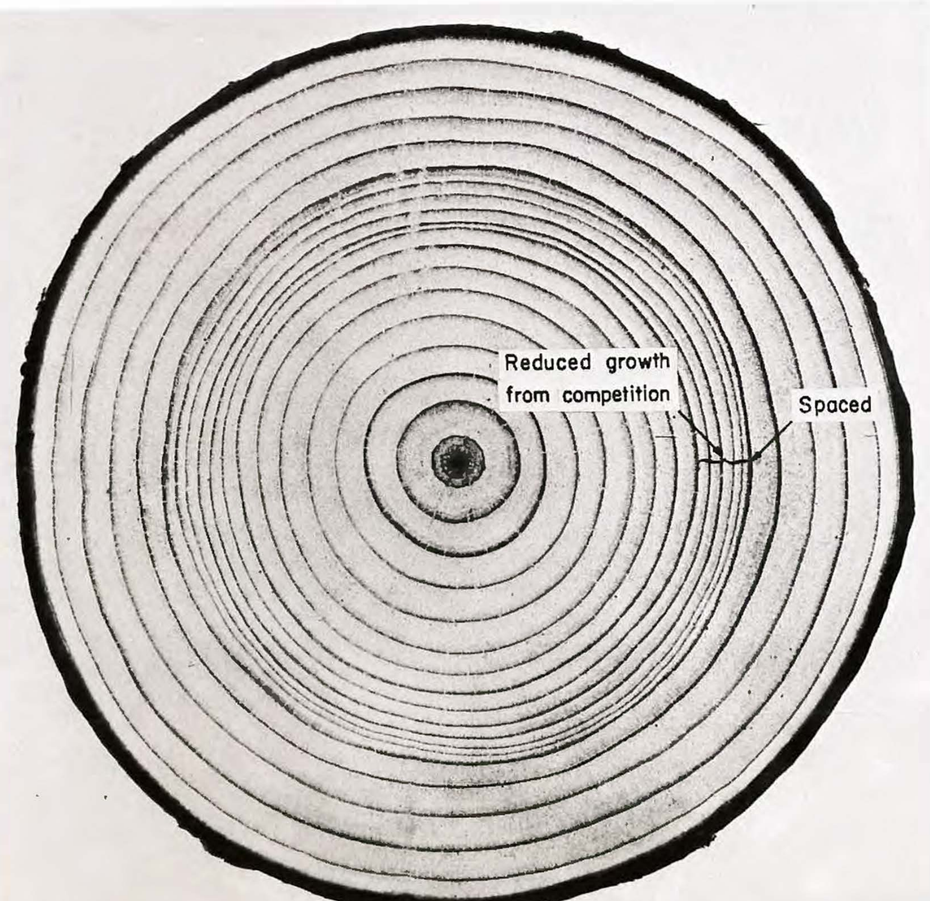

M-X-125
ISSN 0704-769X

EARLY GROWTH RESPONSES TO OPERATIONAL SPACING IN YOUNG BALSAM FIR STANDS ON THE CAPE BRETON HIGHLANDS, NOVA SCOTIA

by
HARALD PIENE

MARITIMES
CANADIAN FORESTRY SERVICE

MARITIMES FOREST RESEARCH CENTRE

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Fredericton, New Brunswick

Information Report M-X-125

Canadian Forestry Service
Environment Canada

1981

Erratum:

page 9, first paragraph, line 22 should read "2400 to 13000 stems/ha"

Table of Contents

Page

INTRODUCTION.. 1

STUDY AREA DESCRIPTION.............................. 1
  Climate... 1
  Vegetation.. 1
  Geology and soils................................. 4

METHODS... 4
  Manual spacing.................................... 4
    Volume and height growth........................ 4
  Corridor spacing.................................. 8
    Volume and height growth........................ 8
  Statistical analyses.............................. 8

RESULTS AND DISCUSSION.............................. 9
  Unspaced stand development........................ 9
    Volume growth................................... 9
    Height growth................................... 15

  Manual spacing.................................... 15
    Volume growth................................... 15
    Height growth................................... 16
    Growth profiles................................. 16
    Insect defoliation.............................. 19

  Corridor spacing.................................. 19
    Volume and height growth........................ 19

  Evaluation of growth response..................... 21
  Time of spacing................................... 23
  Spacing distance.................................. 24

CONCLUSIONS AND RECOMMENDATIONS..................... 27

ACKNOWLEDGEMENTS.................................... 27

LITERATURE CITED.................................... 27

ABSTRACT

Spacing treatment to about 2.4 x 2.4 m in different density, young balsam fir (Abies balsamea (L.) Mill.) stands on the Cape Breton Highlands, Nova Scotia, significantly increased volume growth both on a per tree and per hectare basis. The volume increases on a per tree basis ranged for dominant and codominant trees from 45 to 60% and from 77 to 136% for low and high density stands, respectively, while increases per hectare from 1971 to 1975 (1600 crop trees) ranged from an average of 3.7 to 5.9 m^3.

Corridor spacing did not increase volume growth, but corridor spacing in combination with hand spacing increased volume growth significantly, ranging from 120 to 147% for dominant and codominant trees. No increases in height growth resulting from either manual or corridor spacing were noticed. Volume growth of the 1600 potential crop trees for unspaced forest stands decreased with increasing density. Estimated volume loss in high density stands amounted to 12.3 m^3/ha to stand age 13 years. Height growth for dominant and codominant trees was strongly affected by density: a stand with 35 483 stems/ha showed 1.6 m less height growth than a stand with 6250 stems/ha. Changes in the specific volume increment, as an indicator of time for spacing, for different density forest stands are discussed.

RESUME

Un espacement pratiqué à environ 2,4x2,4 m dans de jeunes peuplements de sapin baumier (Abies balsamea (L.) Mill.) de differentes densités sur les hauteurs du Cap-Breton, Nouvelle-Ecosse, a sensiblement amélioré l'accroissement en volume tant à l'arbre qu'à l'hectare. Les accroissements en volume obtenus à l'arbre ont atteint de 45 à 60% pour les arbres dominants et codominants et de 77 à 136% pour les peuplements de faible et forte densité, respectivement, tandis que de 1971 à 1975 les accroissements à l'hectare (1600 arbres du peuplement final) atteignaient une moyenne de 3.7 à 5.9 m^3.

Sans effet seul, l'espacement en couloir combiné à l'espacement manuel a augmenté l'accroissement en volume de 120 à 147% pour les arbres dominants et codominants. On n'a noté aucun accroissement en hauteur résultant de l'espacement manuel ou mécanique. L'accroissement en volume des 1600 arbres potentiels du peuplement final pour les peuplements forestiers non espacés a été inversement proportionnel à la densité. La perte en volume estimée dans les peuplements de forte densité s'est élevée à 12,3 m^3/ha à l'âge de 13 ans (des peuplements). La densité des peuplements influait considérablement sur l'accroissement en hauteur pour les arbres dominants et codominants: un peuplement de 35 483 tiges/ha a accusé un accroissement en hauteur de 1,6 on inférieure à celui d'un peuplement de 6250 tiges/ha. Les modifications notées à l'accroissement spécifique en volume, en tant qu'indicateur de l'époque de l'espacement, sont discutées pour les peuplements forestiers de differentes densités.

INTRODUCTION

Balsam fir (Abies balsamea (L.) Mill.) covers about 3.8 million hectares of productive forest land in Nova Scotia, of which about 320 000 ha are located on the Cape Breton Highlands. Young stands established either after clearcutting or spruce budworm (Choristoneura fumiferana (Clem.)) outbreaks are often very dense (up to 100 000 stems/ha) and without any silvicultural treatments will stagnate at an early age. A recent study of changes in carbon and nitrogen mineralization rates in forest floor organic matter in one of these young stands indicated that this stagnation may result partly from a deficiency of available nitrogen (Piene 1978).

In 1968, Nova Scotia Forest Industries Ltd. started an intensive forest management program which included both manual spacing to about 2.4 x 2.4 m (8 x 8 ft) and corridor spacing with a Roanoke robot hydraulic highway cutter mounted on a skidder (Axelsson and Routledge 1970). By 1975 about 1000 ha on the Cape Breton Highlands had been spaced when the program was halted because of a severe spruce budworm outbreak.

On request from Nova Scotia Forest Industries, a study was initiated in 1975 to evaluate the Company's operational spacings. The main objective was to assess early growth responses to spacing for stands with widely different original densities. This report discusses the results and makes recommendations for future spacing operations.

STUDY AREA DESCRIPTION

The study area is located on Crowdis Mountain, Cape Breton Highlands, about 8 km northeast of the Cabot Trail in Victoria County, Nova Scotia (Fig. 1). The elevation is about 400 m. The study area is on Crown land under license to Nova Scotia Forest Industries Ltd.

Climate

The climate is humid-temperate with an average maximum and minimum growing season temperature (June-September) of 20.4 and 10.5°C, respectively (Nova Scotia Lands and Forest, Pers. comm.). Nichols (1918) noticed that the daily maximum temperature in summer frequently was higher on the Highlands than on the coast, while the daily minimum was invariably lower. The growing season in the Crowdis Mountain area is about 100 days, about two weeks shorter than in the neighbouring Margaree Valley. Freezing temperatures occur occasionally in June and late August.

Precipitation is distributed evenly throughout the year. Snow usually covers the ground in the Crowdis Mountain area by the middle of October and maximum snow depth (about 1.2 m) occurs in late March. By the last week of May, open areas in the stands are usually bare and by the first week of June the snow has melted in the closed forest stands. Normally, two to three rain storms occur each week during the summer, which keeps the forest floor in the closed stands moist. The rain storms are usually followed by a couple of days of clear windy weather which quickly dries out the litter layer of the forest floor in the more open stands.

Broken leaders and shoots throughout stands at all stages of development are evidence that the wind has a pronounced effect on forest growth in the area. The mature forest seldom reaches a height of 15 m, although in river valleys substantially taller trees are encountered.

Vegetation

Nichols (1918) has presented the most comprehensive study of the vegetation of Cape Breton Island. The

