EARLY RESPONSE OF BALSAM FIR TO SPACING

IN NORTHWESTERN NEW BRUNSWICK

by

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ABSTRACT

Young fir-spruce stands in northwestern New Brunswick, spaced 20 years ago, show greatest yield of merchantable fibre at initial spacings of 1.7 x 1.7 m. Maximum mean merchantable volume was 158.3 m^3/ha, 15% above mean unthinned volume, 20 years after spacing. Average tree diameter increased steadily with increasing spacing. Quadratic mean diameter was up to 26% greater and average above-ground biomass of trees > 9 cm diameter was up to 14% greater in spaced stands than in unspaced stands, 20 years after spacing. Conclusions are based on data from 64, one-fifth acre permanent sample plots established between 1959 and 1967 and remeasured at 5-year intervals.

RESUME

De jeunes peuplements de sapins-épinettes éclaircis il y a 20 ans dans le nord-ouest du Nouveau-Brunswick accusent un rendement maximal en fibres commercialisables, correspondant à des espacements initiaux de 1,7 x 1,7 m. Le maximum de volume marchand moyen se chiffre à 158,3 m^3/ha, soit 15% de plus que dans les peuplements non éclaircis. L'accroissement du diamètre moyen des arbres est directement proportionnel à l'espacement. Le diamètre moyen et la biomasse moyenne des parties épigées des arbres de plus de 9 cm de diamètre y sont respectivement jusqu'à 26 et 14% plus grands que dans les peuplements non éclaircis. Ces conclusions sont fondées sur les données colligées dans 64 placettes d'échantillonnage permanent de 1/5 d'acre établies entre 1959 et 1967 puis remésurées à des intervalles de cinq années.

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INTRODUCTION

Young softwood stands in eastern Canada and northeastern United States are often overstocked, resulting in high mortality rates, long rotations, and high harvesting costs. In Nova Scotia, for example, young softwood stands between 12 and 20 years of age have from 25 000 to 124 000 stems per hectare (Tryon and Hartranft 1977). McArthur (1965) observed stand densities of 62 000 to 74 000 stems per hectare for a 10-year-old balsam fir (Abies balsamea (L.) Mill.) stand in the Gaspé region of Quebec. Overstocking can also be a problem with several other Canadian species such as jack pine (Pinus banksiana Lamb.) and lodgepole pine (P. contorta Dougl.) (Dunfield 1974).

By early thinning (spacing) of such stands it is possible to reduce the rate of mortality, increase the growth rate of merchantable wood, shorten the rotation time, and reduce logging costs by increasing average tree size (Hannula 1971; Axelsson and Routledge 1970; Tryon and Hartranft 1977). Additional benefits obtained through spacing include:

1) species composition can be altered to increase the percentage of favored species,
2) healthier, more vigorous trees are less susceptible to disease,
3) higher ground surface temperatures in spaced stands result in higher rates of carbon mineralization and nitrogen uptake (Piene 1978), and
4) spaced stands are more accessible for later silvicultural treatments (Axelsson and Routledge 1970).

Among the questions that arise in the practical application of spacing and precommercial thinning techniques are:

1) What are the specific effects of spacing on merchantable volume, basal area, average diameter, tree form, timber quality, etc.?
2) When should stands be spaced?
3) What is the relationship between response to spacing and site quality?
4) What is the optimal spacing for a given age, site type, and species?
5) Can spacing or thinning be combined with other silvicultural treatments such as fertilization, and if so, what is the best combination of thinning intensity and fertilizer (Hall et al. 1980)?

The answers to some of these questions involve economic as well as biological and ecological considerations. For example, in evaluations of optimal tree spacing one would consider not only future yield of merchantable fibre but also reductions in harvesting costs resulting from increases in average tree size in spaced stands (Hannula 1971; Baskerville 1966; Tucker 1974). Additional economic considerations would include comparisons of manual versus mechanized thinning (Axelsson and Routledge 1970, Dunfield 1974), and the allowable cut effect.

This report describes, from a mensurational viewpoint, the early development of young balsam fir/white spruce (Picea glauca (Moench) Voss) stands in northwestern New Brunswick which were spaced to several different levels of spacing, about 20 years ago. This is a long-term study, intended originally to follow the development of spaced softwood stands over a complete rotation (Baskerville 1959). Although this study is not yet completed it was felt that the interim, 20-year response data contained in this report would be of some interest to those persons currently involved in spacing treatments or planning to use such practices in the future.

DESCRIPTION OF STUDY AREA

The softwood stands of this study are located in northwestern New Brunswick, about 48 km north of Edmundston (Fig. 1). The area is classified by Rowe (1972) as the Gaspé Section (B.2) of the Boreal Forest Region, and by Loucks (1962) as the Green River Site District of the Gaspé-Cape Breton Ecoregion.

The major tree species are balsam fir, white spruce, black spruce (*Picea mariana* (Mill.) B.S.P.), and white birch (*Betula papyrifera* Marsh.). Near the southern portion of this region, adjacent to Rowe's Great Lakes - St. Lawrence Forest Region one finds an increasing abundance of such species as eastern white pine (*Pinus strobus* L.), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britton).

Climatically, the region is characterized by high summer precipitation and low temperatures. The annual frost-free period is 110 days with a mean monthly summer temperature of 15°C. Annual precipitation is 107 cm, of which 46 cm falls between June and September.

The area comprises an upland plateau with elevations ranging from 300-450 m, occasionally up to 625 m. Soils are mainly stony loams and silt-loams derived from the underlying Paleozoic slates and argillites (Loucks 1962).

DATA COLLECTION

Installation of sample plots

A total of 64, 0.2-acre (0.081 ha) permanent sample plots were established in recently cutover areas between 1959 and 1967. These plots were distributed among six different locations of similar site characteristics, throughout the study area (Fig. 1).

Sixteen of these plots were established in 1959 along Upper Belone Brook. In the following year, 1960, eight more plots were installed near Lower Belone Brook, and eight along Summit Road, about 3.2 km south of Summit Depot. In 1961, eight plots were established near Upper Chisholm Brook and eight near Lower Chisholm Brook.

For the 48 plots established in the years 1959-1961, four experimental treatments were used: 1) control (no thinning), 2) 4 x 4 ft (1.22 m) spacing; 3) 6 x 6 ft (1.83 m) spacing; and, 4) 8 x 8 ft (2.44 m) spacing. In each installation, equal numbers of plots were allocated to each of the four treatments, giving a 3-year total of 12 plots per treatment.

In 1967, 16 more plots were established at the Side Hill site, about 13 km east southeast of Summit Depot, near Fraser's old Camp 52. Eight spacing levels were used, from 2 x 2 ft (0.61 m) up to 16 x 16 ft (4.88 m), at 2 ft intervals, with two plots per treatment.

Plots were thinned late in the growing season, after most growth had ceased, by crews using axes and chain saws. The objective was to leave one free-growing softwood crop tree at or near each spacing coordinate (Baskerville 1959). The area around each plot was also spaced to the same density, thus providing a buffer zone to minimize any edge effects.

Some of the plots contained old strip roads from previous logging operations which tended to regenerate to dense growth of raspberry (*Rubus* sp.), pin cherry (*Prunus pensylvanica* L.f.), birch (*Betula* sp.), and mountain maple (*Acer spicatum* Lam.), with only a few scattered softwoods. No attempt was made during spacing to compensate for these areas and thus the actual spacing was sometimes above the nominal or intended spacing (Baskerville 1959).

A digression on the term 'spacing' may be useful at this point. The

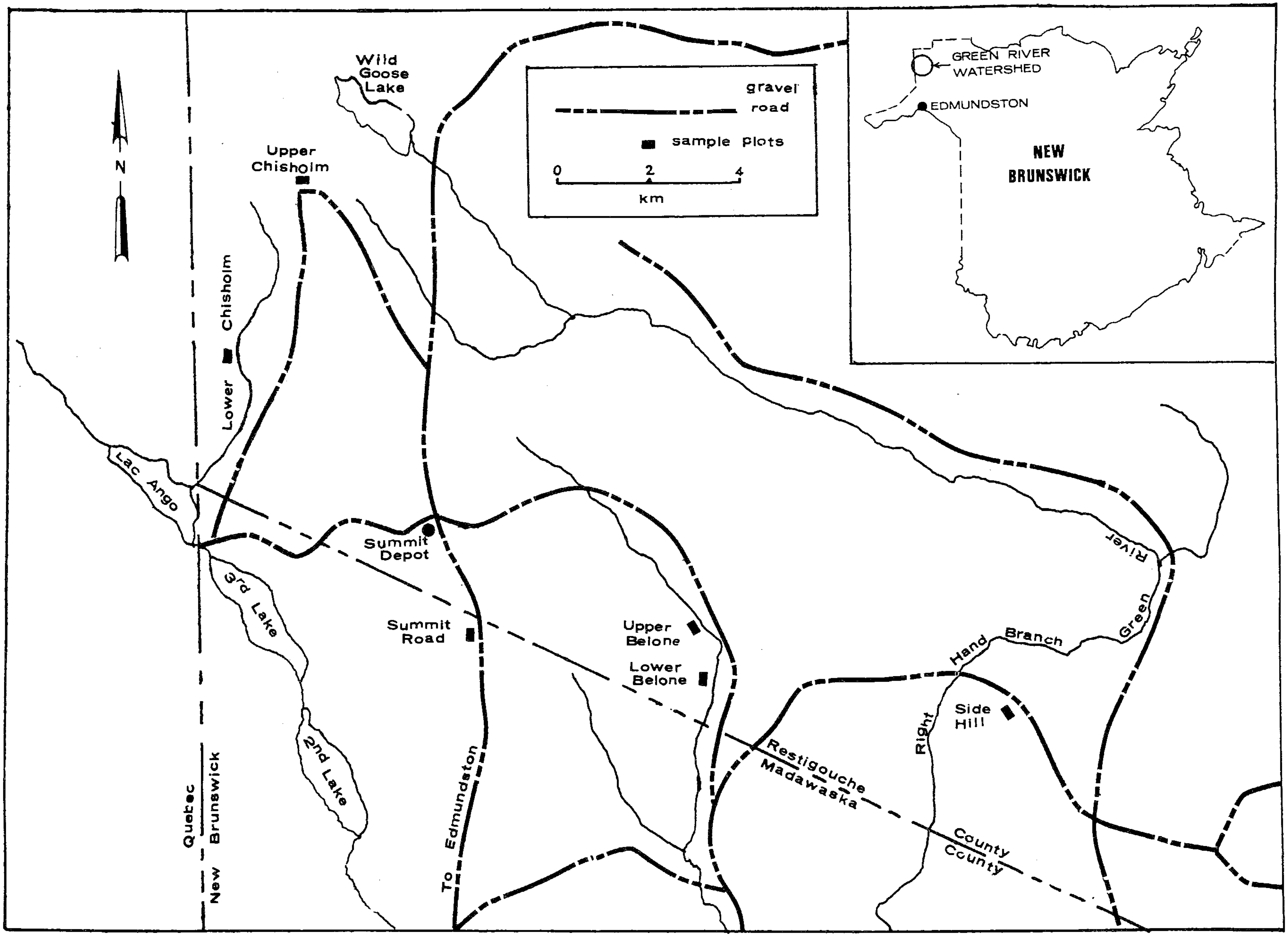

Fig. 1. Location of study area.

average spacing, in metres, of trees in a stand is given by the formula $(10^4/N)^{\frac{1}{2}}$ where N is the number of stems per hectare. Thus, spacing can be defined in several different, but mutually consistent, ways, depending on which trees are included in the definition of number of stems.

Throughout this report we will use the term spacing in two senses, corresponding to two definitions of number of stems. The first is "nominal spacing", used in defining the experimental treatments originally and is based on the intended number of crop trees to be left standing after the thinning operation. The important features of this definition are;

1) no diameter or height limits are used or implied in defining which trees are included,
2) it ignores several small stems which should have been removed in thinning but were missed (usually because they were obscured by slash during thinning), and which later began to form an understory, and
3) it is not based on an exact count of crop trees actually left in the plot.

