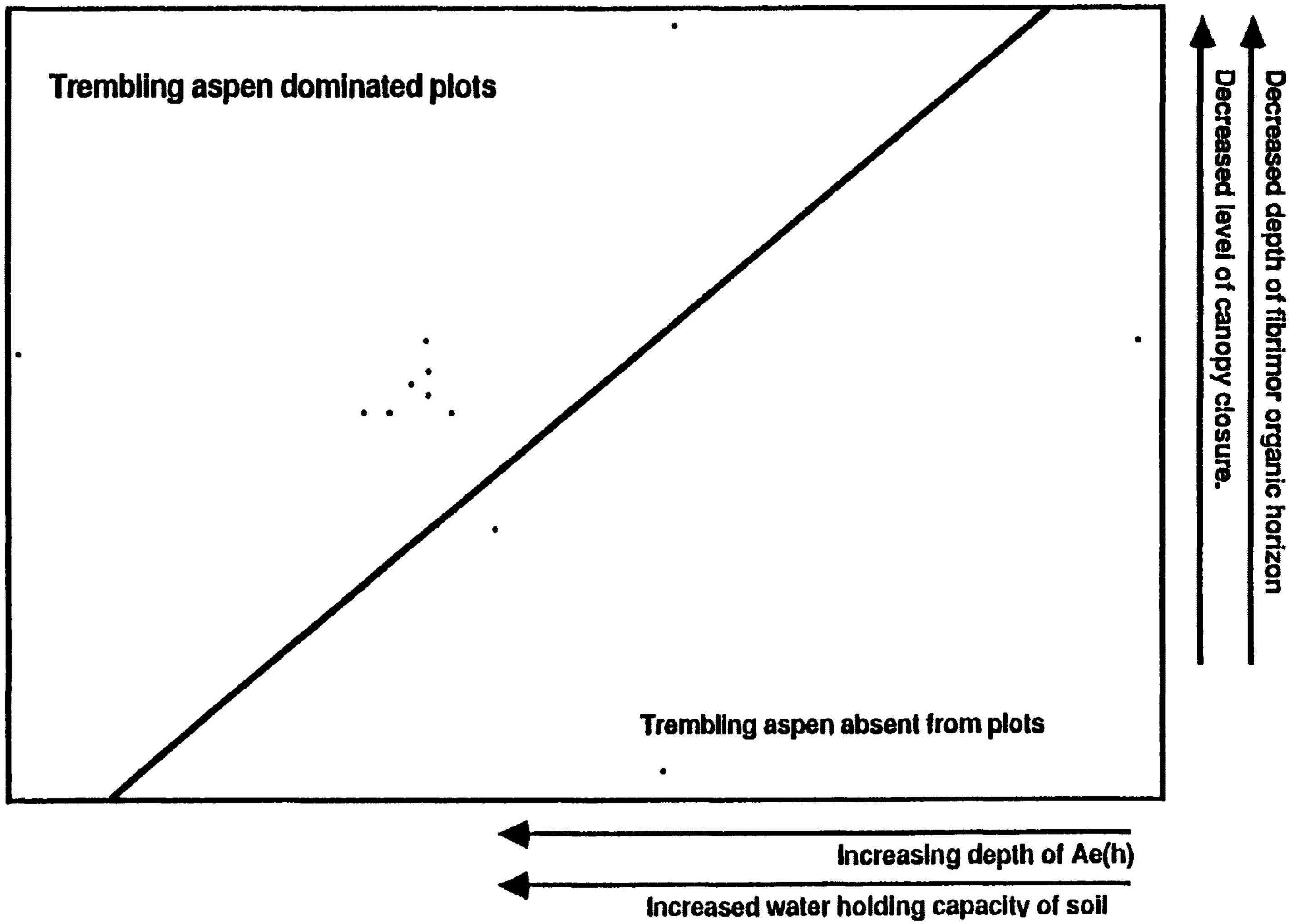


Figure 03. Polar ordination (centred and relativized) for sample plots in plantation III (age 18 years). Boundaries indicate presence or absence of trembling aspen.

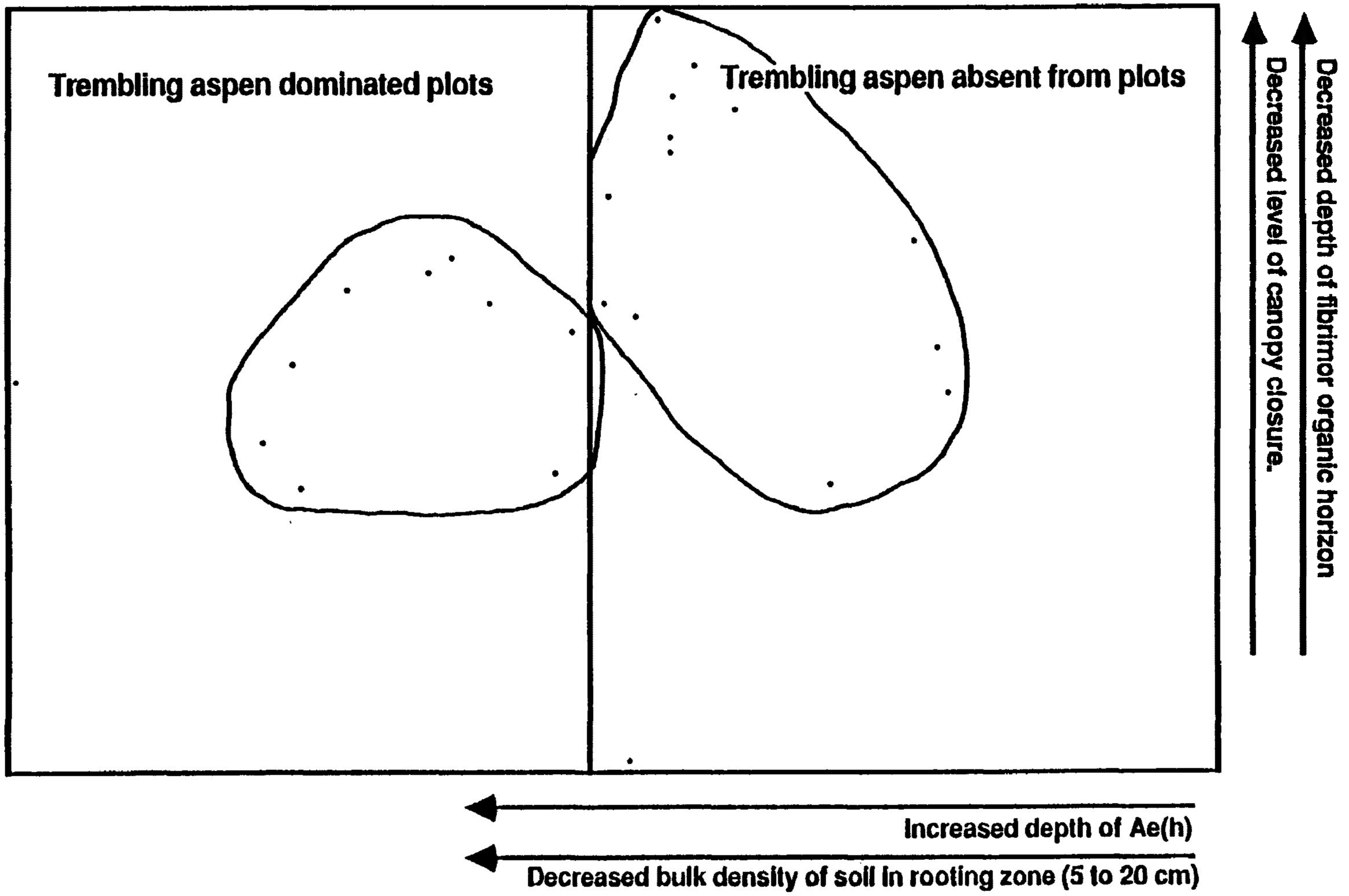


Figure 04. Polar ordination (centred and relativized) for sample plots in plantation IV (age 28 years). Boundaries indicate presence or absence of trembling aspen.

Appendix P. Polar ordinations for species situated in plantations I, II, III, IV.

