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Yield of balsam fir stands in the Gaspé region of Quebec

R. Zarnovican

Information Report LAU-X-64E

Laurentian Forest Research Centre

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ABSTRACT

The yield of balsam fir stands is examined from results of 52 forest stands in the Joffre Lake area in Quebec's Gaspé region.

Site quality was based on site index (i.e. average height at 50 years) and some stand characteristics. Site index curves were established on the basis of Korf's growth function, from stem analysis of 97 dominant balsam fir [*Abies balsamea* (L.) Mill.] trees.

Even though at 50 years the height-growth range represents a sufficiently large variation reflecting the possibility of several site classes, the comparison of height growth and wood density in different plant groups do not confirm these results. Moreover, the ordination of fully stocked stands according to mean dbh indicate that yield level was the same for the group of sites studied and that site indices reflect nothing more than variations in height growth, which may be explained by the effects of repeated spruce budworm outbreaks.

RÉSUMÉ

Le présent travail examine la production stationnelle des sapinières de Gaspésie, au moyen de 52 stations d'étude provenant du massif boisé du Lac Joffre.

L'évaluation de la qualité stationnelle est faite à l'aide des indices dendrométriques et floristiques, mais principalement à l'aide des indices de fertilité à l'âge de 50 ans. Les indices de fertilité sont établis à l'aide de la fonction de croissance de Korf et des données sur la hauteur et l'âge total à partir d'analyse de 97 sapins [*Abies balsamea* (L.) Mill.] dominants.

Bien que le domaine de la croissance en hauteur à 50 ans soit suffisamment grand pour refléter plusieurs classes de fertilité, la comparaison de la croissance apicale de différents groupements végétaux, ainsi que la comparaison de la densité du bois ne les confirment pas. De plus, l'ordination des stations selon la surface terrière de plein boisement et le dhp moyen met en évidence l'existence d'un seul niveau de production. Les résultats indiquent que la qualité stationnelle de l'ensemble de sites considérés est la même et que les indices de fertilité ne reflètent que la variabilité dans la croissance en hauteur, résultat probable des épidémies répétées de la tordeuse des bourgeons de l'épinette et de ses conséquences.

INTRODUCTION

The steady growth of the Quebec lumber industry and its demands for timber will inevitably lead to the implementation of intensive management principles. The elaboration of such principles will be determined by more exact data on the yield of forest stands and, above all, by an understanding of the factors that have a direct effect on production (Bolghari and Vézina 1975). The best methods for measuring wood production must be defined. The environmental factors directly influencing production have also to be analyzed, evaluated and, if possible, quantified.

Some of the most important contributions to the study of Quebec's environmental factors have been by Linteau (1957) and Lafond (1967), both based on the application of Cajander's method; and by Jurdant (1964) based on the methods of Braun-Blanquet.

Of these authors, only Linteau and Lafond tried to evaluate yield and ecological factors on balsam fir [*Abies balsamea* (L.) Mill.] stands. Linteau (1957) developed an ecological classification for forest sites for the sector of "North-East conifers". The forest sites were classified on the basis of vegetation composition and soil characteristics. Yield was estimated by site index at 50 years (I50). The parameters were dominant height and total age. On the basis of the above, each stand was assigned a site index. The set of site index curves represents an "anamorphic" model (Tesch 1981) and it was used with two species, black spruce [*Picea mariana* (Mill.) B.S.P.] and balsam fir.

Lafond (1967) also studied the relationship between site and volume production. The growth habitat was identified and classified on the basis of shrub and herbaceous vegetation to define forest types to which the author assigned site classes. The above cited works show that most of the effort was geared towards studying vegetation and soil rather than towards an evaluation of stand yield.

Definition of the problem and purpose of the study

The capacity of a stand to produce wood is evaluated in terms of the speed of production by means of various indices. This aspect was studied by Decourt (1973) who recognized five important types: climatic, vegetation, yield and ecological indices, plus combinations of these. Generally, site quality of even - aged stands is usually expressed by average height at a given age, known as the site index. Height is chosen because it depends very little on the stand density. This is known as the "extended Eichhorn's law". However, Assmann (1955, 1961, 1965, 1974) showed that the relationship between height and total yield exists if the production level is the same.

There are two principal methods for obtaining sets of site index curves: the spatial method, with anamorphic curves and the temporal method, on the basis of stem analysis, with polymorphic curves (Tesch 1981). The temporal method was preferred by Curtis (1964), Heger (1968), Beck (1971), Carmean (1979), and Griffin and Johnson (1980).

Griffin and Johnson (1980) evaluated the yield of balsam fir stands in Maine using polymorphic site index curves. To our knowledge, this site index has never been established for conifer stands in Quebec, particularly those in the Gaspé region. To validate the effectiveness of various site indices, stand structure will be examined, particularly the evolution in time of the "diametral" structure. The relationship between the number of stems and average dbh will be examined and the results compared with those of other authors, to determine whether the group of 52 research stands can be considered as a growth series as defined by Turnbull (1963)[1]. Then vegetation in the stands will be studied and classified and the coenological groups and their value in predicting conifer stand yields will be established.

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[1] Population dynamics in mixed forest stands. A system of mathematical models of mixed stand growth and structure. Unpublished thesis, Univ. of Washington, 186 p.

Nevertheless, emphasis will be on the examination of height growth in balsam fir and the main factors influencing this growth, to establish polymorphic site index curves. We will examine the practical value of floristic and site indices, by comparing our results to those obtained from dry wood density, and we will also examine the yield level of 52 research stands.

Biophysical description of the study area

The area studied is around Lake Joffre, south of the main chain of the Shickshock Mountains. It is a 45 km^2 rectangle straddling the townships of Joffre and Dunière, Matane County, between 48°43'30" and 48°46'30" North latitude and between 66°34'00" and 66°40'30" West longitude. The altitude varies between 290 and 580 m, and the relief is hilly with sharp slopes in the sections of old alluvial erosion.

Most of the substrate in the territory is a finely grained limestone with few dolomite outcrops. The surface layer consists of 2 to 5 m of saprolite. Glacial drift is practically non-existent, rarely going above a few decimetres (Lebuis and David 1977).

The Shickshock Mountains have a mean annual temperature between 0 to + 2°C, with an annual total precipitation between 1016 and 1219 mn, about half falls as snow (380 to 500 cm) (Gagnon 1970). The growing season does not exceed 80 days per year. The massif forms part of section B.2 - Gaspê (Rowe 1972).

According to the Canadian Commission on the Soil Sciences (CCP) (1978), the soil is classified as subgroup of Orthic Humo-Ferric Podzol; it has a loamy texture and lithic contact generally over one metre. The soil is acid, with the exception of some dolomite profiles where the reaction was neutral. The base saturation barely surpasses 8% in the B horizon.

MATERIALS AND METHODS

Fifty-two circular research plots of 500 m^2 each were established. The radius of the plot was adjusted depending on the slope.

The sites were chosen according to the homogeneity of the following:

- ecological criteria, such as slope, exposure, position on the slope, and drainage, which may have an influence on growth;
- mensurational criteria, such as the state of the tree cover, the presence of disturbances, etc...

The stands were established along transects, where the orientation corresponds to recognizable ecological gradients obtained from black and white aerial photographs at a scale of 1:15 000. Organic deposits or recently cut surfaces were not sampled.

Mensurational protocol

In each stand, starting at 4 cm dbh, stems were counted by intervals of 2 cm; 2 to 4 trees were cut. Trees were chosen among those that did not show any visible defects in the crown or trunk and whose dbh was closest to the dbh at the 95 percentile on the cumulative curve of the number of stems. The trees felled were cut into sections 1 m long, except for the stump which measured 80 cm. The first sample was taken from 40 cm above the ground. Samples were taken from 111 dominant balsam firs and 23 white spruces and they were subjected to a complete stem analysis.

Ecological protocol

Each stand was described on the basis of three series of observations: physical habitat, vegetation of the herbaceous strata, and soil. The physical habitat was described in terms of slope, exposure, the shape of the slope, the position on the slope, and the microrelief.

The linear method (Godron 1971)[2] was used to sample the vegetation of the lower strata. The experimental device used is shaped like a cross, systematically oriented towards the cardinal points and consisting of two perpendicular cords divided into ten sections of 1 m each. The point of intersection of the two cords corresponds to the centre of the

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2 Essai sur une approche probabiliste de l'écologie des végétaux. Unpublished thesis, Univ. of Montpellier (France), 245 p.

stand. The frequency of each species above each section was recorded. The stand composition was analyzed according to the proportion of the different species represented, in percentages of the total basal area of the stand. The soil was studied in a profile located near the centre of the stand and described according to the criteria established by CCP (1978). Our description included thickness, limits, color, pH, consistency, texture, structure, and the presence of rock fragments in the horizons. Finally, we took 5 samples of humus per plot in a systematic fashion: the samples were collected at the mid part of 5 radius separated by 72°, the first radius was oriented northward.

Analysis and processing of data

Mensurational data is obtained exclusively on the basis of stem-analysis. This technique is very effective and it has been used for a long time (Guttenberg 1915). It is well adapted to growth analysis and is especially useful in establishing site index curves (Curtis 1964; Guttenberg 1915; Schwappach 1902; Duchovnikov 1972). We used the methodology of Korf (1953) to carry out the stem analysis and establish the mensurational data: age, height, dbh, basal area, volume, form height, and form coefficient. The site index curves were established using methodologies developed by Panek (1976), and Tveite (1969). Korf's growth function served for the mathematical expression of growth (Zarnovican 1979). In this method parameters are defined using the "PAR" program developed by Biomedical Computer Programs, P-series (Dixon 1977).