The second definition of spacing used in this report is "average initial spacing". This is based on the exact number of crop trees greater than 1 cm diameter at breast height (dbh) left standing after thinning. This will generally be greater than the nominal spacing since some of the crop trees were less than 1 cm dbh. This second definition of spacing was introduced because in most mensurational work one or more lower dbh limits are used to define which trees are included in stand variables such as volume, basal area, etc., and it was considered logically more desirable and consistent to use a measure of spacing that was based on the same subset of trees as all other stand variables. In this report two such dbh limits are used: 1) all crop trees >1 cm dbh (total), and 2) all crop trees > 9 cm dbh ("merchantable"). Thus, the trees used in calculating average initial spacing for each plot were the same as those used in calculating volume, basal area, etc. of all "crop" trees > 1 cm dbh, just after thinning.

The distribution of sample plots by average initial spacing (based on number of crop trees >1 cm dbh) and location is given in Table 1. Table 2 gives the plot distribution by nominal spacing and location.

Most of the hardwood shrub competition was removed during thinning, leaving only the small stems of birch, cherry, mountain ash, (*Sorbus americana* Marsh.) elderberry, (*Sambucus* sp.) and serviceberry (*Amelanchier* sp.), and some large, residual white birch trees. After thinning, about 11% of the softwood stems were white spruce, the remainder was balsam fir.

The release age (no. of years since removal of overstory) of these stands ranged from 1-13 years (van Raalte 1979[1]; Baskerville 1965a) at the time of thinning.

In 1972 a cleaning operation was carried out on all plots (except the 16 plots at Side Hill) to remove the large numbers of small ingrowth stems which were beginning to form an understory and compete with the main stand of crop trees.

In 1973, the Side Hill plots were sprayed with herbicide to remove hardwood competition. In 1977, hardwood competition was removed, by hand, from the same plots, because of a poor hardwood kill in the 1973 spraying.

Tree measurements

All softwood crop trees were numbered and tagged and the following information was obtained for each tree;

1) species,

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1 van Raalte, G. Pers. Comm., Marit. For. Res. Cent., Fredericton, N.B. E3B 5P7.

2) diameter at breast height outside bark to nearest 0.1 inch,
3) total height in feet,
4) crown width in feet,
5) crown length in feet,
6) relative location within plot (x, y coordinates) to nearest 0.1 ft.

These measurements were taken immediately after thinning and, every five years thereafter. Measurements were checked in the field against previous measurements of the same tree to help eliminate any gross errors. Trees were tallied by species and height class in each plot, prior to thinning.

Because of the large numbers of stems in the control plots, it was not possible, with the available manpower, to obtain complete measurements for all of these plots. Eventually this problem was overcome and by the second or third measurement a complete set of data was being obtained from the controls. The number of complete plot measurements available as of 1980 is given in Table 3.

Any stems not tagged originally as crop trees were tallied by species and height class only. Most of these stems were removed in the 1972 cleaning referred to earlier. As the stands developed and the canopy began to close, the number of ingrowth trees declined.

ANALYSIS OF DATA

The data on crop trees were punched on computer cards. Editing programs were written to check the raw data for omissions and inconsistencies when compared with previous measurements on the same trees. The edited file was then merged by tree number with the file of previous measurements and the updated file was stored on magnetic tape.

Additional programs were written to calculate, from the crop tree data of each plot and measurement, the following stand parameters:

1) Volume (m^3/ha),
   Volumes were computed using Honer's (1967) volume equations. For merchantable volume, a stump height of 20 cm and top diameter of 7 cm were used.
2) Basal area (m^2/ha),
3) Quadratic mean diameter (cm),
   This is the diameter corresponding to the mean tree basal area and is given by the formula $QMD = 112.838\ (G/N)^{\frac{1}{2}}$
   where G is stand basal area (m^2/ha) and N is number of stems per hectare,
4) Number of stems per hectare,
5) Mean diameter (cm),
6) Mean height (m),
7) Lorey's height (m),
   Lorey's height is the average tree height of the stand with each tree height weighted by its basal area:
   $h_L = (\Sigma gh)/\Sigma g$
   where h_L = Lorey's height,
   g = tree basal area,
   h = tree height,
   and the summation is over all trees in the subset of interest.
   Lorey's height, together with basal area, enables precise estimation of stand volume and biomass (Evert and Lowry 1971; Johnstone 1977).
8) Dominant height (m),
   This is the average height of the five tallest trees in the stand.
9) Stem wood biomass (oven-dry tonnes/ha) (OD t/ha),
   This and all other biomass parameters were computed using equations of Ker and van Raalte (1981).
10) Stem bark biomass (OD t/ha),
11) Total stem biomass (wood plus bark) (OD t/ha),
12) Branch biomass (OD t/ha),
13) Foliage biomass (OD t/ha),

14) Crown biomass (branches plus foliage (OD t/ha),
15) Total above-ground biomass (OD t/ha)
16) Root biomass (OD t/ha),
17) Total biomass (including roots) (OD t/ha).

Most of these parameters were computed for each of three species categories (fir, spruce, and fir plus spruce) and two size categories (total (dbh > 1 cm) and merchantable (dbh >9 cm)), giving a total of six statistics for each parameter. For the biomass parameters no stump or top deductions were included in calculation of merchantable statistics.

Because the biomass equations of Ker and van Raalte (1981) are not additive, an attempt was made to achieve additivity of biomass estimates by calculating some biomass component weights as the differences between other predicted component weights, rather than using the original equation for that component. For example, stem bark biomass was taken as the difference between total stem biomass (wood plus bark) and stem wood biomass, rather than using the stem bark equation itself. This procedure does not, however, guarantee additivity with respect to size class, and, in a small number of cases, required a slight adjustment of the merchantable biomass statistics to ensure that they were always less than the total stand statistics.

The mean values of these parameters were then calculated for each category of elapsed time and initial spacing. This was done for each of the two spacing variables defined earlier: 1) nominal spacing, and 2) average initial spacing (using intervals of 0.5 m).

EFFECTS OF SPACING ON STAND DEVELOPMENT

Some of the differences between thinned and unthinned stands are evident in Figs. 2-5, which show four of the sample plots, including a control, in 1980, about 20 years after spacing. The major visible differences are a large reduction in number of dead stems and an increase in average tree size. The statistics given for each plot are extrapolations from previous measurements.

The mean values of the various stand parameters are given in Table 4 by average initial spacing and in Table 5 by nominal spacing. These statistics are for fir and spruce combined.

Volume

Merchantable volume yield increases with increased spacing up to a certain maximum and then begins to decrease (Tables 4 and 5, Figs. 6-8). A nominal spacing of 6 x 6 ft (1.83 m) produced the greatest yield of merchantable fibre, with an average of 158.3 m^3/ha, 20 years after spacing (Table 5). These data, when plotted against nominal spacing, indicate a peak yield around 5.5 ft (1.68 m) or 3560 stems/ha (Fig. 8). The mean merchantable volume at the 6 x 6 ft spacing was 15% above the mean control volume 20 years after spacing. The maximum merchantable volume for any one individual plot was 217 m^3/ha.

By comparison, similar volumes in Nova Scotia are achieved after more than 50 years on medium sites. For example, the merchantable (dbh > 9.1 cm) volume of softwoods growing on sites classed as Land Capability Class 4 (former CLI Land Class 5-) is 151 m^3/ha at 50 years (Bailey 1980)[2].

Average growth rate (net PAI) for merchantable volume ranged from 8.0 to 15.4 m^3/ha per year (Table 4, Fig. 7), using the 15 and 20 year volumes. These rates are similar to the maximum rates of growth reported by Meyer (1929) for red spruce/fir in

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[2] Bailey, R.E. 1980. Revised Nova Scotia Softwood Yield Tables (Unpublished) N.S. Dep. Lands For., Truro, N.S.

Fig. 2. Plot 128 in 1980, 20 years after spacing. Spacing = control; Merch. volume = 184 m^3/ha; Quadratic mean diameter (9 cm +) = 15.2 cm.

Fig. 3. Plot 130 in 1980, 20 years after spacing. Nominal spacing = 4 x 4 ft. Avg. initial spacing = 1.85 m; Merch. volume = 218 m^3/ha; Quadratic mean diameter (9 cm +) = 16.0 cm.

Fig. 4. Plot 103 in 1980, 21 years after spacing. Nominal spacing = 6 x 6 ft; Avg. initial spacing = 2.45 m; Merch. volume = 157 m^3/ha; Quadratic mean diamter (9 cm +) = 15.3 cm.

Fig. 5. Plot 126 in 1980, 20 years after spacing. Nominal spacing = 8 x 8 ft; Avg. initial spacing = 2.90 m; Merch. volume = 192 m^3/ha; Quadratic mean diameter (9 cm +) = 19.1 cm.

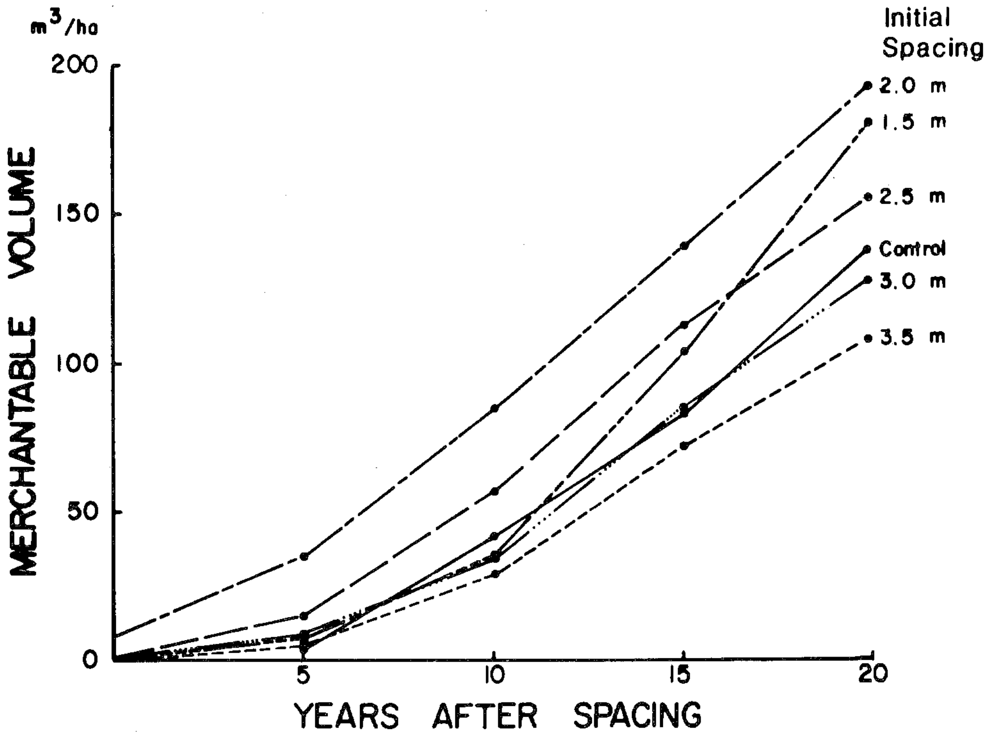

Fig. 6. Merchantable volume (dbh >9 cm).

