DEVELOPMENT OF SECOND-GROWTH BLACK SPRUCE STANDS ON PEATLANDS IN NORTHEASTERN ONTARIO

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ABSTRACT

Twenty-six black spruce (Picea mariana) stands originating after harvesting 50 to seventy years ago were examined on peatland sites in northeastern Ontario. For comparison, fourteen natural stands were also examined.

Most of the trees now present in the second-growth stands originated prior to the harvest. Trees in all size-classes responded to the release provided by harvesting, but the smallest classes showed the greatest growth response.

The productivity of the second-growth stands was acceptable, with present total volumes averaging from 124 to 211 cubic metres per hectare, depending on site type.

The second-growth stands were similar to the natural stands in terms of stem rot, stem form and spatial distribution of crop trees. The size structure of the second-growth stands, however, was dominated by small stems more than in natural stands.

The age-structure of second-growth stands was mainly unevenaged. Half of the natural stands were unevenaged and half were evenaged.

Based on the evidence provided by second-growth forests, preservation of black spruce advance growth is an appropriate regeneration technique. The implications of the unevenage structure of some natural stands for forest management and silviculture are discussed.

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INTRODUCTION

Black spruce (Picea mariana (Mill.)B.S.P. advance growth is abundant in many peatland forests (Groot 1984), and preservation of advance growth is a low-cost regeneration method that may be especially suited to low-quality sites with poor access. Past research has shown that growth of black spruce advance growth and residuals following harvest may be acceptable (Vincent 1965, Crossley 1976, Johnstone 1978). Still, uncertainty persists about the productivity, quality and structure of forests originating from advance growth. Much advance growth is of layer origin, and was in a suppressed condition at the time of logging. As well, these stems tend to be highly clumped, and the height distribution may be uneven.

Large-scale harvesting of black spruce forests for pulpwood began as early as 70 years ago in northeastern Ontario. Although specific measures to ensure regeneration were rarely applied, well-stocked, second-growth forests have developed in some areas. Some of these forests appear to have originated largely from advance growth.

The objective of this study was to examine the structure, quality and productivity of second-growth black spruce forests, and particularly to understand the significance and development of advance growth in these forests.

The study was designed to answer the following questions:

- what is the origin of second-growth black spruce forests?
- is the productivity of second-growth forests acceptable?
- are forest management planning practices based on normal yield tables applicable to second-growth forests?
- is the size structure of second-growth forests more heterogeneous than that of natural stands, and will it cause harvesting or silvicultural problems?
- will the spatial pattern of second-growth forests affect harvesting or silvicultural practice?
- are there decay or stem form problems unique to second-growth forests?
- should forest managers try to emulate in present-day practice the conditions that led to the development of these forests?

Some of these questions could be answered only by comparing second-growth to natural forests, and so a stategy of conducting sampling in both conditions was adopted.

METHODS

Study Area

Sample plots were established in black spruce peatland and transitional forest of the Northern Clay Section (Rowe 1972) of northeastern Ontario in two localities - east of Cochrane (Lat. 49, Long. 80 30') and north of Kapuskasing (lat. 49 30', Long 82 20').

This region has a continental climate. Mean annual temperature is 0.5 C. and mean annual precipitation 82 cm., half of it occurring in the growing season. It is characterized by nearly level topography underlain by Precambrian rocks with surface deposits of lacustrine clay and water-worked tills originating from glacial Lake Ojibway (Rowe 1972).

Black spruce swamp forests prevail on the lowland flats, often alternating with sedge and heath bogs and locally including tamarack (Larix laricina (DuRoi)K.Koch) or cedar (Thuja occidentalis L.) as minor companion tree species. Black spruce also occupies the gently rising uplands intermixed with balsam fir, white spruce and poplars (Populus spp.). A comprehensive forest ecosystem classification (Jones et al. 1983), available for this region, provided a primary basis for sampling. The system allocates stands to vegetation types and "operational groups" (OG's), the latter embracing a group of vegetation types and soil conditions. This study was confined to the following peatland and transitional peatland OG's in which black spruce predominates:

OG 11 - Ledum - wet organic soil 40-160 cm. deep, thick surface fibric horizon with little ground water flow.

OG 12 - Alnus - herb-poor - wet organic soil 40-160 cm. deep, thick surface fibric horizon, with moderate ground water flow.

OG 13 - Alnus - herb-rich - wet, well decomposed, organic soil 40+ cm. deep, thin surface fibric horizon, strong ground water flow.

OG 9 - Conifer-herb/moss rich - mixed conifers on moist, fine clay-loam soil 5-30 cm. organic matter, intermediate to poor drainage.

OG 8 - Feathermoss/sphagnum - moist fine clay-loam soil with 20-40 cm. organic matter, poor drainage.

OG's 9 & 13 were combined here because of the former's rarity and an apparent similarity in productivity, making four site categories in all. Within each of these sites, second growth stands (logged mainly in the 1920's & early 30's) and natural-origin stands were selected for sampling. Acceptable stands were typical black spruce relatively well stocked, undisturbed since origin and homogeneous re site.

Except for balsam fir present in the understory of certain plots and tamarack particularly in OG 13 plots, other tree species were of negligible occurrence.

The sample plots were located within the licences of two forest products companies, Spruce Falls Powere and Paper Co. and Abitibi-Price Ltd., because these companies have maintained cutting records that allowed harvest dates of second-growth forests to be identified.

METHODS cont'd

Field and Laboratory Measurements

The study was carried out in two parts - an initial phase to establish optimum plot size and sampling intensity and a second phase incorporating the main sample. A total of 40 plots was established in the field. The distribution of sample plots by stand origin and site type is summarized in Table 1.

TABLE 1. Distribution of Sample Plots by Study Phase and Treatment

SITE TYPE/ STAND ORIGIN	PHASE 1		PHASE 2		COMBINED	
	Second Growth	Natural	Second Growth	Natural	Second Growth	Natural
OG 11 - Ledum	1	1	7	3	8	4
OG 12 - Alnus- herb poor	1	1	7	3	8	4
OG 9/13 - Conifer- herb/moss rich, Alnus- herb rich	1	1	4	2	5	3
OG 8 Feathermoss Sphagnum	1	1	4	2	5	3
TOTALS	4	4	22	10	26	14

Plots were carefully located to avoid significant transitions in stand structure, stand composition or site type. Second-growth stands were identified from aerial photographs, logging records and ground checks for stumps. Plots in second-growth stands were oriented with the long axis perpendicular to skidways as distinguished on aerial photos.

The size of plot used was 10 x 80 m. in Phase 1 and 10 x 50 m. in Phase 2. Plots were broken down into grids of 1 m. quadrats within which all trees (stems $>$ 1.4 m. height) were tallied as to species, diameter breast height and stem form (presence of basal sweep, lean or forking). Stocking of advance growth (stems $<$ 1.4 m. height) of relevant species was recorded for each quadrat. Dead stems were disregarded in the tally. Heights were taken for all plot trees in Phase 1 and for 30 representative trees in Phase 2. Increment cores through the pith at stump height (25 cm.) were obtained from all trees in each plot for determining age.

Ten trees representing the full diameter range in each plot were felled for detailed stem analysis. Sections were taken at ground level, stump height (.25 m.), 1 m., breast height (1.4 m.) and at every additional metre (2, 3 etc.). In Phase 1, the four largest of these trees were also sectioned 0.1, 0.2 and 0.3 m. below ground (where possible) for age determinations. (cf. McEwen 1966).

In the laboratory, annual rings were counted under a microscope on all increment cores and below-ground discs. Stem analysis was carried out on the computerized Tree Ring Increment Measurement (TRIM) system (Fayle et al 1983) which was developed by the Ontario Ministry of Natural Resources. This system provides a comprehensive analysis of height, diameter and volume growth throughout an individual tree's life history.

METHODS cont'd.

Analyses

Optimum plot size was determined from the Phase 1 data. Relationships of tree diameter, height, volume and age to plot sizes ranging from 10 x 10 m. to 10 x 80 m. were examined in terms of coefficient of variation (CV) for each plot (Snedecor and Cochran 1967, Hegyi 1973). Maximum age of sectioned trees was related to stump height age by a linear regression.

Age class frequency distributions were prepared for each plot using the age at stump height (25 cm.) of all trees taller than 1.4 m. as determined from increment cores.

Stems below 1.4 m. were assessed as to stocking per 1m2 quadrats rather than density. An approximation of the density of stems less than 1.4 m. tall is given by:

$D = -\ln(1-S)$

where D is the density (1m2 basis)

S is the stocking (1m2 basis)

This relation is valid when the number of stems on quadrats is Poisson-distributed (random). Because black spruce advance growth is usually clumped, however, the calculated density is likely to be an underestimate.

This estimate of density, recognized to be conservative, was added to age classes 1-40 years in the age frequency distributions, thus involving all tree stems rather than only those above breast height. Diameter class frequency distributions were prepared for all trees taller than breast height (1.4 m.) in each plot.

In standard practice, advance growth stocking is assessed on quadrats 4 m2 in area. An approximate conversion from the 1m2 data is given by:

$S4 = 1-(1-S1)^4$

S4 is stocking on a 4 m2 basis

S1 is stocking on a 1m2 basis

For second-growth plots, the proportions of stems of pre-harvest and post-harvest origin were determined by applying a 12-year correction to the stump age and comparing this age to the harvest date. Twelve years was the average time taken for stems to reach stump height. Using these proportions, the current volume accounted for by preharvest and post-harvest stems was determined for selected plots. Least squares regression models were used to determine the relationship of volume over diameter, and this relationship was applied to diameter distributions to calculate plot volumes.

Specific volume increment (SVI) for individual trees was calculated from the stem analysis data. SVI is the annual volume increment divided by the cambial surface area, in effect the average annual radial increment produced by the cambium. The relative response of advance growth to release following logging was studied by regressing the current height (H1) of selected trees in each stand against their height at the time of harvest (H0) as determined from stem analysis.

In most cases the logarithmic model (H1= A + B log H0) gave the strongest correlation. The 5-year survivor volume growth for each plot was determined by regressing 5-year volume growth for individual trees against volume and applying the result to the diameter distributions.

Mean annual volume increment for second-growth plots was determined by dividing the volume growth since harvest by years since harvest. Mean annual increment of even-aged natural stands was computed by dividing the present volume by total age.

To test spatial tree distribution in each plot the variance/mean ratios for the number of stems per quadrat were applied according to Pielou (1960). The expected value of this ratio in a random population is one and its standard error is 2/(n-1) (Grieg-Smith 1964). Thus, using a 95% significance level for a 1x1 m. sample grid, variance/mean ratios less than 0.9 indicate uniform distribution, values between 0.9 and 1.1 indicate randomness and higher values aggregation or clumping. This is known as the "clumping index" (C.I.). Since quadrat size could affect this index, (Kershaw & Looney 1985), the data were compared for quadrats ranging from 1x1 m. to 5x5 m. The class limits differ for each size so that the actual indices cannot be compared directly but the classes per se - uniform, random and aggregated - are comparable. Another commonly used measure of spatial pattern, Morista's Index (1957), was tested in several plots.

For ease of presentation, the data were often divided into two general site groups. Operating Groups 11 and 12 were the least productive or "poor swamp" sites while O.G.'s 8, 9 and 13 were more productive, representing transitional peatlands and richer swamps.

RESULTS

Optimum Plot Size

Coefficients of variation for volume, height and age generally decreased with plot size, whereas CV's for age increased in the smaller plot sizes (Fig.1). In allcases, CV's stabilized to constant values at about 500 m.2, so this plot size was used in Phase 2.

Age Determination and Early Height Growth

Results from stem analyses of 32 dominant and co-dominant trees, comparing age counts from discs at stump height (25 cm.), moss surface and below-surface levels, indicated that maximum age most frequently occurs 10 or 20 cm. below surface and may be as deep as 30 cm.

Combining data from all origins and site types, the overall relationship between maximum and stump age is described by the following linear regression:

Max. age = 10.4429 + 1.0187 stump age $r2 = .94$ n=32

Thus for mature trees (100-200 years) the total age averages 12 to 15 years greater than age at stump height.

Initial height growth was much faster in plots of fire origin where it took an average of 4.6 years to reach stump height (25 cm.). In stands of non-fire origin, the comparable figure was 15.1 years.

RESULTS cont'd

Age and Diameter Distribution Patterns

Age and diameter distributions were classified into several types; examples of which are illustrated in Fig. 2. The following age structures were characterized:

- Uneven-aged - Positively Skewed: Trees in many different age classes and declining frequency with increasing age.
- Uneven-aged: Trees in many different age classes with no single age class predominating significantly.
- Even-aged: A single age class (or less frequently two age classes) dominating the age distribution of the canopy trees.
- Composite: Trees in several age classes older than a large even-age cohort.

The following size structures were characterized:

Positive skew - a negative exponential pattern

Normal - a bell curve

Irregular - uneven, often bimodal pattern

The relative occurrence of these patterns in percentage of the 40 plots sampled is presented in Table 2.

TABLE 2. DISTRIBUTION OF PLOTS BY AGE AND DIAMETER PATTERNS

Age Distribution Patterns (Number of Plots)

Origin	Operating Group	Uneven-Positive Skew	Uneven	Composite	Even
Second	11	7	1		
Growth	12	6	2		
	8	2	1	2	0
	13	1	2	2	
Percentage		61	23	16	0
Natural	11		2		2
	12	0	3	1	
	8				3
	13			1	2
Percentage		0	36	14	50

Diameter Distribtution Patterns

Origin	Operating Group	Positive Skew	Normal (Bell-curve)	Irregular
Second	11	4	1	3
Growth	12	6	1	1
	8	1	1	3
	13		1	4
Percentage		42	16	42
Natural	11		1	3
	12		2	2
	8		3	
	13		2	1
Percentage		0	57	43

Most of the second-growth stands in which the canopy was clearcut 50-60 years earl'ier were uneven-aged, the remainder being of composite age structure. In many stands, particularly those with positively skewed age structures, more than half of all stems were under 50 years old. However, this component was insignificant in terms of volume and represented on average only 7% of trees taller than breast height. Remaining stems ranged erratically up to 250 year-old residuals which would have been variously suppressed or otherwise unmerchantable at logging.