The analysis of vegetation in the lower strata and especially the establishment of the ground cover groups, were done by means of a principal component analysis and calculations were obtained using the software SACADOS (Boudoux and Bonenfant 1979).

Soil analysis were made using the methods recommended by the Commission on the Soil Sciences (McKeague 1977). The pH total nitrogen content, humic and fulvic acids contents of the hummus were determined. The texture of the mineral soil was expressed as medium diameter of particles. Wood density was studied on the basis of three samples taken from each third of the tree, which were dried to a constant weight and then measured to determine the specific weight.

RESULTS AND DISCUSSION

Description of the forest stands

In the 52 research stands around Lake Joffre, balsam fir occupies an average of 83% (s_x = 10%) of the basal area; white spruce occupies 14% (s_x = 9%), and other species (white birch [*Betula papyrifera* Marsh.] and black spruce) appear sporadically as 2 to 3% of the basal area.

There have been no historical studies to determine that this composition is climacic in origin. The Inventory Service of the Ministry of Energy and Resources of Quebec has no data prior to 1965, thus it may be useful to review forest composition data for the Gaspé region published by Gobeil in 1938.

Before 1938 the proportion of white spruce and deciduous species was 3 times greater than today (Table 1). The composition of these stands changed not only because of the 1935 and 1940 outbreaks of spruce sawfly [*Gilpinia hercyniae* Htg.] and white spruce dendroctonus [*Dendroctonus piceaperda* Hopk.] (Gobeil 1938; Martineau 1943) and the decline of white birch around the same period (Martineau, personal communication), but also because of severe harvesting. Balsam fir gained ground to the detriment of white spruce and white birch, however, balsam fir has been attacked by the spruce budworm [*Choristoneura fumiferana* (Clem.)]. Considering these facts, it would be presumptuous to try to establish the climacic composition on the basis of present undercover surveys. Balsam fir stands should be developed on the basis of conversion, to form more resistant stands, where the composition will be determined from basic historical and ecological studies.

Table 1. Stand's composition in the Gaspé region before 1938 (Gobeil 1938)

Water shed	Percentage in volume				
	Spruce	Fir	Cedar	Pine	Deciduous
Matane Cap Chat Sainte-Anne	33	49	1		17
Marsouis Madeleine Darmouth	36	52	1	1	10
York Saint-Jean Malbaie Grande Rivière	41	38	3	1	7
Grand Pabos Petit Pabos Duval	27	37	5	4	27
Hall Bonaventure Petite Cascapedia	27	36	2	1	34
Grande Cascapedia Saumons Nouvelle	39	50	1	-	10
Escuminac	20	52	4	1	23
Total	34	46	2	1	17

Details for deciduous trees: White birch 51; Poplar 34; Yellow birch 11.

Structures of stands

There are great morphological similarities between balsam fir and white spruce (Zarnovican 1982). A linear model has been established for predicting the natural stocking of the 52 research stands. Therefore diametral structure of the stands was approached through an examination of their stocking. Figure 1 shows the distribution of the 52 stands according to basal area and number of stems per stand. It demonstrates not only the isolines joining those stands with the same stocking, but also, comparison data from yield tables for balsam fir produced by Ker (1976), Vézina and Linteau (1968), and Boudoux (1978). Also included are Hauser's data from

Korf (1953) for pectinate fir. In spite of evident variations, all the stands form a logical distribution which means that for the same stocking and increased number of stems, the basal area decreases, confirming results reported by the authors cited above. If we compare our maximum occupation rate of 84%, we find a remarkable similarity between our results and those of Ker (1976) while the stocking, reported by Vézina and Linteau (1968), corresponds to about 70% of ours. The comparison also stresses the remarkably lower stocking reported by Boudoux (1978). Further comparisons are made in Figure 2 where 52 stands have been classified according to the available area per tree and per stand and according to the average basal area of the stands. Furthermore, we have included similar data reported by Ker (1976), Vézina and Linteau (1968), and Boudoux (1978). The relationship between available area and average basal area is closer than that illustred in Figure 1, and we can also verify the similarity that exists between our data and Ker's (1976). To evaluate density of our stands we ordinated them according to the number of stems and average basal area. Figure 3 shows our results and those of Ker, Vézina and Linteau, and Boudoux. These observations reveal the existence of a very close relationship between the number of stems observed and the mean basal area of the station. This relationship may be very well adjusted by means of a negative exponential function:

$$n = 242.71 \ st_{mean}^{-1.028095}$$

with a determination coefficient R^2 of 0.965 and the standard error of the estimate is 18.1%. Again, note the remarkable similarity between Ker's data and ours. Contrarily, it is surprising to find a linear relationship with Boudoux's results. Comparison of the stocking and density observed around Lake Joffre and similar data reported by Ker, Vézina and Linteau, and Boudoux, reveals that the natural stocking is variable (Zarnovican 1982); however, it is possible to correct this figure by using the maximum rate of utilization of the available surface to reveal the yield level of the research stands. Our results point to only one yield level for all the 52 stands.

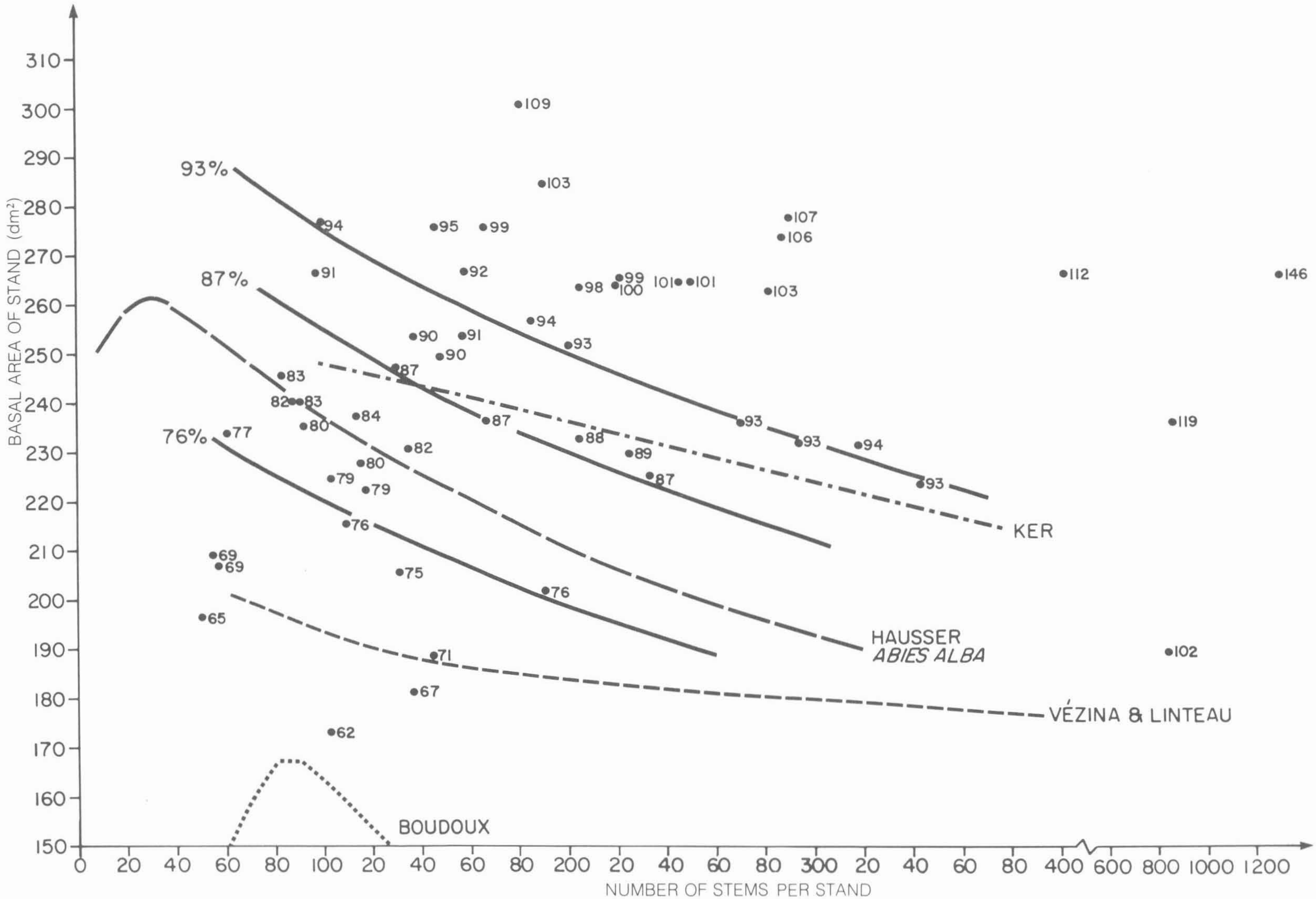

Figure 1. Distribution of research plots according to their basal area and number of stems. Each stand is identified by the rate of occupation of the available space.