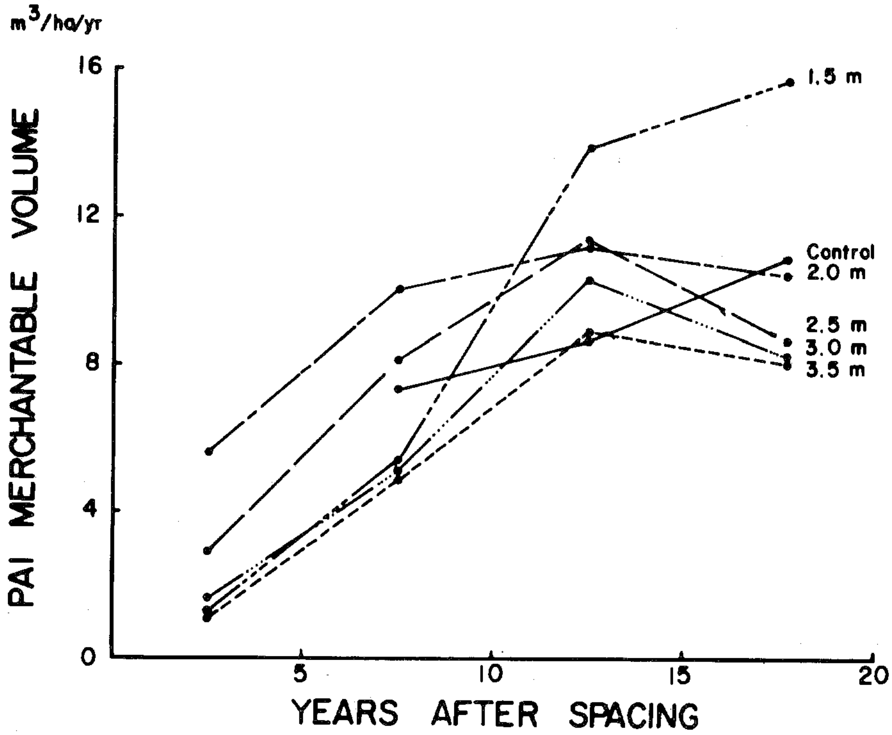

Fig. 7. Net PAI merchantable volume.

MEAN 20 YR MERCHANTABLE VOLUME (CU. M/HA) VS NOMINAL SPACING

PLOT OF VOLUME*SPACING

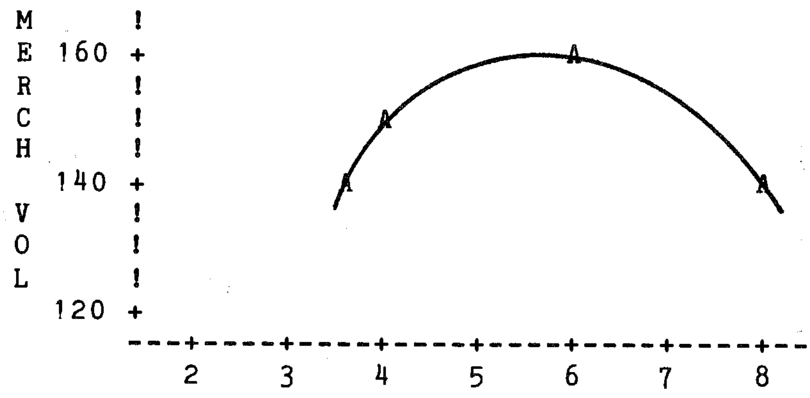

Fig. 8. Mean 20-year merchantable volume versus nominal spacing.

the northeastern United States. These occurred between ages 45 and 50 and ranged from 8.1 m^3/ha per year (net PAI, >4 inch) at site index 40 ft, to 18.6 m^3/ha per year at site index 70 ft. Total volume and net PAI total volume are plotted in Figs. 9-10.

The growth rates shown in Fig. 7 are also well above the average rates for unmanaged softwood forests in New Brunswick (Bickerstaff and Hostikka 1977). These rates, according to one study (Anon. 1936), varied from 3.5 m^3/ha per year for 20-40 year-old softwoods to 2.7 m^3/ha per year for 61-100 year-old softwoods (net current annual increment (CAI), >3.6 inch).

Biomass

The trends for biomass yield depend primarily on: 1) which definition of spacing is used (nominal or average initial spacing), 2) which size class of trees is considered (total or merchantable), and 3) which specific biomass components are considered. The main trends that emerge from the data in Tables 4 and 5 are as follows:

1) For most biomass components the total stand statistics increase with decreasing spacing, when averaged by nominal spacing (Table 5). When averaged by average initial spacing, however, the yields of biomass show a decrease at higher densities (Table 4).
2) For crown biomass components, both total and merchantable, there is a maximum yield at certain spacings, with a decrease in yield at higher and lower spacings. For nominal spacing (Table 5) the maximum yield occurs at the 6 x 6 ft spacing. In terms of average initial spacing (Table 4) the maximum yield occurs at spacings of 1.5 to 2.5 m, depending on time since spacing and component (foliage, branches, or total crown).
3) For all biomass components, the statistics for the merchantable size class follow the same

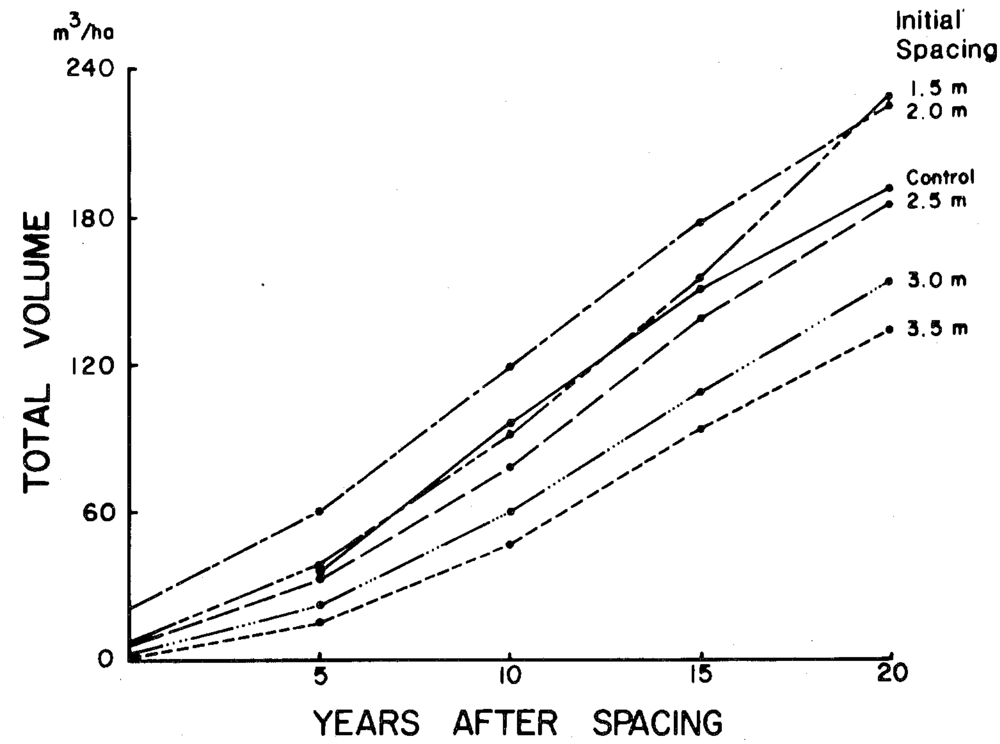

Fig. 9. Total volume (dbh >1 cm).

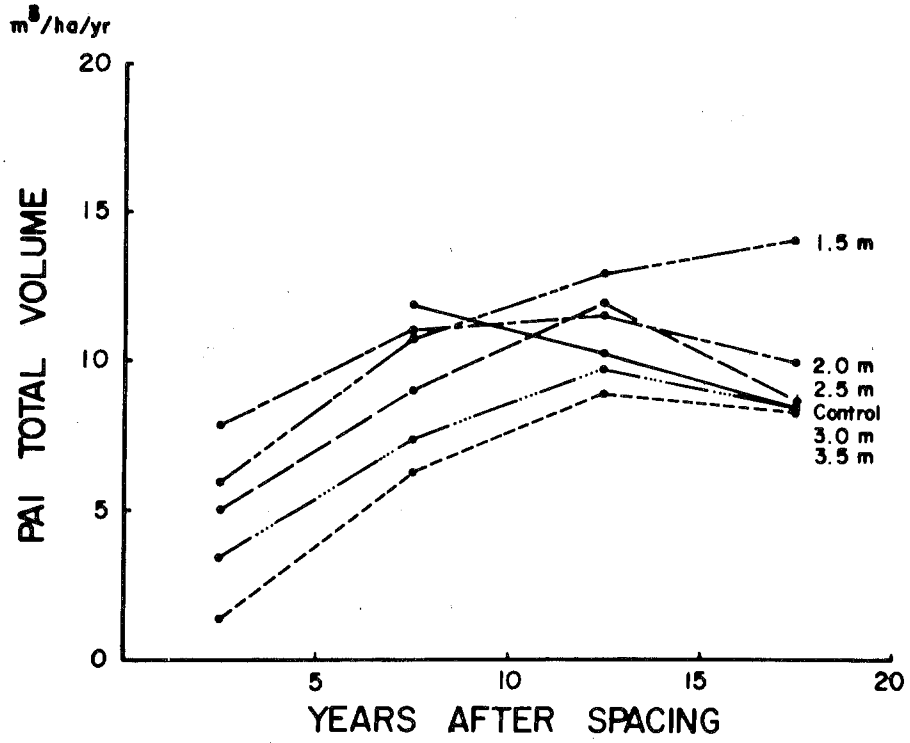

Fig. 10. Net PAI total volume.

pattern as noted in 2) above; namely an increase in yield with decreasing spacing up to a certain maximum, with a decrease in merchantable yield as the spacing approaches that of the controls. This trend is evident in both Tables 4 and 5. Maximum merchantable biomass yield occurs at the 6 x 6 ft spacing (Table 5). For example, the mean dry above-ground biomass for the merchantable portion of the stand is 92 OD t/ha for the 6 x 6 ft spacing, 14% above the mean control weight (Table 5). The statistics for merchantable biomass (Table 5), if plotted against nominal spacing for a given time, suggest a maximum yield at nominal spacings around 5.5 ft (1.68 m) (Fig. 11). The same pattern was noted above for merchantable volume.

In a study of biomass production in unthinned, 38 to 45-year-old fir/spruce stands in northwestern New Brunswick, Baskerville (1965b) found that the oven-dry weight of foliage ranged from 16 to 19 OD t/ha, depending on stand density. By comparison, the dry foliage weights of the stands in this study ranged from 10 to 15 OD t/ha, 20 years after thinning (Table 5). Total above-ground biomass in Baskerville's stands varied from 98 to 149 OD t/ha, compared to 83-96 OD t/ha for the younger thinned stands of this study (Table 5). Mean values of total above-ground biomass and net PAI of above-ground biomass from Table 4 are plotted in Figs. 12 and 13.