Among the natural stands half were even-aged, mainly under 120 years old, exhibiting a unimodal, J-shaped age frequency distribtuion with more than 80% of stems over 40 years old in the one or two oldest age classes. The diameter distribution was generally bell-curved, reflecting full canopy stocking, negligible recruitment in the smaller sizes and little mortality in the larger. The remaining natural stands were uneven-aged with individuals up to 300 years old forming irregular age and size distribution patterns.

The proportions of stems above breast height pre-dating the harvest are indicated for each plot in the Appendix. On average, 83% of stems now above breast-height were of pre-harvest origin. These trees generally accounted for more than 90% of the present volume with the two exceptions being Stands 8 (80%) and 15 (85%). At harvest, the residual stems ranged up to 8 m. in height and, in general, 1-11 cm. in diameter at stump.

RESULTS cont'd

Spatial Distribution of Stems

The clumping index (C.I.) for crop trees only (10+ cm. dbh) indicated random distribution consistently regardless of stand origin or site, hence the data are not presented. When the index was applied to ALL TREES above breast-height, however, differences appeared (Table 3).

Concerning quadrat size, C.I. classes were consistent, either random (R) or aggregated (A), through all quadrat sizes in 9 of 26 second-growth plots and in 8 of 14 natural plots. In the other plots the classes varied erratically with quadrat size. Overall, the occurrence of aggregation was highest (43%) in the 4m2 size.

In terms of stand origin, random distributuion prevailed in 8 of 14 natural plots. In the 26 second-growth plots five were consistently random in pattern, four consistently aggregated and the remainder erratically variable.

Consistently random vs. aggregated second-growth plots are compared in terms of tree density in Table 3.

TABLE 3. Mean Tree Density in Stands with Random vs. Aggregated Spatial Distribution

	RANDOM		AGGREGATED	
	A	B	C	D
	Non-Crop Trees	All Trees	Non-Crop Trees	All Trees
Mean No. of trees per plot	83	160	185	256

It is evident that the plots exhibiting clumping at all quadrat sizes were significantly denser. A vs. C and B vs. D were significantly different by the t-test at the 95% level. Since crop tree distribution is randomized, aggregation is related to the abundance of smaller (non-crop) trees.

Computer plottings of actual tree locations within selected plots provided visual comparison of random vs. aggregated spatial distributions. The distinction was not clear. Two types of aggregation were discernible - a linear one, presumably originating from seedlings or layering developed along an earlier fallen tree or skidways and variable-sized clumps originating either from layering around low-crowned parent trees or from seedling cluster development.

Advance Regeneration

Stocking percentages of advance growth varied widely from plot to plot. The means by stand origin and site are shown in Table 4. Species other than black spruce were mainly balsam fir in all OG's and white cedar on OG's 12 and 13.

In terms of all species on a 4 m2 basis, stocking was greater in second growth stands than in natural stands. In second growth stands, stocking of black spruce on OG's 11 and 12 was roughly double that of OG's 8 and 13.

TABLE 4. ADVANCE GROWTH STOCKING

SECOND GROWTH STANDS

	Black spruce		All species	
	1 m2 basis	4 m2 basis	1 m2 basis	4 m2 basis
OG 11	.39	.83	.45	.88
OG 12	.31	.73	.44	.85
OG 8	.14	.44	.43	.85
OG 13	.12	.34	.55	.94

NATURAL STANDS

OG 11	.43	.78	.44	.79
OG 12	.19	.55	.21	.59
OG 8	.18	.48	.21	.53
OG 13	.05	.19	.28	.69

Release After Logging

The age distribution study indicated that an average 83% of black spruce stems above dbh in second-growth plots was established prior to logging. Evidence of the response to release is available from the SVI (Specific Volume Increment) data.

Figure 3 presents mean 5-year SVI totals for three size classes of subcanopy residuals over 5-year periods before and after clearcutting of the canopy. For comparison as a control, the periodically comparable SVI's of similar-sized trees in plots of natural origin are provided.

Marked growth responses, inversely related to size, are evident in the logged plots. The smallest trees increased most in growth rate, the intermediate-sized trees increased moderately and the largest trees least. The response peaked after 15 years, then declined steadily. Natural plots show a gradual and steady decline in SVI values among all trees. A consistent decline during the period 1945-50 suggests an adverse environmental effect on growth.

Comparing sites as to relative growth rates, in natural plots the transitional OG's 8 and 13 were initially superior to OG's 11 and 12 but the former declined faster after 1955, resulting in similar SVI levels (about .30 cm.) at the end period. In logged plots the SVI levels were higher initially in OG's 8 and 13 but release was greater in OG's 11 and 12. The decline after period 3 was comparable in both site categories and final levels were similar.

Response to release relative to the size of advance growth was further studied by regressing current height of trees against height after harvest. The relationship was strong (r2 = 70+) in over 60% of plots. In these cases the trend, as exemplified in Fig. 4, was curvilinear, with greater growth response exhibited by stems which were more suppressed after harvest.

In other plots exhibiting a weak relationship, a sample of which is also shown in Fig. 4., the original height at harvest had little bearing on present height.

RESULTS cont'd

Productivity

Plot productivity parameters are averaged and summarized in Table 5. Comparison of site effects within the two general stand origin categories - logged second-growth vs. natural - reveals that by most measures OG's 8 and 13 were superior to OG's 11 and 12. The mean differences were significant at the 95% level by the t-test for total and merchantable volume and total and merchantable basal area in both origin types, and for dominant height in logged plots. Variances for V (volume growth of last 5 years) were large within sites making apparent differences non-significant. Differences in total and merchantable stocking also varied widely, with OG's 11 and 8 standing out as significantly higher in total density.

When the means of all plots of logged origin were compared with those of natural origin the latter were higher in total and merchantable volume, merchantable density and dominant height, but wide variances among plots rendered these differences non-significant. Second growth plots averaged higher in total density, recent volume growth and mean annual increment, but again, the differences were not significant.

Comparing mean dominant heights from the even-aged natural plots of this study with Plonski's (1974) site index curves for black spruce (which covers upland as well as swamp sites) (Fig. 5) it appears that the OG 8 and 13 plots were very close to Plonski's average site class 1 values and the OG 11 and 12 plots were intermediate between site classes 2 and 3. Mean annual increment of S.G. plots since harvest is shown in Table 6.

TABLE 5. PRODUCTIVITY SUMMARIES

Origin/ Site(OG)	No.of Plots	Total Vol. m3/ha	Merch.* Vol m3/ha	Total ▲V** m3/ha	Total BA m2/ha	Merch. BA m2/ha	Tot.# Stems /ha	Merch. Stems /ha	Mean Dom. Ht.-m	M.A.I. M3/ha/yr
LOGGED										
OG 11	8	143	123	14.0	31.1	25.6	4401	1519	13.5	2.28
OG 12	8	124	107	12.8	27.0	22.4	3643	1261	13.5	1.96
OG 8	5	211	188	22.5	39.8	33.9	4615	1749	15.3	3.52
OG 13	5	209	198	16.6	34.3	31.5	2604	1280	17.0	2.94
Weighted Average	26	162.9	145.0	15.8	32.1	27.3	3863	1438	14.5	2.55
NATURAL										
OG 11	4	158	147	6.4	31.2	28.2	2965	1691	14.1	1.28
OG 12	4	177	169	15.2	32.1	30.4	2095	1440	15.9	0.90
OG 8	3	264	250	18.4	42.3	38.6	3245	2252	16.5	2.59
OG 13	3	275	271	21.9	40.5	39.5	2109	1739	17.8	2.28
Weighted Average	14	211.2	201.9	14.8	35.8	33.5	2593	1750	15.9	1.67

* Merch. = all stems > 10 cm. dbh.

** ▲V. = volume growth of last 5 years

Table 6. Post-Harvest Mean Annual Increment in Second-Growth Plots

OG	MAI-m3/ha.
11	2.28
12	1.96
13	2.94
8	3.52

Growth was appreciably higher on OG's 8 and 13 than 11 and 12; the respective differences were significant by the t-test (P>0.95). On this basis OG's 8 and 13 rate site class 1 in Plonski's (1974) tables and OG 11 and 12, site class 2. For strict accuracy a few years should be added to the growing period to account for pre-harvest volume, thus decreasing the above MAI's slightly.

In the natural stand sample, MAI values for six plots in OG's 8 and 13 averaged 2.43 m3/h which is equivalent to half way between Plonski's site classes 1 and 2. For three plots in OG's 11 and 12 mean MAI was 1.16 m3/ha., lower than Plonski's site class 3.

Stem Quality

Basal sweep occurred in 30.5% of spruce trees in natural stands, and 32.2% in second growth stands. Butt rot occurred in 8% of trees in natural stands and 4% in second growth stands.

DISCUSSION

What is the origin of second-growth black spruce forests?

The second-growth stands examined here were largely of preharvest origin. Over 80 percent of the stems now above dbh existed as advance growth in the understorey at the time of harvest. These stems now comprise over 90% of the standing volume. Approximately one-third of trees had distinct basal sweep, providing a lower bound on the proportion of layer-origin. Similar proportions of layers (26% - 35%) were identified by Horton & Lees (1961) in an Alberta black spruce stand.

Response to canopy release was inversely related to tree size, the suppressed class increasing markedly, the unsuppressed very little. Suppressed trees can respond well and maintain their relative growth rate as well or better than unsuppressed trees for decades. Lieffers (1986) also found that suppressed black spruce did not become more suppressed with progressive stand development. In the majority of cases trees maintained their relative crown class position since released after harvest.

Are forest management planning practices based on normal yield tables applicable to second-growth forests?

Forest management planning and inventory in Ontario are founded on normal yield tables, developed from even-aged stands (Plonski 1974). If a second-growth stand is presumed to have been established at the time of harvest, then the site class will likely be overestimated. For example, the mean dominant height of second-growth OG 11 stands was 13.4 m, which, for presumed ages of 50 to 60 years, would place them in site class 1. Mean dominant heights in the other site types were even greater. Total volumes would also place most stands in site class 1 or 2 if stand ages were presumed to be 50 to 60 years. Using the actual ages of the stems would also be inappropriate. These stems existed in a suppressed state in the understorey for many years before harvest, and are not indicative of the development of free-growing stems on the same site. Also many second-growth stands retain a component of the uneven-aged character of their parent stands.

It is noteworthy that many of the natural stands examined in this study were also uneven-aged, and consequently forest management planning through the use of normal yield tables based on even-aged stands is also inappropriate for these forests.

Is the productivity of second-growth forests acceptable?

The natural stands rated on average considerably higher than the second-growth stands in terms of current volume and dominant height. This would be expected because of their greater maturity. Seventy percent of stems above breast height were merchantable (>10 cm. dbh) in the natural plots compared with 48% in the second growth. The prevalence of maturing 50 to 70 year old trees in the logged plots implies greater productivity potential over the next few decades. The second-growth plots are impressively productive, considering only a 60-year+/- growth period since logging. Ninety-three percent of total volume growth occurred in that period. OG's 8 and 13 rated site class 1 according to Plonski and OG's 11 and 12 rated site class 2. In the older even-aged natural plots, MAI's for OG's 8 and 13 were half way between Plonski's values for sites 1 and 2 and MAI's for OG's

11 and 12 were lower than Plonski's site 3 equivalent. The MAI of second-growth stands is higher because they did not go through the long regeneration period required by natural stands. This suggests a possible reduction in rotation length.

Is the size structure of second-growth forests more heterogeneous than that of natural stands, and will it cause harvesting or silvicultural problems?

The diameter distribution of second-growth stands in OG's 11 and 12 was frequently positively skewed, compared with the irregular, bi-modal or bell-curved patterns that predominated in the natural stands. The positively skewed pattern is undesirable from a harvesting point of view (especially clear-felling) because a large proportion of the volume is in rather small stems. This pattern may be a function of the slower stand development on OG's 11 and 12, and not attributable to the mode of stand origin. The bell-curve and bimodal patterns were more common than the positively skewed pattern in second-growth stands on OG's 8 and 9/13, where stand height and volume were greater. If, however, the positively skewed diameter pattern does persist until the stands are ready for harvest, it may be necessary to adjust harvesting methods to accommodate this pattern, and to accept a different diameter mix in the harvest than currently comes from these sites.

Will the spatial pattern of second-growth forests affect harvesting or silvicultural practice?

For crop trees (>10 cm. dbh), the spatial distribution for both natural and second-growth stands was generally random. THus, it is unlikely that harvesting methods will have to adapt to new spatial distributions as the second-growth forests are ready for harvest

Are there decay or stem form problems unique to second-growth forests?

Decay was negligible in the plots examined - less than 4% on average in second-growth stands, and 8% in natural stands. The frequency of stem rot was generally related to the maximum stand age. In both natural and second-growth stands about one-third of the stems had pronounced basal sweep. Overall second-growth black spruce forests appear to have good stem quality.

Should forest managers try to emulate in present-day practice the conditions that led to the development of these forests?

This study indicates that where advance growth is abundant in peatland stands, its preservation would be an appropriate regeneration strategy. Advance growth stems respond to release after 5 to 10 years, and advance-growth origin second-growth stands can produce good stand volumes in relatively short periods of time. In over 60% of plots the dominant advance growth remained dominant, but suppressed stems are capable of responding well to release and are worth salvaging.