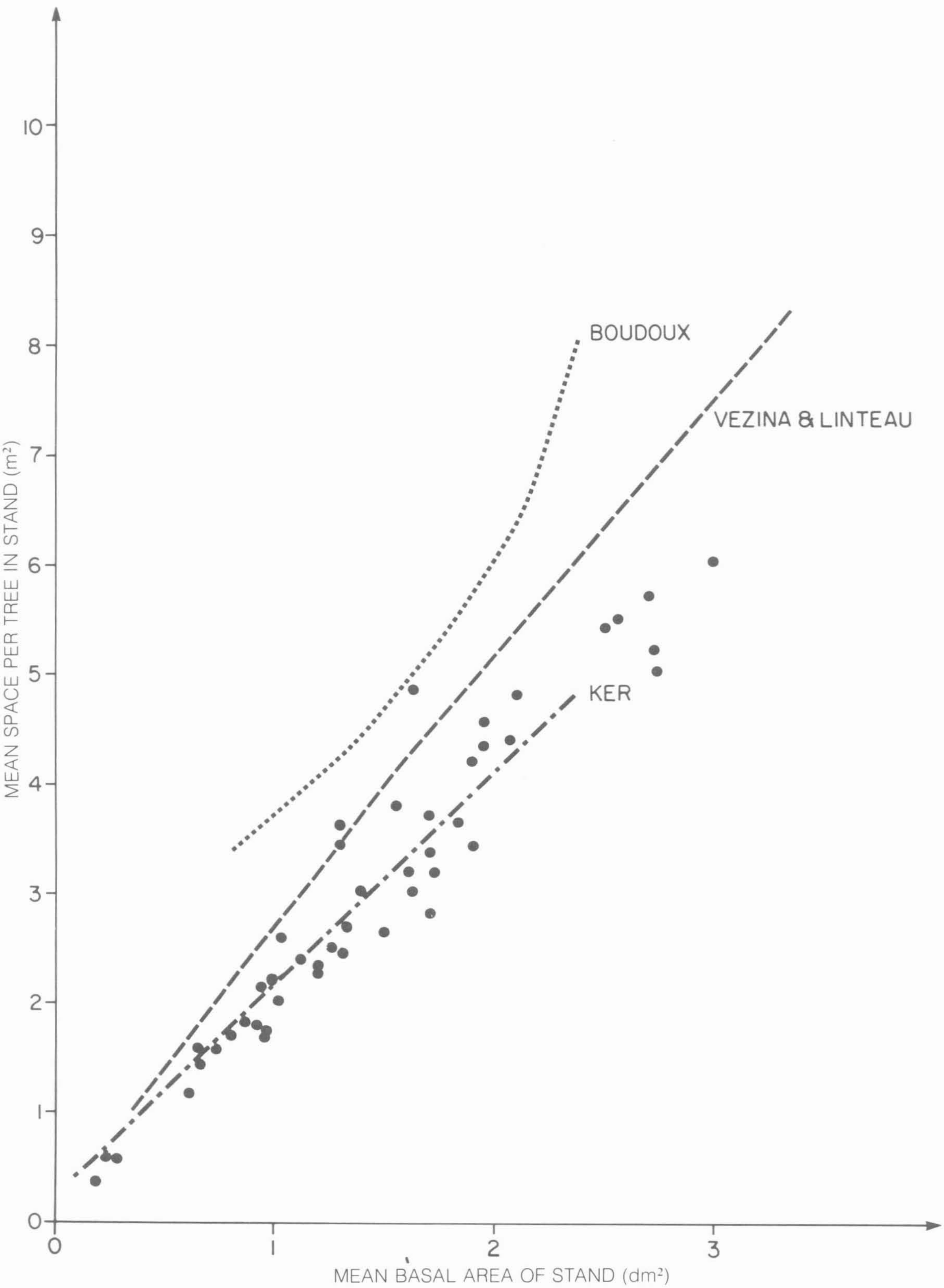

Figure 2. Mean space occupied per tree, according to the mean basal area in the 52 plots.

An important characteristic in determining yield is the height form of stands. The height form represents the ratio between standing volume and corresponding basal area. This concept of height form was introduced in Quebec by Popovich (1974), for the evaluation of yield in white spruce plantations. He called it "volume per unit of basal area". For the wooded area, distribution of research stands according to height form and average basal area (Figure 4) reveals a close relationship between the height form and basal area, this can be adjusted by means of an exponential function:

$$h_{red} = 5.5486\ st_{mean}^{\ 0.32906}$$

which gives the following results: the determination coefficient is 0.956 and the standard error of the estimate is 4.4%. Contrarily to the above observations, Figure 4 reveals a similarity between our observations and data reported by Vězina and Linteau (1968); however, Figure 4 reveals that Ker's height form is clearly higher than ours for an average basal area of between 0 and 2 dm^2 and that it levels out after 2 dm^2. On the basis of the results obtained from the classification of the research stands as a function of basal area, the number of stems and the height form (Figures 1, 2, 3, and 4), it is natural to consider that the 52 stands represent a growth series. Thus, it seems logical to examine the evolution of the diametral structure of stands over time. This examination will reveal whether an asymmetrical diametral structure will persist over time or whether, the balsam fir stands will tend to form a normal diametrical distribution. Figure 5 shows the distribution of several stems per diameter class for two stands. On the left of the figure the distribution corresponds to the young stand, where the mean arithmetical dbh is 5.6 cm. This is a negatively skewed distribution, with a skew coefficient of 1.4 and a kurtosis of 1.1 (values calculated for the real number of stems per dbh class). The distribution on the right of the figure represents an older stand with an almost normal distribution, where the mean arithmetic dbh is 18.2 cm, the skew coefficient is 0.1 and the kurtosis is -0.009. To find

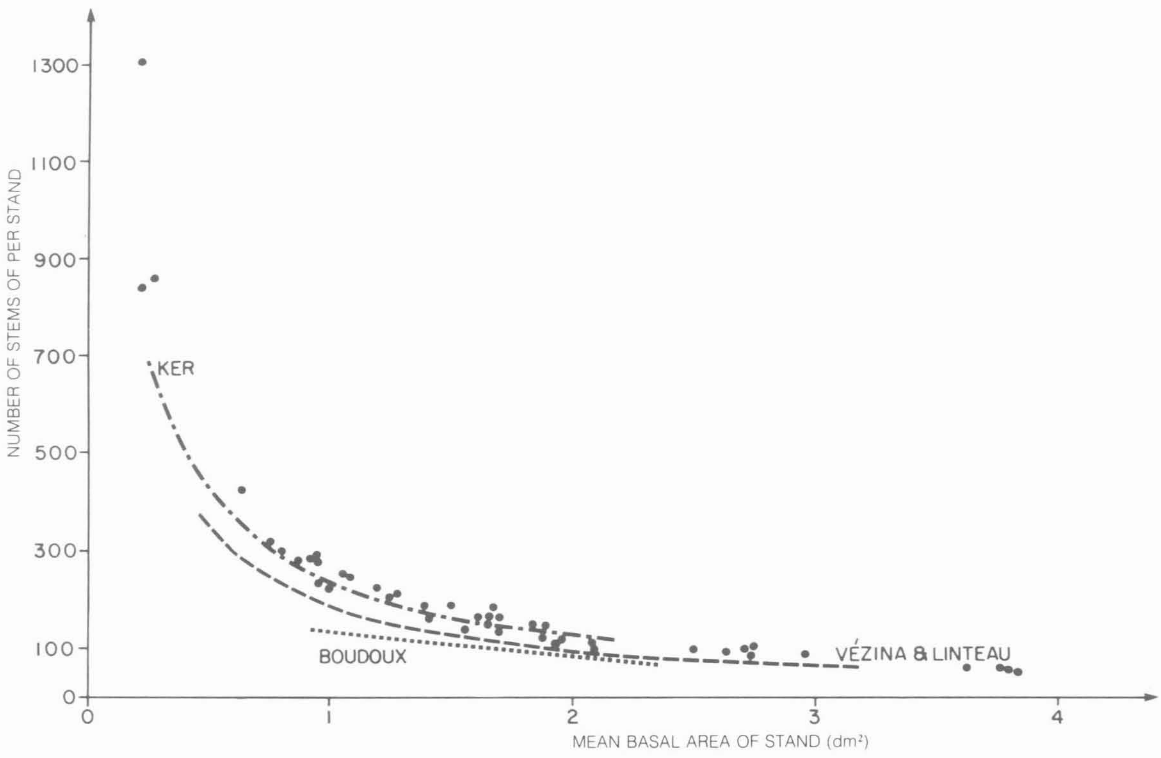

Figure 3. Distribution of the plots according to the number of stems and mean basal area.