The relationship between stand density and the distribution of biomass among the different stand components in this study is similar to that observed by Baskerville (1965b). The biomass of both foliage and

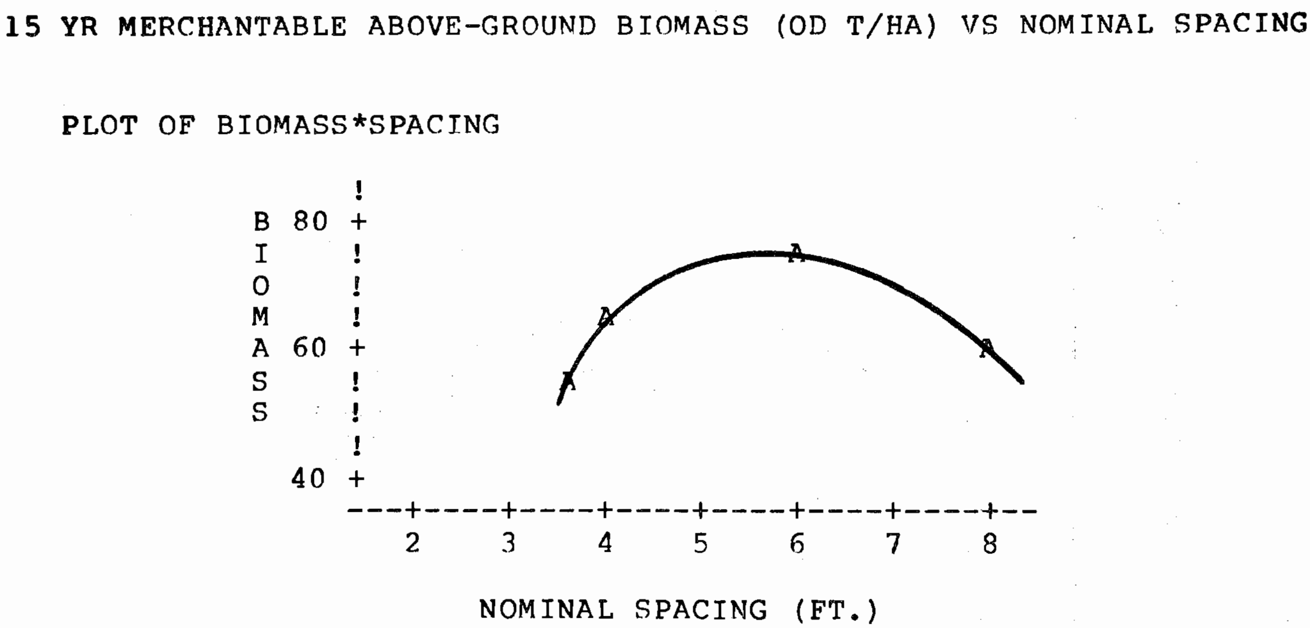

Fig. 11. Mean 15-year above-ground merchantable biomass versus nominal spacing.

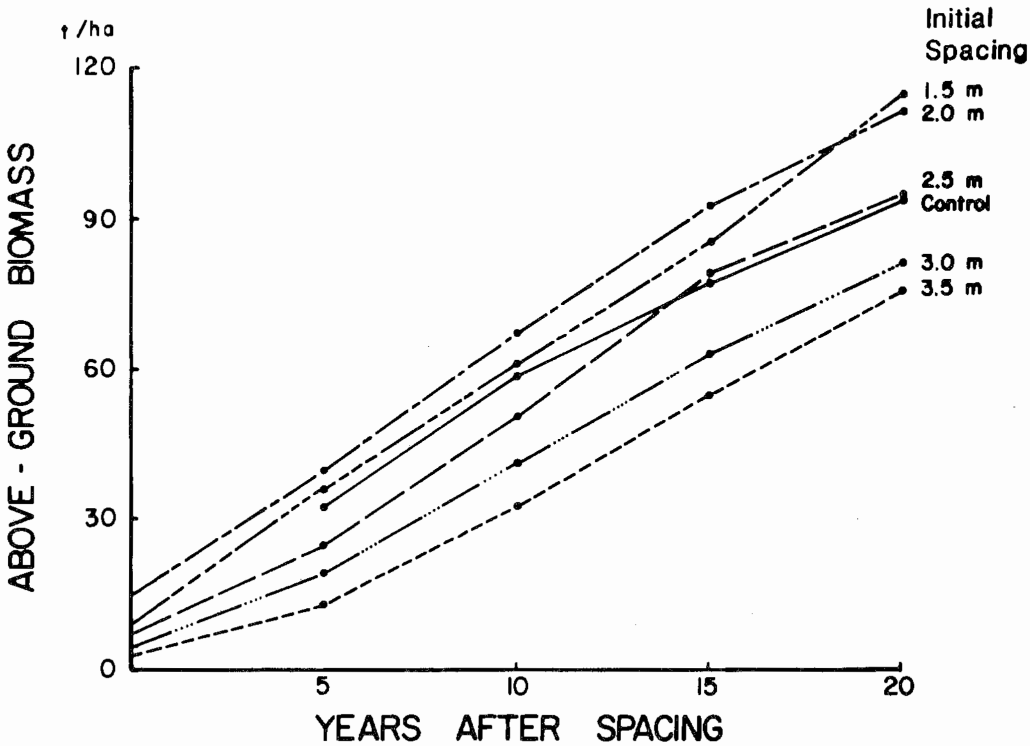

Fig. 12. Above-ground biomass (dbh >1 cm).

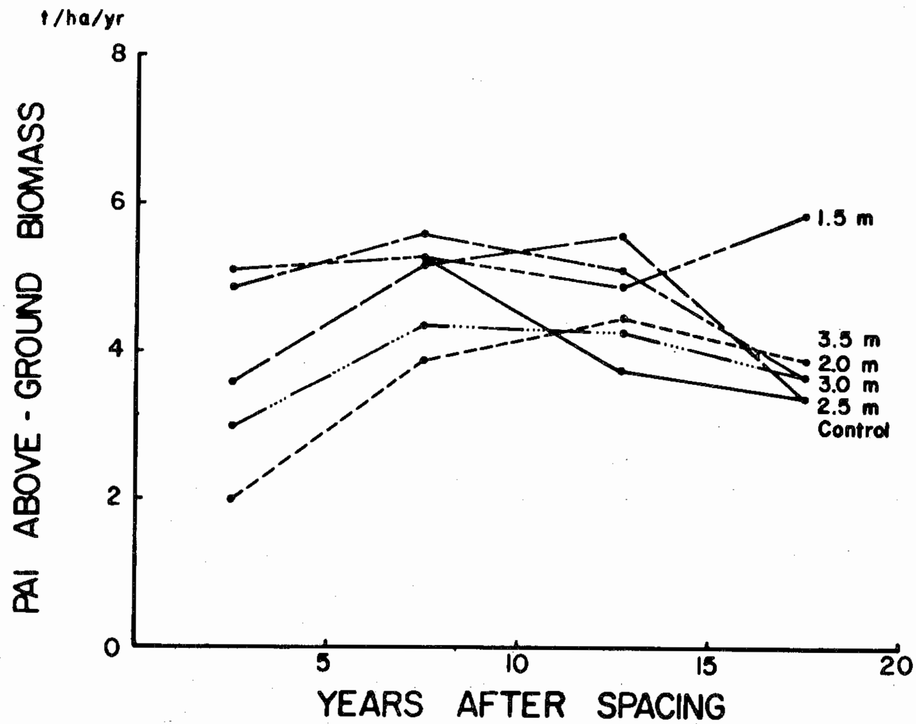

Fig. 13. Net PAI above-ground biomass.

branches, as a percentage of above-ground biomass, decreases with increasing stand density, while the proportion of stem biomass (wood plus bark) increases with increasing density.

For example, using the 20-year figures (Table 5), the proportion of foliage decreased from 17% at the 8 x 8 ft spacing to 10% for the controls. Baskerville noted a decrease from 16% at the lowest stand density to 13% at the highest. Branch biomass decreased from 20 to 14%, compared to a decrease of from 18 to 11% for Baskerville's data. Total stem biomass increased from 62% of above-ground biomass at the 8 x 8 ft spacing to 76% for the controls. Baskerville's data show a similar change, from 66% at the lowest density to 75% at the highest density.

Mean total biomass, including roots, for all trees larger than 1 cm dbh varied from 111 to 127 OD t/ha, 20 years after spacing (Table 5). By comparison, mature softwood stands in Maine have about 188 OD t/ha of biomass above and below ground, including all woody stems above 1 ft in height, according to a biomass inventory in Maine (Young et al. 1976). The overall Maine average, for all age classes and cover types combined, was 155 OD t/ha (Young et al 1976).

The distribution of biomass among different components reported by Young et al. (1976) is similar to that observed in our study. For example, the stump/root system is about 20% of the total tree, according to Young, compared to 24-25% for the 20-year data (Table 5). The ratio of oven-dry softwood foliage to total tree biomass is 11% in the Maine study, compared to 8-13% for the 20-year means of Table 5.

Basal area

Merchantable basal area, like volume and biomass, was greatest at the 6 x 6 ft spacing (Table 5). The mean values of merchantable basal area and net PAI are plotted in Figs. 14 and 15, using the data of Table 4. Total basal area, and net PAI (total basal area) are plotted in Figs. 16 and 17, based on the means in Table 4.

Number of stems

The average numbers of crop trees above 1 and 9 cm dbh are plotted in Figs. 18 and 19, respectively, based on Table 4. These numbers reflect the combined effects of ingrowth of crop trees into the 1 and 9-cm dbh-class, survival, and mortality. The average spacing of live crop trees for each time/initial spacing category is given at the end of Tables 4 and 5, based on the number of crop trees above 1 cm dbh, and the formula $(10^4/N)^{\frac{1}{2}}$.

As noted earlier, a large number of small, untagged stems began to form an understory 5 to 10 years after spacing and were removed in a cleaning operation in 1972. The statistics from the 1969 measurement of plots 100 to 115 give some indication of the number and size of these untagged trees. The average number of untagged softwood stems 1 ft and over in height was 4845/ha. Most of these were less than 1.3 m in height, with an average height of 0.9 m. Untagged hardwood species such as white birch, pin cherry, mountain ash, poplar (Populus sp.) and red maple (Acer rubrum L.) averaged about 5246 stems/ha with an average height of 2.8 m. These untagged stems are not included in the data of Tables 4 and 5.

Quadratic mean diameter

The quadratic mean diameters (Table 4) are plotted in Figs. 20 and 21. There is a fairly consistent trend to larger diameters at wider spacing, both for quadratic mean diameter and mean diameter.

Since harvesting costs are inversely related to average tree size

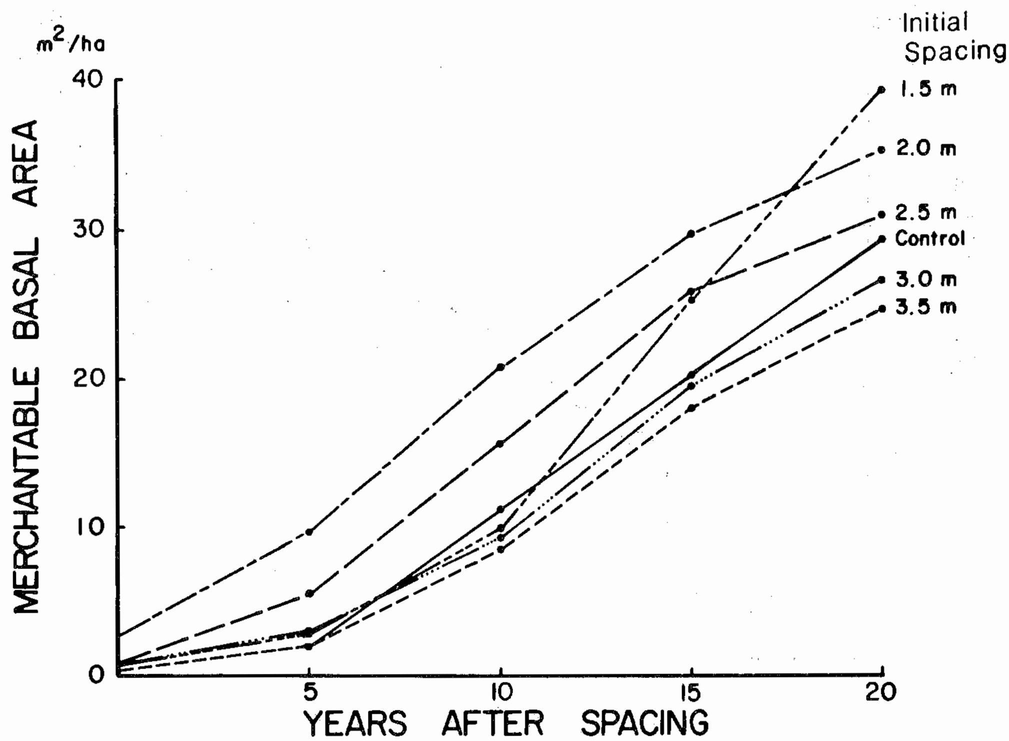

Fig. 14. Merchantable basal area (dbh >9 cm).