The second-growth stands in this study originated after harvesting by handsaw and forwarding with horses. Whether modern-day mechanized harvesting can duplicate to a sufficient degree the conditions that resulted from the earlier harvesting method is not known. It has been shown that mechanized winter harvesting or summer harvesting using wide-tired forwarders does reduce the impact of equipment on the site (Groot 1987). It seems likely that further development of harvesting equipment and techniques could further reduce impacts.

Densities of crop trees in the well-stocked second-growth stands is in the order of 1500 stems per ha. Thus a suggested minimum number of surviving stems that must remain after harvest is 1500 stems per ha., preferably in the 3 metre to 7 metre size range, to produce stands similar to those studied. Smaller trees are also valuable in many cases; however, since not all stems will respond well to release, a desirable density would be greater than 1500 per ha.

What are the overall silvicultural implications?

From a strictly silvicultural point of view many of these black spruce swamp stands could be managed as uneven-aged forests. The tendency to uneven-aged structure supports this, together with the species' ability to release from suppression and to regenerate in a variety of natural conditions. However, uneven-aged management would be generally incompatible with modern, mechanized systems of pulpwood logging involving clearcutting and artificial regeneration. Nevertheless there may well be local situations where selective logging and natural regeneration silviculture is appropriate, including long term experimental demonstrations.

Clearcutting is the standard method of logging black spruce swamp stands. Economics and established operational systems, now highly mechanized, dictate this. Silviculturally, also, some form of clearcutting appears best for black spruce in many situations, particularly for even-aged stands (Vincent 1965). Various experiments have shown that though black spruce may regenerate under a moderate cover, it requires full light for best development (Heinselman 1957 A & B). Suitability of seedbeds for natural regeneration depends on the species of sphagnum and feather moss present, moisture availability and light intensity. The density of underbrush, especially alder, is often critical, extending the regeneration period as long as 40 years. (Holt 1950, Vincent 1965).

This study has shown that understory black spruce in general has the potential to release well after canopy removal and develop into a productive stand. The extra costs of preserving such advance growth during logging should be weighed against the advantages of salvage where appropriate. Savings would include all replanting costs, the regeneration period (up to 10 years) plus the time required to match the size of the advance growth. Most of the second-growth stands studied had large funds of trees in the smaller size classes - generally more than the natural stands on similar sites. This implies that these black spruce peatland forests could be managed on an ongoing basis using advance growth for natural regeneration in subsequent rotations.

In view of this, consideration should be given to developing modern harvesting methods which would take advantage, or at least partial advantage, of this free and productive regeneration capability. For example, it might be feasible to clearcut in strips with mechanical tree harvesters in a manner that would leave at least 50% of the ground (and advance growth) relatively undisturbed. The disturbed portions of strips could be regenerated by natural seeding or, failing that, by planting.

LITERATURE CITED

Crossley, D.I. 1976. Growth response of spruce and fir to release from suppression. For.Chron. 52:189-193.

Fayle, D.C.F., MacIver, D. and Bentley, C.V. 1983. Computer - graphing of annual ring widths during measurement. For.Chron.59(6):291-293.

Greig-Smith, P. 1983. Quantitative plant ecology. Third edition. University of California Press, Berkeley, California, U.S.A.

Groot, A. 1987. Silvicultural consequences of forest harvesting on peatlands: site damage and slash conditions. Can.For.Serv., Great Lakes For.Res.Cent., Info.Rept. 0-X-384.

Groot, A. 1984. Stand and site conditions associated with abundance of black spruce advance growth in the northern clay section of Ontario. Dep.Environ., Can.For.Serv., Great Lakes For.Res.Cent., Info.Rept. 0-X-358.

Hegyi, F. 1973. Optimum plot dimensions for experimental designs in jack pine stands. Can.For.Serv., Great Lakes For.Res.Cent. Info.Rept. 0-X-181.

Heinselman, M.L. 1957(a). Wind-caused mortality in Minnesota swamp black spruce in relation to cutting methods and stand conditions. Soc.Amer.For.Proc. 1957; 74-77.

Heinselman, M.L. 1957(b). Silvical characteristics of black spruce (Picea mariana). U.S.D.A. Lake States F.E.S. Stn. Paper 45.

Holt. L. 1950. Cutting methods in pulpwood operations of eastern Canada. Woodlands Research Index No. 84 (F-2) Pulp & Paper Res.Inst. of Canada. Montreal.

Horton, K.W. and J.C. Lees, 1961. Black spruce in the foothills of Alberta. Can.Dept.For. For.Res.Br. Tech. Note 110.

Johnstone, W.D. 1978. Growth of fir and spruce advance growth and logging residuals following logging in west-central Alberta. Dep.Environ., Can.For.Serv., Edmonton, Alta. Inf. Rep. NOR-X-203. 16.p.

Jones, R.K., Pierpoint, G., Wickware, G.M., Jeglum, J.K, Arnup, R.W., and Bowles, J.M. 1983. Field guide to forest ecosystem classification for the Clay Belt, Site Region 3E. Ont.Min.Nat.Res. Toronto.

Kershaw, K.A. and J.H.H. Looney. 1985. Quantitative and dynamic plant ecology. 3rd Ed. Edward Arnold Publ., Baltimore. U.S.A.

Lieffers, V.J. 1986. Stand structure, variability in growth and intraspecific competition in a peatland stand of black spruce. Holarctic Ecol. 9:58-64. Copenhagen.

McEwen, J.K. 1966. An effect of Sphagnum on the growth of black spruce. For.Chron. 42:175-183.

Morista, M. 1957. A new method for the estimation of the spacing method applicable to non-randomly distributed population. Physiol. Ecol. 7:134-144.

Pielou, E.C. 1960. A single mechanism to account for regular, random and aggregated populations. J.Ecol. 48:575-84.

Plonski, W.L. 1974. Normal Yield Tables (metric) for major forest species of Ontario. Ont.Min.Nat.Res., Div. of Forestry Rpt.

Rowe, J.S. 1972. Forest regions of Canada. Can.Dept. North.Aff.&Nat.Res. For.Br. Bull. 123.

Snedecor, G.W. & W.B. Cochran. 1967. Statistical methods. Iowa State Univ.Press. Ames. 593.p.

Vincent, A.B. 1965. Black spruce. A review of the silvics, ecology and silviculture. Can.Dept.For. Publ. No.1100.

APPENDIX 1 - SITE AND PRODUCTIVITY PARAMETERS - NATURAL STANDS

FEC O.G.	PLOT	PEAT DEPTH cm.	TOT. VOL. m3/ha *	MERCH VOL. m3/ha **	TOT. B.A. m2/ha	MERCH B.A. m2/ha	TOT. STEMS /ha	MERCH STEMS /ha	DOM. HT. m	TOT. ▲V m3/ha ***	MERCH. ▲V m3/ha	REGEN. STOCK. 1x1m. Sb	REGEN. STOCK. 1x1m. All spp	REGEN. STOCK. 2x2m. Sb	REGEN. STOCK. 2x2m. All spp	MAI m3/ha/yr	BASAL SWEEP % OF STEMS	STEM ROT % OF STEMS	STAND AGE ****
11	3	60	140.7	132.3	28.2	25.7	2662	1425	14.5	6.2	5.4	72	75	99	100	-	26.3	2.8	-
	10	85	149.6	130.0	30.8	25.9	3700	1660	14.0	6.4	5.4	22	22	62	62	-	22.2	9.7	-
	17	75	149.2	138.5	29.3	26.3	2960	1760	13.0	6.0	5.4	59	59	97	97	0.93	19.6	7.4	160
	33	>175	192.1	186.1	36.4	34.9	2540	1920	15.0	6.9	6.8	18	20	55	58	1.64	43.3	2.4	117
	MEAN		157.9	146.7	31.2	28.2	2965	1691	14.1	6.4	5.7	43	44	78	79	1.28	27.8	5.6	-
12	2	>175	151.2	147.2	29.6	28.4	1800	1362	15.5	12.2	11.7	12	15	41	49	-	44.4	10.4	-
	5	65	157.8	144.7	32.6	29.6	3040	1960	14.5	13.1	11.6	29	29	75	75	0.90	37.5	11.8	175
	13	100	189.5	183.1	32.5	31.1	1600	1100	17.0	15.6	14.7	15	15	47	47	-	38.7	23.7	-
	28	85	207.4	203.0	33.8	32.5	1940	1340	16.5	19.9	19.2	19	24	57	67	-	40.2	6.2	-
	MEAN	-	176.5	169.5	32.1	30.4	2095	1440	15.9	15.2	14.3	19	21	55	59	0.90	40.2	13.0	
8	4	25	212.3	190.0	38.6	32.0	3775	2237	16.5	28.6	25.9	1	2	5	9	2.72	41.7	1.0	78
	26	22	309.5	300.4	44.2	42.1	2860	2160	18.0	11.2	10.9	31	39	77	86	2.73	21.7	1.4	113
	34	25	270.0	260.2	44.2	41.6	3100	2360	15.0	15.5	15.0	21	22	62	63	2.31	27.7	10.3	117
	MEAN	-	263.9	250.2	42.3	38.6	3245	2252	16.5	18.4	17.3	18	21	48	53	2.59	30.4	4.2	-
13	9	75	230.0	226.9	34.1	33.3	1887	1537	19.5	19.9	19.5	2	28	6	75	1.81	16.6	8.8	127
	31	85	312.7	311.6	45.8	45.5	2140	1920	18.0	21.6	21.6	2	39	9	86	2.61	28.0	5.1	120
	36	75	283.4	276.1	41.6	39.7	2300	1760	16.0	24.1	23.5	12	15	41	47	2.42	25.2	10.4	117
	MEAN	-	275.4	271.5	40.5	39.5	2109	1739	17.8	21.9	21.5	5	28	19	69	2.28	23.3	8.1	-

NOTES:

* All volumes apply to total stem, inside bark.
** Merchantable = all stems> 10 cm. d.b.h.
*** ▲V = volume growth of last 5 years.
**** Even-aged stands only.

APPENDIX 2 - SITE AND PRODUCTIVITY PARAMETERS - SECOND GROWTH STANDS

FEC OG	PLOT	PEAT DEPTH cm	TOT VOL m3/ha *	MERCH VOL m3/ha **	TOT BA m2/ha	MERCH BA m2/ha	TOT STEMS /ha	MERCH STEMS /ha	DOM HT m	TOT ▲V m3/ha ***	MERCH ▲V m3/ha	REGEN. STOCK. 1x1 Sb	REGEN. STOCK. 1x1 All Spp	REGEN. STOCK. 2x2 Sb	REGEN. STOCK. 2x2 All Spp	MAI m3/ha /yr	BASAL SWEEP % of stems	STEM ROT % of stems	YRS SINCE HARV	VOL GROWTH SINCE HARV m3/ha	PRE-HARVEST ORIGIN % of stems
11	1	140	145.6	133.9	32.1	27.5	4125	1675	13.5	17.6	15.4	.31	.32	.77	.78	2.08	32.1	0.6	69	143.7	64
	11	65	102.8	80.3	25.0	19.3	5000	1240	13.0	7.8	5.7	.46	.46	.91	.91	1.84	19.6	0.4	57	102.8	88
	14	>175	162.8	143.4	34.0	29.5	3440	1700	14.5	9.7	8.7	.32	.32	.79	.79	2.36	27.3	3.5	58	137.1	98
	20	>175	201.6	191.5	36.4	33.7	2500	1660	14.0	22.4	21.4	.21	.58	.61	.97	3.16	28.0	4.3	63	199.2	83
	22	150	129.2	108.9	31.1	25.1	4720	1740	13.5	12.4	10.5	.54	.54	.95	.96	1.90	44.1	1.7	69	129.2	85
	25	130	155.0	136.2	31.6	26.9	3760	1480	13.0	15.0	13.2	.27	.28	.71	.73	2.61	26.1	1.1	57	149.0	87
	29	80	133.0	95.4	30.7	21.1	6960	1360	13.5	16.2	12.1	.55	.62	.96	.98	2.25	37.1	0.6	57	128.3	87
	39	155	112.2	91.2	28.1	21.8	4700	1300	13.0	11.1	9.3	.47	.49	.92	.93	2.07	45.5	3.0	58	112.2	78
	MEAN	-	142.8	122.6	31.1	25.6	4401	1519	13.5	14.0	12.0	.39	.45	.83	.88	2.28	32.5	1.9	-	137.7	84
12	8	65	103.8	88.5	22.8	18.7	3025	925	14.5	13.3	10.8	.23	.45	.64	.91	1.62	26.4	2.8	63	102.1	49
	15	45	111.8	88.0	26.3	20.1	4240	1380	12.0	9.0	6.5	.39	.40	.86	.87	1.66	10.8	2.4	59	98.2	66
	21	80	147.3	127.8	28.8	23.9	4140	1340	13.5	20.5	17.8	.30	.53	.76	.95	2.35	19.8	2.6	62	145.6	65
	23	90	152.6	139.5	31.0	27.7	2920	1560	13.0	7.0	6.1	.32	.62	.79	.98	2.33	56.8	6.2	57	133.0	93
	27	125	144.6	136.7	30.3	27.9	2440	1400	14.5	14.2	14.1	.05	.09	.20	.31	2.06	34.4	4.1	69	141.9	82
	37	95	110.9	93.1	25.8	20.5	4060	1220	12.5	14.0	11.7	.37	.49	.84	.93	1.99	38.4	3.0	57	110.9	78
	38	100	104.4	80.9	26.2	19.2	5360	1160	13.5	15.0	10.5	.46	.58	.92	.97	1.71	48.1	2.4	58	99.1	82
	40	75	114.4	101.4	24.9	21.3	2960	1100	14.5	9.5	8.2	.34	.38	.81	.85	1.97	47.3	2.4	49	96.4	95
	MEAN	-	123.7	107.0	27.0	22.4	3643	1261	13.5	12.8	10.7	.31	.44	.73	.85	1.96	35.2	3.2	-	115.9	76
8	7	18	268.4	263.6	42.0	40.8	2337	1787	18.2	19.2	18.9	.05	.63	.18	.98	4.50	34.8	2.9	57	256.3	98
	19	30	173.2	133.0	36.5	25.8	6400	1780	12.0	20.4	16.7	.19	.21	.56	.61	2.85	16.6	0.6	59	168.1	86
	24	30	201.2	184.5	38.5	34.1	4080	1640	15.8	21.6	20.2	.15	.54	.47	.95	3.51	31.4	1.2	57	200.2	83
	30	22	234.3	201.1	45.1	36.1	6340	2040	15.5	36.0	32.3	.08	.40	.27	.87	3.86	36.0	0.5	58	223.9	75
	32	27	177.0	158.8	37.0	32.6	3920	1500	14.5	15.0	13.7	.26	.39	.71	.86	2.86	40.3	7.3	57	163.1	94
	MEAN	-	210.8	188.2	39.8	33.9	4615	1749	15.3	22.5	20.4	.14	.43	.44	.85	3.52	31.8	2.5	-	202.3	87
9	6	18	158.0	136.7	30.5	25.2	3962	1362	17.0	13.8	11.2	.38	.47	.85	.92	2.22	48.6	3.1	69	153.5	51
9	12	30	269.7	256.9	44.0	40.7	2660	1500	17.5	21.4	20.3	.03	.78	.13	1.0	4.11	22.6	1.0	63	259.0	95
9	35	35	222.3	213.6	33.3	30.9	2200	1140	17.5	19.0	18.2	.09	.49	.32	.93	3.51	28.2	0	56	196.7	98
13	16	>175	183.4	171.8	30.4	27.5	2780	1200	17.0	11.1	10.4	.10	.41	.34	.88	2.36	5.0	6.6	63	149.0	94
13	18	>175	209.5	208.4	33.4	33.1	1420	1200	16.2	17.5	17.4	.01	.60	.04	.97	2.49	40.8	32.8	63	156.9	100
	MEAN	-	208.6	197.5	34.3	31.5	2604	1280	17.0	16.6	15.5	.12	.55	.34	.94	2.94	29.0	8.7	-	183.0	88