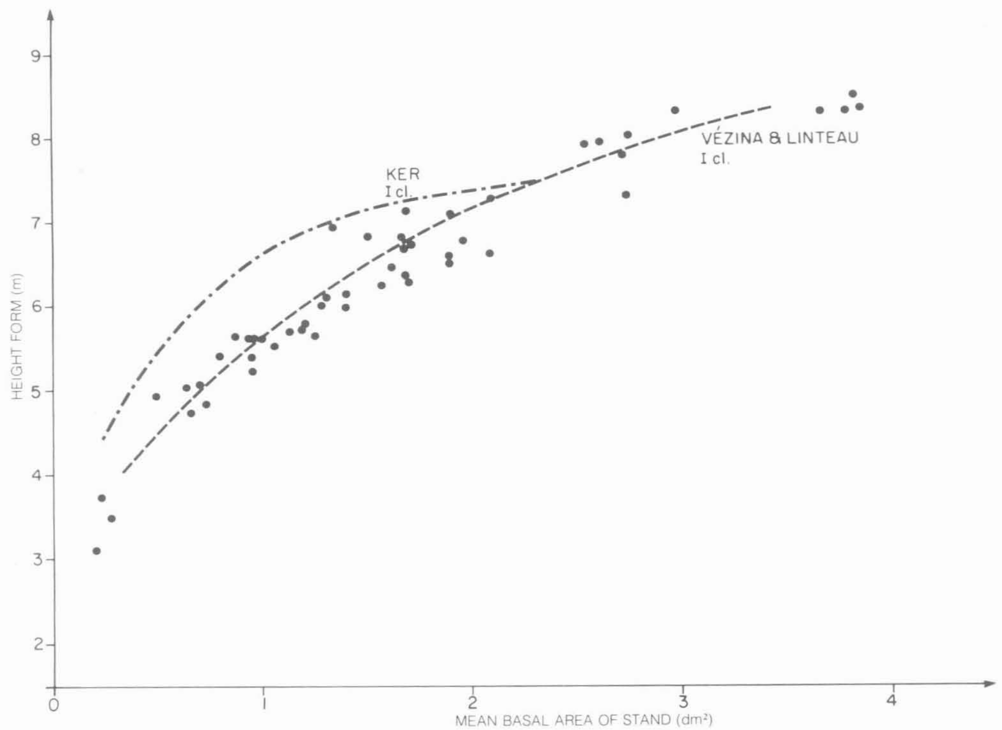

Figure 4. Distribution of plots according to their height form and their mean basal area.

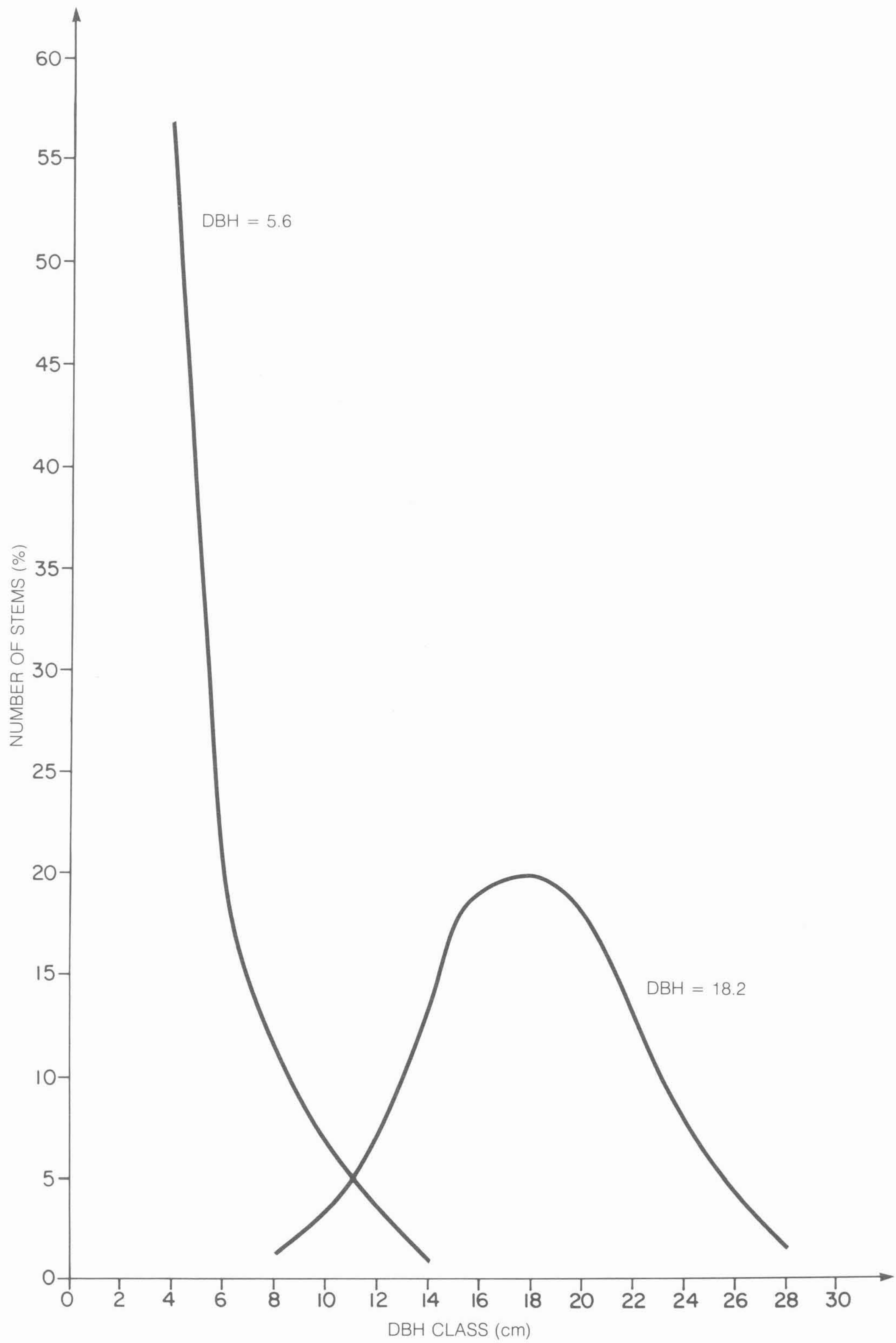

Figure 5. Distribution of the number of stems according to dbh class.

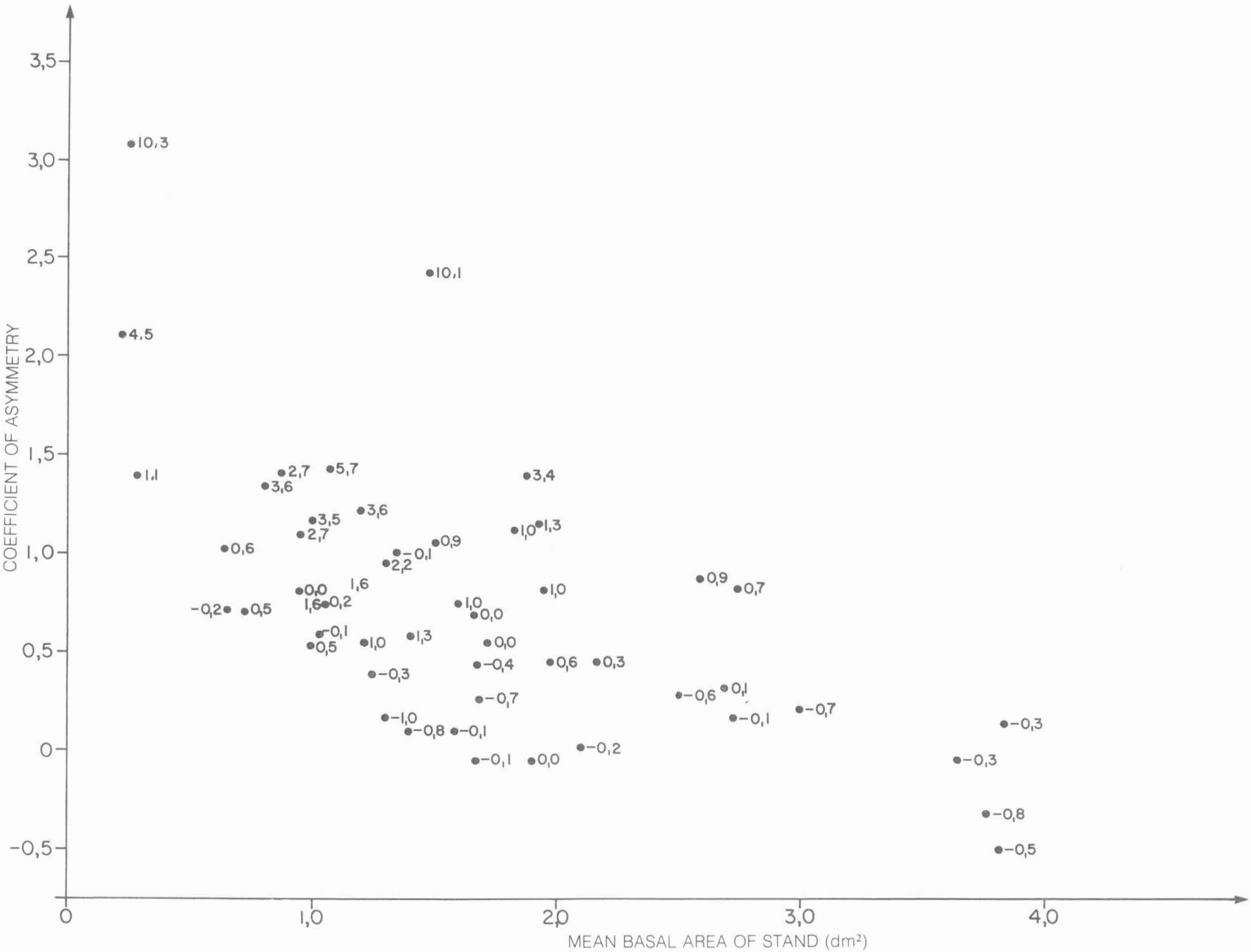

Figure 6. Distribution of plots according to the coefficient of asymetry and mean basal area. Each plot is identified by the kurtosis.

out, at least in part, what is the relative tendency in the diametral distribution of conifer stands over time, we classified the research stands as a function of the skew coefficients and their average basal area. This classification is illustrated in Figure 6, where we have included not only the coordinates (skew in relation to the average basal area), but also the value of the kurtosis. This figure reveals that, over time, balsam fir stands generally tend to go from a negatively skewed, leptokurtic distribution towards a normal or positively skewed, flatter distribution. This confirms Jurdant's (1964) observations that old forests tend to take on the aspect of homogeneous stands, by normalizing themselves over time to form single stratum forests.