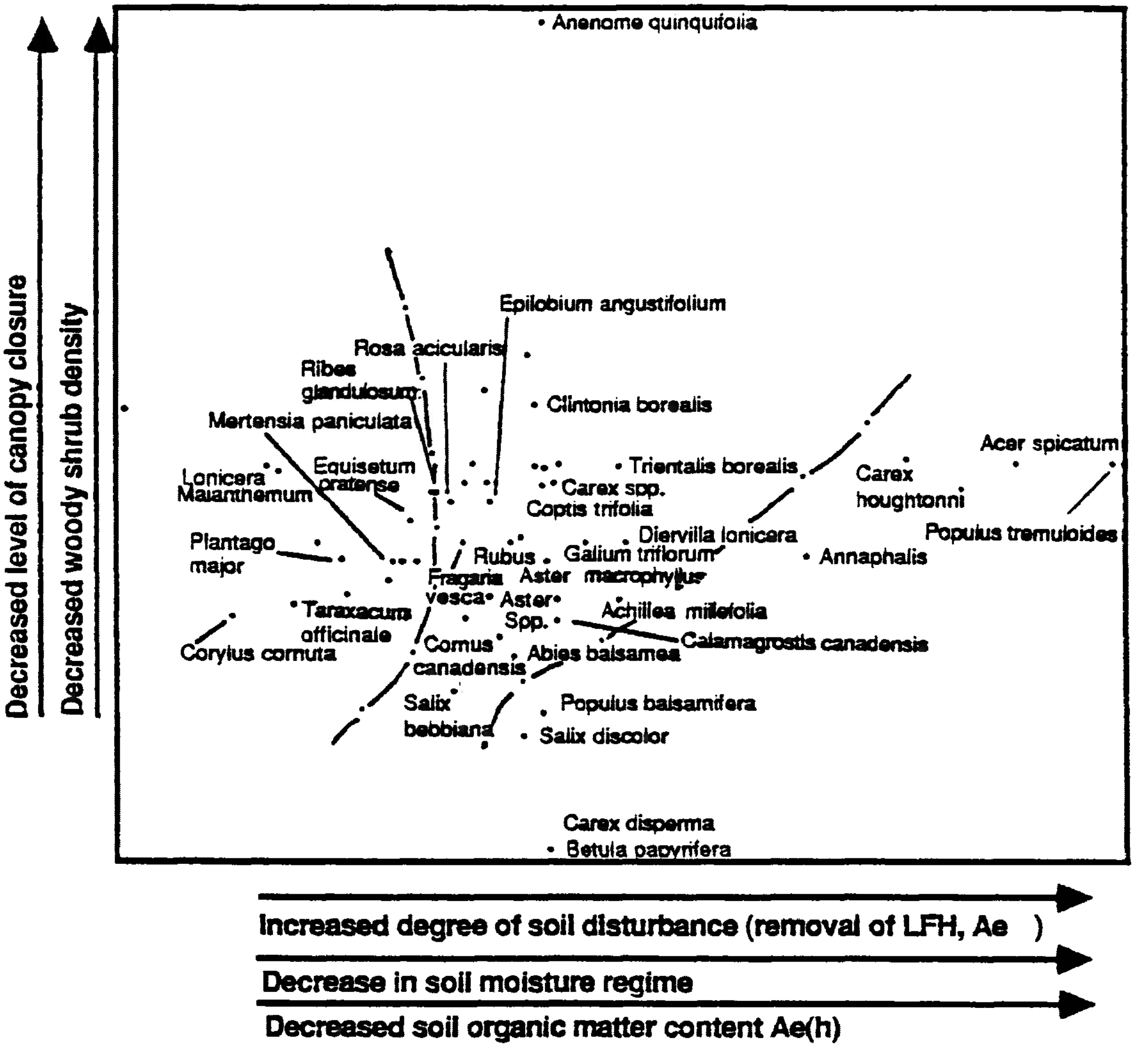


Figure P1. Polar ordination (centred and relativized) for herbaceous, woody shrub and tree species in plantation I (age 4 years).

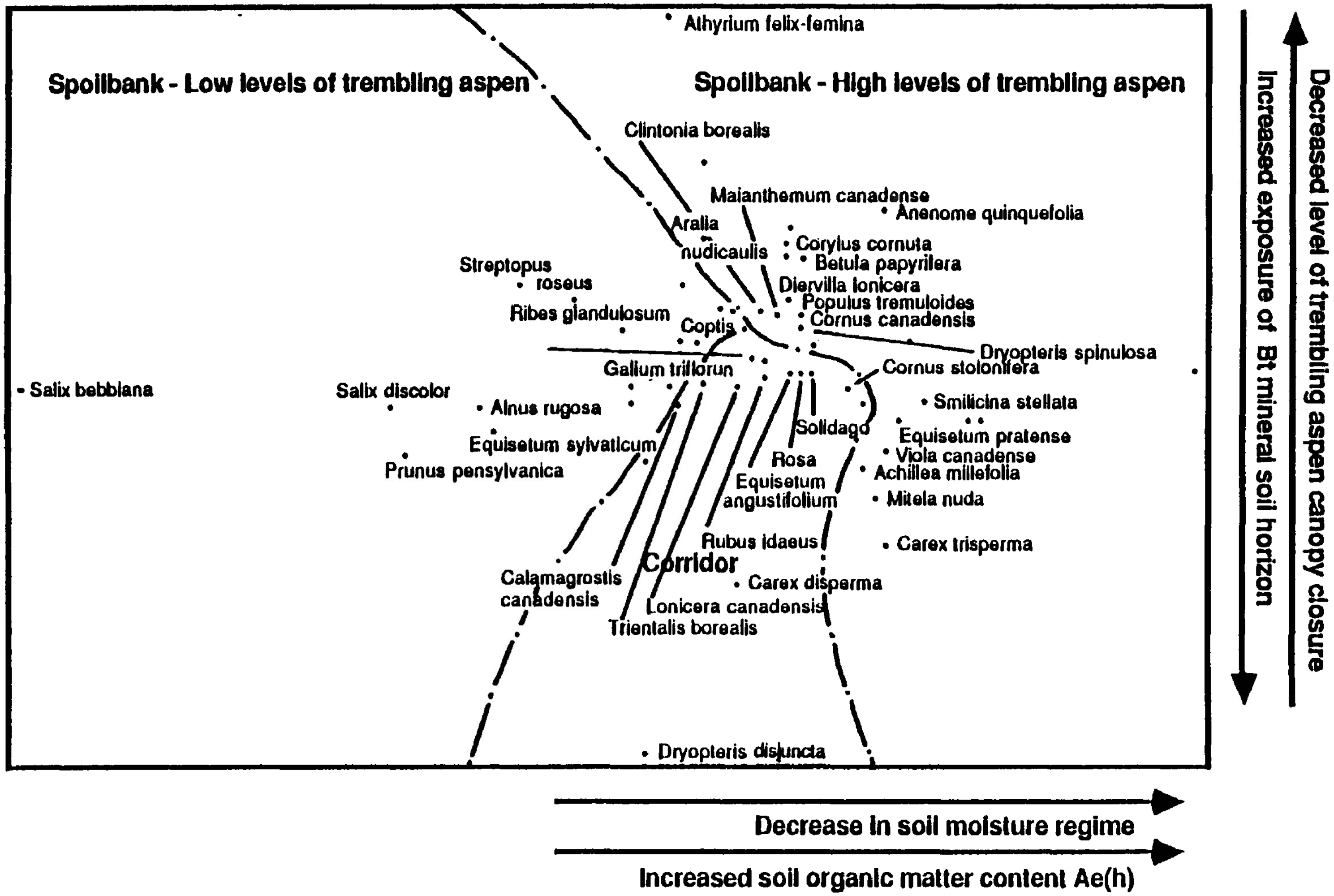


Figure P2. Polar ordination (centred and relativized) for herbaceous, woody shrub and tree species in plantation II (age 10 years).