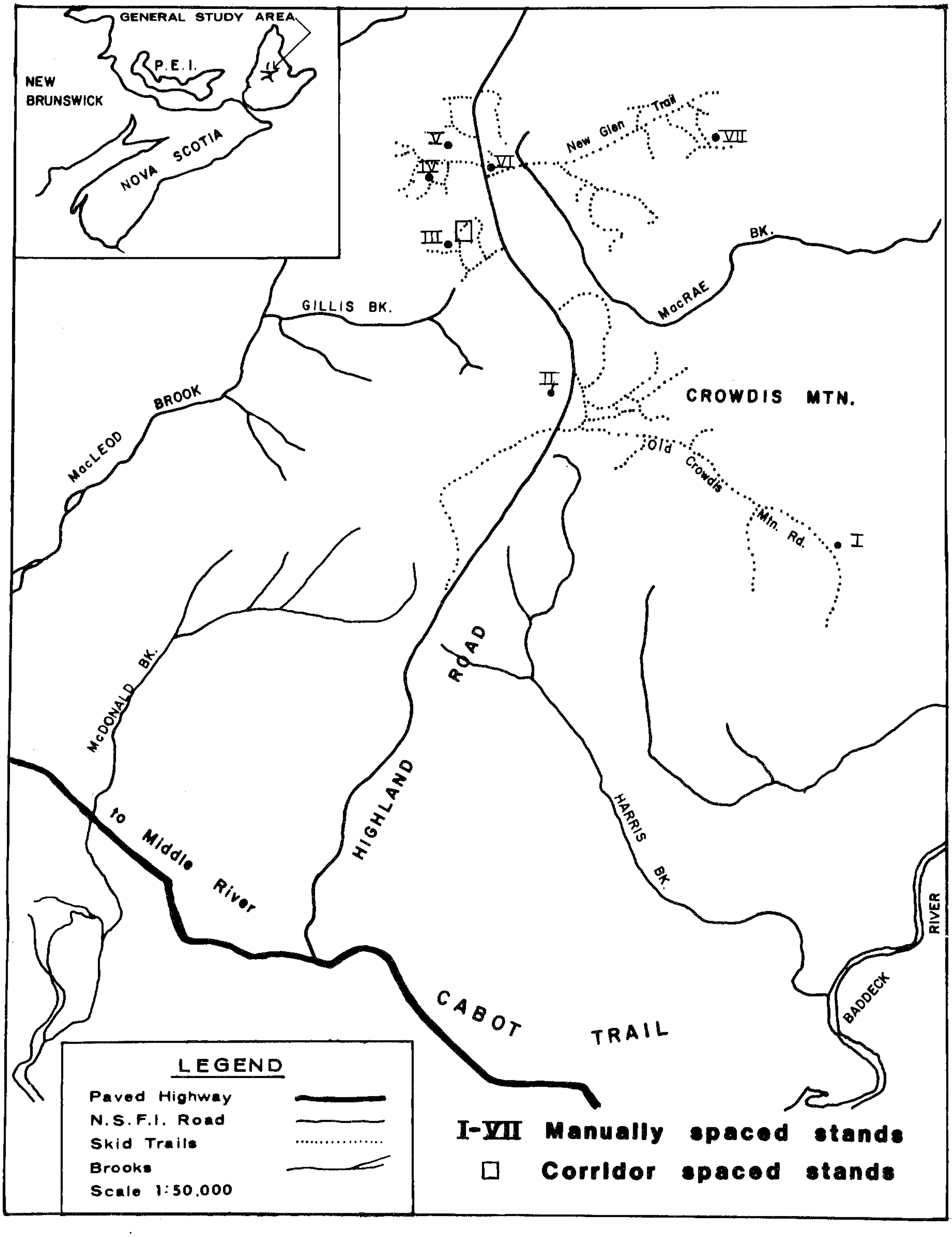

Fig. 1. Location of the manual and corridor spaced forest stands.

most distinctive feature of the island is a large central plateau with an elevation of 300 to 450 m. This region is considered a transition zone between the deciduous forest and the boreal forest which is found in large parts of eastern Canada (Collins 1951). Loucks (1959-60) in his forest classification for the Maritime provinces, divided the plateau into two regions, the Cape Breton Plateau Ecoregion in the north, and the Gaspé - Cape Breton Ecoregion in the south. The northern region in covered with stunted black spruce (Picea mariana (Mill.) B.S.P.), balsam fir, and white birch (Betula papyrifera Marsh.) mixed with shrubs, barrens, and peat bogs. The forest in the southern part, where the present study area is located (Crowdis Mountain), is covered with an almost pure balsam fir forest with scattered white spruce (Picea glauca (Moench) Voss), white birch, yellow birch (Betula alleghaniensis Britton), sugar maple (Acer saccharum Marsh.), American mountain-ash (Sorbus americana Marsh.) red maple (Acer rubrum L.) and pin cherry (Prunus pensylvanica L. f.). Large areas of this forest were clear-cut in the mid-1950's, leaving patches of mature forest which are presently 50 to 70 years old. The ground vegetation in the mature forest consists of a nearly continuous cover of mosses. The dominant species are: Schreber's moss (Pleurozium schreberi (BSG.) Mitt.), Bazzania trilobata (L.) S.F. Gray, Dicranum spp., together with small patches of Hylocomium splendens (Hedw.) BSG. and plume moss (Hypnum crista-castrensis Hedw.). The herbs consist of patches or scattered plants of wood-sorrel (Oxalis montana Raf.), goldthread (Coptis groenlandica (Oeder) Hult.), bunchberry (Cornus canadensis L.), bluebead-lily (Clintonia borealis (Ait.) Raf.), creeping snowberry (Gaultheria hispidula (L.) Muhl.), wild sarsaparilla (Aralia nudicaulis L.), American star-flower (Trientalis borealis Raf.) and wood aster (Aster acuminatus Michx.). The spinulose shield-fern (Dryopteris austriaca (Jacq.) Woynar var. intermedia (Muhl.) Morton)is the most important fern.

The ground vegetation in the unspaced 25-year-old balsam fir stands which were established after the clear-cutting in the mid 1950's, is characterized by a less continuous moss cover, especially where light intensity is low. The major species of mosses are the same as in the mature forest stand, however Dicranum spp. are more common while Bazzania trilobata and plume moss are less frequent. The species of herbs and ferns are generally the same as for the ground vegetation in the mature forest.

The ground vegetation in the spaced stands is characterized by the same moss species as found in the mature forest, although Bazzania trilobata is nearly absent probably because of the frequent drying of the forest floor L- layer. The herb layer is characterized by large patches of bunchberry and includes all the herbs found in the mature stand. In addition, wild lily-of-the-valley (Maianthemum canadense Desf.), twinflower (Linnaea borealis L. var. americana (Forbes) Rehd.), skunk-currant (Ribes glandulosum Grauer), small white violet (Viola pallens V. Macloskey, Lloyd), ground pine (Lycopodium obscurum L. var. dendroideum (Michx.) Eat.), ground-cedar (Lycopodium tristachyum Pursh) and red raspberry (Rubus idaeus L. var. strigosus (Michx.) Maxim.) are present. The ferns include spinulose shield-fern and cinnamon fern (Osmunda cinnamomea L.). In some spaced stands, especially along the old Crowdis Mountain road (Fig. 1) the bracken fern (Pteridium aquilinum (L.) Kuhn, var. latiusculum (Desv.) Underw.) forms dense cover.

Geology and Soils

The geology of the Cape Breton Highlands has been of interest for many years. Kelley (1967) and Milligan (1970) presented detailed geological studies of the southern part of the Highlands. It is uncertain if the Highlands ever were glaciated (Collins 1951). The sharp edged rocks found in the area indicate little evidence of any transportation of materials.

The occurrence of rocks belonging to the Devonion time period, like syenite mixed with granite, is extensive in the Crowdis Mountain area. Installations III, IV, V, VI, and VII are located in this section (Fig. 1) and soil pits (two pits were dug near each plot in each installation) also revealed diorite and volcanic rocks belonging to the Precambrian period. The rocks found around installation I and II belong to the George River Group (Precambrian) (Milligan 1970) and characteristically consist of schists and volcanic rocks of uncertain origin. Intrusive into this group are rocks of Devonian origin like granite, diorite, and syenite.

The soil in the area is a ferro-humic podzol with 16.6 to 21.5% organic matter in the B-horizon. The parent material is a sandy loam (Table 1). The combined L-F-H layers range in thickness from 4 to 15 cm, and the Ae-horizon varies from a trace in installations I and II to 10-20 cm in installations III and IV. The B-horizon ranges from 15 cm in installation III to 40 cm in installation I and II.

METHODS

Manual spacing

A pair of 0.025-ha (15.8 x 15.8 m) plots were established in an unspaced (control) and an adjacent spaced stand in the spring of 1976 at seven locations with different original stand densities (Fig. 1). Thus, a total of 28 plots were established. The unspaced plots were located in stands that had not been spaced in 1971. Age, height, and original densities were carefully measured at the time of plot establishment to ensure uniformity within plot pairs. This was done in eight 1-m wide strips in each plot. In the unspaced plots, all trees in the strips, live and dead, were tallied by 2-cm diameter breast height (dbh) classes, while original densities in the spaced plots were estimated by counting the stumps in the eight strips in each plot (Table 2). Original density is here defined as stand density at age 5 years. By using mortality data published by Frisque *et al*. (1978) for different density balsam fir stands in eastern Canada, the sum of the live and dead trees tallied at age 22 approximated stand densities at age 5. Stand density and age in this paper refer to the original density and release age, respectively, if it is not otherwise noted. The diameter and volume distribution is presented for the unspaced plots in Fig. 2 for the seven different stands.

Volume and height growth: Volume increments were calculated from the time of spacing in the fall of 1971 up to and including 1975. The 1976 volume increments were discarded because of the effects from a severe spruce budworm outbreak.

Periodic increments were based on ring width measurements from 1297 increment cores from the seven different installations taken during the summer and fall of 1977. All trees in the spaced plots and the same number of comparable trees in the unspaced plots were tagged and increment cores were taken based on an average dbh. Additional increment cores were taken to cover all diameter classes present in the unspaced plots. In the field, the cores were treated with 40% polyethyleneglycol to prevent drying. Ring widths were measured to the

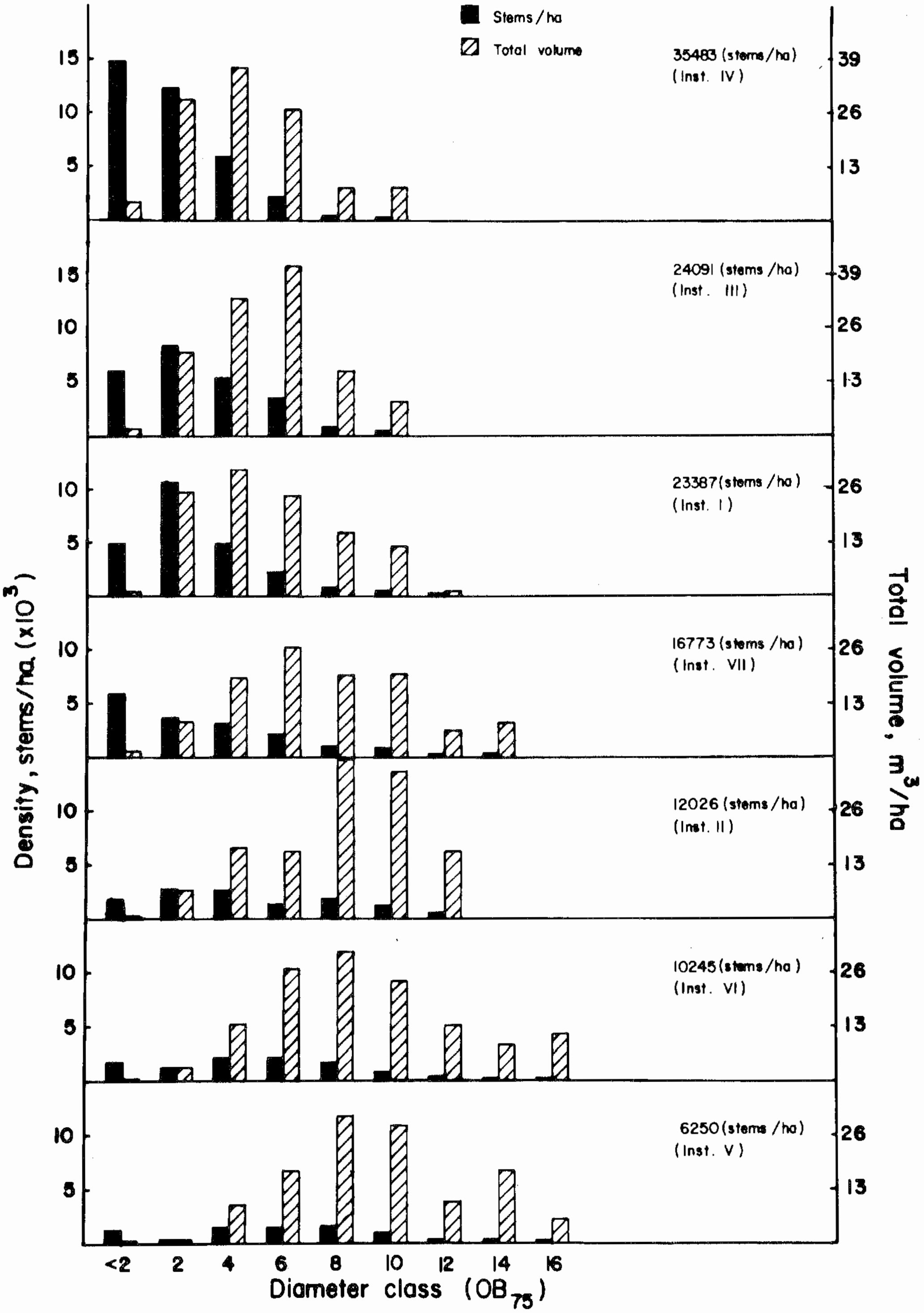

Figure 2. Stand density and total volume per hectare at age 21 (1975) by diameter class for the seven unspaced forest stands. (Average of two plots in each stand).