Ground cover vegetation

One of the bases for evaluating the site quality of balsam fir stands in Quebec is their ground cover composition. The works of Lafond (1967), Linteau (1957), and Jurdant (1964) reveal the importance granted to the ground cover in relation to the upper layer for the definition of site quality in different stands and even for their classification into different groups.

On the basis of the ground cover composition of balsam fir stands two site classes are distinguished:

- the first class is attributed to forest stands with a dominance of herbaceous, broad-leaved plants and ferns;
- the second class is attributed to forest stands with a dominance of feather mosses in the lower strata.

Lafond and Linteau's classifications served as the basis for many studies on stand yield in Quebec, especially those in the vicinity of Lake Joffre, (Bolghari and Vézina 1974; Veuilleux and Sheedy 1978; Villeneuve 1971). Furthermore, the significance of the vegetation composition of conifer stands on productivity of fir forests in the Montmorency Experimental Forest, has been expressed by Jurdant (1964): "the moss cover is thicker as the site is poorer". It was important to understand the vegetation composition of our research stands, as expressed by the main coenological groups, and to determine if this composition had a significant effect on yield.

a. Establishment of the ground cover vegetation groups

Floristic data on all stands, expressed in terms of frequency of appearance, were converted into relative frequencies to form the basis for establishing the coenological groups. Species present in only three of fewer stands were not included in our calculations. Thus, only 17 species were retained. Interspecific relationships were evaluated using simple correlation coefficients (Table 2), which were used to classify species into groups by means of a principal component analysis. Table 3 shows the parameters of the analysis for the first three components. The coordinates of the 17 species in space K^3 are shown in Table 4. Even though the cumulative percentage of the total variation explained by the first three components is sufficiently large, the fidelity of the representation of each species in reference to space K^{17} is included (Table 4). The principal component analysis led to the identification of five ground cover groups:

1st group
Pleurozium schreberi
Ptilium crista-castrensis
Hylocomium splendens
Linnaea borealis

2nd group
Coptis groenlandica
Streptopus roseus
Chiogenes hispidula
Maianthemum canadense

3rd group
Dryopteris spinulosa
Clintonia borealis
Oxalis montana

4th group
Trientalis borealis
Aralia nudicaulis
Acer spicatum
Cornus canadensis

5th group
Litter
Hylocomium umbratum

It is important to understand the practical value of each of the five coenological groups, through an evaluation of their relative importance in the floristic area available in each of the research stands. Their importance was measured by means of the ratio between the average frequency of the group and the sum of the average frequencies of the five groups. Results of the calculation of the relative importance of the groups are shown in Table 5. An examination of this table shows that coenological

Table 2. Matrix of simple correlations between the 17 species

Species		Species																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	*Pleurozium schreberi*	x	.65	.63	.05	-.30	-.20	-.16	.32	.26	-.14	.08	-.15	.20	.08	.05	-.24	-.43
2	*Pitlium c.-castrensis*		x	.58	-.13	-.25	-.15	-.29	.31	.47	.00	-.07	-.06	.04	.03	.14	-.23	-.36
3	*Hylocomium splendens*			x	.02	-.45	-.07	-.08	.44	.34	-.02	.14	-.04	.31	.22	.26	-.24	-.23
4	*Oxalis montana*				x	.44	.64	-.18	.32	.04	.50	.47	.30	.10	.13	-.06	.14	-.53
5	*Dryopteris spinulosa*					x	.62	-.22	-.09	-.09	.42	.04	.26	-.15	-.21	.02	.29	-.24
6	*Clintonia borealis*						x	-.20	.42	.09	.69	.33	.46	.16	.14	.00	.32	-.48
7	*Hylocomium umbratum*							x	-.18	-.14	-.25	-.23	-.16	.04	.28	-.11	-.06	.45
8	*Maianthemum canadense*								x	.51	.42	.52	.32	.45	.52	.02	.04	-.40
9	*Linnaea borealis*									x	.29	.15	.17	.08	.27	-.03	-.01	-.17
10	*Cornus canadensis*										x	.45	.68	.33	.18	.14	.16	-.37
11	*Trientalis borealis*											x	.39	.52	.32	.10	.02	-.37
12	*Aralia nudicaulis*												x	.27	.14	.04	.32	-.28
13	*Coptis groenlandica*													x	.49	.54	.03	-.05
14	*Streptopus roseus*														x	.05	-.11	-.09
15	*Chiogenes hispidula*															x	-.06	-.02
16	*Acer spicatum*																x	.15
17	*Litter*																	x

groups 2 and 4 are only variants of groups 1 and 3. Groups 2 and 4 are not taken into account for the identification of the stands, because of their minor importance within the available floristic space. The 52 research stands were classified according to the following criteria:

- a stand was typical of a coenological group when the group species occupied 70% or more of the available lesser vegetation;
- the coenological group was dominant in the stand when the species in the group occupied 51% or more (but less than 70%) of the available vegetation;
- two coenological groups were codominant in the stand, when their elements together occupied more than 75% of the available space in the stand; and when the two preceding criteria were not applicable. However, the stand carried the name of the more important of the two groups;
- where none of the preceding conditions were met, we considered the stand to be "mixed".

Next only groups 1, 3, and 5 were taken into account to study the relationship between yield and ground cover groups.

b. Observations on the synecology of the three main coenological groups

Before clarifying the forest production meaning of the undercover groups, the relationship between these groups and variables of the stands had to be examined. Therefore, we calculated the simple correlation coefficients between the ground cover groups and stand variables. The results are presented as a simple correlation matrix in Table 6. There are several close relationships, not only between groups, but also between the groups and the observed variables. In view of the results on the relationship between groups and the space occupied in the stand per tree, we can say that the three ground cover groups reflect quite clearly the phases of successive development of balsam fir stands over time. Their appearance is closely linked to the opening of the shrub cover or, to the natural decrease in the

Table 3. Eigen values, percentages, and cumulative percentages for K^3 for the principal component analysis of the matrix species-species

Component	Eigen value	Percentage of variance	Cumulative percentage
1	4.49626	26.45	26.45
2	3.35390	19.73	46.18
3	1.98313	11.67	57.85

Table 4. Coordinates of 17 species in K^3 space with the fidelity of their projection into K^3

	Species	Axis 1	Axis 2	Axis 3	Fidelity of projection in %
1	*Pleurozium schreberi*	0.289	0.707	0.322	69
2	*Pitlium c.-castrensis*	0.247	0.711	0.420	74
3	*Hylocomium splendens*	0.350	0.763	0.040	71
4	*Oxalis montana*	0.640	-0.358	0.158	56
5	*Dryopteris spinulosa*	0.270	0.723	0.311	69
6	*Clintonia borealis*	0.708	-0.490	0.120	76
7	*Hylocomium umbratum*	-0.370	0.016	-0.576	47
8	*Maianthemum canadense*	0.764	0.289	-0.162	69
9	*Linnaea borealis*	0.429	0.367	0.078	32
10	*Cornus canadensis*	0.763	-0.362	-0.060	72
11	*Trientalis borealis*	0.686	-0.400	-0.267	54
12	*Aralia nudicaulis*	0.603	-0.352	-0.137	51
13	*Coptis groenlandica*	0.510	0.233	-0.641	72
14	*Streptopus roseus*	0.396	0.255	-0.610	59
15	*Chiogenes hispidula*	0.187	0.188	-0.274	15
16	*Acer spicatum*	0.118	-0.485	-0.074	25
17	*Litter*	-0.678	-0.101	-0.494	71

Table 5. Relative presence (%) of five ground cover groups in 52 plots which are identified in terms of the leading group