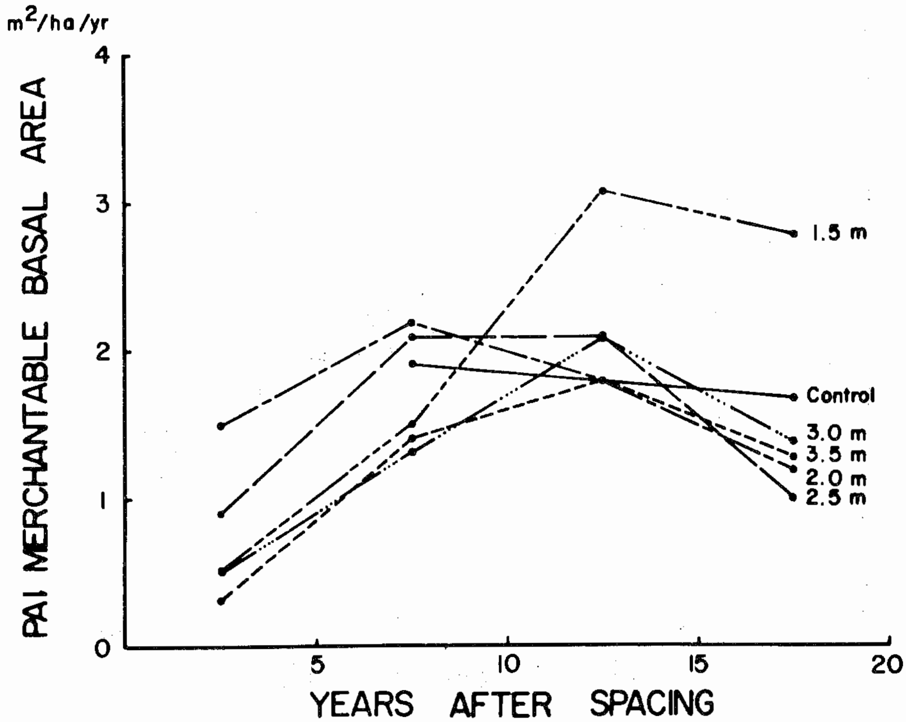

Fig. 15. Net PAI merchantable basal area.

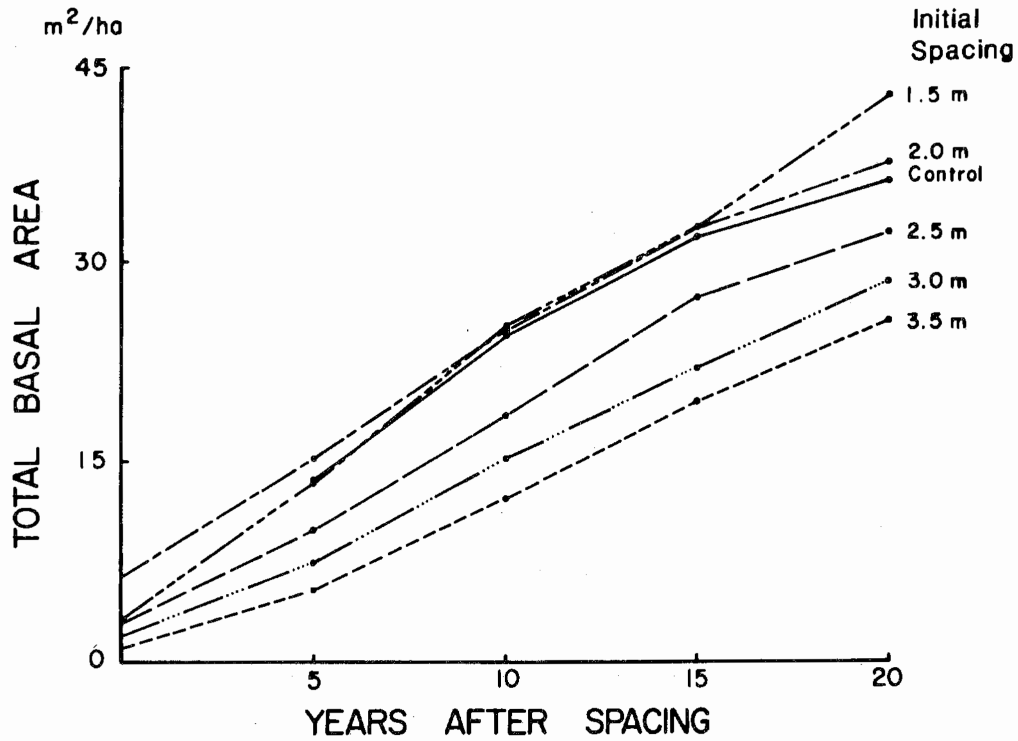

Fig. 16. Total basal area (dbh >1 cm).

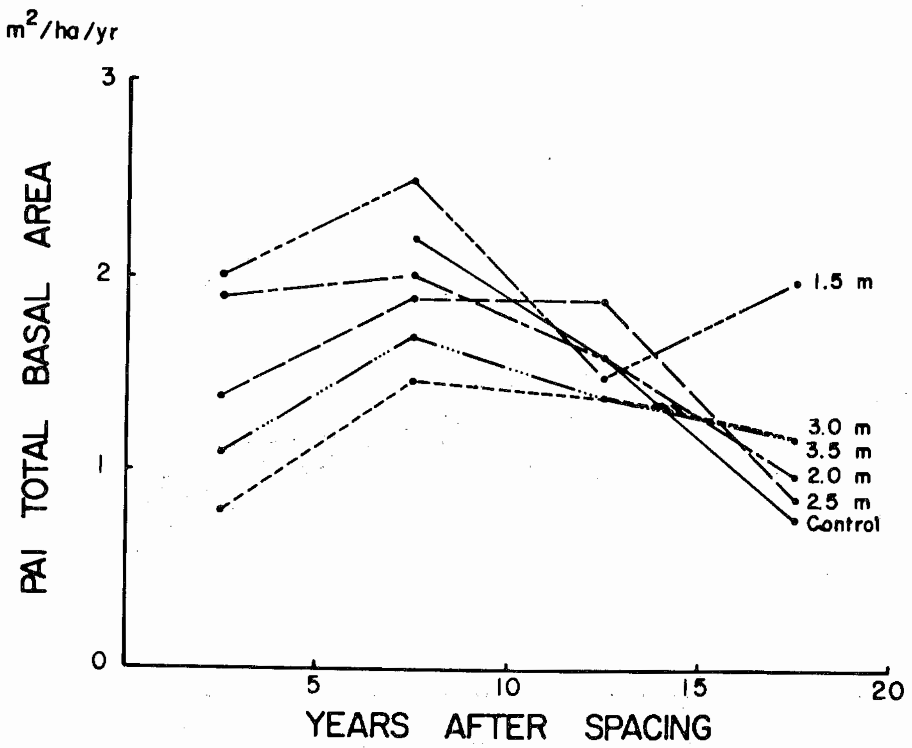

Fig. 17. Net PAI total basal area.

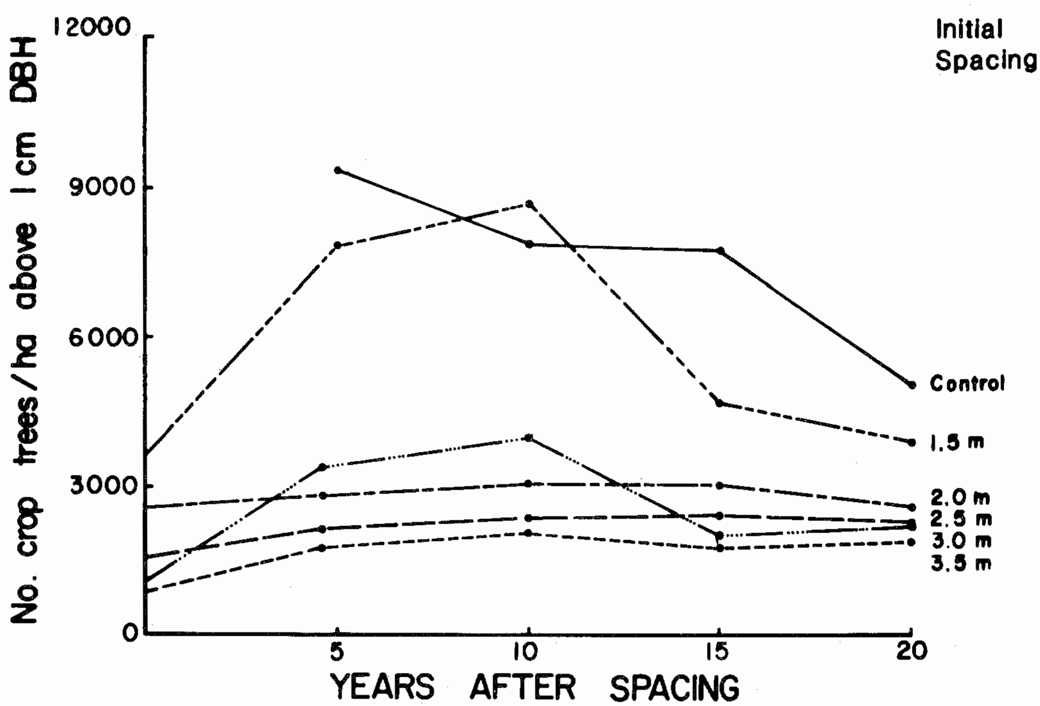

Fig. 18. Number of crop trees per hectare (dbh ≥1 cm).

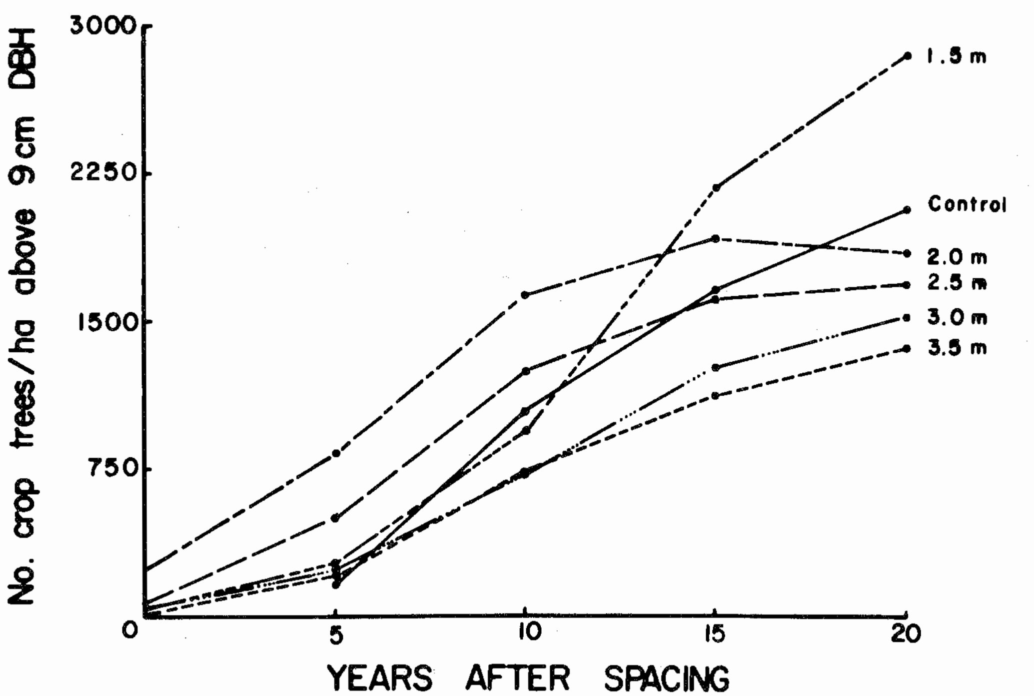

Fig. 19. Number of crop trees per hectare (dbh ≥9 cm).