Table 1. Soil characteristics for the seven installations

Installation	Horizon	Percent			Percent	Parent	
		Sand	Silt	Clay	O.M.*	material	Geology
I	B	59.1	34.9	6.0	20.0	sandy loam	diorite
	C	49.6	40.8	9.6		loam	granite
II	B	62.2	32.9	4.9	20.9	sandy loam	shist, volcanic rocks
	C	56.9	36.6	6.5		loam	granite
III	B	61.7	35.1	3.2	21.5	sandy loam	granite
	C	49.4	42.0	8.6		loam	syenite
IV	B	60.9	36.0	3.1	19.1	sandy loam	granite
	C	48.6	45.7	5.7		sandy loam	diorite
V	B	60.0	35.8	4.2	19.8	sandy loam	volcanic rocks
	C	45.8	45.3	8.9		loam	
VI	B	62.1	34.5	3.4	19.5	sandy loam	shist-granite
	C	40.6	49.8	9.6		silt	diorite
VII	B	56.2	39.4	4.4	16.6	sandy loam	granite
	C	43.9	45.1	11.0		loam	diorite volcanic rocks shist

* O.M. Organic matter.

nearest 0.01 mm with an Addo-X ring measuring machine. Because of similarity in growth responses due to spacing, installations I, III, and IV (ranging in density from 32 951 to 47 192 stems/ha), were combined as high density stands and II, V, VI, VII (ranging in density from 11 669 to 23 260 stems/ha, Table 2) as low density stands for purpose of analysis.

Periodic annual increments (PAI) were evaluated on a per tree and on a per hectare basis. On a per tree basis, growth responses are presented by 2-cm dbh classes using the lower boundary as designation, e.g., class 3 = 3.0 - 4.9 cm. Growth response of individual trees was obtained by comparing unspaced trees with spaced trees which had the same initial dbh in 1971. Separate diameter-height curves were made for 1971 and for 1975 (last year of experimental period).

How best to evaluate treatment response on a per hectare basis is still an open question. Large differences in tree frequency distribution created by the removal of trees in spacing operations in dense young coniferous forest stands mask the treatment response. Analysis of the crop trees is an alternative to solve this problem. The primary management objective in thinning and spacing operations is to speed up the growth of the potential crop trees. Evaluation of response of the potential crop trees to thinning treatment would be a logical approach that probably would appeal to forest managers. Therefore, 40 of the biggest evenly-distributed trees per plot

Table 2. Mensurational data from the seven different forest stands

		Unspaced plots					Spaced plots				
				Dominant and codominant trees (1971)					Dominant and codominant trees (1971)		
		Density (stems/ha)					Density	Average			
Installation	Plot	Live	Live and dead	Release age (stump)	Height (m)	dbh (cm)	Stumps and crop trees (stems/ha)	spacing (m)	Release age (stump)	Height (m)	dbh (cm)
I	1	16694	27454	17.5	4.79	7.27	21420	2.5 x 2.5	15.4	4.57	6.99
	2	30079	40280	15.4	3.81	4.96	36455	2.4 x 2.4	14.0	4.05	5.18
II	1	13054	26187	16.6	6.02	9.02	28798	2.3 x 2.3	17.7	5.57	7.76
	2	10997	20333	16.0	6.58	9.22	17468	2.4 x 2.4	17.4	6.35	9.11
III	1	22627	32595	16.9	4.92	6.70	33051	2.5 x 2.5	15.6	3.71	4.91
	2	25554	33307	16.5	4.64	6.77	22608	2.5 x 2.5	16.4	4.51	6.16
IV	1	43354	54826	15.6	4.19	6.14	73047	2.2 x 2.2	15.4	3.33	4.34
	2	27612	39558	16.9	4.68	6.74	44248	2.3 x 2.3	16.5	4.10	5.60
V	1	7674	13685	17.2	6.66	9.88	11888	2.4 x 2.4	17.1	5.76	8.02
	2	4826	9652	17.9	6.52	10.64	11966	2.5 x 2.5	16.2	5.85	7.96
VI	1	9335	20254	16.8	5.70	8.68	13904	2.5 x 2.5	16.8	5.37	9.10
	2	11154	22072	17.1	6.11	9.42	17627	2.3 x 2.3	17.6	5.28	9.91
VII	1	17722	25396	16.7	5.57	9.02	19132	2.3 x 2.3	15.2	4.98	6.93
	2	15823	19225	15.9	5.13	8.88	16558	2.3 x 2.3	14.6	5.22	7.51

(1600 stems/ha) were selected to represent the potential crop trees in both the unspaced and spaced plots. This is about the same number of trees that is found in natural mature balsam fir stands in the area.

Periodic annual increment for the experimental period (1971-75) for single tree and crop tree measurements were obtained by subtracting the volume of each tree in 1971 from that in 1975 using Honer's (1967) volume equations. Volume growth estimations from stem analysis of 25 spaced trees were used to adjust Honer's volume equation to local conditions.

Growth responses to spacing were examined in detail on 66 trees, 50 from around the periphery of the spaced and unspaced plots in installation IV (high density plot), and 16 from around the spaced plot in installation VII (low density plot). Trees of average plot dbh were felled and a disk was cut half-way between each node. Ring widths were measured along two average diameters of each disk. Growth increments were calculated for each year from 1971 to 1975 by summing the growth increase for each section of a tree.

Height growth responses to spacing were measured on 30 dominant and codominant trees in each plot. The internodal lengths on each tree were measured to the nearest 0.03 m with a height pole.

Corridor spacing

Volume and height growth: In the summer of 1978, an additional 30 plots were randomly selected along chosen compass lines in three treatments (Fig. 1): 1) Unspaced (control), 2) Corridor spaced (machine cut, with 3-m wide strips alternating with about 4-m wide uncut strips) and 3) Corridor spaced combined with manual spacing (the uncut strips were spaced to about 2.4 x 2.4 m (8 x 8 ft)).

At plot establishment, care was taken to ensure that all 30 plots had about the same densities (Table 3). This was done by counting all the stumps in six 1-m strips in the corridor and manual-spacing treatment, and in two 1-m strips in the other two treatments.

In each of the 30 plots, 30 trees covering the diameter classes present were felled and a disk was taken at breast height. Height in 1971 and 1975 was recorded. The trees selected in the corridor-spaced plots were growing on the edges (0.6-m wide strips) of the plots where the greatest release in growth would likely occur. In addition, the 10 biggest trees in each of these plots were felled a disk was cut at breast height, and the distance between the tree and the nearest release strip was measured.

The disks were taken to the laboratory where ring widths were measured along an average diameter to the nearest 0.01 mm. Individual tree growth responses from 1971 (time of spacing) to 1975 were determined.

Growth response of individual trees was obtained by comparison of measurement of unspaced trees to spaced trees which had the same initial dbh in 1971. Honer's (1967) volume equations (modified) were used.

Statistical analyses

Treatment responses were evaluated by analysis of variance and by a t-test. Differences in initial heights and basal areas necessitated the use of covariance analysis in assessing volume responses on a per hectare basis (crop trees), volume responses related to distance from the leave strip in the corridor spacing, and height responses for the manual and corridor spacing. Volume, basal area, and height in 1971 were used as covariates. All statistical tests were conducted at the 0.05 level of significance.

Table 3. Mensurational data from the corridor spaced plots

			Dominant and codominant trees				
Treatment	Plot No.	Plot size (m)	Height 1971 (m)	Crown length %	dbh 1971 (OB,cm)	Release age (dbh)	Stems/ ha
Control	1-10	5x12	3.53 (3.78-3.18)	44.6 (40.1-51.8)	4.17 (4.38-3.89)	20.1 (17.8-21.5)	71125 (60883-87083)
Corridor	11-20	5(4.2-6.1)*x12	3.13 (3.40-2.76)	45.7 (43.0-48.4)	3.66 (4.09-3.20)	19.1 (17.4-20.6)	71708 (57083-91667)
Corridor and manual	21-30	18x18	2.45 (2.66-2.30)	69.2 (64.6-76.0)	3.10 (3.65-2.77)	17.2 (16.2-19.4)	70611 (54000-81778)

* Range.

RESULTS AND DISCUSSION

Unspaced stand development

Volume growth: The total standing crop for all living trees in the seven different forest stands at age 21 showed no relationship to stand density over a range from 6250 to 35 483 stems/ha (Fig. 3A). This indicates that full occupancy of the forest sites has been achieved. This agrees with the hypothesis postulated by Möller et al. (1954) who stated that "production increases with increased stocking up to the point where full occupancy of the site is achieved". Beyond this point increased density does not affect production, until extremely high densities where crowding limits the growth. Vincent (1962) observed a slight increase in total volume with increasing stand density ranging from 1000 to 5000 stems/ha for 25-to 35-year-old balsam fir stands in the Green River Watershed, although the relationship was not significant. Similarly, Baskerville (1965) observed increased total volume production with increasing densities for 40-year-old balsam fir stands also in the Green River Watershed. However, total current volume increments increased with increasing stand densities (ranging from 1700 to 12000 stems/ha) suggesting that these stands were not fully occupied.

Merchantable volume per hectare (trees >9 cm dbh) is inversely related to stand density (Fig. 3B). Merchantable volume increases little in stands with decreasing densities from about 35 000 to 23 000 stems/ha, but below this value significant increases are observed with a further decrease in density. Total standing crop and merchantable volumes reported in the present study are comparable to volumes measured in similar age and density stands in the Green River Watershed (van Raalte)[1].

Figure 4 shows changes in volume with increasing stand density for the 1600 biggest crop trees per hectare at age 21. The volume decreased with increasing density, however the decrease was not linear. It is accelerated after a density of about 23 000 stems/ha, and the volume is little affected above a density of about 30 000 to 35 000 stem/ha. This pattern of change in

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[1] van Raalte, G.D. 1981. Pers. Comm., Maritimes Forest Research Centre, Fredericton, N.B.