Stand	Ground cover group 1	2	3	4	5	Leading group
1	26	0	28	0	46	Mixed
2	74	9	4	0	13	Typical Group 1
3	49	9	36	6	0	Groups 1, 3 codominant
4	29	4	57	10	0	Group 3 dominant
5	51	10	25	14	0	Group 1 dominant
6	58	5	26	0	11	Group 1 dominant
7	65	2	33	0	0	Group 1 dominant
8	30	8	38	0	24	Mixed
9	52	2	40	6	0	Group 1 dominant
10	39	7	44	10	0	Groups 3, 1 codominant
11	64	1	32	3	0	Group 1 dominant
12	17	5	70	8	0	Typical Group 3
13	80	3	17	0	0	Typical Group 1
14	84	0	16	0	0	Typical Group 1
15	59	7	33	1	0	Group 1 dominant
16	61	0	21	0	18	Group 1 dominant
17	26	4	70	0	0	Typical Group 3
18	2	1	85	12	0	Typical Group 3
19	29	18	33	20	0	Mixed
20	49	4	47	0	0	Groups 1, 3 codominant
21	31	0	0	0	69	Group 5 dominant
22	21	0	17	0	62	Group 5 dominant
23	24	0	56	13	7	Group 3 dominant
24	38	0	45	3	4	Groups 3, 1 codominant
25	20	3	52	6	19	Group 3 dominant
26	36	1	57	4	2	Group 3 dominant
27	38	0	34	0	28	Mixed
28	10	1	77	12	0	Typical Group 3
29	6	0	74	20	0	Typical Group 3
30	1	2	73	24	0	Typical Group 3
31	26	0	65	9	0	Group 3 dominant
32	45	2	31	5	17	Groups 1, 3 codominant
33	44	1	23	1	31	Groups 1, 5 codominant
34	29	8	30	4	29	Mixed
35	41	3	17	0	39	Groups 1, 5 codominant
36	40	1	48	11	0	Groups 3, 1 codominant
37	45	1	42	3	9	Groups 1, 3 codominant
38	35	7	40	8	10	Groups 3, 1 codominant
39	8	1	48	4	39	Groups 3, 5 codominant
40	0	0	12	0	88	Typical Group 5
41	14	0	20	0	66	Group 5 dominant
42	32	1	11	5	51	Group 5 dominant
43	28	7	11	2	32	Mixed
44	13	3	25	0	59	Group 5 dominant
45	54	2	16	2	26	Group 1 dominant
46	28	0	28	3	41	Mixed
47	9	0	8	3	80	Typical Group 5
48	29	0	13	0	58	Group 5 dominant
49	15	3	31	3	48	Groups 5, 3 codominant
50	21	0	30	1	48	Groups 5, 3 codominant
51	45	14	21	4	16	Mixed
52	0	4	16	0	80	Typical Group 5

Table 6. Matrix of simple correlations between the ground cover groups and between these and the main mensurational and soil variables

	Group 1 *Pleurozium-Hylocomium*	Group 3 *Dryopteris-Oxalis*	Group 5 *Litter-Hylocomium umbratum*
Group 3	-.38	x	-.62
Group 5	-.49	-.62	x
Humus pH	-.49	.31	.13
Total Humus Nitrogen	-.42	.54	-.15
Humic C	-.45	.54	-.12
Humic/Fulvic	-.57	.50	.02
C/N Humus	.43	-.50	.10
Median particle diameter	-.03	.24	-.20
Average basal area of the stand	-.39	.87	-.49
Available surface per tree in the stand	-.38	.88	-.50

number of stems in the station, or to a decrease resulting from mortality due to budworm defoliation.

To illustrate this finding (Figure 7) we went back to the stand distribution shown in Figure 2 and identified each stand according to its respective coenological group. If Figure 7 is examined from the relationship between the space per tree, the average basal area of the stand, and the dominance of the coenological group, a group order over time will be revealed since basal area is a function of time.

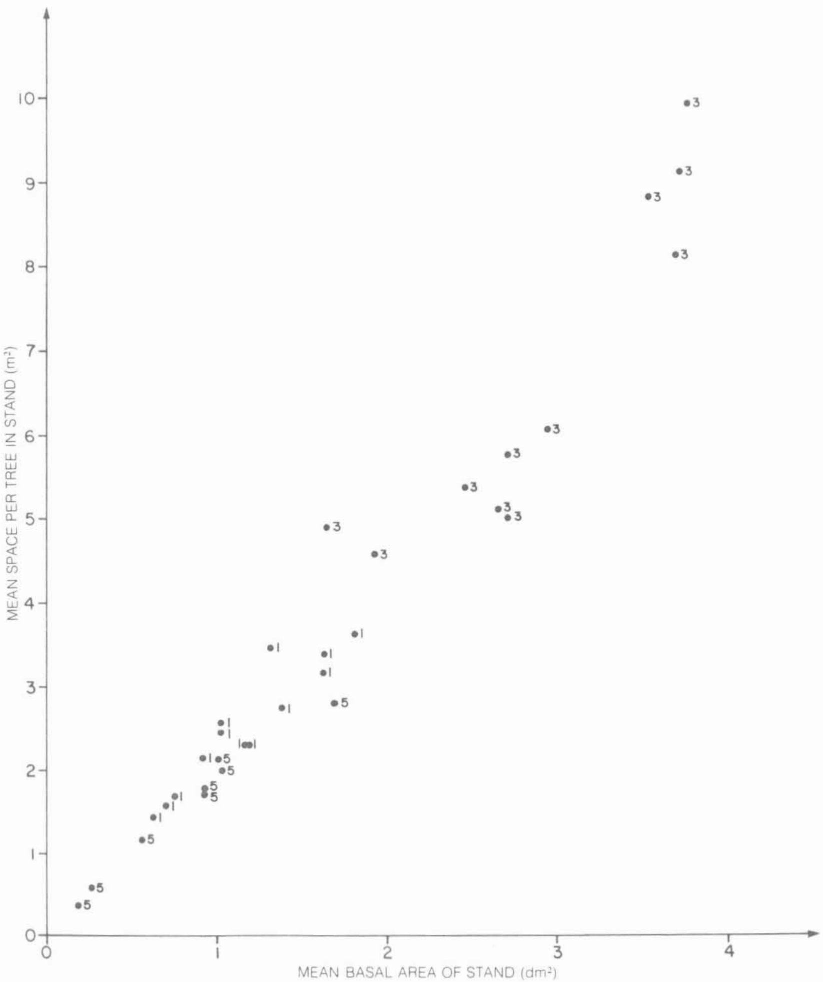

Figure 7. Distribution of typical and dominant ground cover groups in the stands according to mean surface per tree and mean basal area.

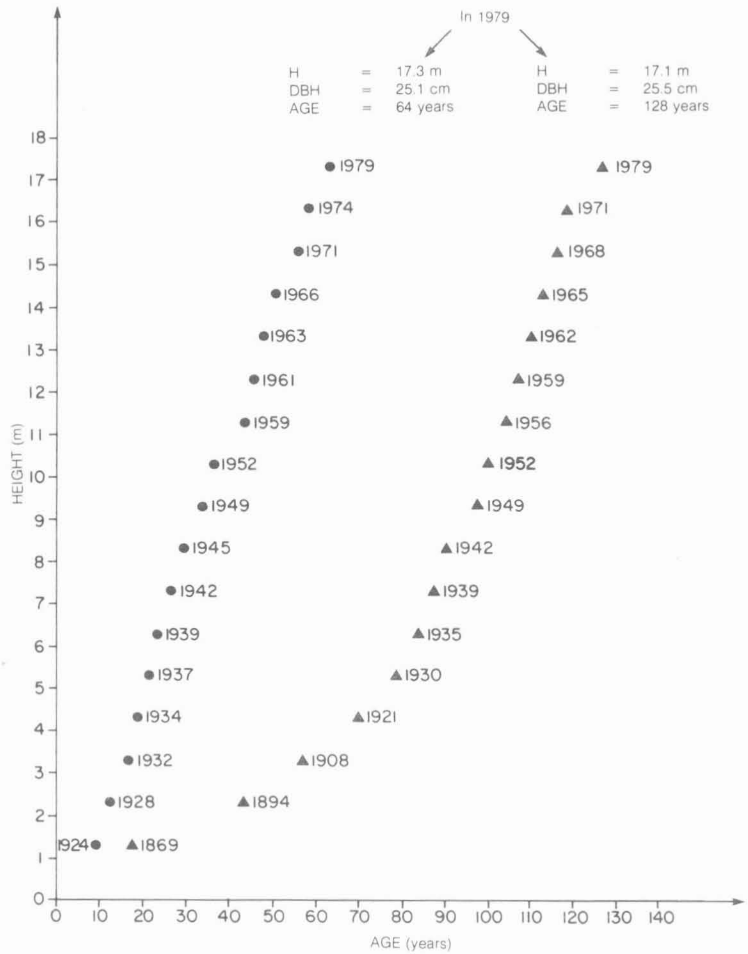

Figure 8. Height growth of two balsam firs.

The respective position of the three ground cover groups in Figure 7 confirms the conclusion of Busby et al. (1978) that "Feather mosses are limited by radiation damage and evaporation stress in open habitats, by depression of net assimilation and other delerious effects of saturation in wet habitats, and insufficient rainfall under tree canopies". The position of the third group (see also the correlations between this group and the state of the humus in Table 6), confirms Piene's (1978) results and conclusions, that "a decrease in the number of stems stimulates the rate of mineralization of organic carbons and raises the mineral nitrogen content. Increased mineralization of organic matter can be attributable to an increase in summer temperatures in the layer of litter". This has been well confirmed by the correlations between the three coenological groups and humus nitrogen, the proportion of humic acid and the C/N ratio.

Tree height as an index of stand quality

In current forestry practice stand quality is evaluated in terms of the height of trees at a given age. Furthermore this evaluation is possible if the yield level of the stands is known (Assmann 1961). Therefore we carried out a detailed examination of the stands structure and their level of production (Zarnovican 1982).

Apical growth - A brief examination

Trees grow in height through an yearly elongation of the leader. This growth is a function of age and can be expressed graphically by an S-shaped curve. The curve's shape reflects quite faithfully not only the genetic characteristics of the species, but also the social position of the tree (or the available space) and the quality of the stand. Stem analysis has made it relatively easy to reconstruct apical growth. Figure 8 shows the results of stem analyses on two firs.