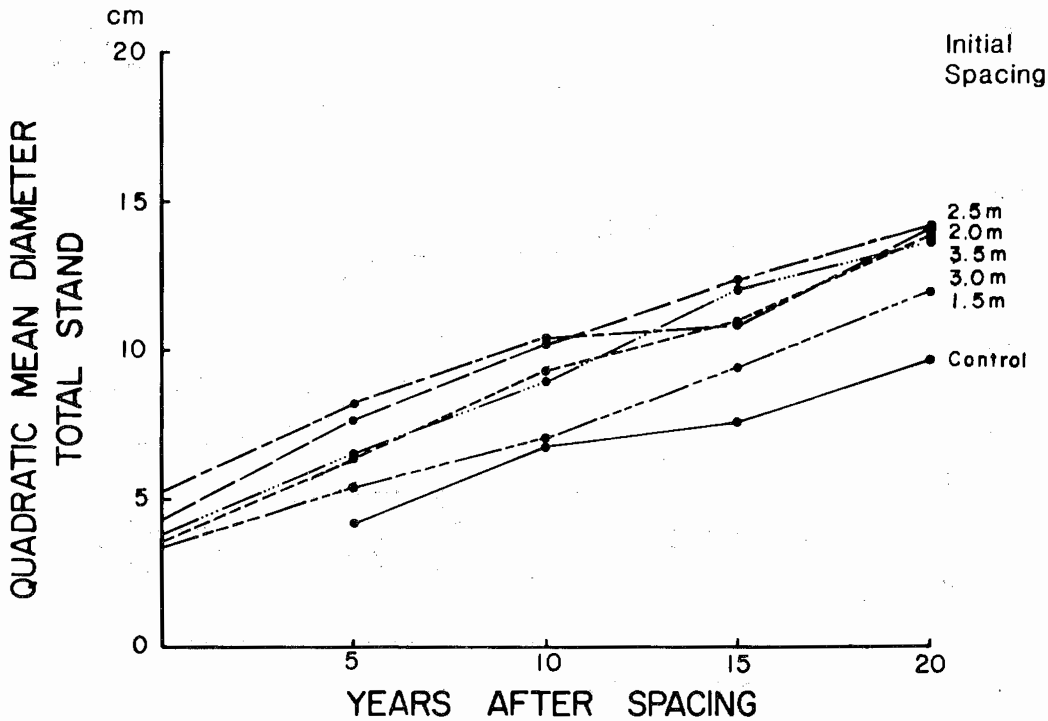

Fig. 20. Quadratic mean diameter (dbh >1 cm).

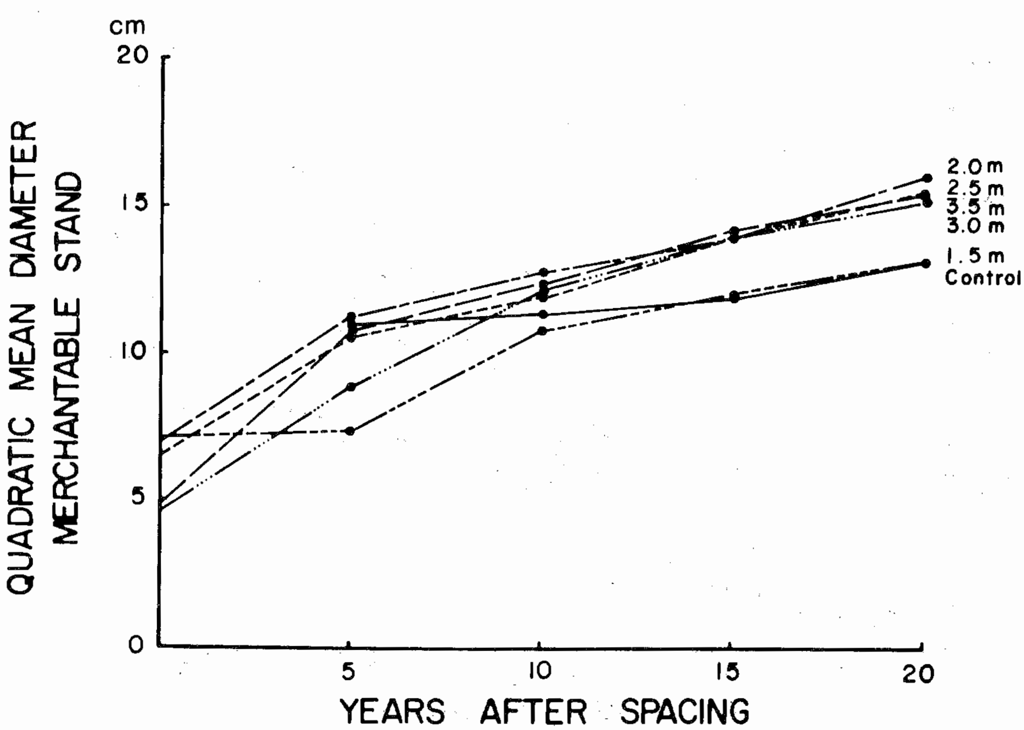

Fig. 21. Quadratic mean diameter (dbh >9 cm).

(Hannula 1971), we can expect some reduction in harvesting costs for thinned stands. The optimal level of spacing, beyond which the advantages of reduced harvesting costs would be offset by the effect of higher thinning costs and decreased merchantable volume, would depend on such factors as:

- the relationship between spacing, merchantable volume, and average diameter,
- type of logging system,
- time between spacing and harvesting,
- the relationship between initial spacing cost and level of spacing,
- existence of an allowable cut effect.

Tucker (1974) developed economic models for evaluating factors such as those listed above, using the net present worth approach. Although Tucker's paper was concerned with evaluation of fertilizer treatments, his general approach could probably be applied also to the analysis of the economics of spacing.

Dominant height

The average dominant heights (Table 4) are plotted in Fig. 22. Most of the 20-year mean dominant heights, with the exception of the 16.5 m figure for the 2.0 m spacing, ranged from 13.8 to 14.9 m. The variation in 20-year dominant heights in Table 5 (nominal spacing) was even less, from 14.6 to 15.3 m. No strong relationship between dominant height and spacing is evident from the data of Tables 4 and 5. This tends to confirm the validity of using dominant

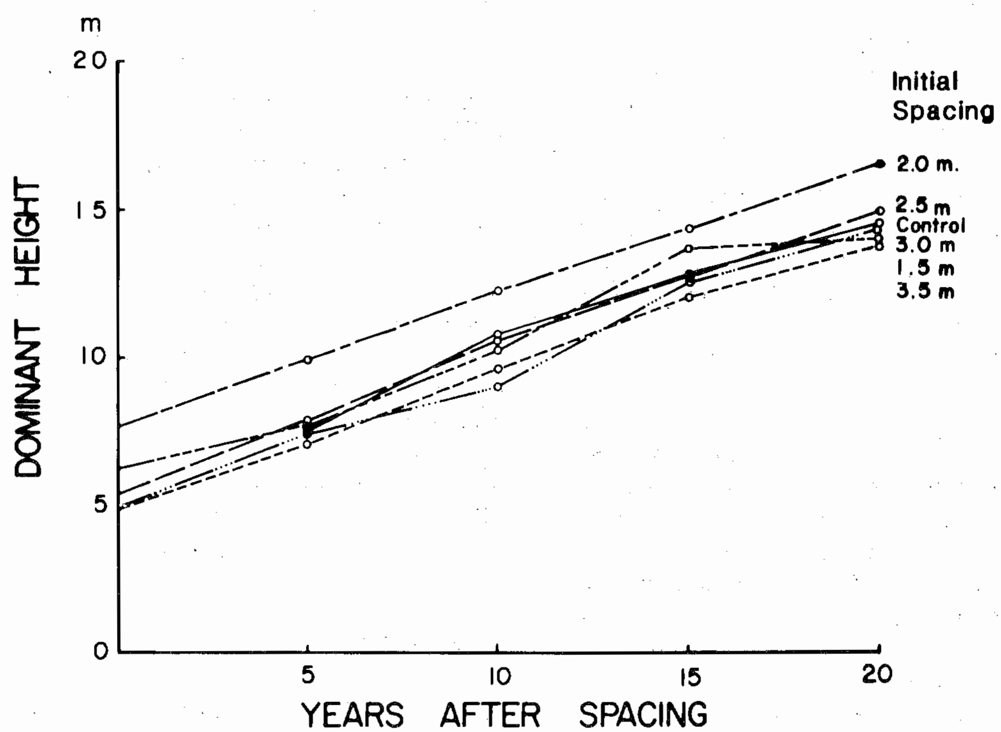

Fig. 22. Dominant height of stand.

height/age relationships as indicators of site quality, the premise of this approach being that dominant height is independent of stand density.

SUMMARY

Young fir/spruce stands in northwestern New Brunswick were thinned, between 1959 and 1967, to a range of spacings, from no thinning (controls) up to 16 x 16 ft. Sixty-four, 0.2-acre (0.081 ha) sample plots were established in these stands. The softwood crop trees remaining after thinning were numbered, tagged, and measured for dbh, height, crown width, and crown length, at the time of plot establishment and every five years thereafter. Any untagged trees were tallied by height class and species only. In 1972, 48 of the plots were cleaned to remove the numerous small untagged softwood and hardwood stems which were beginning to form an understory.

Major stand parameters such as volume, basal area, biomass, quadratic mean diameter, etc. were calculated using the tagged (crop) tree data for each plot and measurement. Mean values of these parameters were then derived for each combination of initial spacing and time elapsed since initial treatment. This was done for each of two alternative definitions of spacing:
1) average initial spacing based on actual number of crop trees above 1 cm dbh in the year of plot establishment (Table 4), and 2) the nominal or intended spacing (Table 5).

Merchantable yield parameters (volume/ biomass) were consistently greatest at nominal spacings of 6 x 6 ft (1.83 x 1.83 m).

Merchantable volume for the 6 x 6 ft spacing averaged 158.3 m^3/ha 20 years after treatment, an increase of 15% over the average untreated stand volume.

Average tree diameter increased steadily with increasing spacing. For example, the average 20-year quadratic mean diameter of trees above 9 cm dbh was 16.7 cm for the 8 x 8 ft. spacing, an increase of 26% over that of the untreated stands.

Evaluation of "optimal" spacing levels will involve an economic analysis of such factors as cost of spacing, the relationship between merchantable yield and initial spacing, the influence of average tree size on logging costs, and relative costs and benefits of alternative silvicultural treatments such as fertilization.