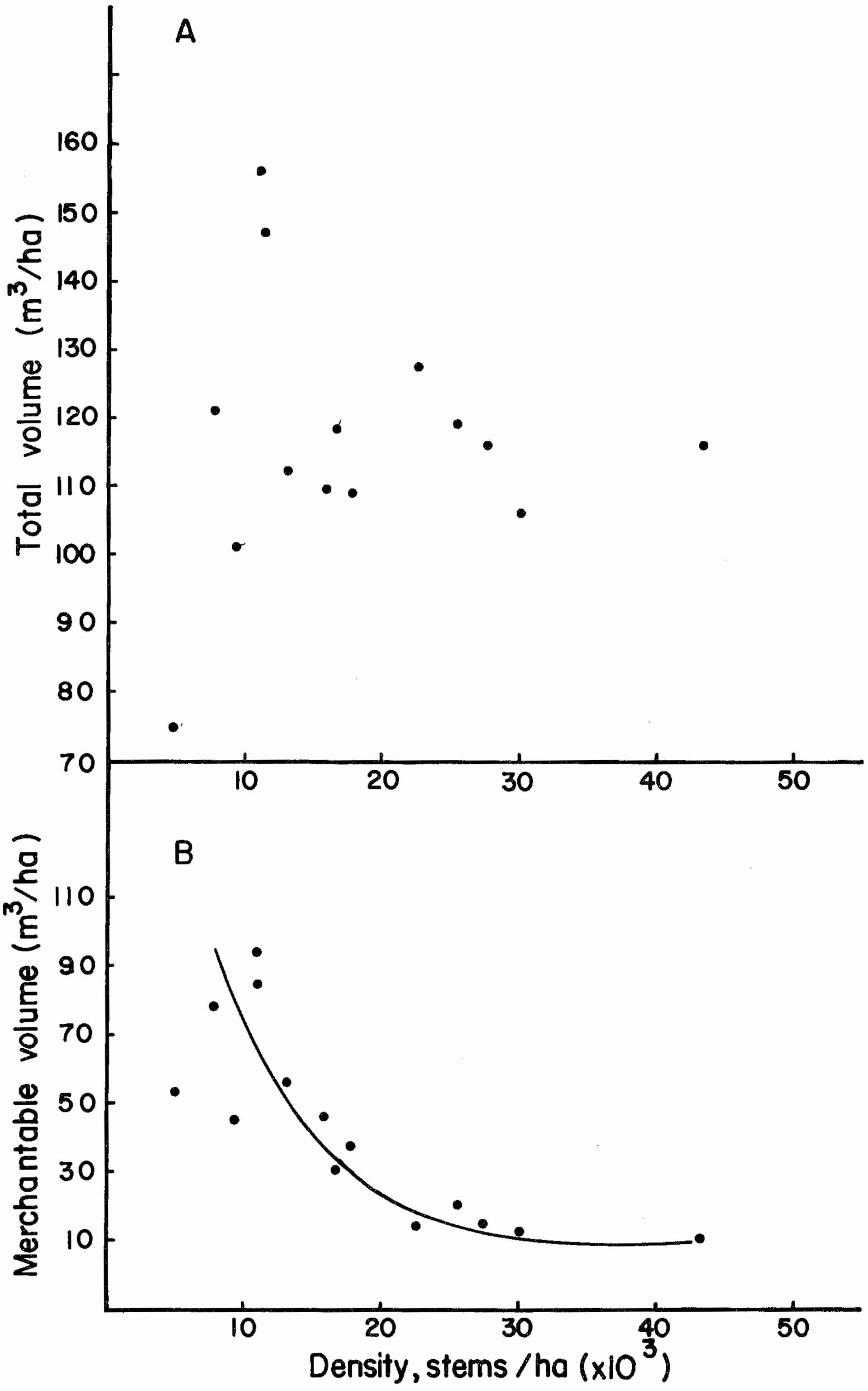

Figure 3. A. Total and B. Merchantable volume at age 21 (1975) per hectare for the seven different unspaced forest stands. (Plot averages; Curve hand-fitted)

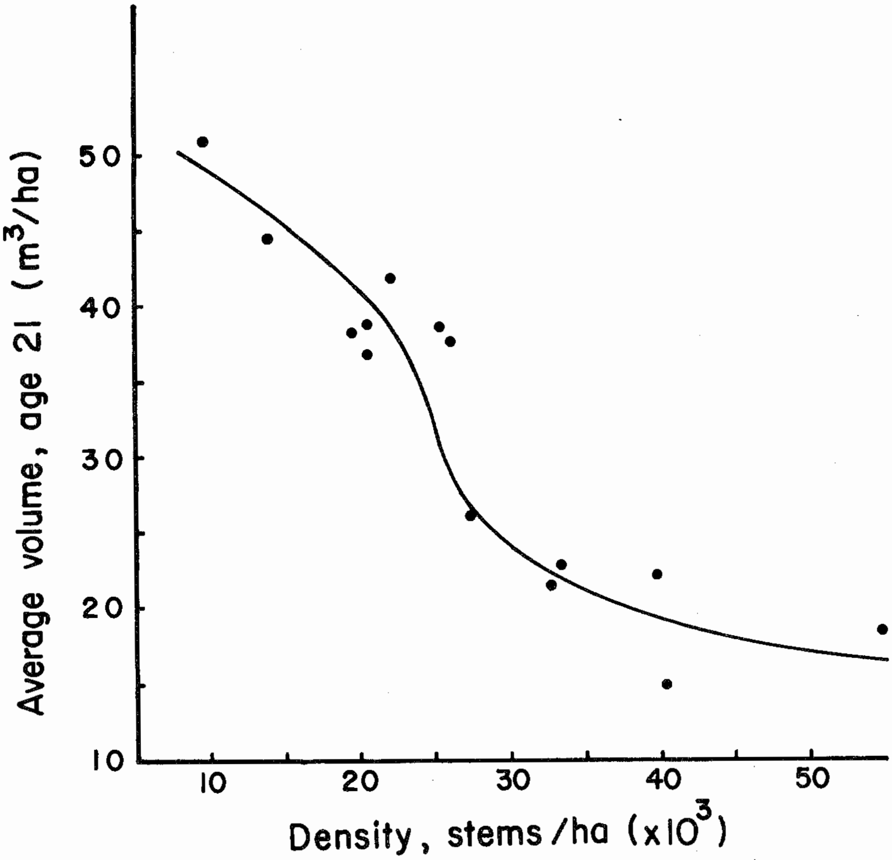

Figure 4. Changes in volume for the 1600 crop trees per hectare with stand density at age 21 (1975) for the seven different unspaced forest stands. (Plot averages; Curve hand-fitted)

volume growth with stand density closely follows changes in diameter and height growth for these forest stands (Fig. 5A,B).

Kairiukstis and Juodvalkis (1976) also found that total volume growth in 19-year-old Norway spruce (Picea abies (L.) Karst.) plantations was little affected by high stand densities down to about 25 000 stems/ha, after which a drastic increase occurred with decreased stand densities. Jones (1977) found a similar trend for slash pine (Pinus elliottii Englm. var. elliotii) that was precommercially thinned. At age 23, significant decreases in diameter growth of dominant and codominant trees were observed for increasing stand densities up to about 3700 stems/ha, after which little change occurred with increasing densities. Decreases in diameter and volume growth with increasing stand densities have also been observed by Tadaki et al. (1970) for Veitch fir (Abies vietchii) and by Satoo et al. (1954) for Japanese red pine (Pinus densiflora); both studies in Japan.

The actual volume lost on crop trees as a result of stagnation in the most overdense stand (installation IV) may be estimated by comparing the volume growth with that for the stand with the lowest density (installation V, Table 2). Changes in the specific volume growth for the low density stand show that volume growth started to decrease after the age of about 13 years (Fig. 6). The total volume growth for this stand to age 13 was 22.0 m^3/ha and may be considered optimum for this site in the Crowdis Mountain area. This

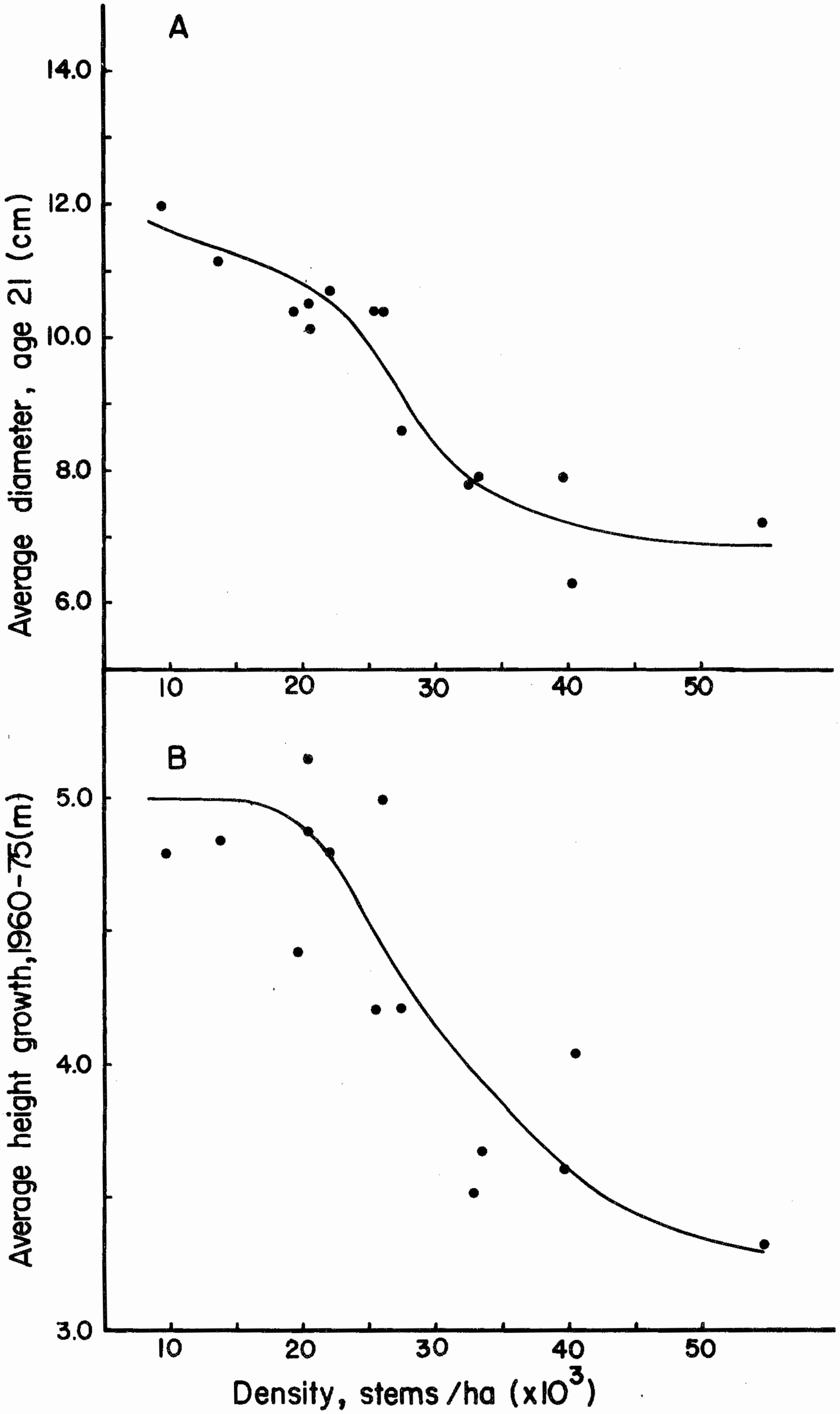

Figure 5. Average changes in (A) diameter at age 21 (1975) for 1600 crop trees per hectare and (B) average height growth from 1960 to 1975, with stand density for the seven unspaced forest stands. (Plot averages; Curves hand-fitted)