* all volumes apply to total stem, inside bark ** Merchantable = all stems >10 cm. dbh

*** ▲V = volume growth of last 5 years

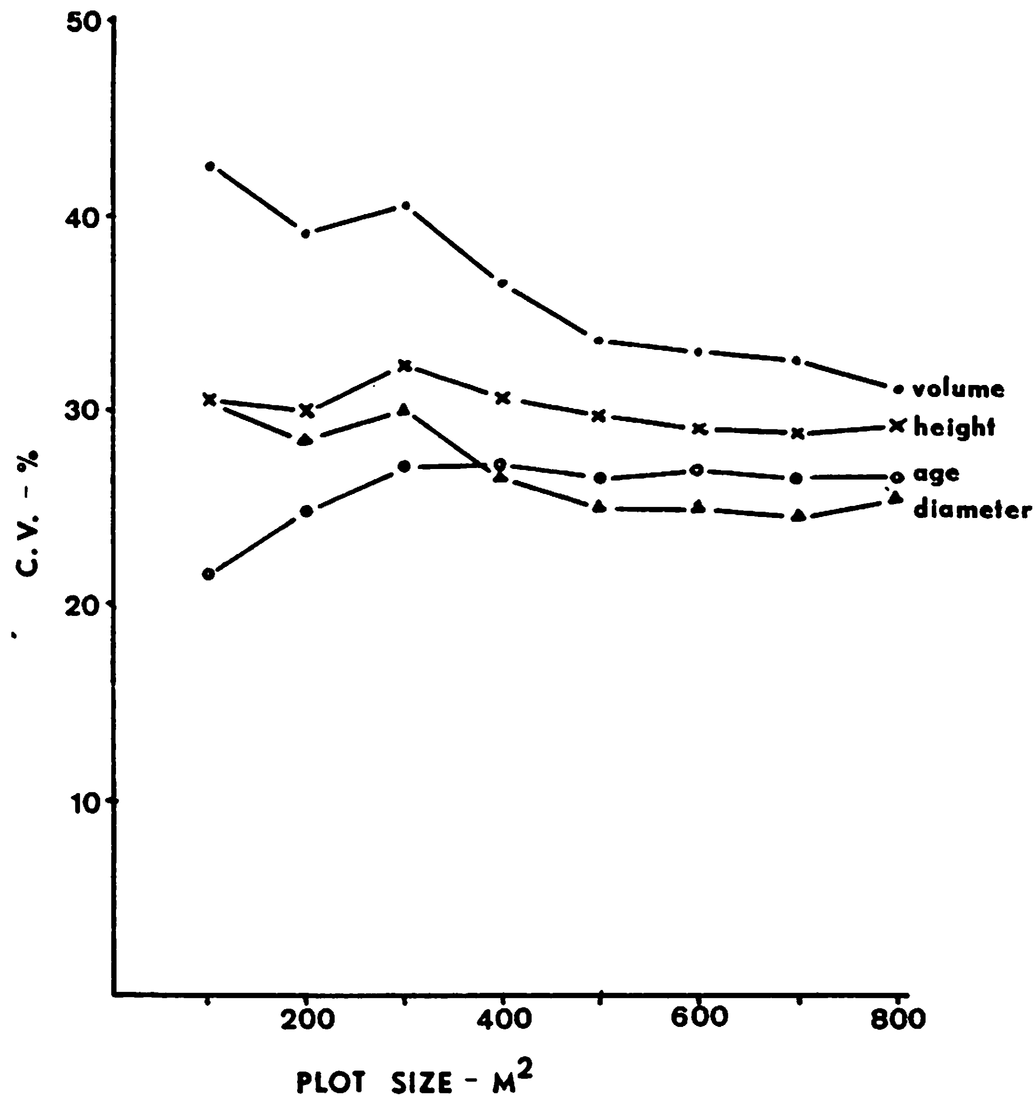


FIGURE 1

Coefficient of variation of mean volume, height, age and diameter for Phase 1 plots vs. plot size

FIGURE 2

Age and diameter class frequency distributions for 4 black spruce stands

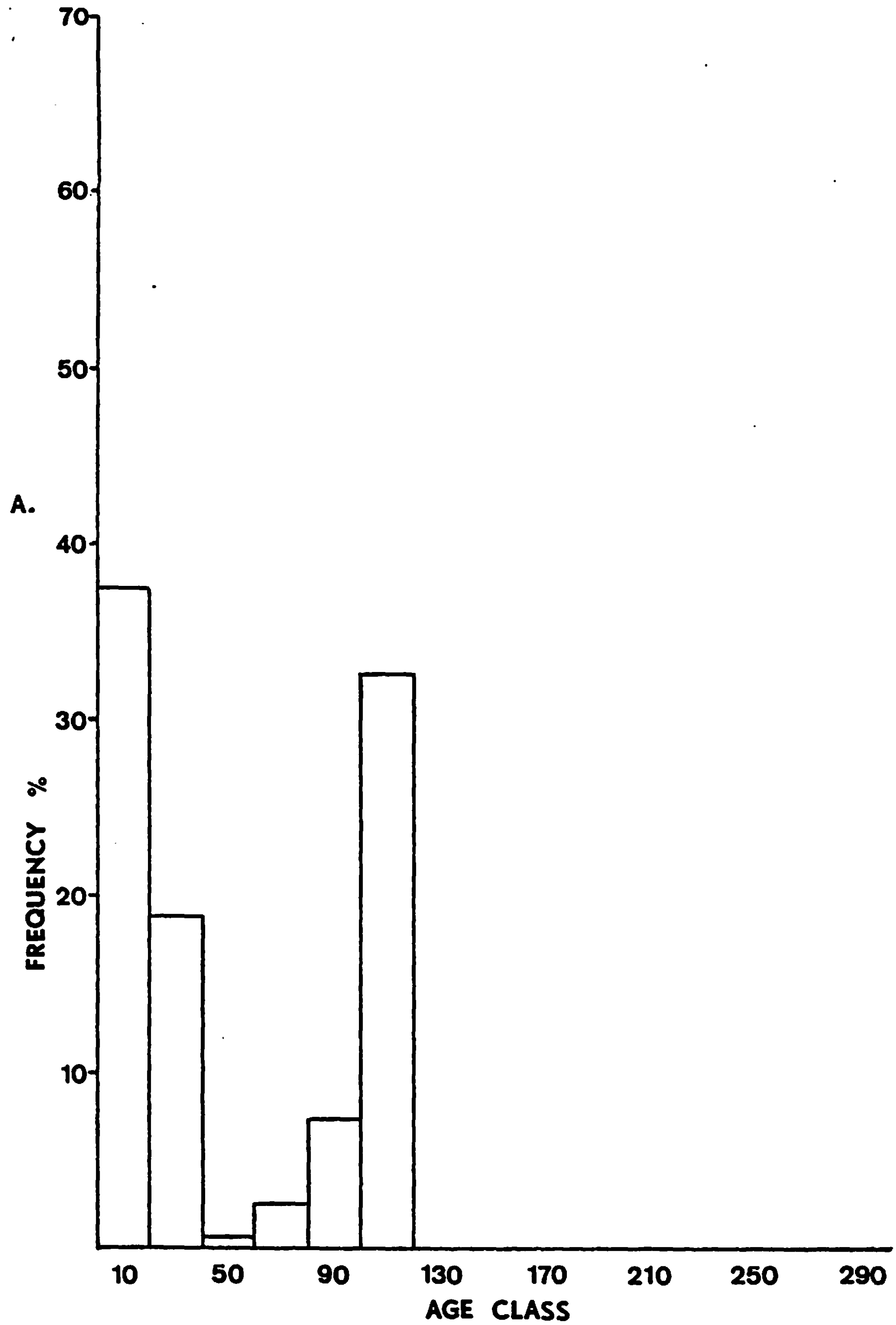
A+B - Stand 26, natural origin, even-age structure, normal diameter distribution

C+D - Stand 28, natural origin, uneven-age structure, irregular diameter distribution

E+F - Stand 38, second-growth origin, uneven-age/positive skew age structure, positive skew diameter distribution

G+H - Stand 12, second-growth origin, composite age structure, irregular diameter distribution