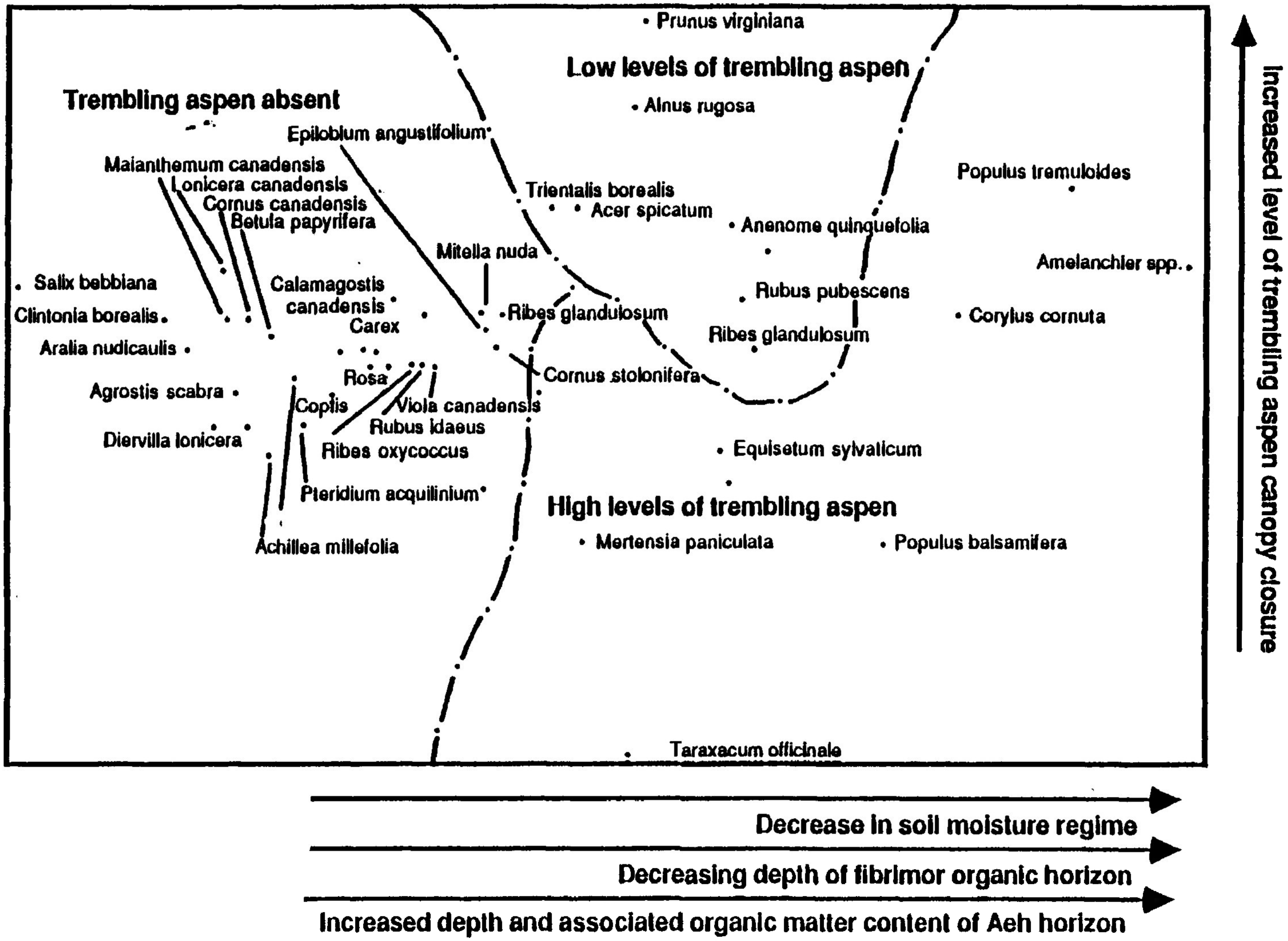


Figure P3. Polar ordination (centred and relativized) for herbaceous, woody shrub and tree species in plantations III and IV (age 18 and 28 years, respectively).

Appendix Q. Stem analysis of white spruce crop trees and trembling aspen from plantations I, II, III, IV.

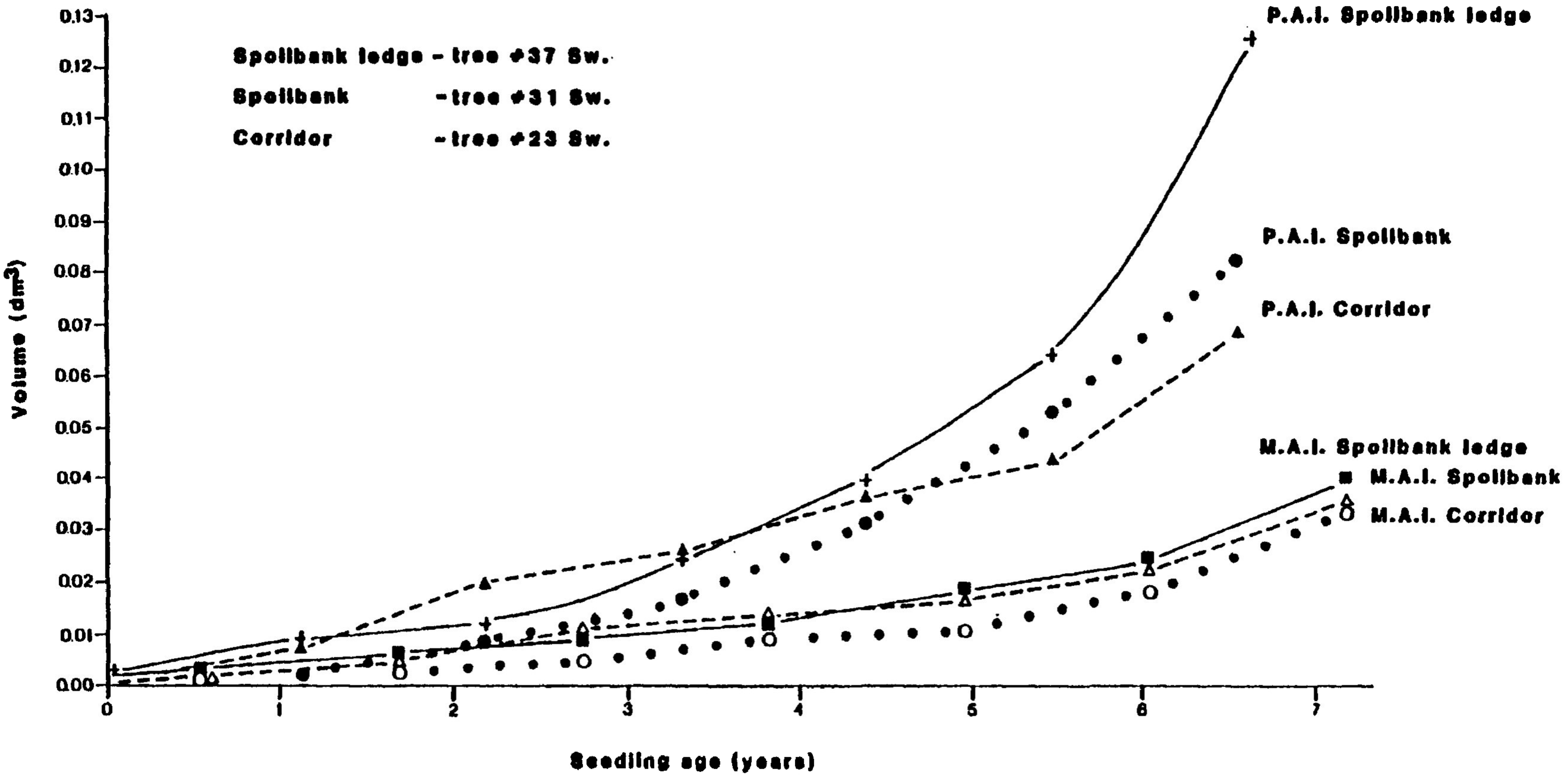


Figure Q1. Stem analysis of selected 'Free-to-Grow' white spruce planted on the corridor, spoilbank ledge and spoilbank micro-sites in plantation I (age 4 years).