The dbh and total height indicate that the two trees are practically identical. However, they are 64 and 128 years old (read at the stump), a considerable age gap. Furthermore, knowing the ecology of the balsam fir, we realize that the 128 year old tree, because of its particular social position in the stand, has been a victim of prolonged oppression since its youth. About 1930, when the 128 year old tree was 5.3 m high, this oppression was eliminated and it was able to resume normal growth, so that height growth in the two trees was practically the same since 1930. Stem analysis has made it possible to define the length of the period of oppression and to adjust the physical age of the trees. Nevertheless it is almost impossible to measure the effects of certain other factors on apical growth, such as disease or insect attacks. We will illustrate the effect of insect outbreaks on apical growth by means of time of passage. The time of passage corresponds to the years necessary for the leader to grow 1 m. Figure 9 illustrates the mean and standard deviation of these times of passage in periods of 4 years from 1948 to 1967. We can see that, in general, the mean is 3 years. However, between 1956 and 1959, the mean was 6 years, which indicates that apical growth was very slow during this period. The works of Blais (1961) and Blais and Martineau (1960) established that this decrease in apical growth or increase in the time of passage was the result of spruce budworm outbreaks in the 1950s. However, it is impossible to quantify these effects.

The genetic characteristics of the species is a factor influencing apical growth. Even though we do not have data on this aspect, the work of Robinson and Thor (1969) indicates that the fir population of the Lake Joffre area is genetically homogeneous.

Finally, height growth is also an indication of the quality of a stand. Figure 10 illustrates the effect of stand quality on height growth by means of current increment curves for black spruce. The data were obtained from a previous work by Zarnovican (1979). The stand at an altitude of 180 m, has a site index of 17 m at 100 years, is dominated by black spruce with feather mosses, a drainage of 2 - 3, and a clay loam texture. At an altitude of 240 m, the station with the 4 m index at 100 years is dominated by black spruce with ericaceous shrubs and sphagnum, a drainage of 5, and a silty clay texture. The two stands form part of the Lake Matagami Ecological Region (Zarnovican et al. 1976). Figure 10 shows that apical growth in the black spruce varies as a function of the stand. The stand with an index of 17 m at 100 years produced a maximum annual growth of 26.5 cm at 18 years, while in the stand with an index of 4 m this growth was only 5.3 cm at 63 years. Thus, stand quality has a direct effect on the apical growth curve, and especially on its slope, for the period of full growth. This is compatible with the results and conclusions of other authors (Beck 1971; Curtis 1964; Assman 1961).

The differences in stand quality are shown through comparison at the phase of full growth only, because a comparison between the juvenile stage (when it is impossible to measure the influence of the stand) and the full growth phase, for example, (when on the contrary, the effect of the stand is quite evident), may lead to the wrong conclusions.

Determination of the site index curves

Before the family of site index curves could be established, it was necessary to evaluate the length of the period of oppression and to adjust the physical ages of the trees to make them comparable. To establish the age necessary to reach a height of 40 cm, we used data on height growth under non-oppressive conditions (Logan 1969). For heights between 1.3 m and 2.3 m we used the age data obtained in our previous study (Zarnovican 1982). Thus, we were able to determine the length of the juvenile period for 97 balsam fir specimens. The set of site index curves was established on the basis of height and age data on 97 balsam firs.

From the analysis of 97 stems, we were able to establish 1 193 sets of height and age data. Then, using the method developed by Tveite (1969), we regrouped the height data in age categories of 5 years each, to define the height growth range. Table 7 shows the regrouped data and the range is defined by five series of heights, which correspond to the average height plus or minus one time and two times the standard deviation of the height per age class. Figure 11 illustrates the height growth range by means of an average curve and upper and lower curves according to age. The relationship between the standard deviation and the coefficient of variation according to age is shown in Figure 12. It is interesting to point out that

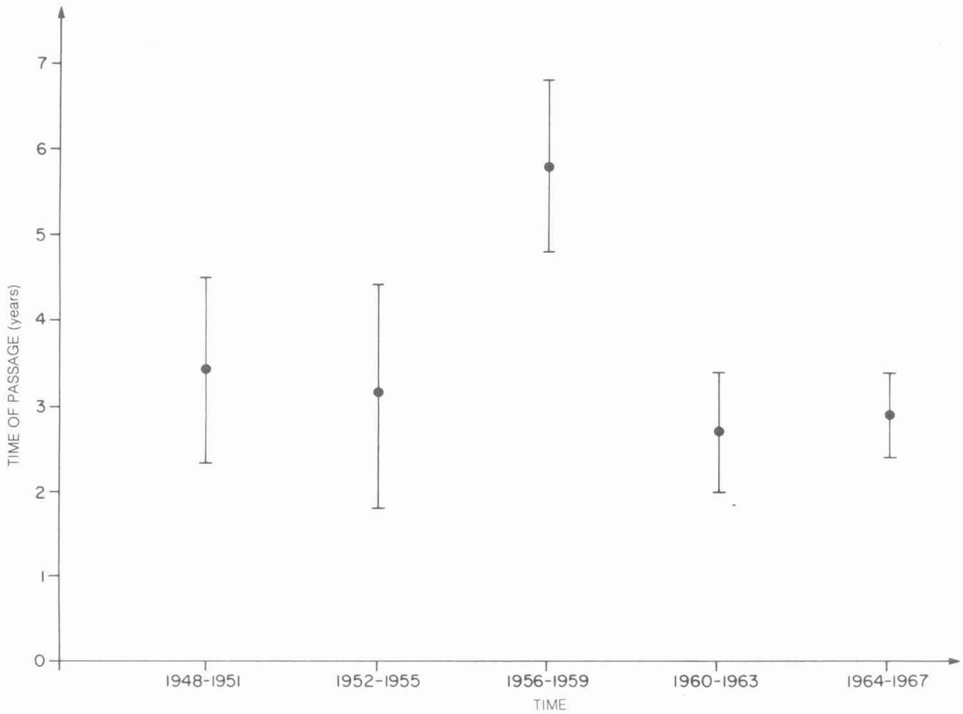

Figure 9. Time of passage in the balsam fir as a function of time.

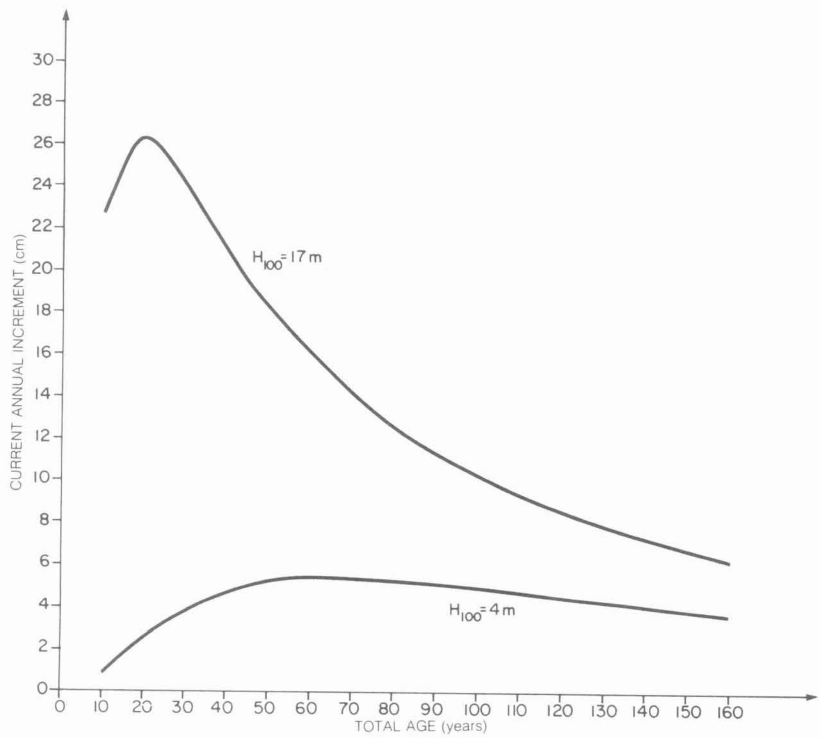

Figure 10. Current annual height growth in black spruce in two different sites.