S refers to seedlings under 1.4 m. in height


A.
70
60
50
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30
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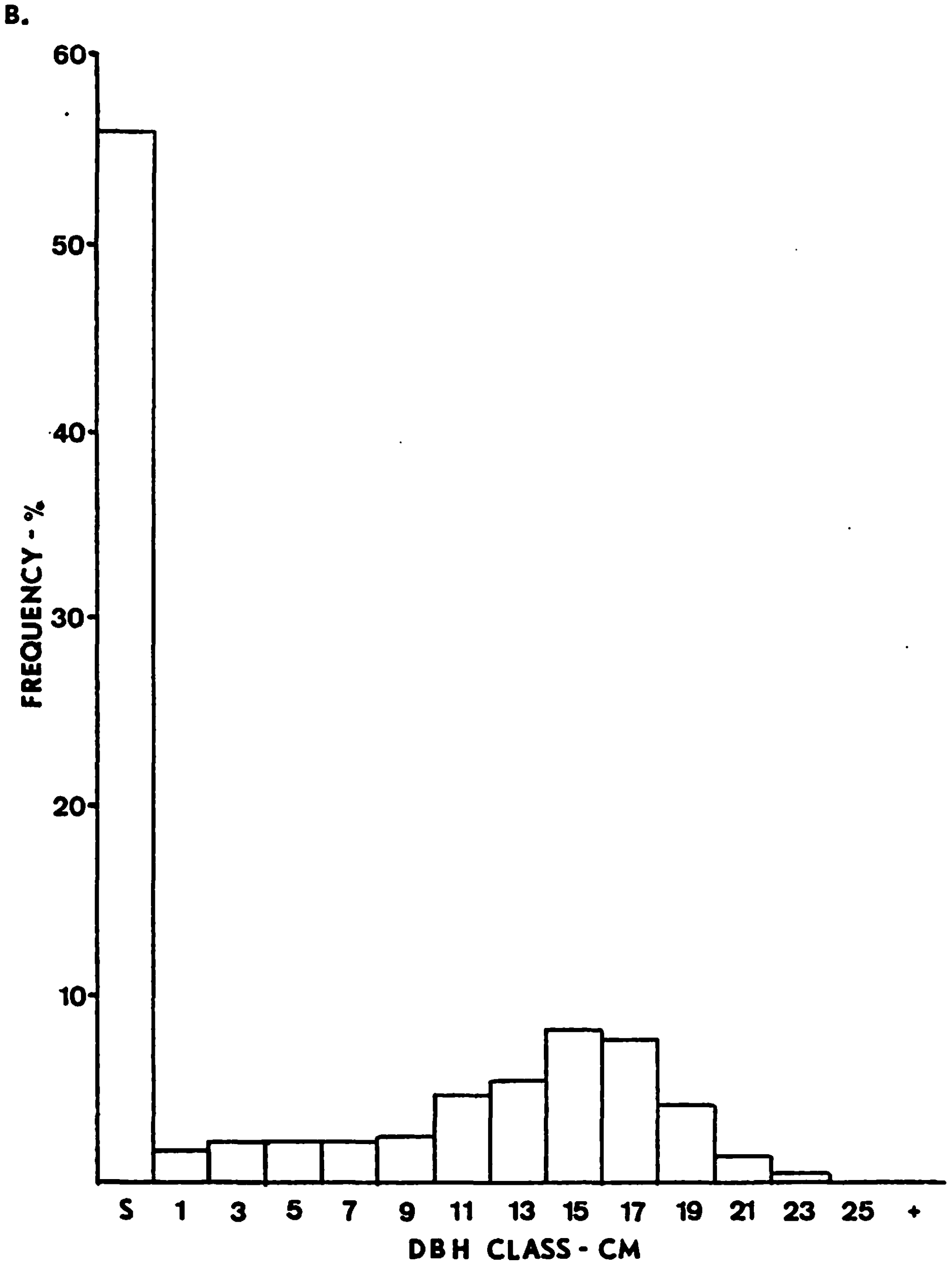
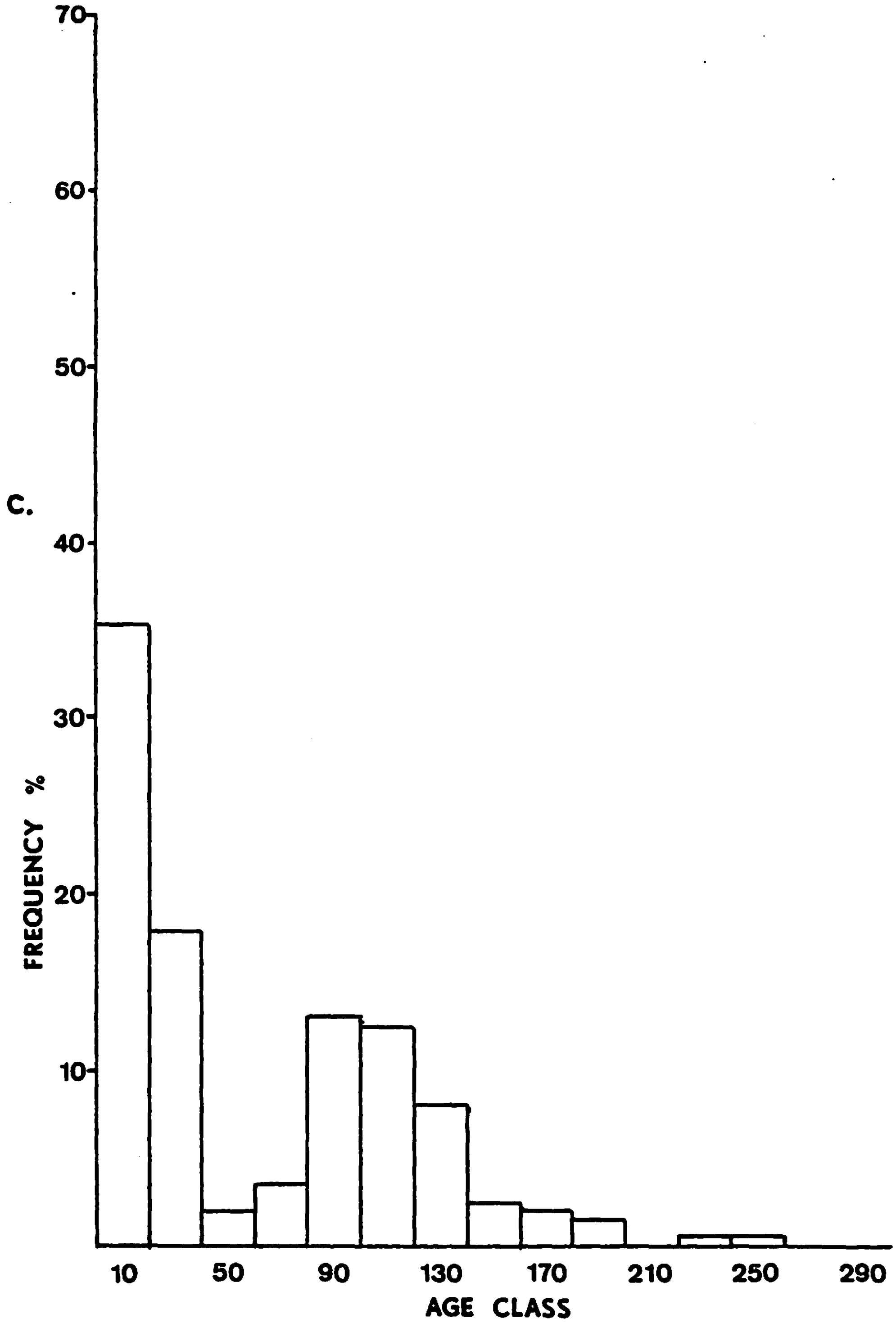
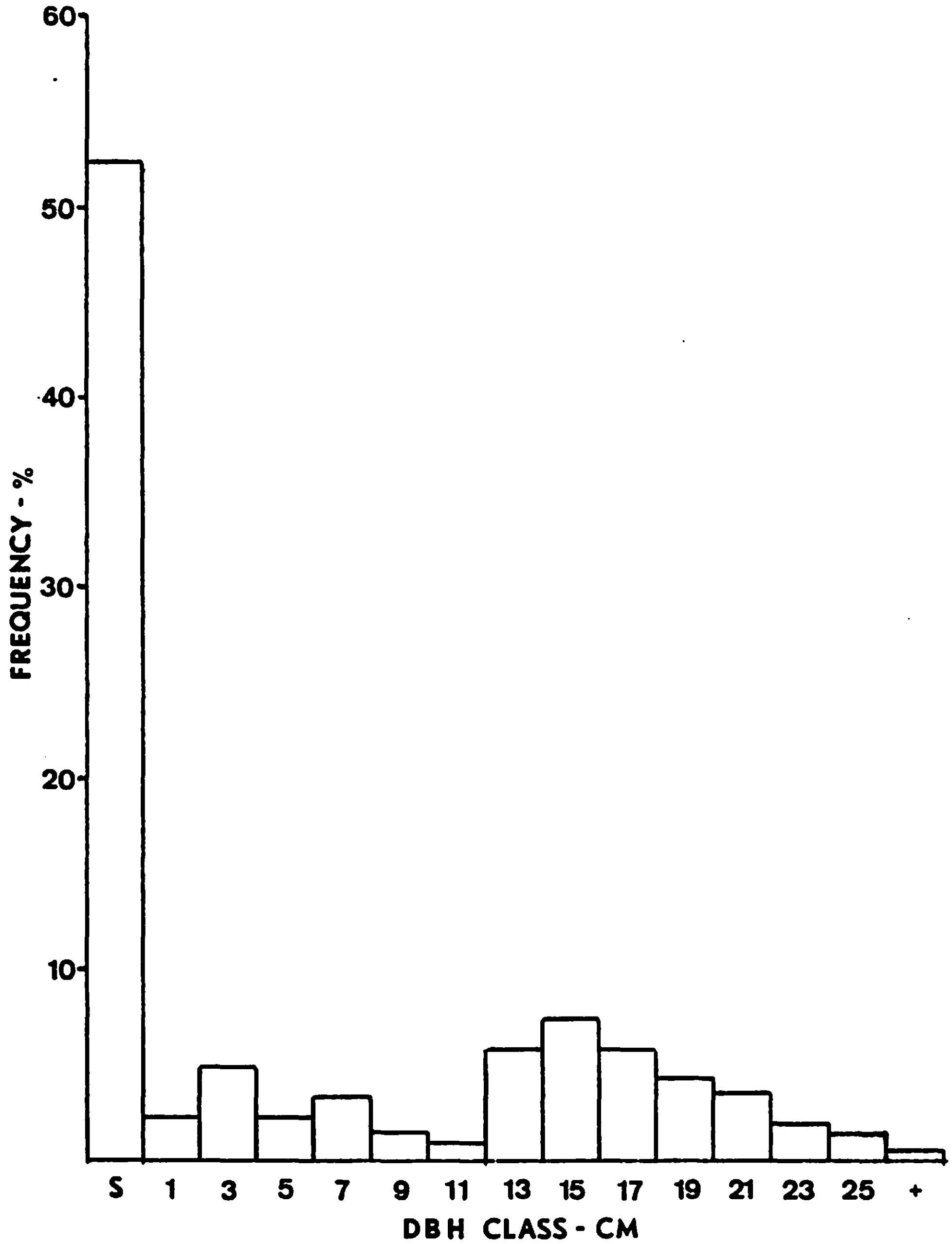
10
FREQUENCY %
10
50
90
130
170
210
250
290
AGE CLASS


B.
60
50
40
30
20
10
FREQUENCY - %
S
1
3
5
7
9
11
13
15
17
19
21
23
25
+
DBH CLASS - CM



C.
70
60
50
40
30
20
10
FREQUENCY %
10
50
90
130
170
210
250
290
AGE CLASS

D.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FREQUENCY - %
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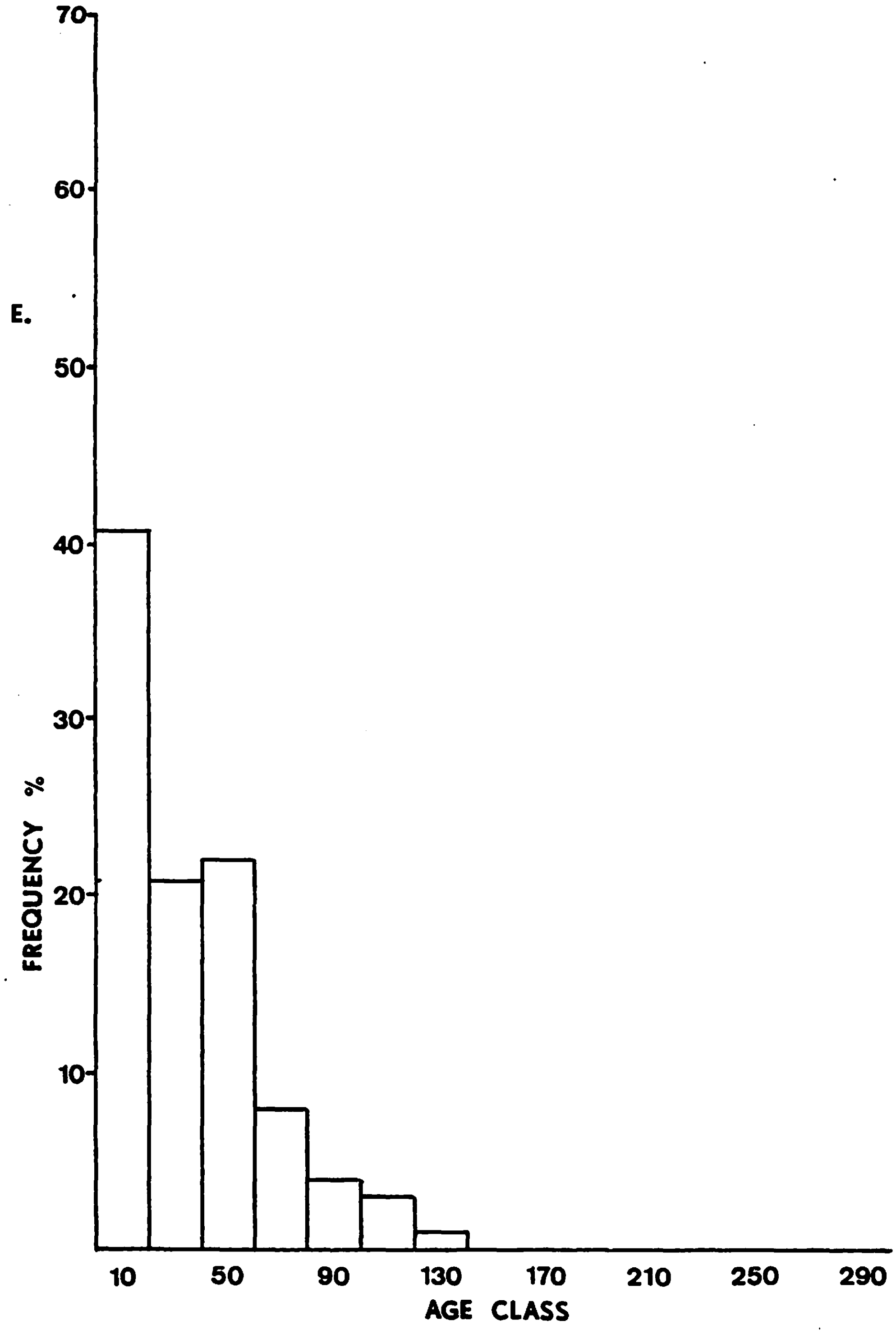
DBH CLASS - CM



E.
70
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FREQUENCY %
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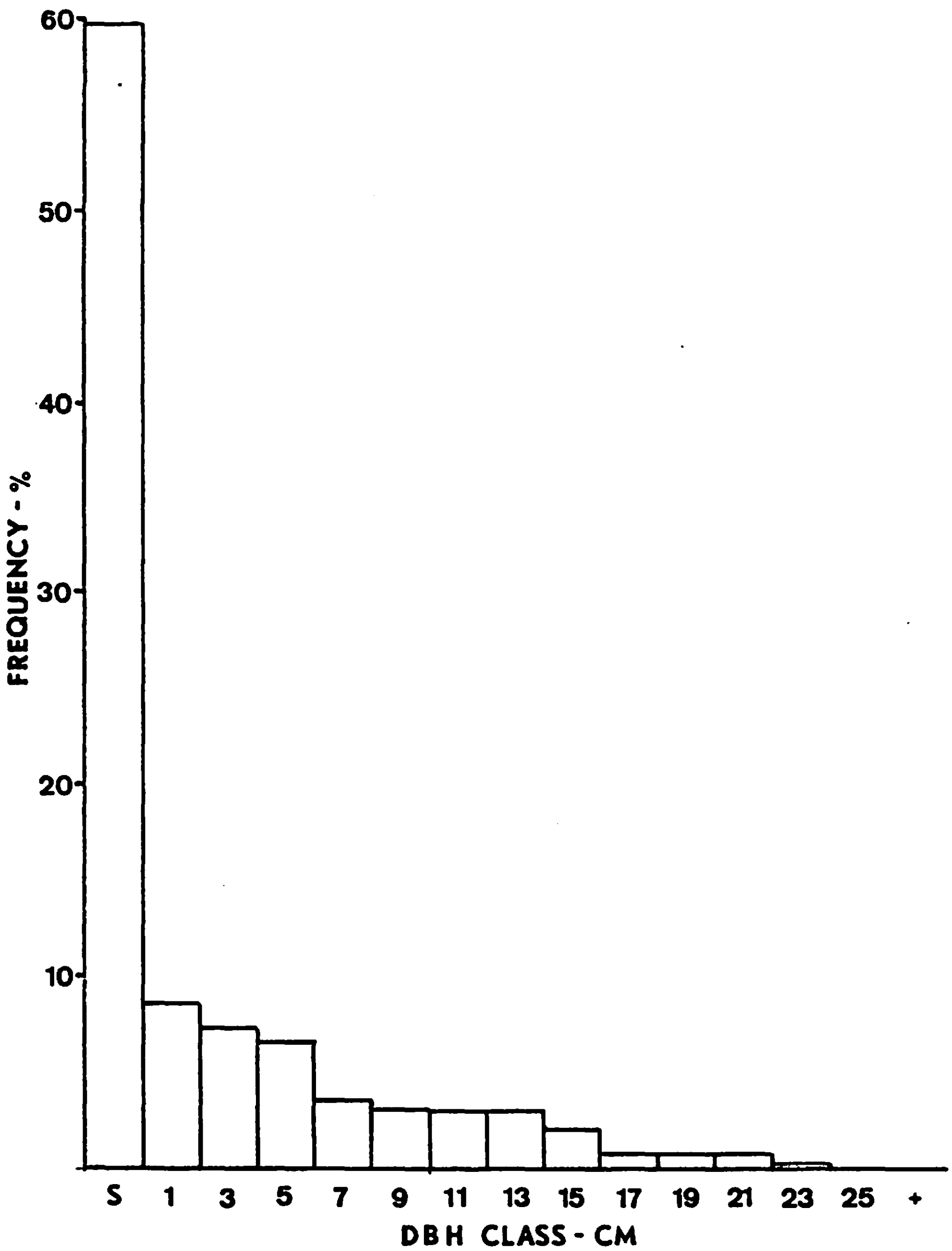
210
250
290
AGE CLASS

F.