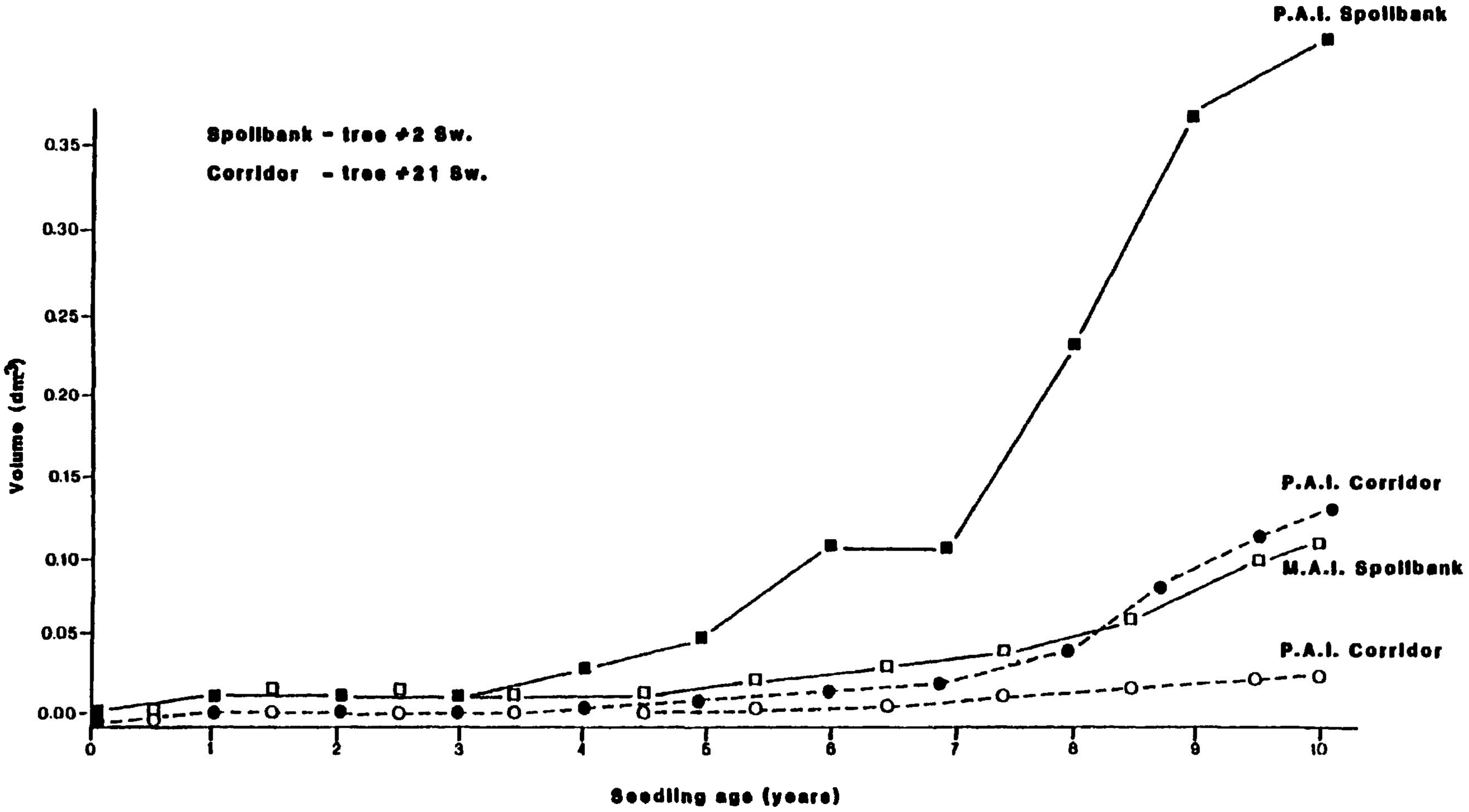


Figure Q2. Stem analysis of selected 'Free-to-Grow' white spruce planted on the corridor and spoilbank micro-sites in plantation II (age 10 years).

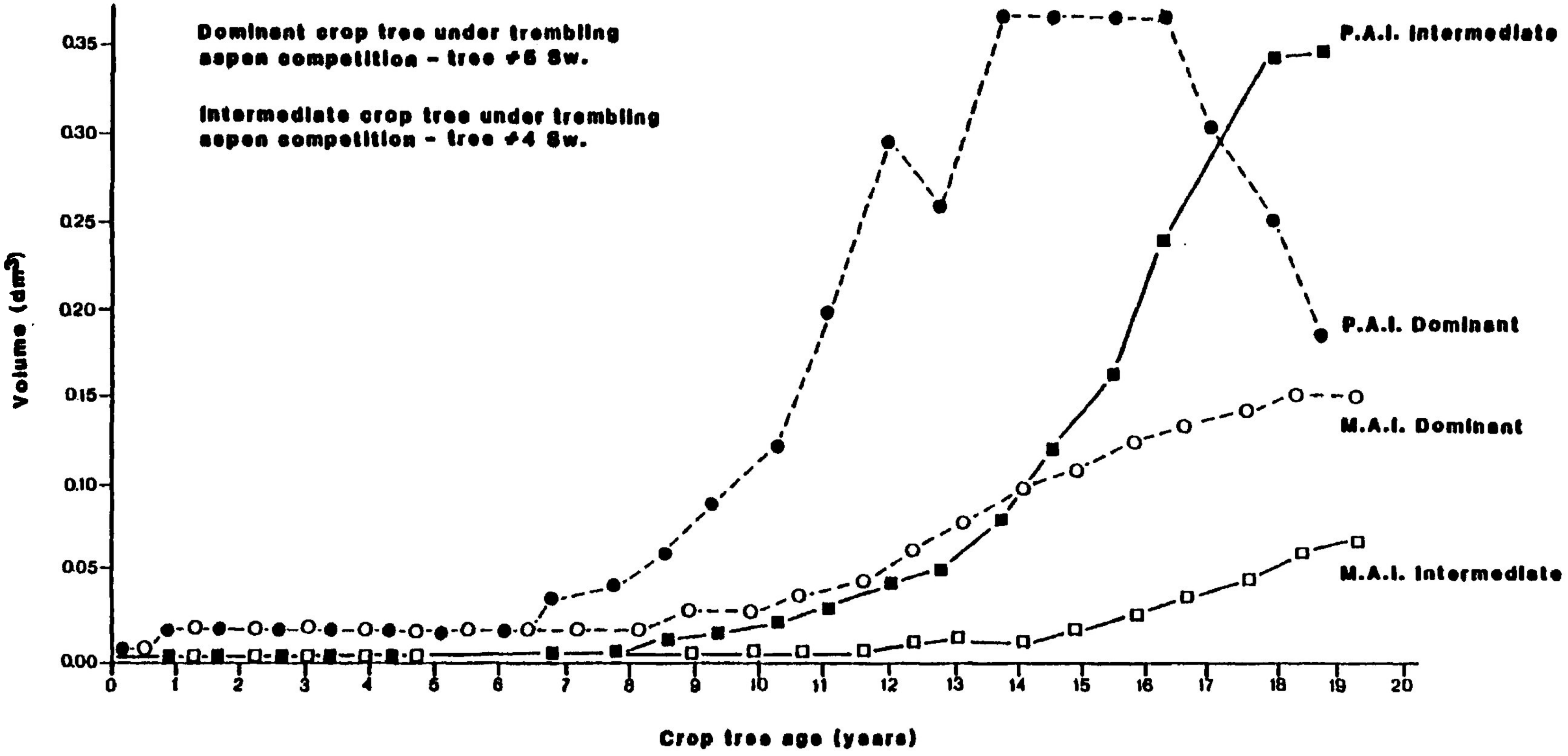


Figure Q3. Stem analysis of a light and moderately suppressed planted white spruce growing under trembling aspen in plantation III (age 18 years).