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Table 1. Distribution of sample plots for Green River spacing trials, by average initial spacing, based on number of crop trees above 1 cm dbh

Plot Numbers	Year established	Location	Average initial spacing (m) Control	1.5	2.0	2.5	3.0	3.5	>3.5	Total
			No. of Plots							
100-115	1959	Upper Belone Brook	4	1	2	4	3	2	0	16
116-123	1960	Lower Belone Brook	2	0	0	0	3	3	0	8
124-131	1960	Summit Road	2	0	4	1	1	0	0	8
133-140	1961	Upper Chisholm Brook	2	0	1	3	0	1	1	8
141-148	1961	Lower Chisholm Brook	2	1	2	1	1	1	0	8
149-164	1967	Side Hill (Camp 52)	0	1	0	0	2	1	12	16
Totals			12	3	9	9	10	8	13	64

Table 2. Distribution of sample plots for Green River spacing trials, by nominal spacing

Plot Numbers	Year established	Location	Nominal spacing (ft.) Control	2	4	6	8	10	>10	Total
			No. of Plots							
100-115	1959	Upper Belone Brook	4	0	4	4	4	0	0	16
116-123	1960	Lower Belone Brook	2	0	2	2	2	0	0	8
124-131	1960	Summit Road	2	0	2	2	2	0	0	8
133-140	1961	Upper Chisholm Brook	2	0	2	2	2	0	0	8
141-148	1961	Lower Chisholm Brook	2	0	2	2	2	0	0	8
149-164	1967	Side Hill (Camp 52)	0	2	2	2	2	2	6	16
Totals			12	2	14	14	14	2	6	64

Table 3. Number of complete plot measurements available as of 1980, by average initial crop tree spacing (dbh >1 cm) and time since spacing

Years since spacing	Average initial spacing (m)						
	Control	1.5	2.0	2.5	3.0	3.5	>3.5
0	0	3	9	9	10	8	13
5	4	3	9	9	10	8	13
10	12	3	9	9	10	8	13
15	12	2	9	9	8	7	1
20	8	1	6	5	7	5	0

Table 4. Mean values of stand parameters by average initial spacing (based on number of crop trees above 1 cm dbh) and number of years since thinning

Stand parameter	No. of years after spacing	Average initial spacing (m)					
		Control	1.5	2.0	2.5	3.0	3.5
Volume (total)* (m^3/ha)	0	NA	7.3	20.2	7.1	4.2	2.1
	5	36.0	37.3	59.9	32.5	21.7	14.1
	10	96.1	91.3	116.6	78.8	59.4	46.
	15	148.1	156.7	175.6	139.5	108.6	91.0
	20	190.9	227.7	225.6	183.6	151.4	133.0
Volume (merch)** (m^3/ha)	0	NA	1.5	8.0	1.8	1.6	0.5
	5	4.8	7.6	35.9	16.4	9.7	5.3
	10	41.2	34.6	85.7	57.1	35.2	29.6
	15	84.1	104.2	141.8	114.1	86.5	73.8
	20	137.9	181.3	193.9	156.9	127.5	113.6
Basal area (total) (m^2/ha)	0	NA	3.4	6.2	2.6	1.6	0.9
	5	13.9	13.4	15.5	9.7	7.4	5.1
	10	25.0	25.7	25.3	19.0	15.9	12.6
	15	32.8	33.2	33.1	28.4	22.7	19.8
	20	36.6	43.1	37.9	32.8	28.7	26.0
Basal area (merch) (m^2/ha)	0	NA	0.4	2.4	0.6	0.5	0.2
	5	1.6	2.7	9.8	5.3	2.9	1.9
	10	11.1	10.0	20.8	15.6	9.6	8.9
	15	20.2	25.6	29.8	26.0	19.9	18.1
	20	28.9	39.4	35.9	31.0	26.9	24.5
Quadratic mean diameter (total) (cm)	0	NA	3.3	5.3	4.3	3.8	3.6
	5	4.1	5.3	8.3	7.8	6.6	6.5
	10	6.7	7.0	10.5	10.4	9.0	9.3
	15	7.6	9.5	12.0	12.5	12.2	12.1
	20	9.7	12.0	14.1	14.2	13.6	13.9
Quadratic mean diameter (merch) (cm)	0	NA	7.2	7.1	4.9	4.6	6.6
	5	11.0	7.4	11.5	10.9	8.9	10.6
	10	11.4	11.0	12.9	12.5	12.3	12.2
	15	12.1	12.2	14.1	14.4	14.2	14.2
	20	13.3	13.3	15.8	15.4	15.2	15.4

Table 4. Cont.

Stand parameter	No. of years after spacing	Average initial spacing (m)					
		Control	1.5	2.0	2.5	3.0	3.5
No. of stems/ha (total)	0	NA	3661	2523	1603	1103	861
	5	10397	7882	2892	2130	3464	1756
	10	7987	8726	3021	2334	4079	2088
	15	7800	4719	3055	2424	2057	1752
	20	4983	3805	2471	2177	2096	1773
No. of stems/ha (merch)	0	NA	37	244	66	47	11
	5	166	276	842	505	250	193
	10	1029	959	1566	1254	731	738
	15	1710	2162	1922	1613	1277	1159
	20	2058	2841	1849	1687	1526	1346
Mean diameter (total) (cm)	0	NA	2.8	4.8	3.9	3.4	3.1
	5	3.7	5.0	7.7	7.3	6.0	5.8
	10	6.0	6.6	9.7	9.8	8.4	8.4
	15	6.6	8.7	11.1	11.5	11.3	11.3
	20	8.6	11.3	13.1	13.5	12.7	12.8
Mean diameter (merch) (cm)	0	NA	7.1	7.0	4.8	4.6	6.6
	5	10.9	7.3	11.4	10.9	8.8	10.4
	10	11.2	10.8	12.6	12.4	12.1	12.0
	15	11.9	12.0	13.8	13.9	14.0	13.9
	20	13.1	13.1	15.3	15.1	14.9	15.1
Lorey's height (total) (m)	0	NA	3.8	5.3	4.1	3.9	4.1
	5	4.7	5.2	7.3	6.0	5.4	5.2
	10	7.5	7.1	9.4	8.2	7.4	7.2
	15	9.2	9.8	11.3	10.3	9.9	9.5
	20	11.0	11.3	13.1	12.1	11.2	10.8
Lorey's height (merch) (m)	0	NA	5.5	5.0	3.3	3.1	3.7
	5	6.6	5.0	8.1	6.8	5.6	6.4
	10	9.0	8.5	9.9	8.6	8.2	7.9
	15	10.5	10.4	11.7	10.6	10.3	9.8
	20	11.9	11.6	13.4	12.4	11.5	11.1

Table 4. Cont.

Stand parameter	No. of years after spacing	Average initial spacing (m)					
		Control	1.5	2.0	2.5	3.0	3.5
Mean height (total) (m)	0	NA	2.8	4.2	3.4	3.1	2.8
	5	3.7	4.3	5.9	5.1	4.4	4.1
	10	5.7	5.9	7.9	7.1	6.2	5.9
	15	6.5	8.1	9.4	8.9	8.4	8.0
	20	8.3	10.1	11.1	10.8	9.6	9.3
Mean height (merch) (m)	0	NA	5.0	4.9	3.2	3.1	3.7
	5	6.5	4.8	7.9	6.6	5.5	6.1
	10	8.8	8.3	9.6	8.4	7.9	7.6
	15	10.2	10.1	11.2	10.3	9.9	9.3
	20	11.4	11.3	12.7	11.9	10.9	10.6
ODW*** stem wood (total) (t/ha)	0	NA	1.42	5.80	1.80	1.02	0.39
	5	10.31	9.75	17.00	8.30	5.18	3.24
	10	32.01	28.74	34.63	21.81	16.32	12.07
	15	49.90	50.10	53.36	39.94	30.86	24.92
	20	61.90	70.64	68.80	54.60	43.80	37.30
ODW stem wood (merch) (t/ha)	0	NA	0.53	2.89	0.69	0.55	0.16
	5	1.74	2.63	12.28	5.37	3.07	1.62
	10	15.39	12.74	29.42	18.54	11.25	9.28
	15	31.78	38.72	49.05	37.14	27.98	23.05
	20	50.13	65.58	66.15	52.44	41.67	35.82
ODW stem bark (total) (t/ha)	0	NA	0.58	1.12	0.45	0.26	0.13
	5	3.39	2.73	2.56	1.30	1.17	0.65
	10	5.55	5.23	4.88	2.85	2.70	1.67
	15	7.75	7.11	7.83	5.52	4.19	3.29
	20	9.21	10.30	10.68	8.11	6.17	5.16
ODW stem bark (merch) (t/ha)	0	NA	0.07	0.37	0.08	0.07	0.02
	5	0.21	0.30	1.57	0.63	0.39	0.16
	10	2.05	1.64	3.98	2.25	1.40	1.06
	15	4.44	5.29	7.10	5.03	3.69	2.94
	20	7.30	9.46	10.25	7.75	5.79	4.87
ODW total stem (total) (t/ha)	0	NA	2.00	6.92	2.25	1.29	0.52
	5	13.70	12.48	19.56	9.60	6.35	3.89
	10	37.57	33.97	39.52	24.66	19.02	13.73
	15	57.65	57.20	61.19	45.47	35.05	28.22
	20	71.11	80.94	79.49	62.71	49.97	42.46

Table 4. Cont.

Stand parameter	No. of years after spacing	Average initial spacing (m)					
		Control	1.5	2.0	2.5	3.0	3.5
ODW	0	NA	0.60	3.26	0.78	0.62	0.17
total	5	1.95	2.93	13.85	6.00	3.47	1.79
stem	10	17.44	14.37	33.40	20.79	12.65	10.33
(merch)	15	36.22	44.01	56.15	42.16	31.66	25.99
(t/ha)	20	57.43	75.04	76.39	60.19	47.46	40.68
ODW	0	NA	3.03	3.30	1.75	1.17	0.83
branches	5	8.57	8.99	8.83	6.23	5.43	3.63
(total)	10	11.05	13.05	14.90	12.19	10.48	8.63
(t/ha)	15	11.59	13.85	16.72	16.46	14.07	13.34
	20	13.42	17.93	17.74	18.66	16.18	15.58
ODW	0	NA	0.19	1.28	0.32	0.29	0.09
branches	5	1.06	1.53	5.68	3.28	1.82	1.25
(merch)	10	6.27	6.49	12.92	10.30	6.64	6.21
(t/ha)	15	9.34	12.35	15.85	15.58	12.88	12.40
	20	12.37	17.37	17.34	18.09	15.54	15.08
ODW	0	NA	3.31	4.31	2.23	1.36	0.99
foliage	5	9.60	12.15	10.74	8.18	7.00	4.96
(total)	10	9.62	13.31	12.62	13.36	11.38	9.62
(t/ha)	15	8.13	13.65	14.60	16.30	13.41	12.92
	20	9.63	15.46	13.94	13.65	14.89	15.80
ODW	0	NA	0.25	1.69	0.41	0.37	0.14
foliage	5	1.02	2.20	6.71	4.20	2.34	1.75
(merch)	10	5.39	5.29	10.75	11.19	6.52	6.65
(t/ha)	15	7.15	12.73	13.86	15.35	12.08	11.87
	20	9.15	15.16	13.77	13.22	14.22	15.23
ODW	0	NA	6.34	7.60	3.98	2.53	1.81
crown	5	18.17	21.14	19.56	14.41	12.43	8.59
(total)	10	20.67	26.36	27.52	25.55	21.86	18.24
(t/ha)	15	19.73	27.50	31.33	32.76	27.48	26.26
	20	23.04	33.39	31.69	32.31	31.07	31.38
ODW	0	NA	0.44	2.96	0.73	0.65	0.23
crown	5	2.08	3.73	12.39	7.47	4.16	3.00
(merch)	10	12.40	11.77	23.67	21.49	13.17	12.86
(t/ha)	15	17.36	25.07	29.71	30.92	24.96	24.27
	20	21.89	32.54	31.12	31.31	29.76	30.31

Table 4. Cont.

Stand parameter	No. of years after spacing	Average initial spacing (m)					
		Control	1.5	2.0	2.5	3.0	3.5
ODW	0	NA	8.33	14.52	6.23	3.82	2.34
above-ground	5	31.87	33.62	39.12	24.01	18.78	12.48
biomass	10	58.24	60.33	67.04	50.21	40.88	31.98
(total)	15	77.38	84.70	92.51	78.23	62.53	54.48
(t/ha)	20	94.15	114.33	111.18	95.02	81.04	73.84
ODW	0	NA	1.04	6.22	1.50	1.28	0.40
above-ground	5	4.03	6.66	26.24	13.47	7.63	4.79
biomass	10	29.32	26.15	57.07	42.28	25.82	23.20
(merch)	15	54.45	69.08	85.85	73.09	56.62	50.26
(t/ha)	20	81.08	107.57	107.51	91.50	77.21	70.99
ODW	0	NA	3.14	5.44	2.29	1.47	0.92
roots	5	11.54	9.47	13.73	9.33	5.81	4.37
(total)	10	22.15	23.22	24.54	18.05	15.55	12.46
(t/ha)	15	28.91	27.32	28.62	25.94	22.24	20.11
	20	31.84	38.69	32.18	31.41	27.80	24.29
ODW	0	NA	0.34	2.14	0.55	0.46	0.15
roots	5	1.69	2.34	8.88	5.16	2.83	1.91
(merch)	10	10.72	10.89	21.05	15.51	10.36	9.47
(t/ha)	15	17.10	21.59	26.01	24.11	20.27	18.72
	20	24.37	35.30	30.22	29.90	26.12	23.16
ODW	0	NA	11.48	19.97	8.52	5.29	3.26
total biomass	5	43.41	43.09	52.85	33.35	24.59	16.86
(incl. roots)	10	80.39	83.55	91.58	68.26	56.43	44.43
(total)	15	106.30	112.02	121.13	104.17	84.78	74.59
(t/ha)	20	125.99	153.01	143.35	126.43	108.84	98.12
ODW	0	NA	1.39	8.36	2.06	1.74	0.55
total biomass	5	5.72	9.00	35.11	18.63	10.46	6.69
(incl. roots)	10	40.04	37.03	78.12	57.79	36.17	32.67
(merch)	15	71.55	90.68	111.87	97.20	76.90	68.98
(t/ha)	20	105.46	142.87	137.73	121.40	103.34	94.15

Table 4. Cont.