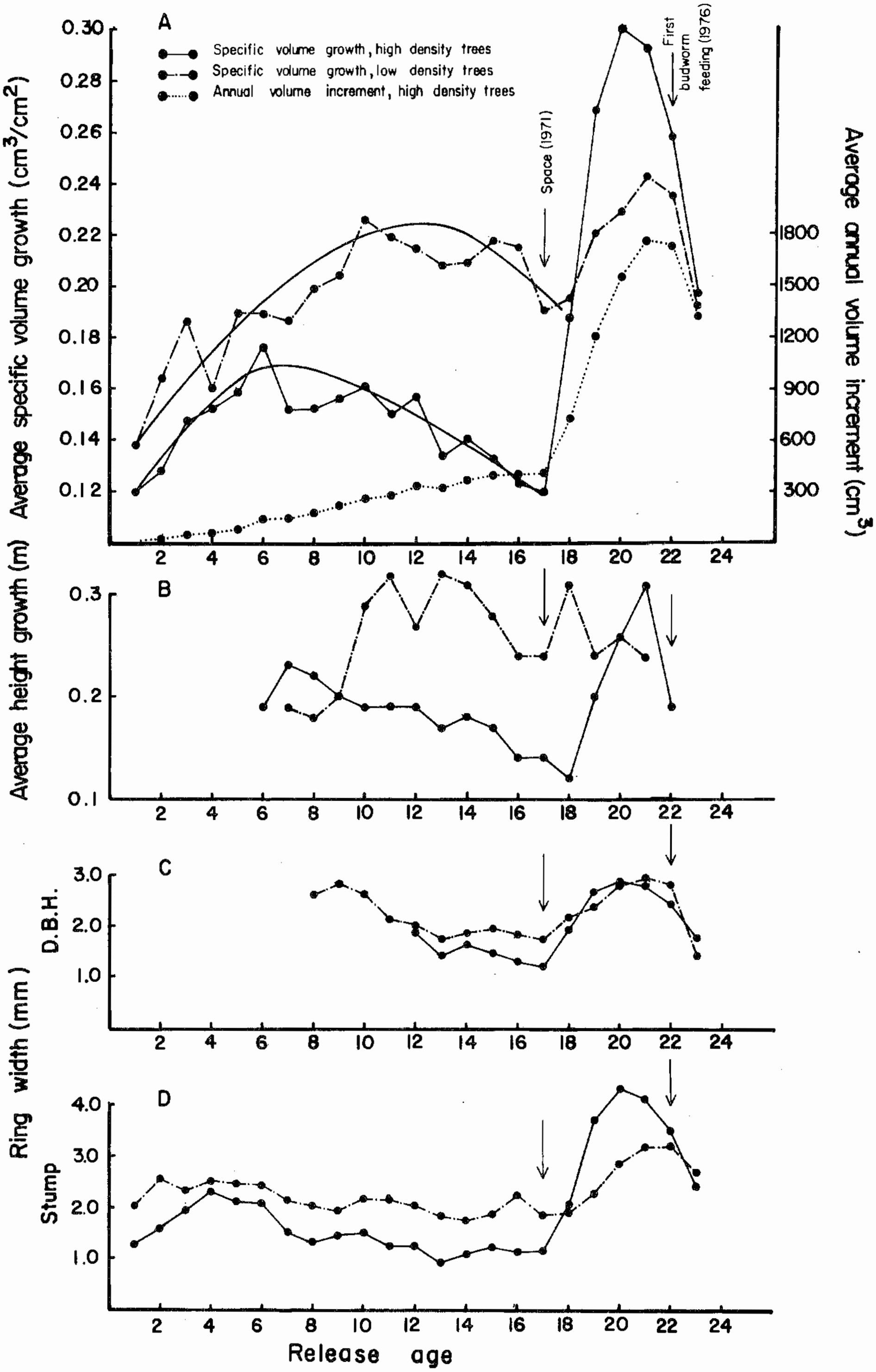

Figure 6. Changes in (A) average specific volume growth and annual volume increment (Curves hand-fitted), (B) average height growth, and ring width at (C) dbh and (D) stump for 30 high and 17 low density trees, with age.

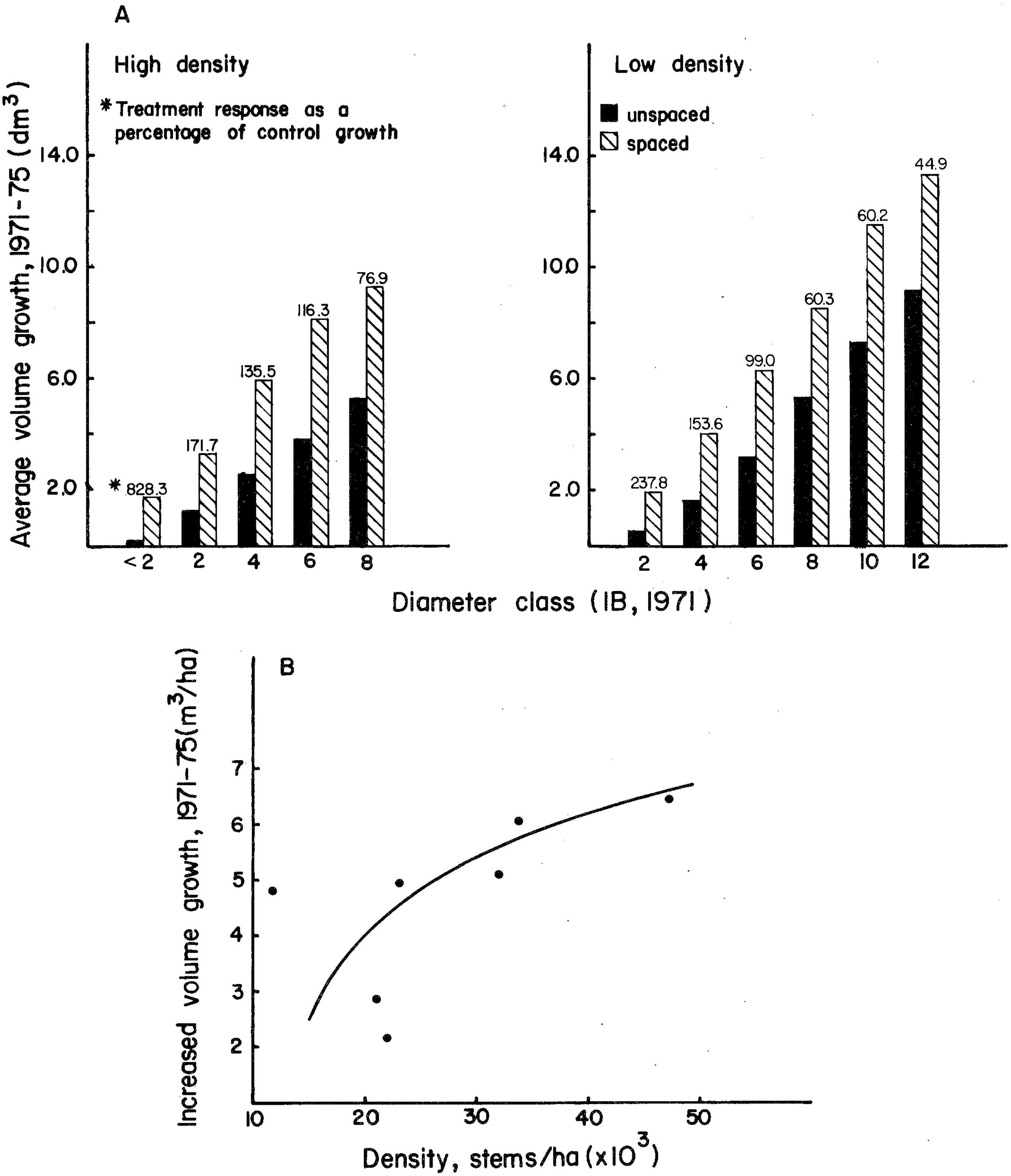

Figure 7. A. Average volume growth response to spacing per diameter class from 1971 to 1975 for high and low density stands. B. Average volume growth response from 1971 to 1975 for 1600 crop trees per hectare with different densities. (Averages of two plots per stand; Curve hand-fitted)

compares with a total volume growth up to age 13 for the high density stand of only 9.7 m^3/ha, or a loss of 12.3 m^3/ha, due to competition. The corresponding averages for dbh and height for the low and high density stands were 8.0 vs. 4.7 cm and 5.1 vs. 3.6 m, respectively. This emphasizes the importance of early spacing in these overdense balsam fir stands to avoid drastic losses in volume growth.

Analysis of individual tree data consistently showed that for a given tree size, certain features are essentially independent of stand density. For example, a 7-cm (dbh) dominant tree in a stand with 35 483 stems/ha (in 1975) appears to be similar to an 7-cm dbh intermediate or suppressed tree in a stand with 12 026 stems/ha (1975). (Similar observations have been noted by Baskerville (1965) for different density 40-year-old balsam fir stands.) They have identical stem volume and similar heights, although the trees in the high density stand were slightly shorter due to competitive stress from neighbors. This means that the 7-cm trees in the two extremes of stand densities have experienced similar past competition. However, the 7-cm trees in the stand with 35 483 stems/ha are becoming dominants and are experiencing competition mainly from the side, resulting in increased growth rates relative to neighboring trees. In contrast, the 7-cm trees in the stand with 12 026 stems/ha are meeting competition not only from the side, but also from above, thus falling further behind their neighbors in growth rate. Thus although the 7-cm tree in the two extremes of stand density appear similar at one point in time, they will experience different future growth rates. This is demonstrated in Fig. 7A where the codominant or intermediate trees in the high density stands (dbh-class 4 and 6) show significantly higher growth rates from 1971 to 1975 than the intermediate or suppressed trees of the same size in the low density stands.

Height growth: Figure 5B shows decreases in average height growth for dominant and codominant trees (from 1960 to 1975), for unspaced forest stands, with increasing densities. The stand with the highest density (35 483 stems/ha) showed about 1.6 m less height growth over 15 years than the stand with the lowest density (6250 stems/ha).

Vincent (1962) found that height growth of dominant and intermediate trees was weakly correlated with stand densities while height growth for codominant trees significantly decreased with increasing densities for young balsam fir stands in the Green River Watershed. Decreases in height growth with increasing stand densities have also been observed by Chrosciewicz (1971) for jack pine (*Pinus banksiana* Lamb.) in Canada, and by Braathe (1957) for Norway spruce in Scandinavia.

Manual spacing

Volume growth: Figure 7A shows volume response from 1971 to 1975 on an individual tree basis for high and low density stands. For both groups, significant increases in volume growth due to spacing occurred for all the dbh classes. On a relative basis, suppressed and intermediate trees showed a consistently higher growth response than codominant and dominant. Also, codominant and dominant trees in the high density stands showed higher relative response than those in the low density stands (Fig. 7A). This is expected since the codominant and dominant trees in low density stands had better developed crowns and were growing at a higher rate prior to spacing than those in the high density stands.

Spacing operations to 1.4 x 1.4 m in young dense (>15 000 stems/ha) balsam fir stands in mainland Nova Scotia (Gillis 1977), showed an average increase in diameter growth of 78% above unspaced trees during the first 4 years after spacing. This is comparable to the average increase of 104% recorded for the high density stands in the present study.

Growth responses to spacing for the potential crop trees (1600 stems/ha) increased with increasing stand densities as shown in Fig. 7B. The increases were equivalent to an average of 3.7 m^3/ha for the four low density stands and 5.9 m^3/ha for the three high density stands. This represents average increases over the unspaced crop trees of 91.4 and 49.1% for the high and low density stands, respectively.

Height growth: Height growth measurements from 1971 to 1975, based on 30 dominant and codominant trees in each plot, showed no response to spacing for either low or high density stands. Total height growth (adjusted means) for the high and low density stands were 0.99 m (unspaced) - 1.00 m (spaced), and 1.12 (unspaced) - 0.99 m (spaced), respectively. Similar results have been noted in other spacing studies and are discussed by Braathe (1957).

Changes in height growth with age for 30 dominant high density and 16 dominant low density trees are shown in Fig. 6B. Height growth changes for those two groups of trees are representative for trees in the high and low density plots. Height growth for the low density trees shows little change with increasing age until the time of spacing in 1971, then a slight increase occurred followed by a steady decrease likely caused by wind. In comparison, changes in height growth for the high density trees show an increase to about age 7, and then a slow decrease, caused by competitive stress from neighbors, until time of spacing. Interestingly, the high density trees showed no response to spacing in 1972, rather a decrease was observed compared to the low density trees that responded immediately to the spacing treatment (Fig. 6B). The response to spacing up to 1975 is clearly shown, however in 1976 the height growth decreased. The cause of this decrease may be attributed to two factors: firstly, 1976 was the first year of defoliation on these trees, and 60-100% of the current foliage was consumed by spruce budworm; secondly, large numbers of spittelbugs, belonging to the genus Aphrophora were observed on the developing leaders. These beetles consume the cambium and a characteristic "spit" is formed around the shoot.