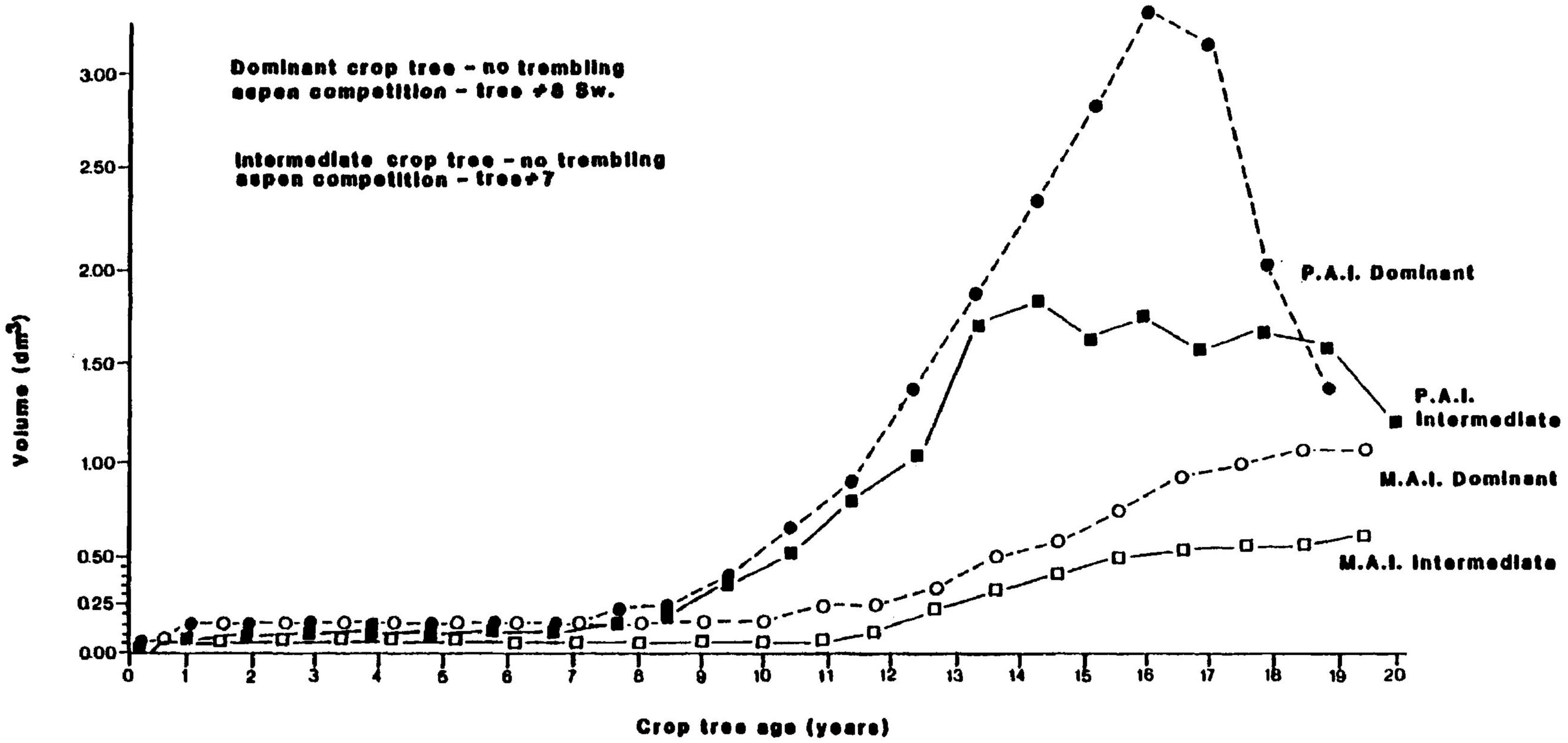


Figure Q4. Stem analysis of a 'Free-to-Grow' dominant and intermediate planted white spruce in the absence of trembling aspen in plantation III (age 18 years).

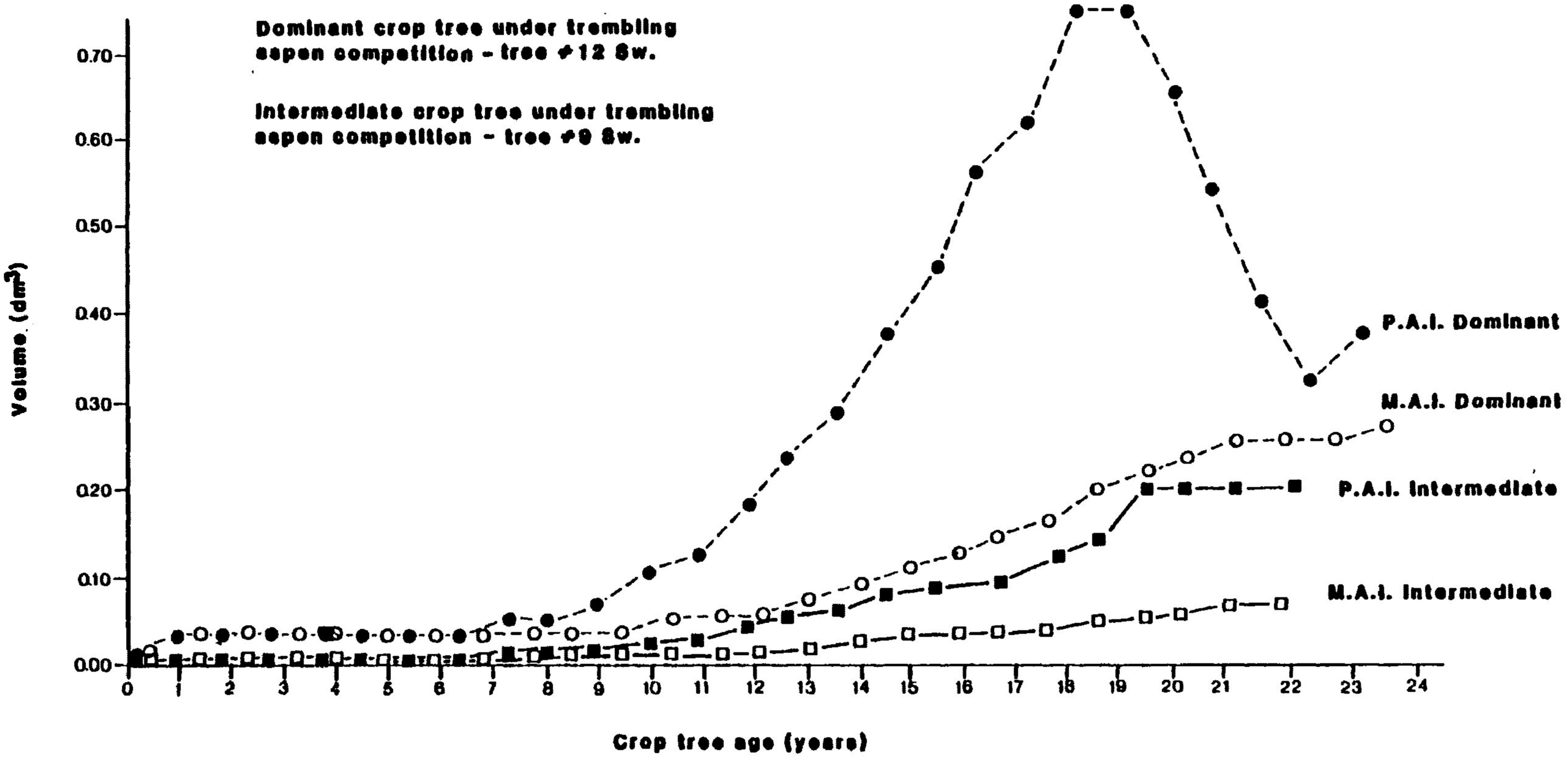


Figure Q5. Stem analysis of a light and moderately suppressed planted white spruce growing under trembling aspen in plantation IV (age 28 years).