60
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FREQUENCY - %
S
1
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19
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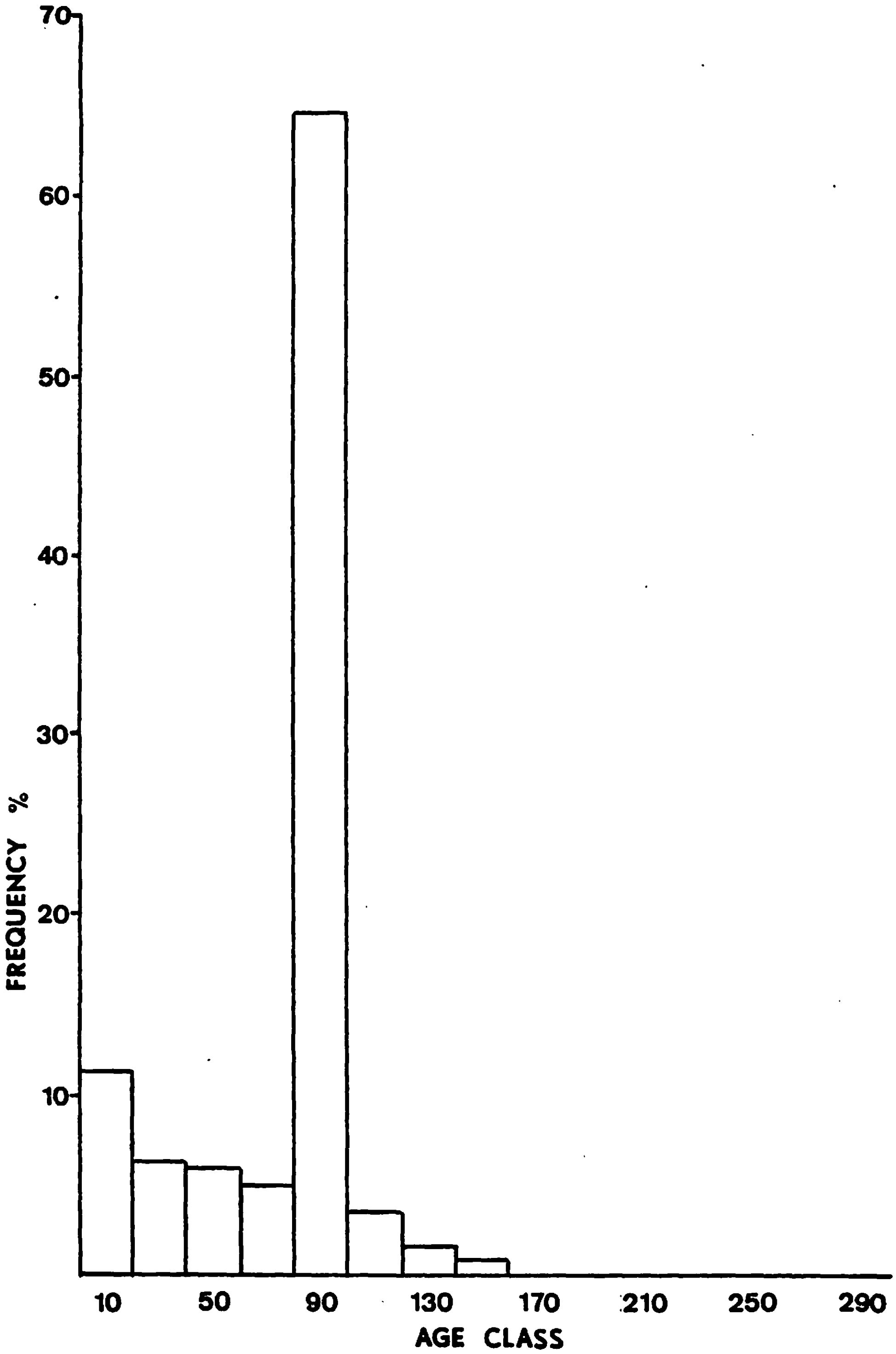
23
25
+
DBH CLASS - CM

G.



70
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10
FREQUENCY %
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90
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210
250
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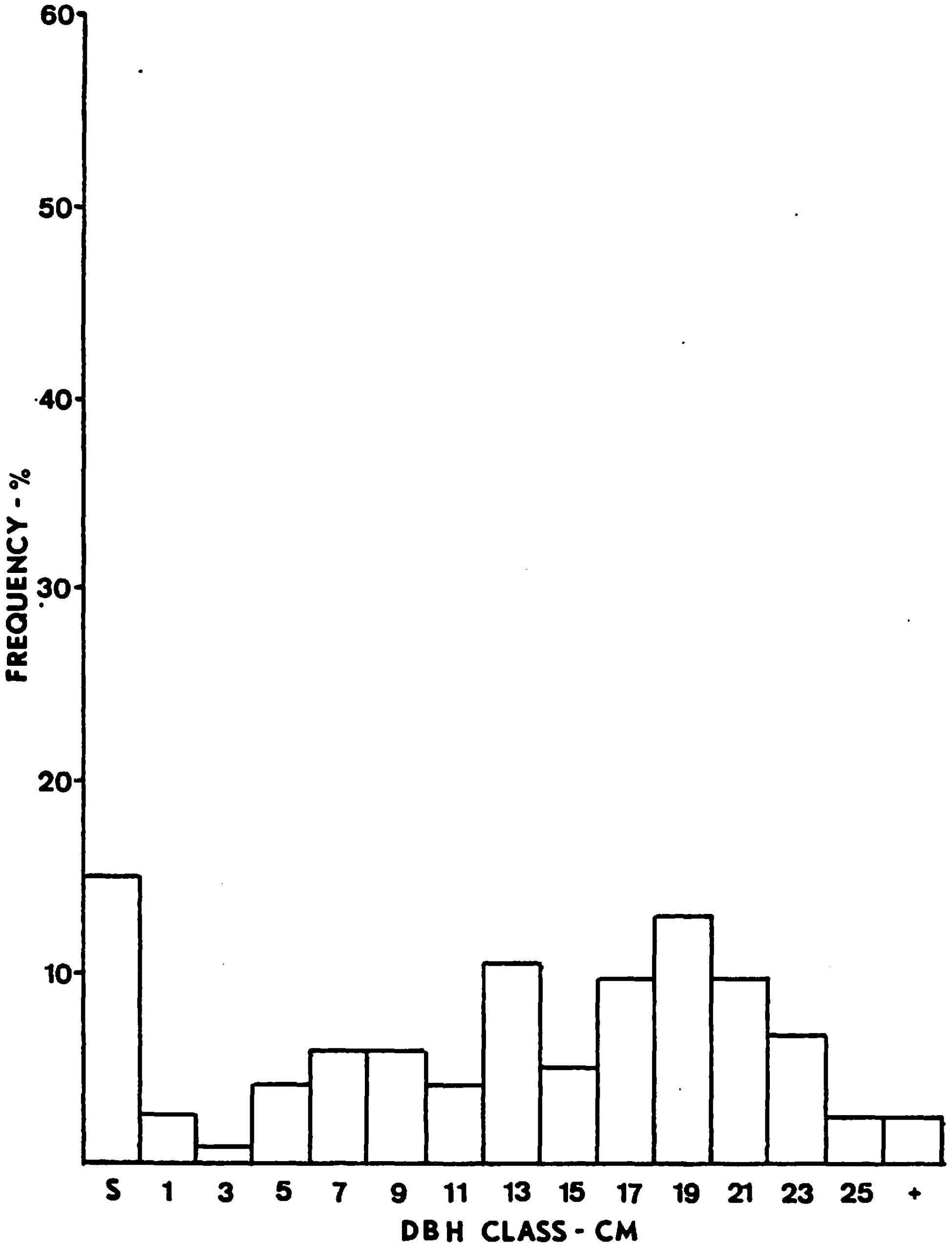
AGE CLASS

H.



60
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20
10
FREQUENCY - %
S
1
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+
DBH CLASS - CM