Growth profiles: Figures 8 and 9 show growth profiles of trees from the high and low density stands. The growth profiles for individual trees within each group were similar and were therefore averaged and presented on a per group basis. For the high density trees, slow growth prevailed until 1971, and increased significantly thereafter as a result of the spacing treatment. The spaced and unspaced stand (installation IV) was exceedingly dense (average 52 920 stems/ha), and had been under competitive stress for about 10 years prior to the spacing treatment. This influenced the growth response the year after spacing in 1972, as shown in both Fig. 8A (narrower ring widths, as compared to 1973) and 9A, where sheets of wood laid down each year, represented by the ring width sequence down the tree, lies well below the family of curves for 1973 to 1975. This is identical to the oblique sequence described by Duff and Nolan (1957).

The typical pattern of the oblique growth sequence is a rapid increase in ring width to a maximum in the third to seventh internode from the apex of the tree, and a gradual decline in ring width in successively lower internodes (Mott et al. 1957). This pattern is clearly shown for the

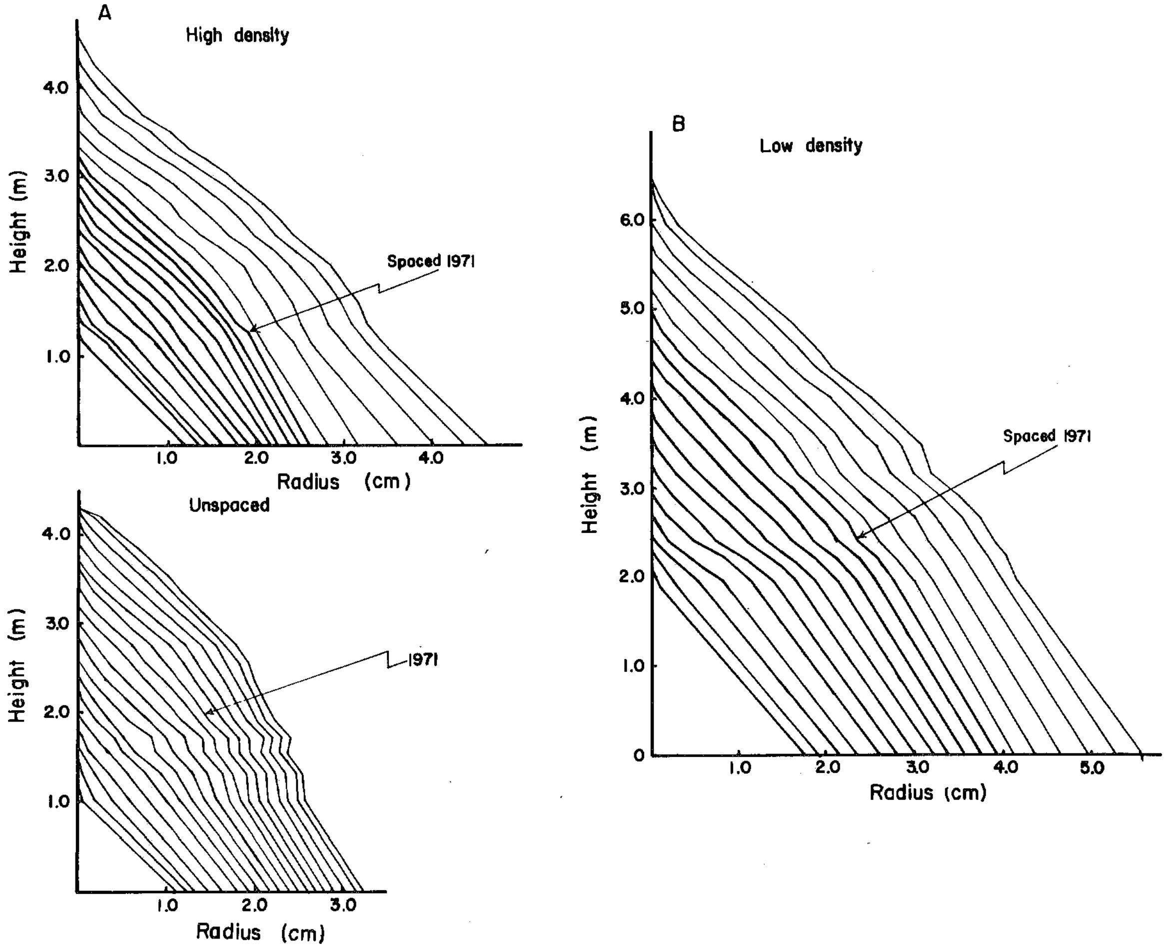

Figure 8. A. Growth profiles for 30 spaced and 20 unspaced trees (high density stand); and B. For 16 spaced trees (low density stand).

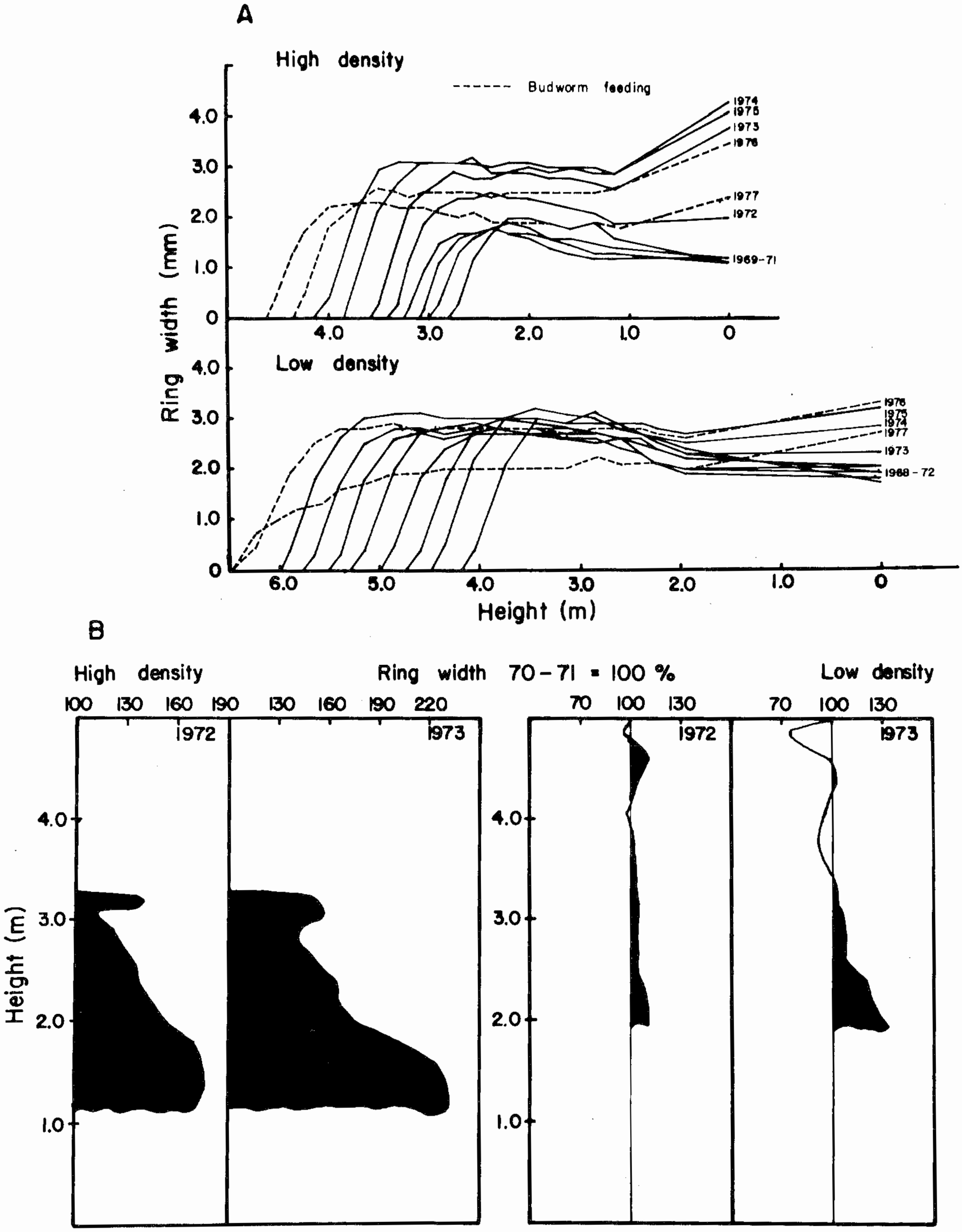

Figure 9. A. Average changes in ring width down the stem from 1969-1977 (oblique sequence); B. Average relative changes in ring width for 1972 and 1973 down the stem (vertical sequence), for 30 high and 17 low density trees.

high density trees prior to spacing (Fig. 9A). In the two years following spacing treatment, there is a change in the pattern of the typical oblique sequence, where ring widths lower down the stem are increasing relative to the widths farther up the stem. This is also shown in Fig. 9B, where average ring widths down the stem for the high density trees in the two years prior to spacing (1970-71) are compared to ring widths in the two years after spacing (1972-1973). Ring widths from the same internode number from the apex are compared, and represent Duff and Nolan's (1957) vertical sequence. The result is a gradual increase in the taper of the tree after spacing, which has been observed and discussed by Braathe (1957) for Norway spruce and Scots pine (Pinus sylvestris L.) and by Bramble et al. (1949), Barry (1971) and Stiell and Berry (1977) for red pine (Pinus resinosa Ait.). As a result of the spacing treatment in the high density stands, bigger crowns develop and also the wind velocity through the stand increases. The trees, therefore, have to resist greater forces by developing a stronger trunk and root system. This too is demonstrated by the high density trees in the form of a larger increase in ring width at stump level than at breast height (Fig. 6D).

The changes in growth pattern after spacing for the low density trees are quite different than for the high density trees (Figs. 8B, 9A,B). There is no relative increase in ring width down the stem, except for a slight increase towards breast height and stump in 1973. Throughout the stand life these low density trees have been relatively "open" grown compared to the high density trees, thus developing longer crowns and stronger root systems.

Insect defoliation: The influence of insect defoliation on tree growth is shown for 1976 (the first year of insect feeding) and 1977, for the two groups of trees (Fig. 9A). In 1976, there was a relatively greater decrease in growth at midcrown than at breast height for the high density trees that had lost one age-class of needles (Piene 1980). This is in comparison with the trees that had lost an additional age-class of needles in 1977, where there was a relatively greater volume loss towards the base of the trees. This trend is reflected in relative changes in the pattern of the oblique sequence for 1976 and 1977 (Fig. 9A). The low density trees, which on average lost the same amount of foliage in 1976 as the high density trees (between 60 and 100% of the current foliage) showed less decrease in ring width as compared to the high density trees. The explanation may be that these trees were growing more vigorously prior to budworm feeding in 1976, as shown by higher values for the specific volume increment for these trees. In 1977, an extremely high budworm population consumed the current and the equivalent of three other age-classes of foliage on the trees in the low density stands. This heavy consumption of foliage resulted in drastic decreases in ring width, especially in the midcrown (Fig. 9A).