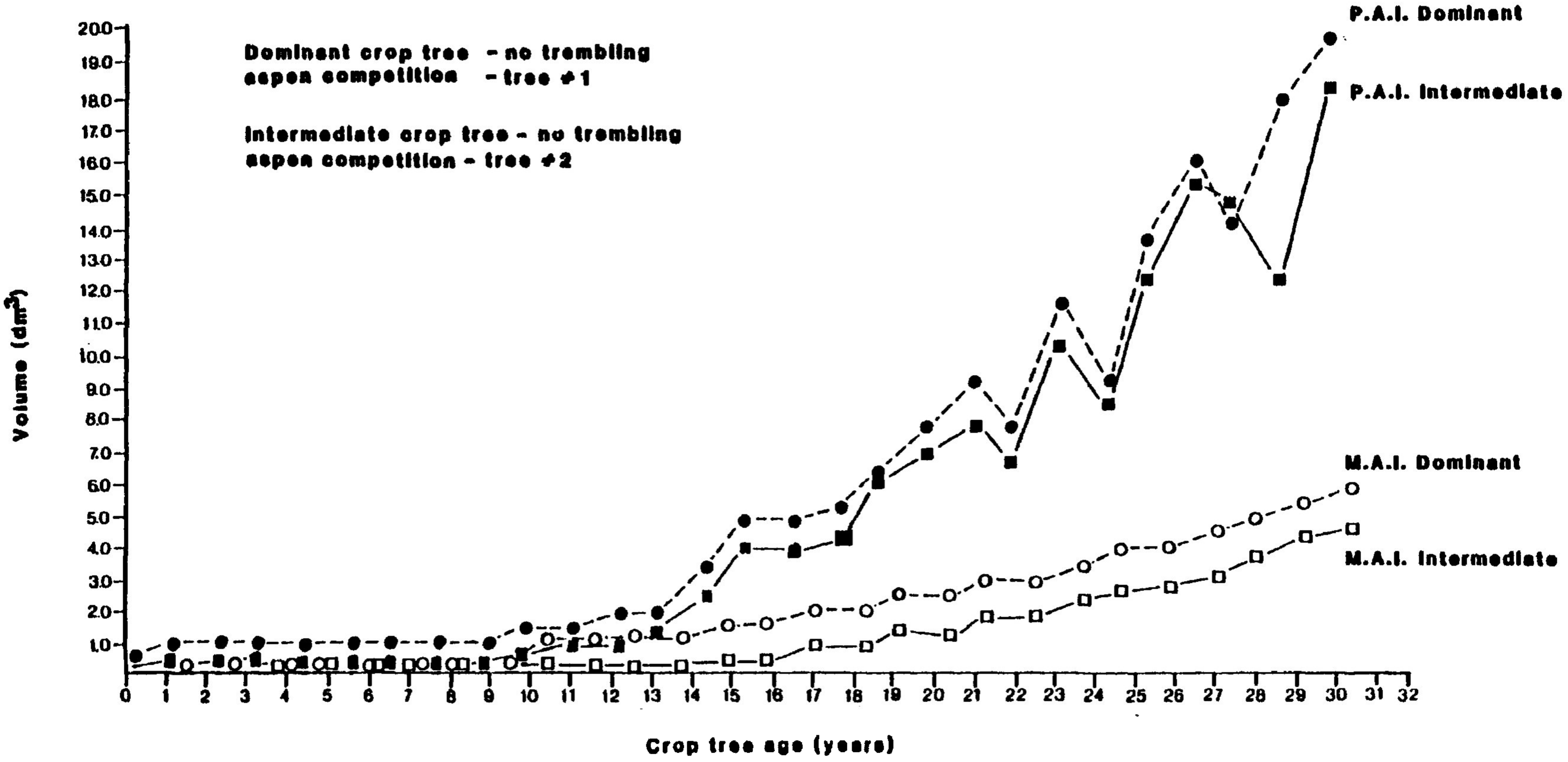


Figure Q6. Stem analysis of a 'Free-to-Grow' dominant and intermediate planted white spruce in the absence of trembling aspen in plantation IV (age 28 years).

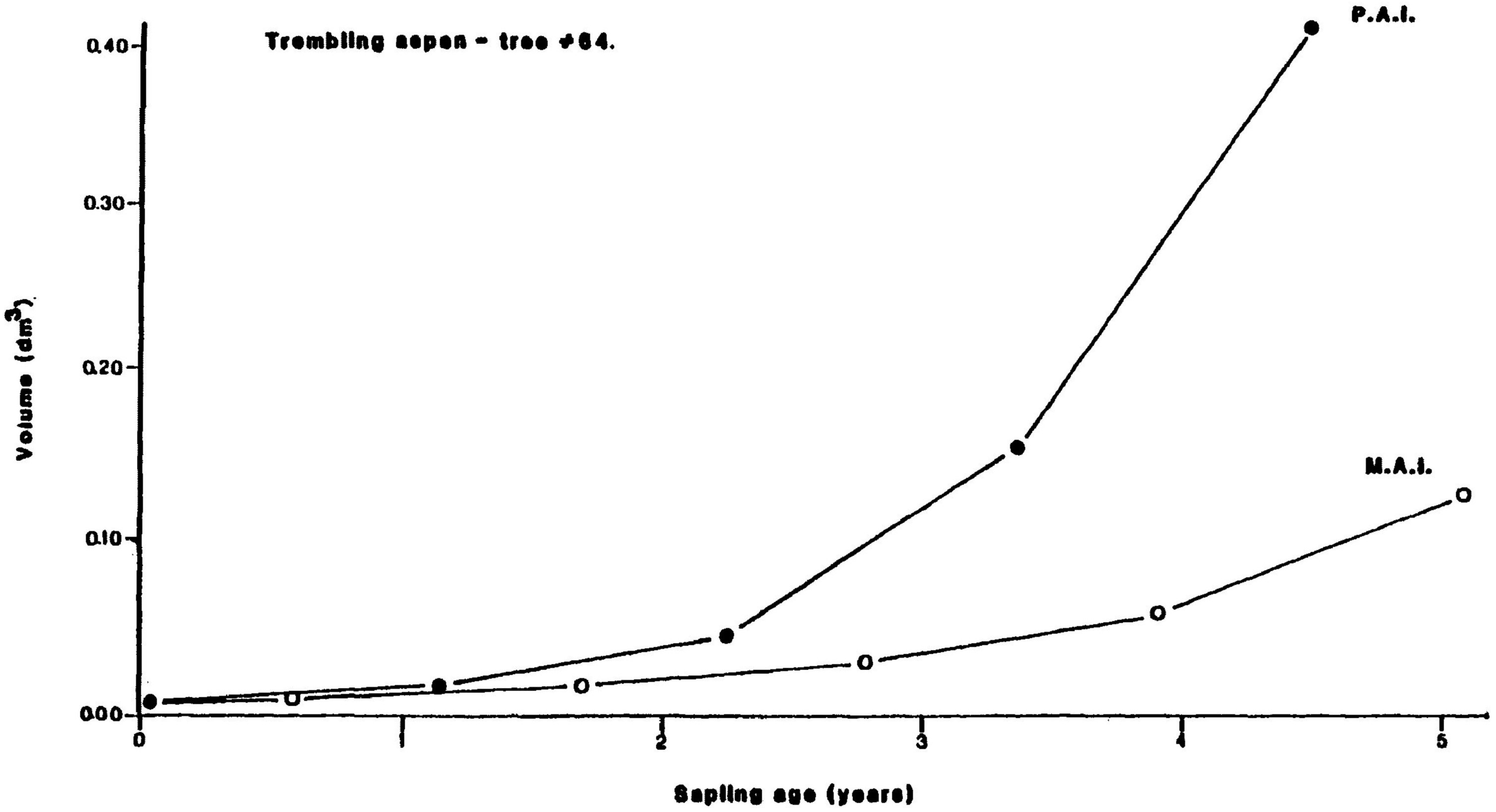


Figure Q7. Stem analysis of a dominant 'Free-to-Grow' trembling aspen sucker in plantation I (age 4 years).

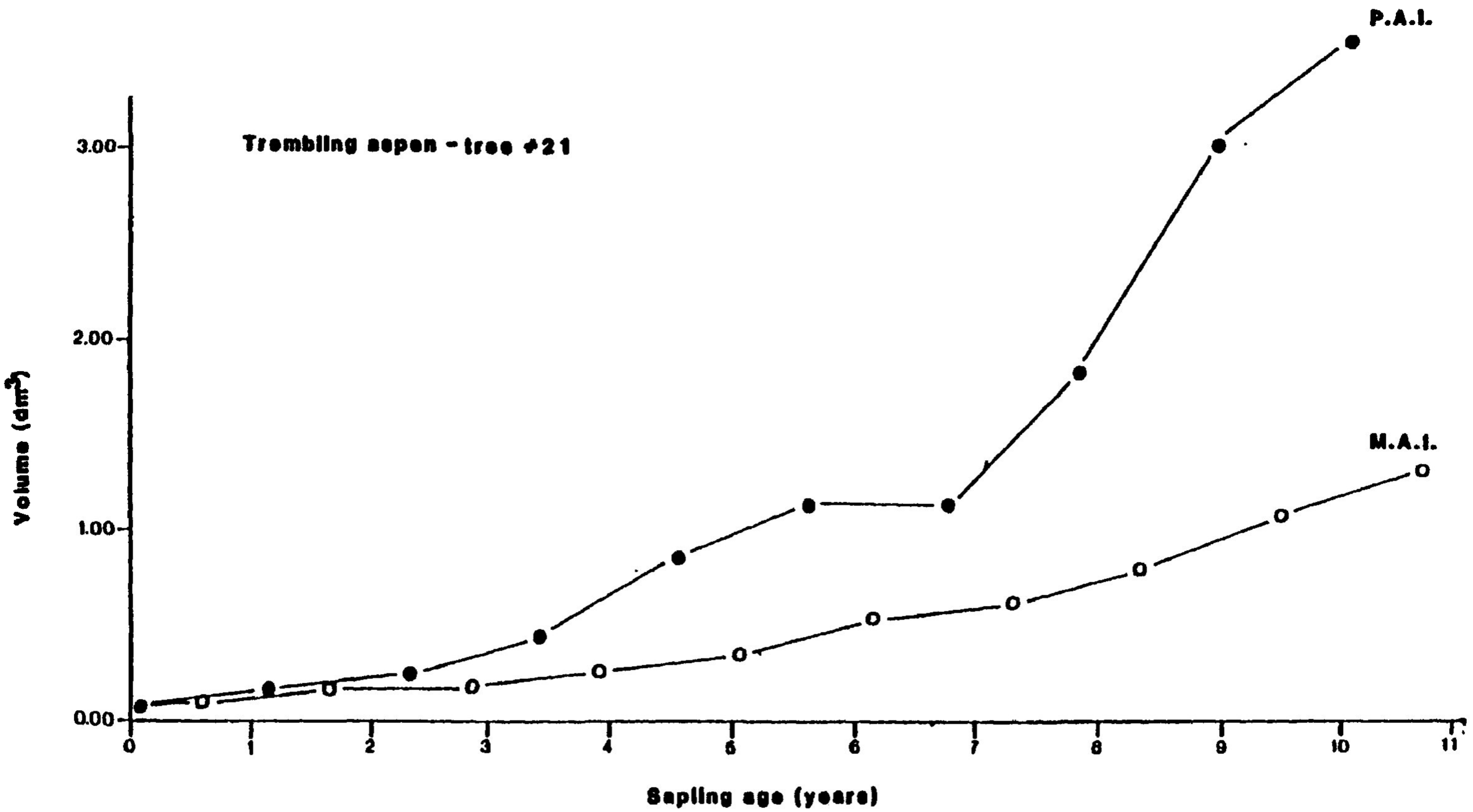


Figure Q8. Stem analysis of a dominant 'Free-to-Grow' trembling aspen tree in plantation II (age 10 years).