Stand parameter	No. of years after spacing	Average initial spacing (m)					
		Control	1.5	2.0	2.5	3.0	3.5
Dominant height (m)	0	NA	6.3	7.6	5.4	5.0	4.9
	5	7.6	7.7	10.0	7.9	7.4	7.1
	10	10.8	10.2	12.3	10.6	9.9	9.7
	15	12.9	13.7	14.4	12.8	12.6	12.0
	20	14.7	14.1	16.5	14.9	14.4	13.8
Average spacing (m) (based on total no. stems/ha)	0	NA	1.65	1.99	2.50	3.01	3.41
	5	0.98	1.13	1.86	2.17	1.70	2.39
	10	1.12	1.07	1.82	2.07	1.57	2.19
	15	1.13	1.46	1.81	2.03	2.20	2.39
	20	1.42	1.62	2.01	2.14	2.18	2.37

* All crop trees >1cm dbh.
** All crop trees >9cm dbh.
*** Oven-dry weight.

Table 5. Mean values of stand parameters by nominal spacings and time since thinning

Stand parameter	No. of years after spacing	Nominal spacing (ft.)			
		Control	4	6	8
Volume (total)* (m^3/ha)	0	NA	8.8	8.9	5.6
	5	36.0	32.7	33.7	23.2
	10	96.1	78.4	76.8	58.2
	15	148.1	140.7	143.9	109.9
	20	190.9	185.7	184.2	158.2
Volume (merch)** (m^3/ha)	0	NA	3.0	2.8	2.2
	5	4.8	12.9	18.6	13.9
	10	41.2	44.7	55.6	44.6
	15	84.1	102.6	119.3	93.5
	20	137.9	150.8	158.3	139.6
Basal area (total) (m^2/ha)	0	NA	3.1	3.0	1.9
	5	13.9	10.2	9.6	6.6
	10	25.0	19.8	18.2	13.7
	15	32.8	29.5	28.4	21.9
	20	36.6	34.6	32.9	28.2
Basal area (merch) (m^2/ha)	0	NA	0.9	0.9	0.7
	5	1.6	3.9	5.6	4.1
	10	11.1	12.4	14.6	11.7
	15	20.2	24.4	26.4	20.6
	20	28.9	31.5	31.5	27.1
Quadratic mean diameter (total) (cm)	0	NA	3.7	4.2	4.2
	5	4.1	6.1	7.3	7.6
	10	6.7	8.3	9.9	10.6
	15	7.6	10.3	12.6	13.3
	20	9.7	12.2	14.1	15.3
Quadratic mean diameter (merch) (cm)	0	NA	5.6	5.8	5.0
	5	11.0	9.3	9.9	11.4
	10	11.4	11.5	12.3	13.0
	15	12.1	12.8	14.3	15.2
	20	13.3	14.0	15.4	16.7

Table 5. Cont.

Stand parameter	No. of years after spacing	Nominal spacing (ft.)			
		Control	4	6	8
No. of stems/ha (total)	0	NA	2079	1522	894
	5	10397	3381	2092	1351
	10	7987	3684	2300	1540
	15	7800	3572	2278	1568
	20	4983	2968	2125	1539
No. of stems/ha (merch)	0	NA	90	86	70
	5	166	359	522	345
	10	1029	1121	1140	830
	15	1710	1884	1620	1131
	20	2058	2038	1695	1240
Mean diameter (total) (cm)	0	NA	3.3	3.8	3.8
	5	3.7	5.6	6.8	6.9
	10	6.0	7.7	9.2	9.7
	15	6.6	9.5	11.6	12.4
	20	8.6	11.3	13.3	14.2
Mean diameter (merch) (cm)	0	NA	5.5	5.7	4.9
	5	10.9	9.2	9.8	11.2
	10	11.2	11.3	12.1	12.8
	15	11.9	12.5	13.9	14.8
	20	13.1	13.7	14.9	16.4
Lorey's height (total) (m)	0	NA	4.0	4.4	4.1
	5	4.7	5.5	6.0	5.9
	10	7.5	7.5	8.1	8.1
	15	9.2	9.8	10.6	10.4
	20	11.0	11.3	12.1	12.0
Lorey's height (merch) (m)	0	NA	4.1	3.9	2.9
	5	6.6	6.1	6.5	7.0
	10	9.0	8.4	8.6	8.6
	15	10.5	10.3	10.8	10.6
	20	11.9	11.7	12.3	12.2

Table 5. Cont.

Stand parameter	No. of years after spacing	Nominal spacing (ft.) Control	4	6	8
Mean height (total) (m)	0	NA	3.1	3.4	3.3
	5	3.7	4.5	5.0	4.9
	10	5.7	6.3	6.9	6.8
	15	6.5	8.1	9.0	8.8
	20	8.3	9.6	10.6	10.4
Mean height (merch) (m)	0	NA	3.9	3.8	2.9
	5	6.5	5.9	6.3	6.8
	10	8.8	8.2	8.3	8.3
	15	10.2	10.0	10.4	10.1
	20	11.4	11.2	11.7	11.6
ODW*** stem wood (total) (t/ha)	0	NA	2.25	2.41	1.49
	5	10.31	8.88	9.01	5.89
	10	32.01	23.24	21.53	15.66
	15	49.90	43.02	41.58	30.55
	20	61.90	56.44	54.58	45.18
ODW stem wood (merch) (t/ha)	0	NA	1.08	1.03	0.78
	5	1.74	4.41	6.28	4.42
	10	15.39	15.78	18.33	13.97
	15	31.78	36.35	39.23	29.25
	20	50.13	52.40	52.77	44.26
ODW stem bark (total) (t/ha)	0	NA	0.53	0.56	0.31
	5	3.39	1.68	1.42	0.90
	10	5.55	3.43	2.95	2.06
	15	7.75	6.09	5.84	4.19
	20	9.21	8.27	8.14	6.58
ODW stem bark (merch) (t/ha)	0	NA	0.14	0.14	0.10
	5	0.21	0.54	0.78	0.54
	10	2.05	2.04	2.34	1.70
	15	4.44	4.98	5.42	3.94
	20	7.30	7.61	7.81	6.39

Table 5. Cont.

Stand parameter	No. of years after spacing	Nominal spacing (ft.) Control	4	6	8
ODW	0	NA	2.79	2.97	1.79
Total	15	13.70	10.56	10.43	6.79
stem	20	37.57	26.67	24.48	17.72
(total)	15	57.65	49.11	47.42	34.74
(t/ha)	20	71.11	64.71	62.72	51.77
ODW	0	NA	1.22	1.17	0.88
Total	5	1.95	4.95	7.06	4.96
stem	10	17.44	17.81	20.67	15.67
(merch)	15	36.22	41.33	44.65	33.19
(t/ha)	20	57.43	60.01	60.58	50.65
ODW	0	NA	2.06	1.82	1.19
Branches	5	8.57	6.30	5.95	4.31
(total)	10	11.05	11.69	11.68	9.51
(t/ha)	15	11.59	14.29	16.66	14.36
	20	13.42	16.77	17.46	16.88
ODW	0	NA	0.47	0.46	0.40
Branches	5	1.06	2.27	3.36	2.55
(merch)	10	6.27	7.78	9.55	8.17
(t/ha)	15	9.34	12.80	15.86	13.68
	20	12.37	15.96	17.05	16.51
ODW	0	NA	2.55	2.33	1.52
Foliage	5	9.60	8.17	7.71	5.54
(total)	10	9.62	11.83	11.86	9.51
(t/ha)	15	8.13	14.53	15.53	12.99
	20	9.63	14.72	14.87	14.24
ODW	0	NA	0.65	0.58	0.52
Foliage	5	1.02	2.82	4.24	3.16
(merch)	10	5.39	7.38	9.50	7.94
(t/ha)	15	7.15	13.04	14.74	12.26
	20	9.15	14.06	14.49	13.90

Table 5. Cont.

Stand parameter	No. of years after spacing	Control	4	6	8
			Nominal spacing (ft.)		
ODW	0	NA	4.60	4.15	2.71
Crown	5	18.17	14.48	13.65	9.85
(total)	10	20.67	23.53	23.54	19.03
(t/ha)	15	19.73	28.81	32.19	27.35
	20	23.04	31.48	32.33	31.11
ODW	0	NA	1.11	1.04	0.91
Crown	15	2.08	5.09	7.60	5.71
(merch)	20	12.40	15.16	19.04	16.11
(t/ha)	15	17.36	25.83	30.60	25.94
	20	21.89	30.02	31.53	30.40
ODW	0	NA	7.39	7.11	4.50
Above-ground	5	31.87	25.03	24.09	16.65
biomass	10	58.24	50.20	48.02	36.75
(total)	15	77.38	77.92	79.61	62.09
(t/ha)	20	94.15	96.19	95.04	82.88
ODW	0	NA	2.33	2.21	1.79
Above-ground	5	4.03	10.03	14.66	10.67
biomass	10	29.32	32.97	39.72	31.78
(merch)	15	54.45	67.16	75.25	59.13
(t/ha)	20	81.08	90.03	92.12	81.05
ODW	0	NA	2.86	2.60	1.64
Roots	5	11.54	8.56	8.59	6.19
(total)	10	22.15	18.26	17.67	14.27
(t/ha)	15	28.91	24.83	26.43	22.13
	20	31.84	30.76	29.70	27.65
ODW	0	NA	0.79	0.77	0.66
Roots	5	1.69	3.56	5.21	3.96
(merch)	10	10.72	12.51	14.78	12.60
(t/ha)	15	17.10	20.99	24.84	21.09
	20	24.37	27.89	28.41	26.80

Table 5. Cont.

Stand parameter	No. of years after spacing	Nominal spacing (ft.) Control	4	6	8
ODW	0	NA	10.26	9.71	6.14
Total biomass	5	43.41	33.59	32.68	22.84
(incl. roots)	10	80.39	68.47	65.69	51.03
(total)	15	106.30	102.75	106.04	84.22
(t/ha)	20	125.99	126.95	124.74	110.53
ODW	0	NA	3.13	2.97	2.45
Total biomass	5	5.72	13.60	19.86	14.63
(incl. roots)	10	40.04	45.48	54.50	44.38
(merch)	15	71.55	88.15	100.10	80.22
(t/ha)	20	105.46	117.92	120.53	107.85
Dominant	0	NA	5.7	5.8	5.2
height	15	7.6	7.8	8.2	7.7
(m)	20	10.8	10.3	10.7	10.3
	15	12.9	12.9	13.3	12.8
	20	14.7	14.6	15.3	14.7
Average	0	NA	2.19	2.56	3.34
spacing (m)	5	0.98	1.72	2.19	2.72
(based on	10	1.12	1.65	2.09	2.55
total no.	15	1.13	1.67	2.10	2.53
stems/ha)	20	1.42	1.84	2.17	2.55

* All crop trees >1cm dbh.
** All crop trees >9cm dbh.
*** Oven-dry weight.