Corridor spacing

Volume and height growth: Figure 10 shows treatment responses on an individual tree basis for codominant and dominant trees. For corridor spacing alone, no significant increase in volume growth was observed for the first four years after treatment. These stands were exceedingly dense (Table 3), and as a result had poorly developed crowns (average crown length 45.7%) and root systems which were incapable of taking full advantage of the release from one side. These results are only preliminary and significant increases in volume growth may occur at a later date. For comparable density in

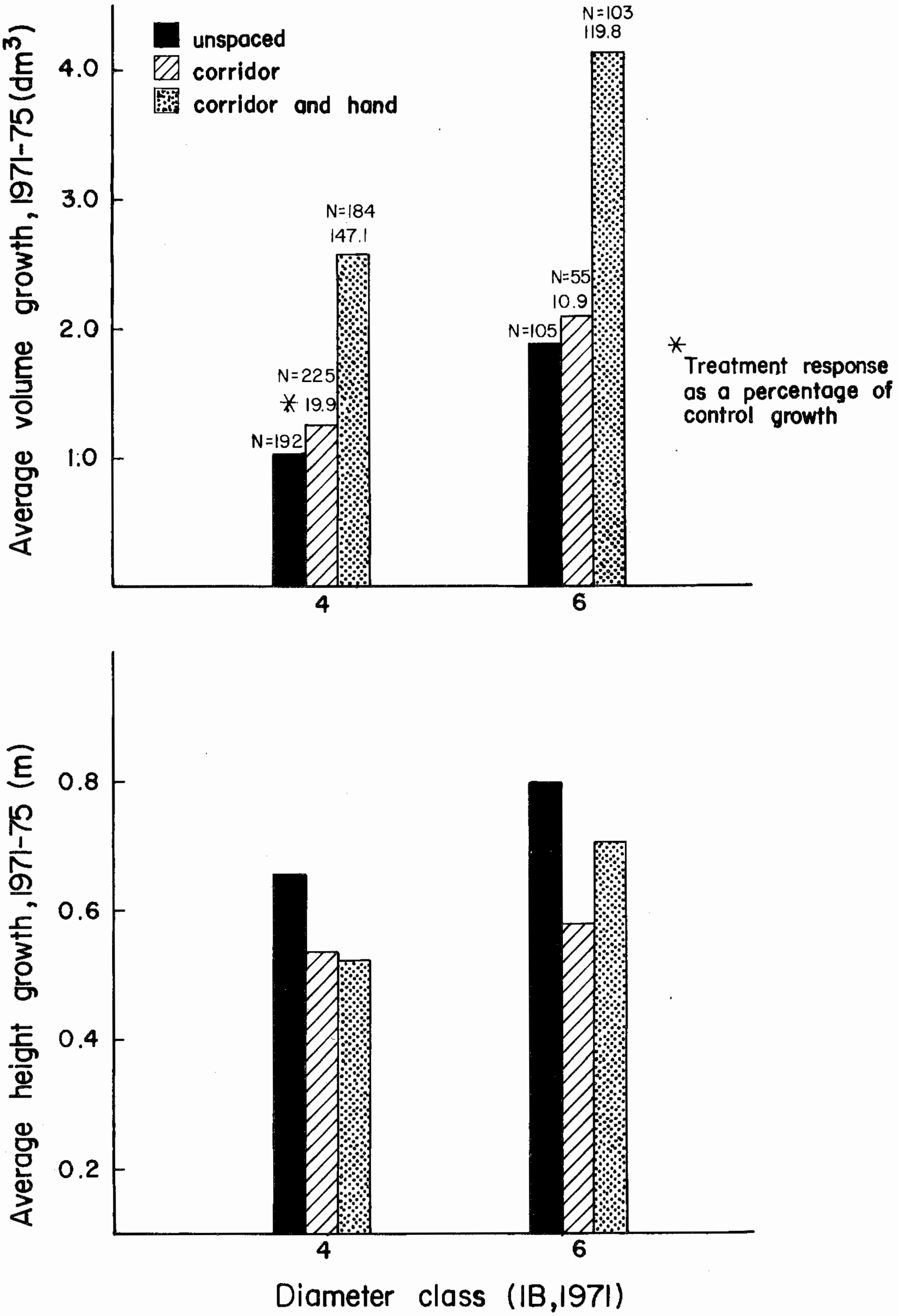

Figure 10. Average volume and height growth response from 1971 to 1975 for corridor and corridor in combination with manual spacing.

25-year-old lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) stands, Bella (1972) noticed increases in basal area growth for the first five years after treatment, ranging from 54-102% depending on the dbh-class.

Corridor spacing in combination with manual spacing (to about 2.4 x 2.4 m) produced significant increases in growth above that of the unspaced trees, 147.1 and 119.8% for dbh classes 4 and 6, respectively (Fig. 10). Thus, the trees in dbh-class 4 (codominant) showed higher relative growth, while the trees in dbh-class 6 (dominant) showed higher absolute growth from 1971 to 1975. Similarly, Grano (1969) found that a combination of corridor and manual spacing gave the best diameter growth in young loblolly pine (Pinus taeda L.) in southern Arkansas.

Comparisons of volume growth for corridor spacing in combination with manual spacing from 1971 to 1975 with that of the high density manual-spaced stands (Fig. 7A) (dbh class 4 and 6), show a much greater response for the manual-spaced stands. This is expected since the corridor and manual spaced stands were exceedingly dense before spacing (average density 71 148 stems/ha compared to 38 000 stems/ha for the manual-spaced stands), and as a consequence the trees have poorly developed crowns which were unable to take full advantage of the release during the first four years. The treatment of combined corridor and manual spacing left these trees more open as compared to the manual spacing alone, and damage from wind storms in some areas was extensive.

Basal area growth for the 10 largest trees per plot in the corridor spacing showed that the trees along the edge of the leave strip grew slightly better, although not significantly so, than those towards the middle (Fig. 11). This is consistent with results obtained for the volume growth of trees located on the edge of the strip as compared to the unspaced trees. Bella (1966) found no relationship between diameter growth and distance to leave strip in young jack pine stands after two years on "fresh" and "moist sites" in Manitoba, but after 10 years a significant response was noted on the "fresh" sites only (Bella 1974). Steneker (1969) noticed increased diameter growth of trees located on the edge of leave strips in a 30-year-old jack pine stand. These stands were much less dense (about 8500 stems/ha) than the stands reported in the present study, and the trees were probably able to react to the corridor spacing because of well developed crown and root systems.

Height growth measurements from 1971 to 1975 showed, for both dbh classes, a negative response to treatment (Fig. 10). This is often termed "thinning shock" and may be caused by a combination of low production of carbohydrates (due to poorly developed crowns) and a sharp increase in cambial respiration (Staebler 1956).

Preliminary results from this study suggest that corridor spacing alone in young dense stands is not desirable, while corridor spacing in combination with manual spacing seems promising. It is recommended that such thinning operations be performed at an earlier age (see discussion for "time of spacing") when crown and root systems are still relatively well developed and the trees could respond better to the treatments. This is especially important on the Cape Breton Highlands where high winds prevail during the summer months and trees with poorly developed root systems are susceptible to wind damage.

Evaluation of growth response

The evaluation of treatment responses to spacing, thinning, and

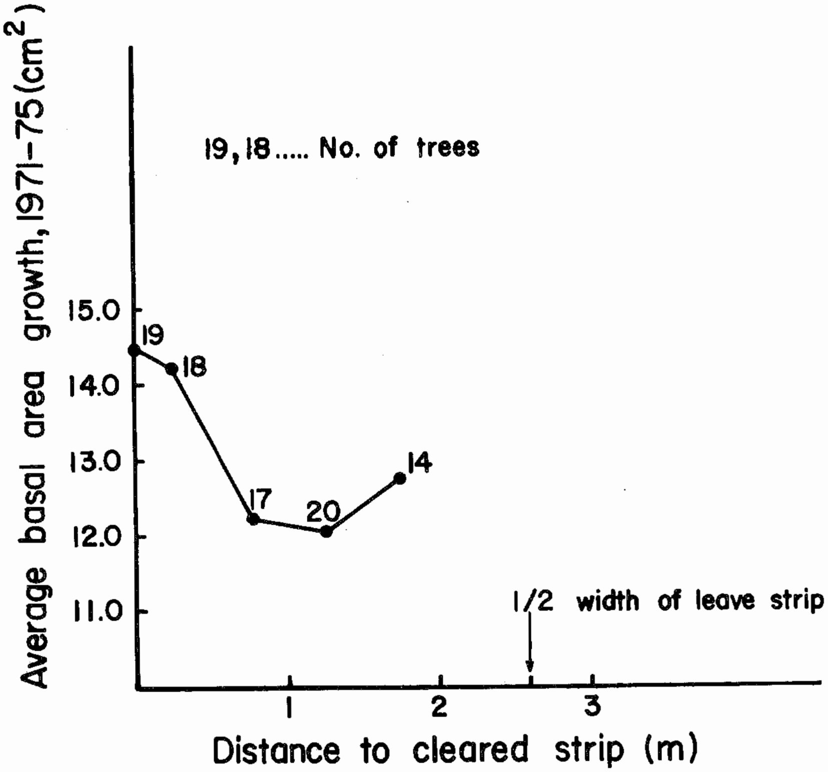

Figure 11. Average basal area growth from 1971 to 1975 for the 10 largest balsam fir trees per plot in relation to their distance from the nearest cleared strip.

fertilization in natural forest stands presents problems because it is difficult to find homogeneous stands where several plots can be located. Even in carefully planned experiments, differences in number of trees, basal area, volume, and, thus growth rates on a per tree and stand basis always exist. These differences will most certainly strongly influence the magnitude of the treatment response on a per tree or stand basis.

In an attempt to overcome these inherent problems, different methods have been used to evaluate responses to various silvicultural treatments. These include treatment responses presented on a per dbh-class basis (Crown _et al_. 1977), the "single tree method" where responses are measured on paired trees (Gagnon 1975) or by using different competition indices (Ker 1980). Unfortunately, comparisons are usually made only at one time in the development of the trees, disregarding previous growth rates that influence future treatment responses. Recently, Salonius _et al_. (1981) in a fertilization experiment used the 10 years growth prior to treatment for individual trees as a control for the 10 years growth after treatment. Such an approach assumes no changes in the natural growth development curve for the individual trees with time, which in many cases may be questionable. Statistical approaches include evaluation of treatment responses on a per hectare basis by using covariate analysis where initial plot differences are "corrected". This method can only be used where relatively small differences in basal area or volume exist prior to treatment.

An alternative method is the use of the specific volume increment (SVI) in evaluation of treatment responses. SVI is a measure of the annual volume produced relative to the cambial surface area from which it is derived (Duff and Nolan 1957). It is a sensitive measure of the balance between supply and demand of raw materials, which results in changes in the activity of the meristematic tissues and thus subsequent tree growth. A reduction in SVI reflects an imbalance in the supply-demand relationships. Current annual height growth is another specific growth parameter which reflects the apical activity of the meristematic tissue. In contrast, gross growth parameters are measures of the total amount of growth in any period of time. The distinct advantage of using SVI to assess treatment responses is that trees or plots with widely differing growth rates prior to treatment can accurately be compared. The use of this method in forest research has been limited and it has only recently been used to assess growth responses in hardwood stands to fertilization treatments (Lea _et_ _al_. 1979).

In the present study, growth responses to spacing were evaluated on a per tree (for each dbh-class) and per hectare (1600 crop trees per ha) basis. It is interesting to compare responses determined by these methods to those based on increases in SVI.

For both the spaced and unspaced trees, total cambial surface area for each tree from 1972 to 1975 was derived, based on relationships between dbh and surface area from the 66 stem-analyzed trees (see methods). The values for the cambial surface area were then added for all the trees within each dbh class, and for the 40 crop trees per plot, and were compared to the respective total volume growth from 1971 to 1975.

Percent increases in volume growth due to spacing, presented on a per dbh class basis for the low density plots, show close agreement with increases based on SVI (Table 4). This is especially true for the codominant and dominant trees (dbh-class 8) that most likely would survive to the end of the rotation period. Percent increases in volume growth for the 40 crop trees per plot ranged from 8.8 to 99% (unadjusted means, Table 5). The adjustment of the plot means by covariate analysis showed similar percent increases (except installation V and VII) as those based on increases from SVI.