Appendix R. Height/age curves for white spruce crop trees and trembling aspen from plantations I, II, III and IV.

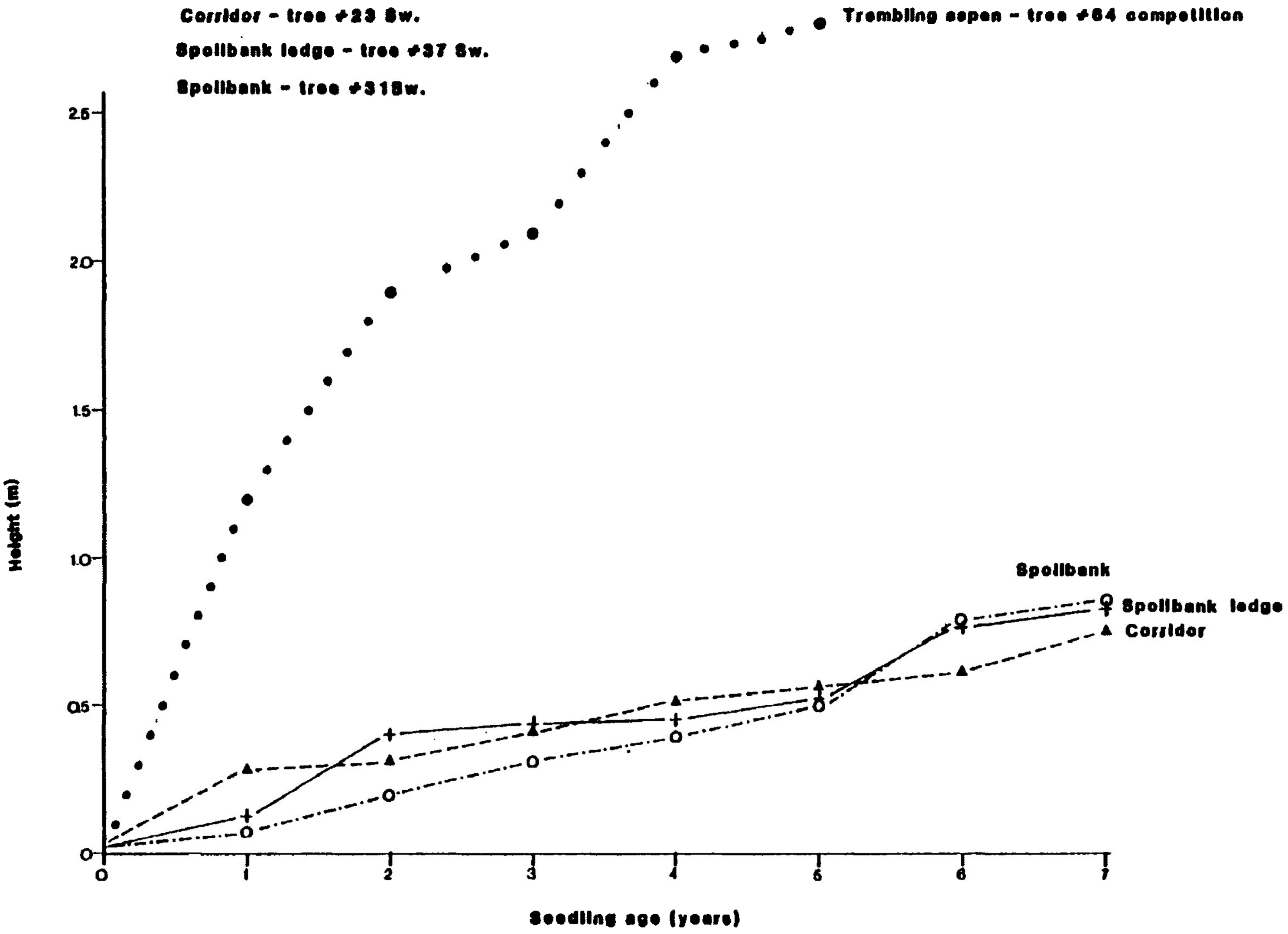


Figure R1. Height / age relationships for representative 'Free-to-Grow' planted white spruce located on the corridor, spoilbank ledge and spoilbank micro-sites in plantation I (age 4 years).

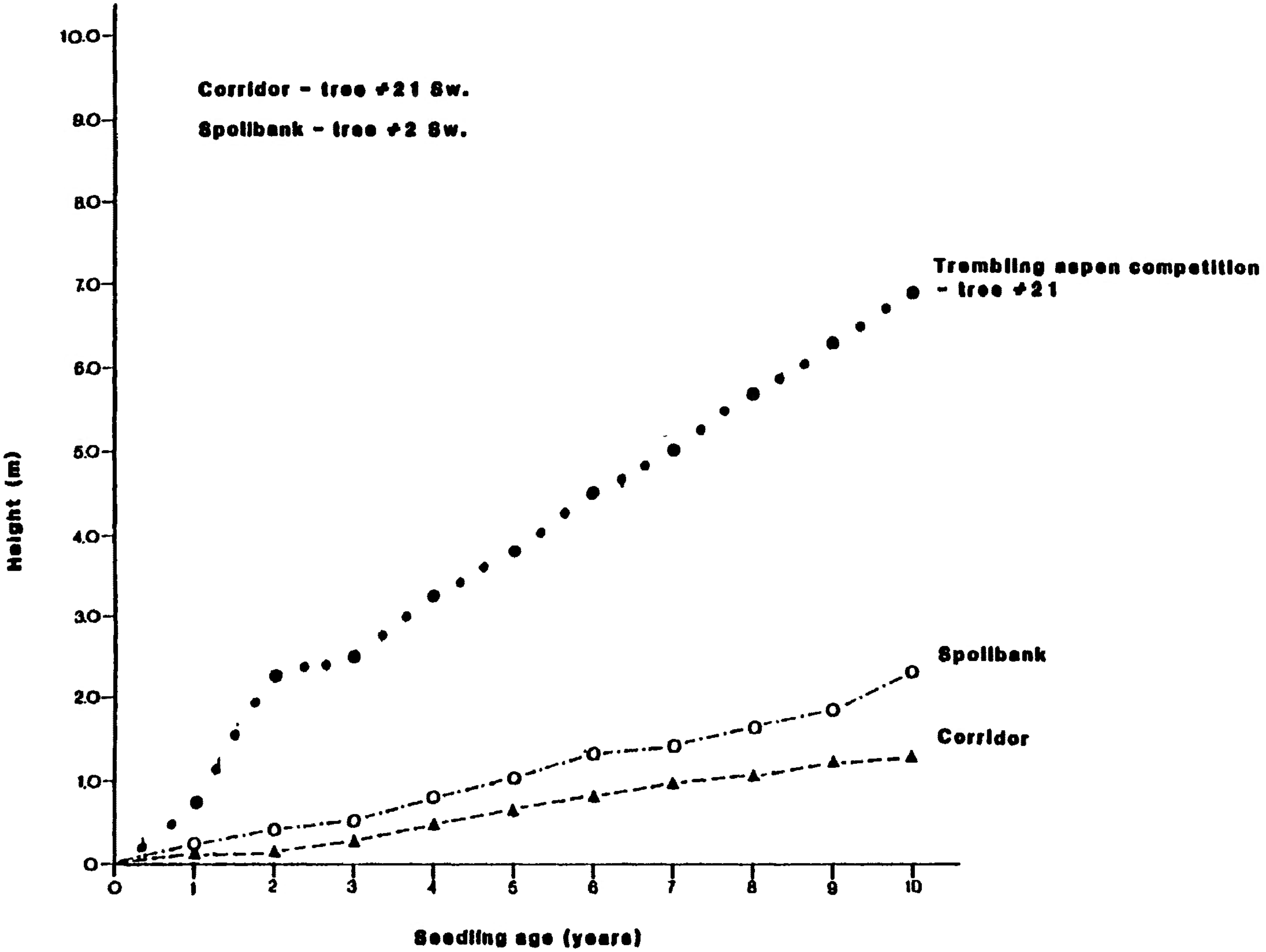


Figure R2. Height / age relationships for representative 'Free-to-Grow' planted white spruce located on the corridor and spoilbank micro-sites in plantation II (age 10 years).