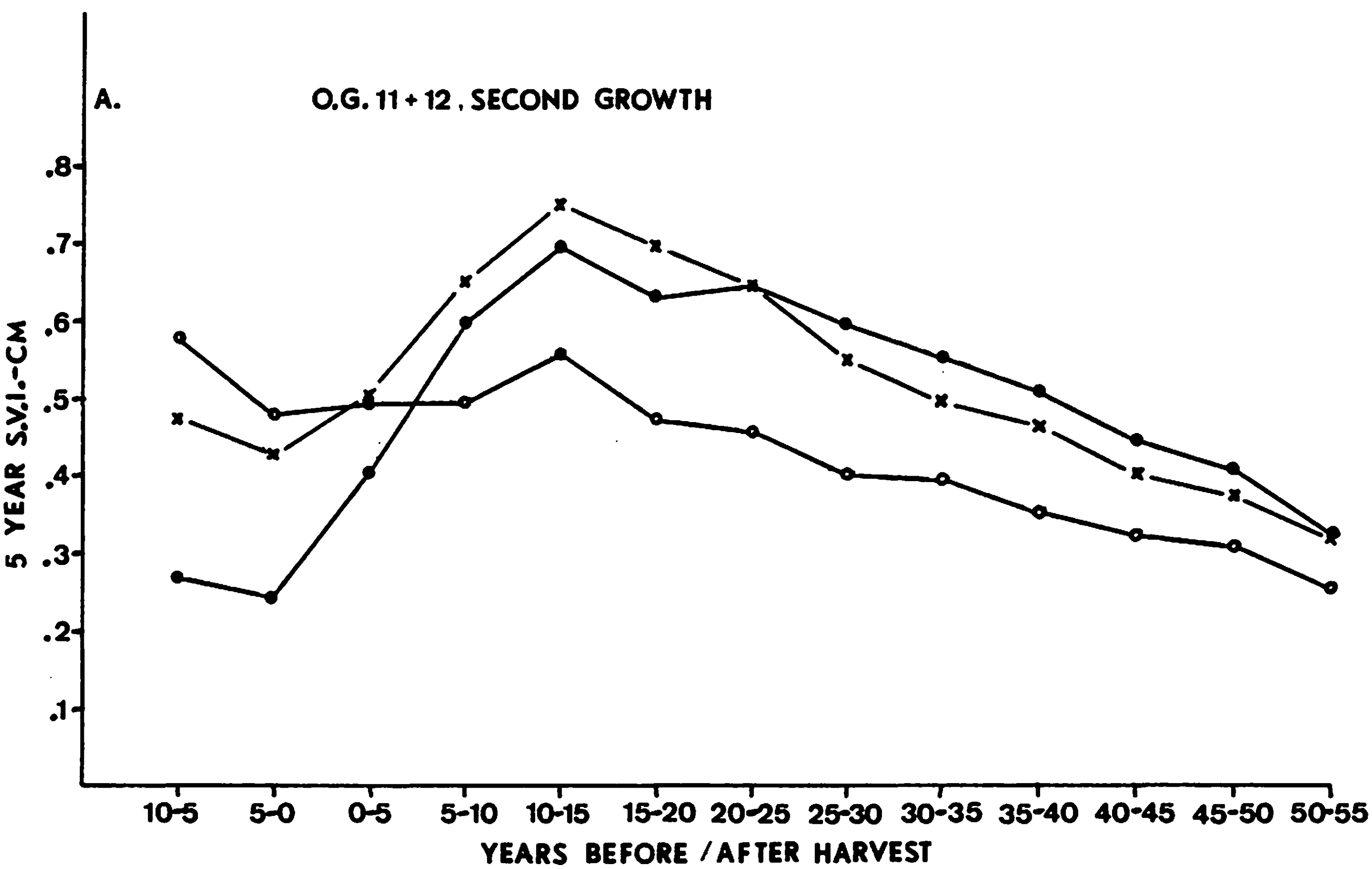
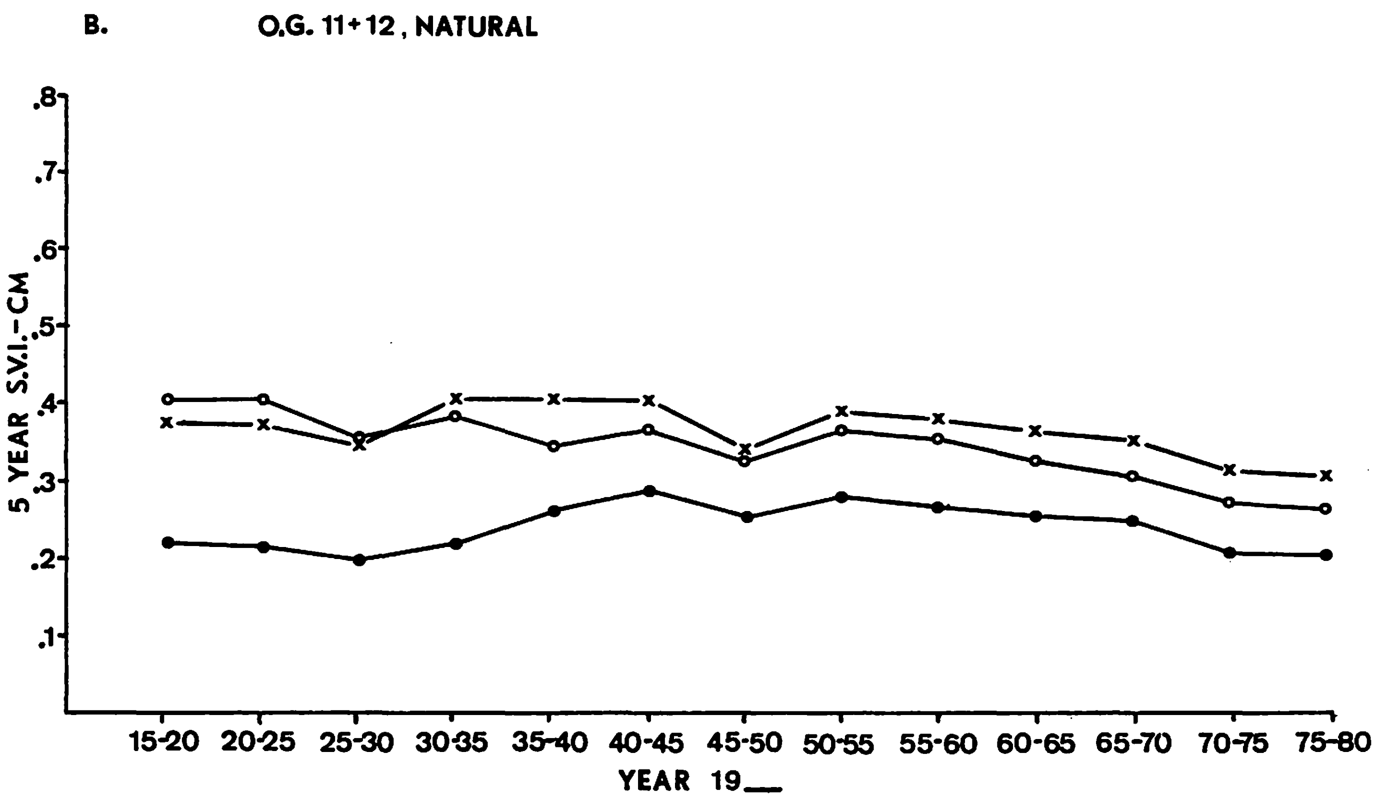
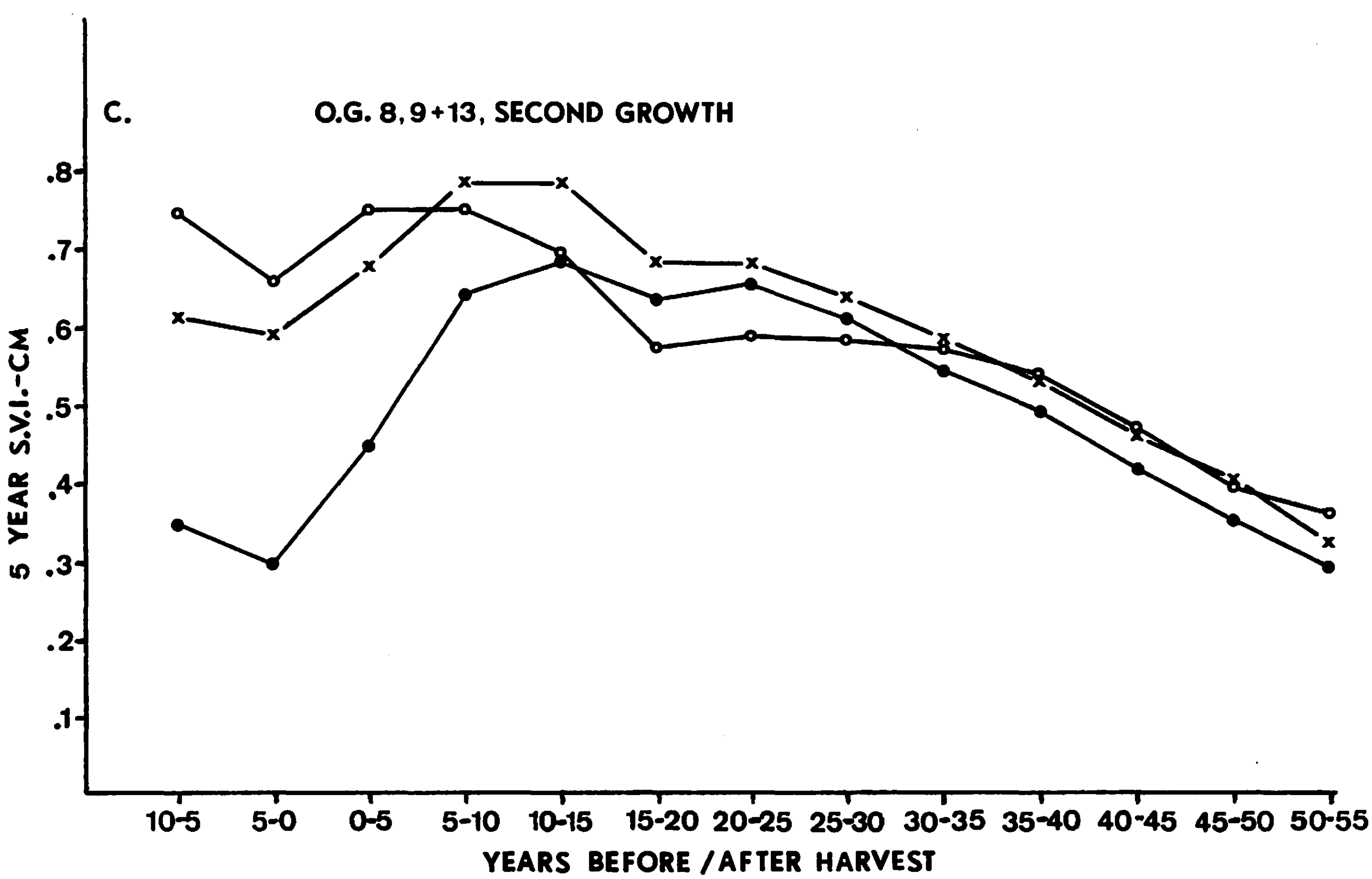


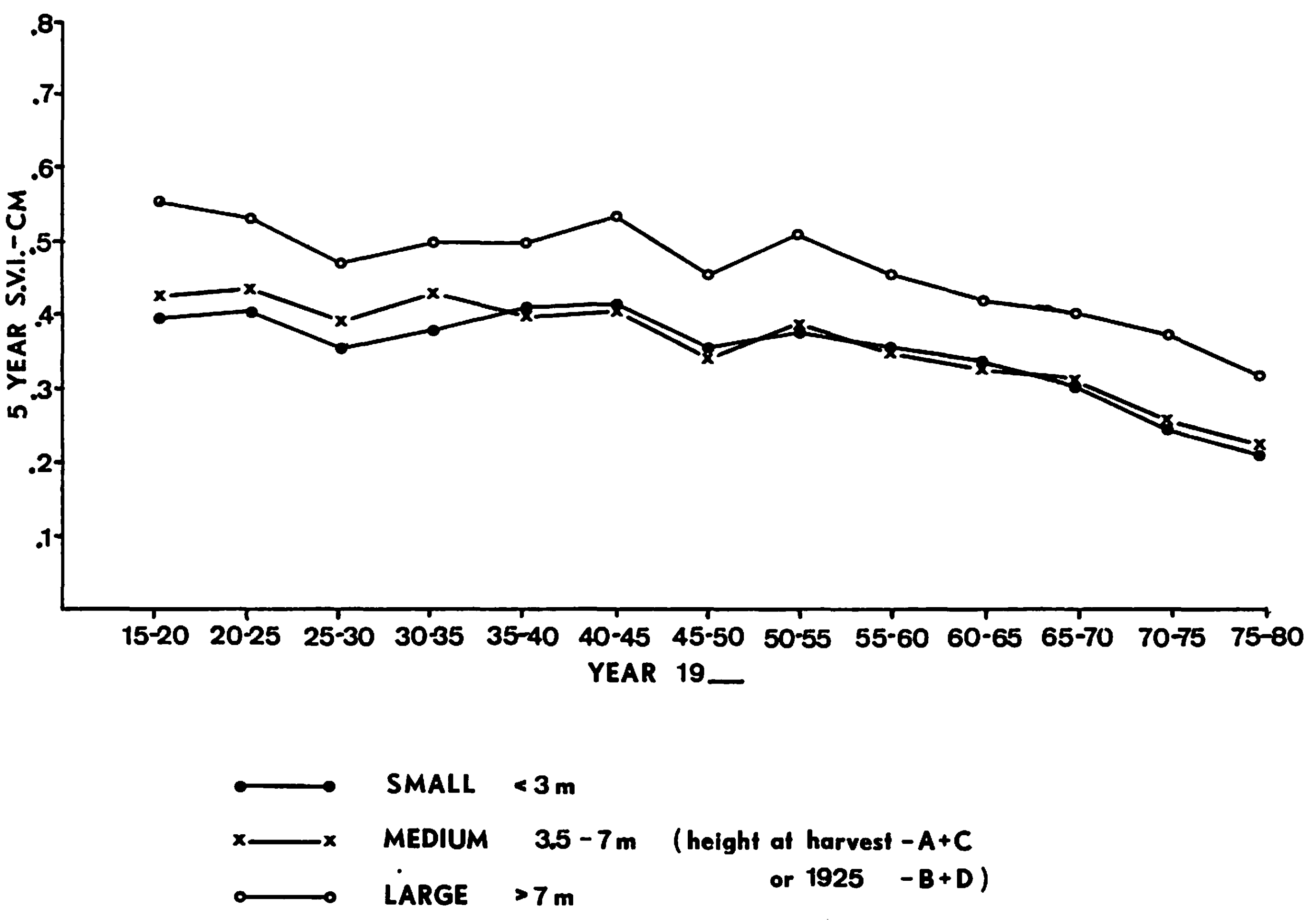
FIGURE 3

Specific volume increment (S.V.I.) over time for large, medium and small trees in natural and second-growth stands. S.V.I. represents the average radial increment of the entire cambial sheath


B.
O.G. 11+12, NATURAL
5 YEAR S.V.I.-CM
.8
.7
.6
.5
.4
.3
.2
.1
15-20
20-25
25-30
30-35
35-40
40-45
45-50
50-55
55-60
60-65
65-70
70-75
75-80
YEAR 19__


C.
O.G. 8, 9 + 13, SECOND GROWTH
5 YEAR S.V.I.-CM
.8
.7
.6
.5
.4
.3
.2
.1
10-5
5-0
0-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
50-55
YEARS BEFORE / AFTER HARVEST