The determination of SVI requires detailed analysis. However, it is a method that can accurately assess treatment responses on individual trees or plots. It serves as a reference to which other growth evaluation methods can be compared, and it should be used, if possible, when responses to silvicultural treatments are being evaluated. The use of SVI in the present study proved to be very valuable and gave confidence in the other methods of evaluating effects of the spacing treatments.

Time of spacing: The seven forest stands which had widely different original densities (Table 2) were spaced in 1971 at an average age of 17. These forest stands and especially the high density ones should have been spaced at an earlier age when tree growth was still vigorous, to avoid loss in stand volume. To get an indication of when these forest stands should have been spaced, several approaches were examined. The most attractive alternative was the use of SVI, (see definition in previous section) as an indicator of approximate time of spacing. Figure 6A shows changes in SVI with age for 30 trees cut outside the plots in installation IV (high density plot), and 15 trees cut outside the plots in installation VII (low density plot.). The average SVI for the 30 high density trees shows a sharp increase up to about age 6 (height 1.5 m), and then a steady decrease, indicating that there is an imbalance in the supply - demand relationships. This is in comparison with the current annual volume increment which is steadily increasing (Fig. 6A). This imbalanced condition results from competitive stress from neighboring trees. That this is the case is shown in the drastic increase in SVI after the spacing treatment at age 17 (in 1971). Assuming that changes in SVI for these trees approximate changes on a stand basis, these results indicate that this stand should have been spaced at about age 6 so as to avoid a decrease in SVI. Such early spacing operations would prevent the development of poor crowns and root systems and thus maintain vigorous tree growth. Similarly, the low density stands should have been spaced at about age 13 (height 4.2 m) at the culmination of their SVI.

The SVI curves for the two groups of trees are based on detailed stem analyses and cambium surface area measurements. From a practical point of view, it would be beneficial if such relationships could be predicted from more easily measured parameters. In this regard, ring width at breast height was found to be closely correlated with changes in SVI (Fig. 6C). Ring width at stump height was the second best parameter and height growth, third. These results suggest that ring width at breast height can be effectively used to predict corresponding changes in the SVI. Such relationships have also been noted by Fayle and MacDonald (1977) for sugar maple. Using these relationships, approximate time of spacing for the different forest stands examined in the present study was estimated from increment cores collected from all trees in the spaced plots. The recommended release age for spacing treatment was estimated by counting the rings in the increment core taken at dbh, from the time of start of release to the beginning of a steady decrease in ring width due to competitive stress from neighbors, and adding this to the years it takes for a tree to grow to breast height (4 years) (Fig. 12). For example, at original densities of 40 000 stems/ha, spacing treatment should be applied at about age 8 at an average stand height of approximately 2 m. This is in comparison with a stand with an original density of 15 000 stems/ha, that should have been spaced at about age 11 years with an average stand height of 3.5-4 m.

Spacing distance: When considering forest management alternatives in spacing and thinning operations, the economic benefits for each alternative must be compared. To do this, it is necessary to isolate growth changes resulting from various treatments and their effects on cost and return. The assessment of profitability is complicated and was outside the scope of the present study. Spacing to approximately the same distance and at the same age in all seven forest stands (Table 2) precluded the assessment of growth changes for different spacing alternatives. Although the following discussion is only speculative, it may give some ideas on spacing distance.

It has been shown that leaf biomass of an even-aged forest stand reaches maximum immediately before or after canopy closure (Tadaki 1966, Tadaki and Kawaski 1966, Long and Turner 1975). At the time of crown closure, crown competition begins and reduction of volume increment follows (Mitchell 1975). Based on several planting trials in conifer plantations, Wardle (1967) found that canopy closure (and thus reduction in volume growth) occurred at age 17 to 20 with a planting distance of 2.4 x

Table 4. Percent increase in volume growth and specific volume increment (1971-75) per dbh-class for installations II, V, VI and VII (low density plots)

	Mean volume growth (dm^3)			Average specific volume increment (cm^3/cm^2)		
DBH-class	Unspaced	Spaced	% increase	Unspaced	Spaced	% increase
2	0.5603	1.8930	237.8	0.051	0.147	188.2
4	1.5591	3.9541	153.6	0.071	0.164	131.0
6	3.1333	6.2351	99.0	0.088	0.159	80.7
8	5.2929	8.4855	60.3	0.095	0.146	53.7
10	7.2018	11.5404	60.2	0.096	0.150	56.3
12	9.1796	13.3052	44.9	0.097	0.140	44.3

Table 5. Percent increases in volume growth (1971-75) for 40 crop trees per plot based on unadjusted and adjusted means and specific volume increments for the seven installations (treatment averages of two plots)

		Average volume growth (dm^3), 1971-75					
Installation	Treatment	Unadjusted Mean	Percent Increase	Adjusted Mean	Percent Increase	S.V.I.	Percent Increase
I	Unspaced	154.75		185.59		0.129	
	Spaced	307.99	99.0	336.75	81.4	0.221	71.3
II	Unspaced	222.04		179.97		0.097	
	Spaced	326.60	47.1	303.86	68.8	0.153	57.7
III	Unspaced	140.13		147.70		0.104	
	Spaced	222.35	58.7	274.71	86.0	0.200	92.3
IV	Unspaced	135.96		151.70		0.108	
	Spaced	247.32	81.9	313.73	106.8	0.240	122.2
V	Unspaced	251.90		201.05		0.093	
	Spaced	320.89	27.4	307.76	53.1	0.162	74.2
VI	Unspaced	233.27		198.87		0.103	
	Spaced	275.29	18.0	270.96	36.2	0.147	42.7
VII	Unspaced	237.84		202.29		0.106	
	Spaced	258.84	8.8	255.17	26.1	0.156	47.2

S.V.I. = Specfic volume increment.

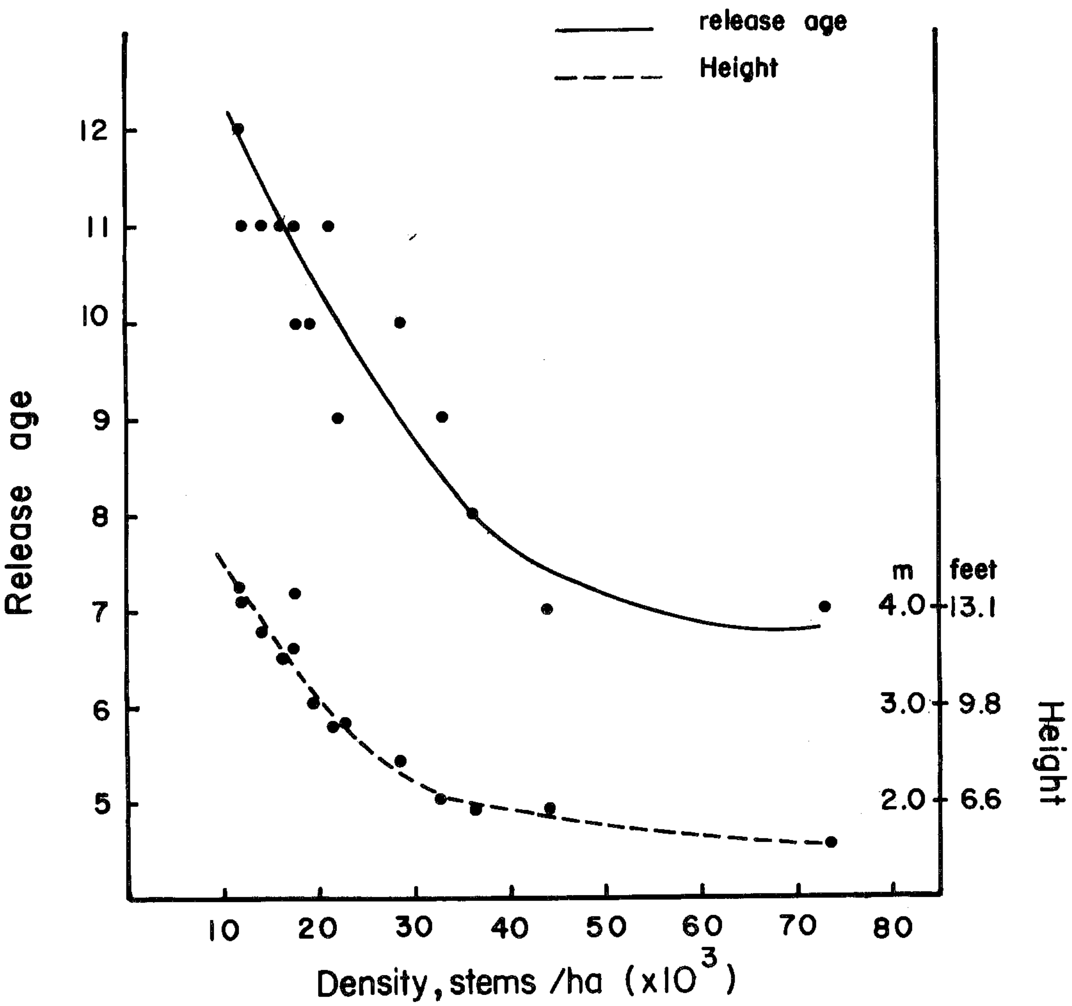

Figure 12. Recommended ages and corresponding heights for spacing treatment of different density forest stands.

2.4 m, as compared to age 10 to 12 for 0.9 x 0.9 m spacing for Sitka spruce (Picea sitchensis (Bong.) Carr.), Scotch pine, and Norway spruce. Similar observations were made by Low (1974). Although it may be dangerous to apply this information to natural forest stands, the balsam fir stands on the Cape Breton Highlands that were spaced at age 17 will again be closed at about age 37. (That this is not unreasonable, is indicated from crown developments after spacing in the different stands on the Cape Breton Highland.) Assuming a rotation age of 45 to 50 years, these balsam fir stands might, ideally, have to be spaced again around age 37 to avoid decreases in volume growth. Similarly, if they were spaced to 2.4 x 2.4 m at the apparent optimum age of 7 to 12 (see Time of spacing) to avoid decrease in volume growth, another spacing may be required at about age 30.

CONCLUSIONS AND RECOMMENDATIONS

1. Four-year-growth responses to manual spacing to 2.4 x 2.4 m in 17-year-old balsam fir stands with widely different original densities (ranging from 11 669 to 47 192 stems/ha) showed significant increases over unspaced stands for all dbh classes. For dominant and codominant trees these increases ranged from 77 - 136% and from 45 - 60% above the unspaced growth for high and low density stands, respectively. Average growth responses for the potential crop trees (1600 stems/ha) ranged from 3.7 - 5.9 m^3/ha for the low and high density stands, respectively.
2. Corridor spacing in young balsam fir stands produced no significant increases in volume growth for dominant and codominant trees. Only corridor spacing in combination with manual spacing (2.4 x 2.4 m) showed significant increases ranging from 120 - 147% above the unspaced growth for stands with original densities ranging from 54 000 to 91 667 stems/ha.
3. No significant height growth response was detected either for manual spacing or for corridor in combination with manual spacing.
4. These young dense balsam fir stands were spaced at a release age of about 17 years. These stands should have been spaced at an earlier age when the crown and root systems were still well developed. Recommended approximate time of spacing ranges from release age 7-8 for a 60 000 stem/ha stand to release age 12-13 for a 10 000 stem/ha stand. The benefits from such early spacing operations is suggested from growth studies in unspaced young forest stands where a gain of about 12 m^3/ha for the potential crop trees (1600 stems/ha) might have been obtained to age 13.

ACKNOWLEDGEMENTS

I am indebted to Nova Scotia Forest Industries Ltd. for their cooperation throughout this study. I also thank Dr. R.A. Fisher, and Dr. Y.S. Park for statistical advice, Mr. H. Hinds for identifying some of the plants, and Mr. L.R. Butcher for assistance in the field.

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