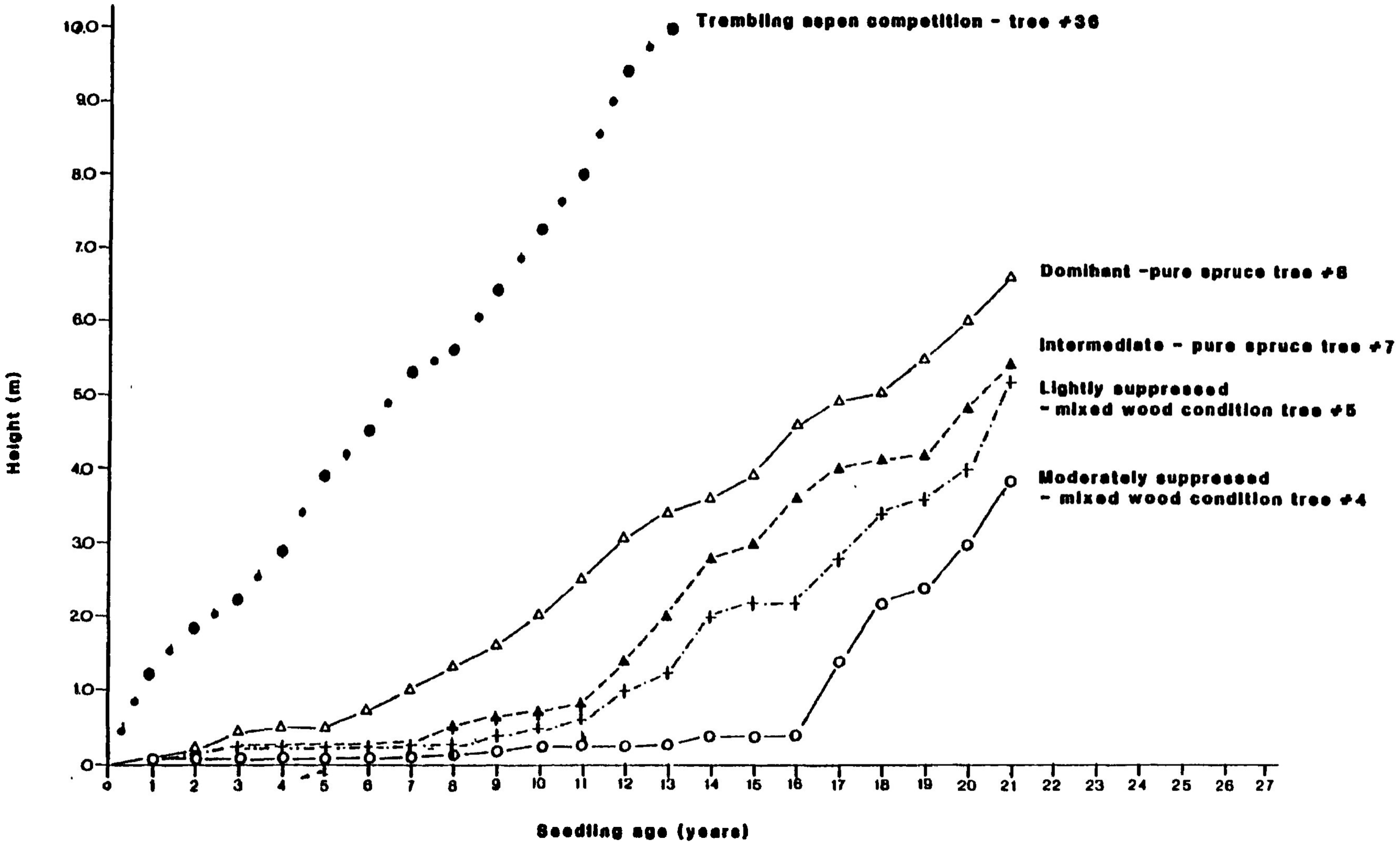


Figure R3. Height / age relationships for a representative planted white spruce from the dominant and intermediate crown class and a lightly and moderately suppressed planted white spruce from plantation III (age 18 years).

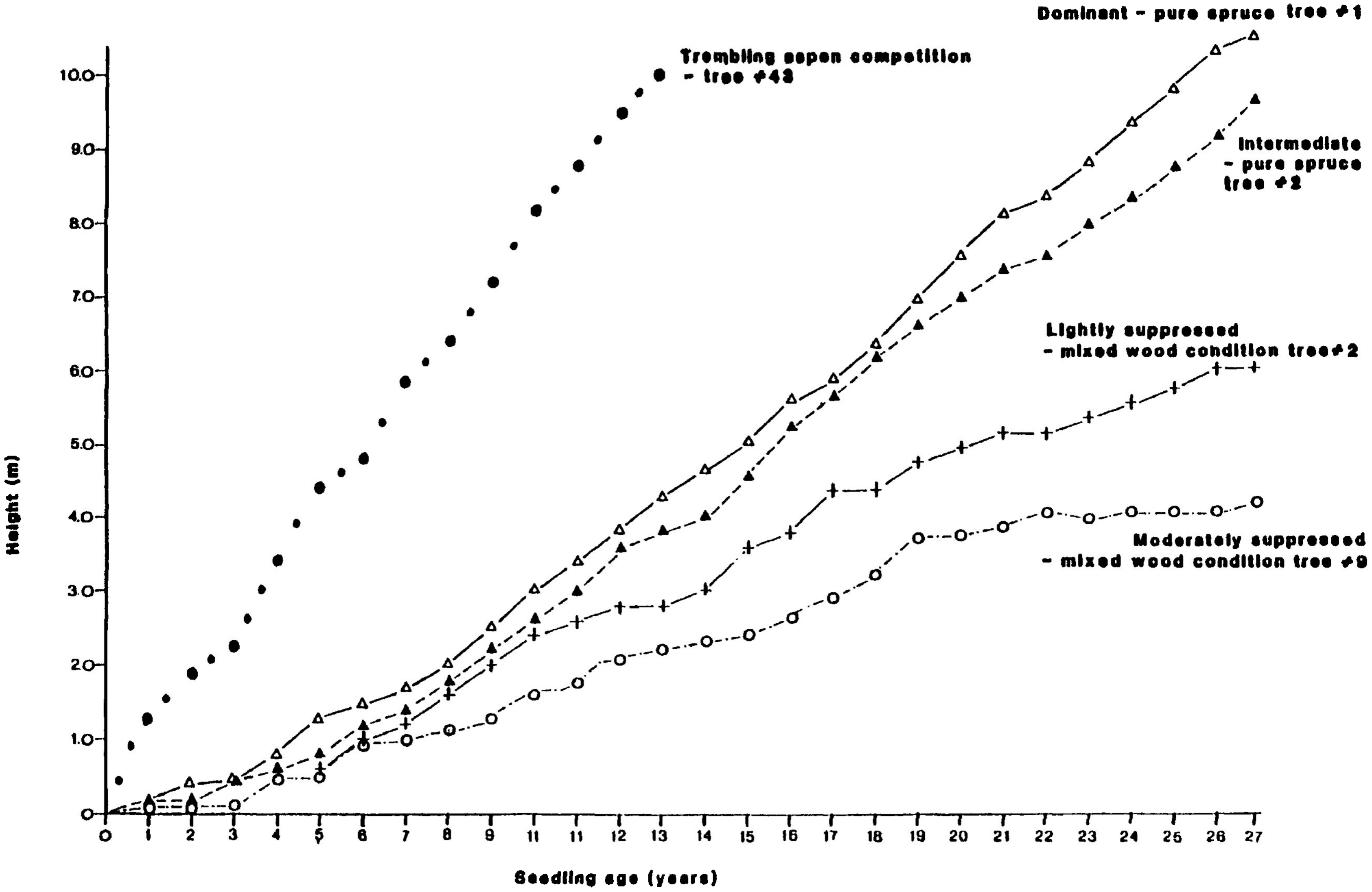


Figure R4. Height / age relationships for a representative planted white spruce from the dominant and intermediate crown class and a lightly and moderately suppressed planted white spruce from plantation IV (age 28 years).