D. O.G. 8, 9 + 13, NATURAL



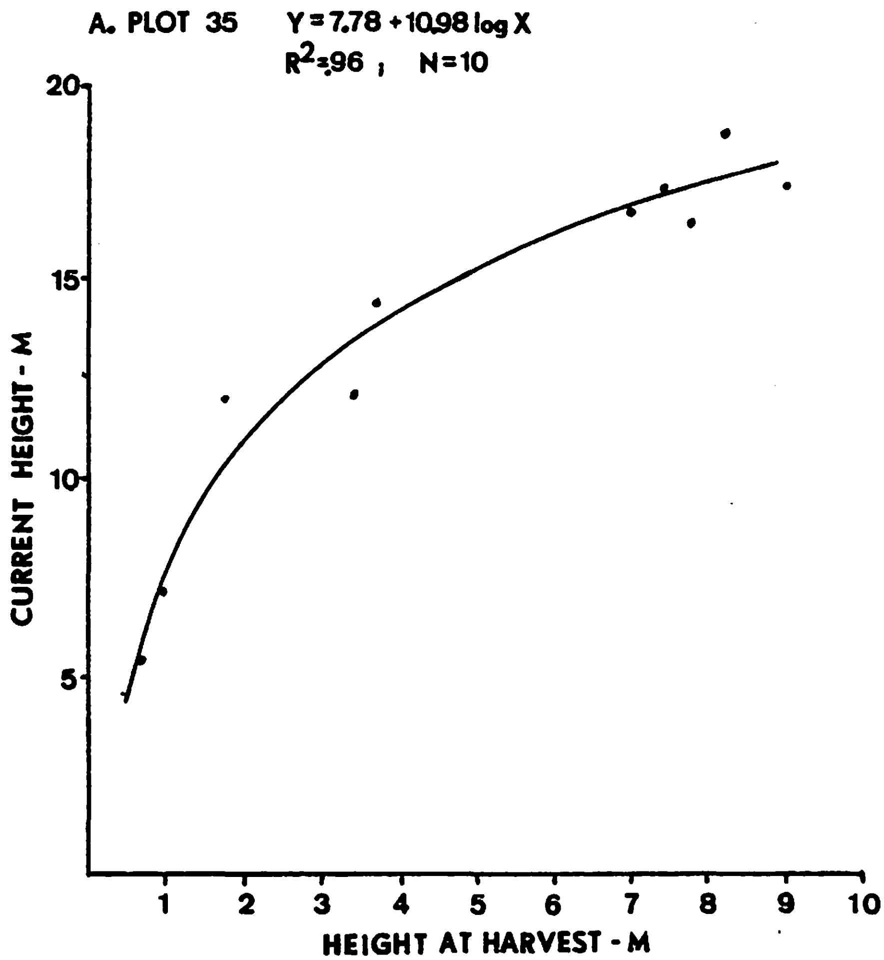
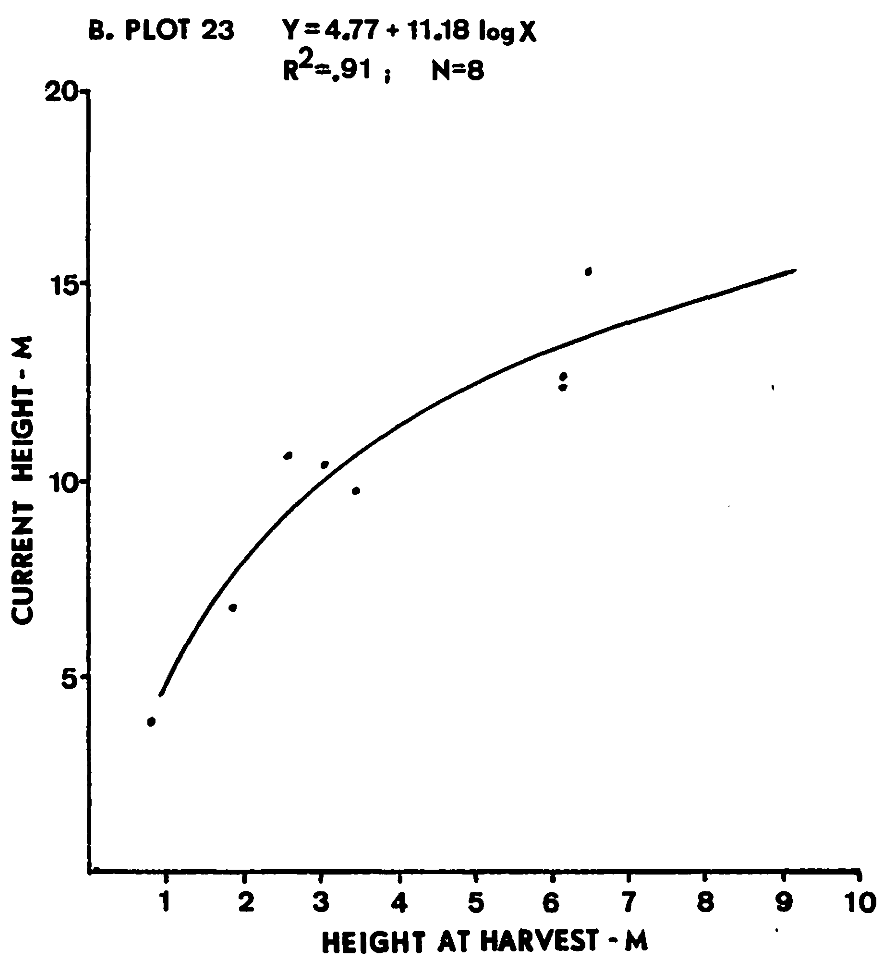
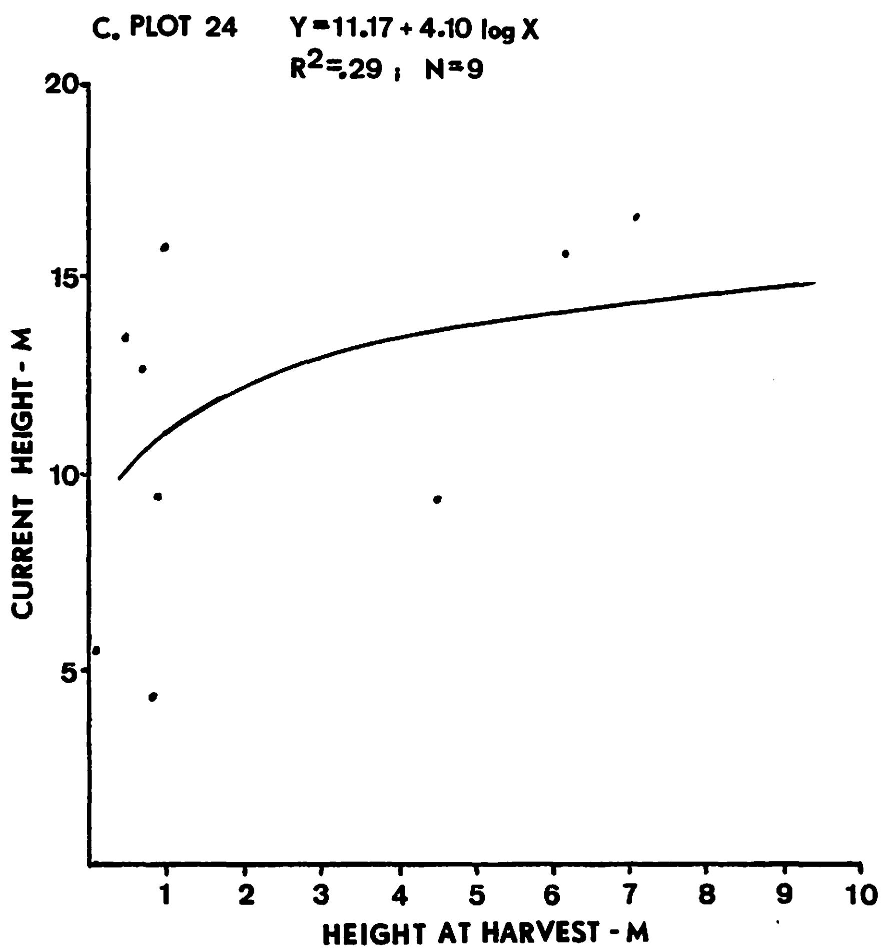
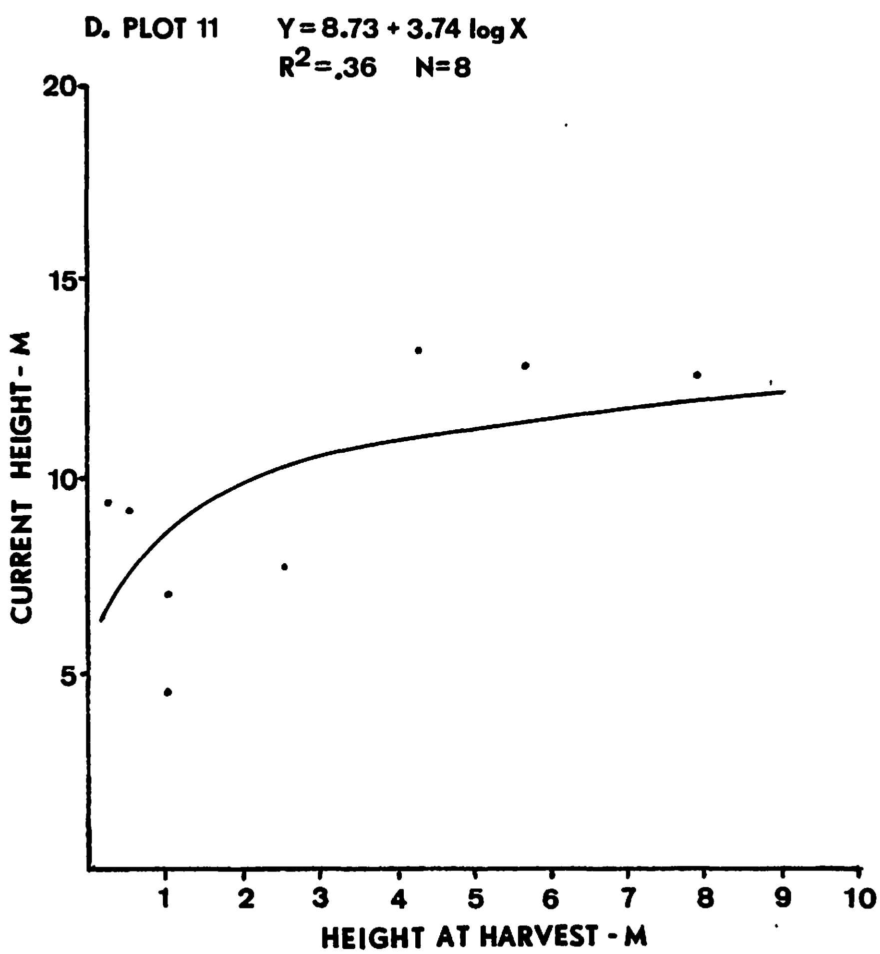


FIGURE 4

Regressions of current height over height at the time of harvest for a range of trees in 4 second growth stands


B. PLOT 23
Y = 4.77 + 11.18 log X
R2=.91 ; N=8
CURRENT HEIGHT - M
20
15
10
5
1
2
3
4
5
6
7
8
9
10
HEIGHT AT HARVEST - M


C. PLOT 24
Y=11.17 + 4.10 log X
R2=.29 ; N=9
20
15
10
5
CURRENT HEIGHT - M
1
2
3
4
5
6
7
8
9
10
HEIGHT AT HARVEST - M


D. PLOT 11
Y = 8.73 + 3.74 log X
R^2 = .36 N=8
CURRENT HEIGHT - M
20
15
10
5
1 2 3 4 5 6 7 8 9 10
HEIGHT AT HARVEST - M

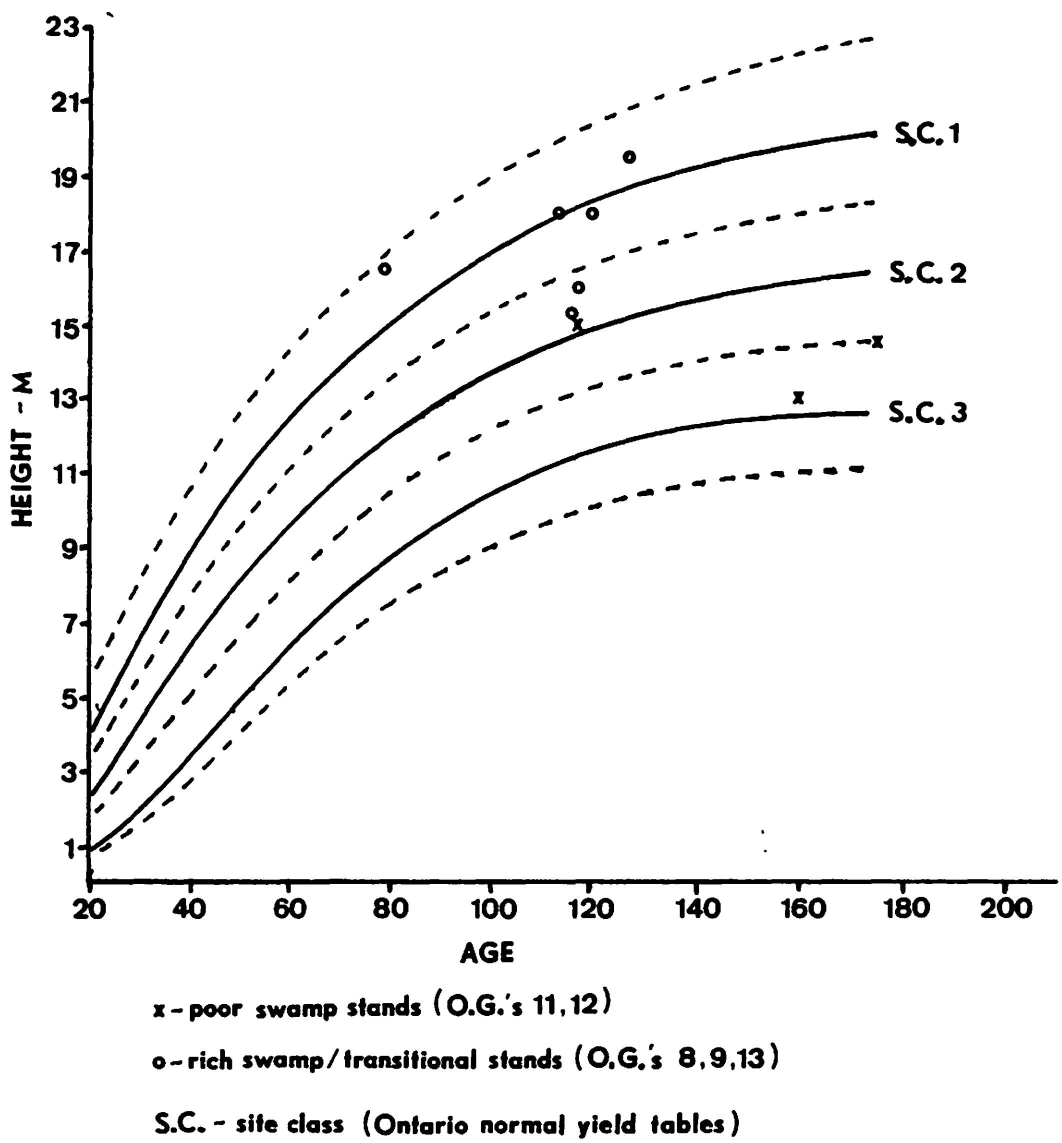


FIGURE 5

Comparison of mean dominant heights in even-aged natural black spruce stands with Ontario normal yield tables site index curves (Plonski, 1974)