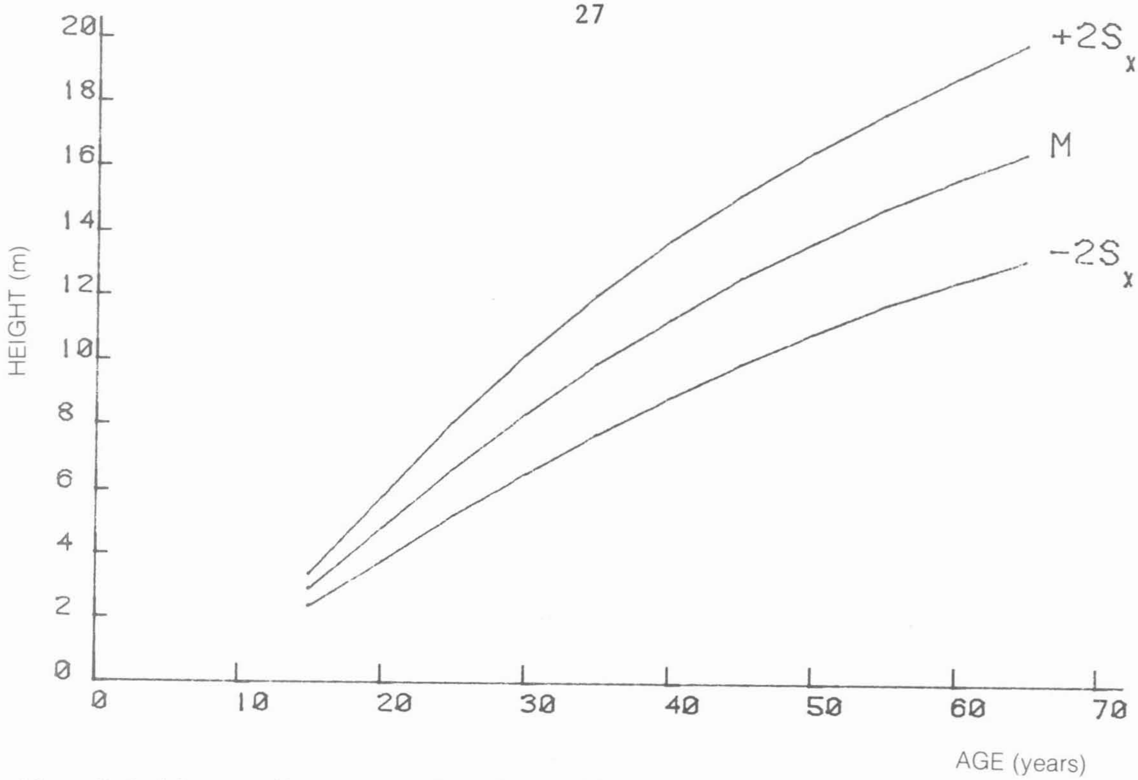

Figure 11. Height growth range of balsam fir.

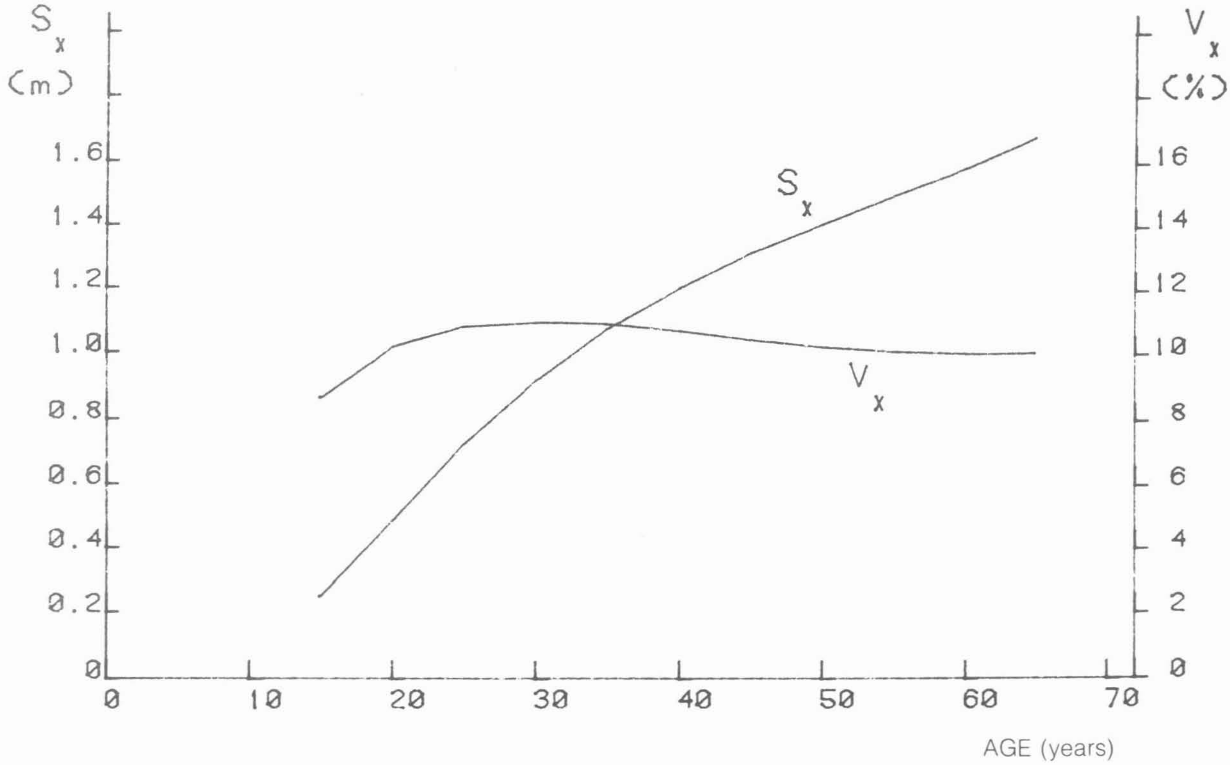

Figure 12. Variations in height growth as a function of age.

Table 7. Height growth range for balsam fir per age class of 5 years

Age (Years)	Number of observations	Average height H_m (m)	Standard deviation s_x (m)	Coefficient of variation (%)	Height $H_m + 2s_x$ (m)	Height $H_m + s_x$ (m)	Height $H_m - 2s_x$ (m)	Height $H_m - s_x$ (m)
15	98	2.88	0.25	8.7	3.37	3.13	2.63	2.38
20	120	4.80	0.49	10.2	5.78	5.29	4.31	3.82
25	126	6.65	0.72	10.9	8.09	7.37	5.93	5.20
30	128	8.36	0.92	11.0	0.20	9.28	7.44	6.52
35	129	9.91	1.08	10.9	12.07	10.99	8.83	7.75
40	144	11.31	1.21	10.7	13.73	12.52	10.10	8.89
45	107	12.58	1.32	10.5	15.21	13.89	11.26	9.95
50	118	13.73	1.41	10.3	16.54	15.13	12.32	10.91
55	72	14.77	1.49	10.1	17.75	16.26	13.27	11.78
60	52	15.72	1.58	10.1	18.88	17.30	14.14	12.56
65	46	16.59	1.68	10.1	19.94	18.26	14.91	13.24
70	53	17.38	1.78	10.2	20.94	19.16	15.60	13.82
Total	1 193							

the coefficient of variation shown in Figure 12 stabilizes at about 20 years and oscillates by about 10% thereafter.

Usually, one uses point scatter around the mean-curve to establish the family of curves in a proportional manner (Bruce and Schumacher 1950). The coordinates of these curves are calculated by means of formulas containing the standard deviation or the variation coefficient (Bolghari 1977; Decourt 1965; Cantiani 1964). However, when using the growth function, one prefers to calculate these coordinates by means of the modified growth func-

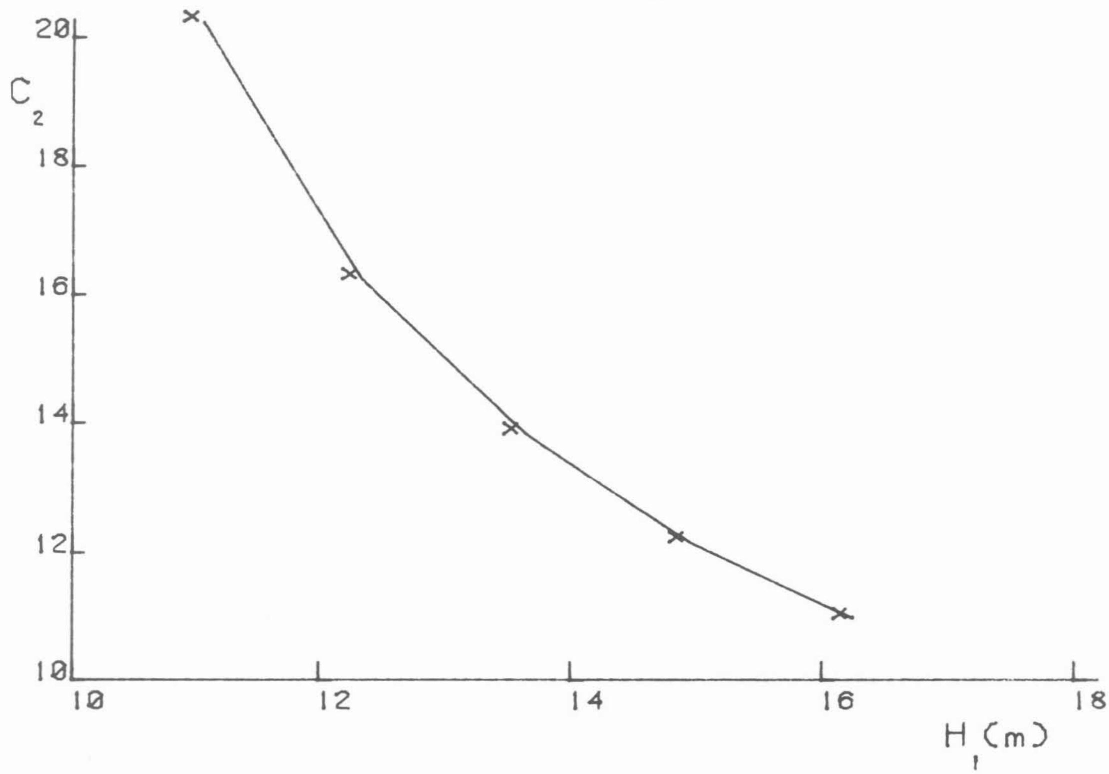

Figure 13. The relationship between C_2 and H_{50}.

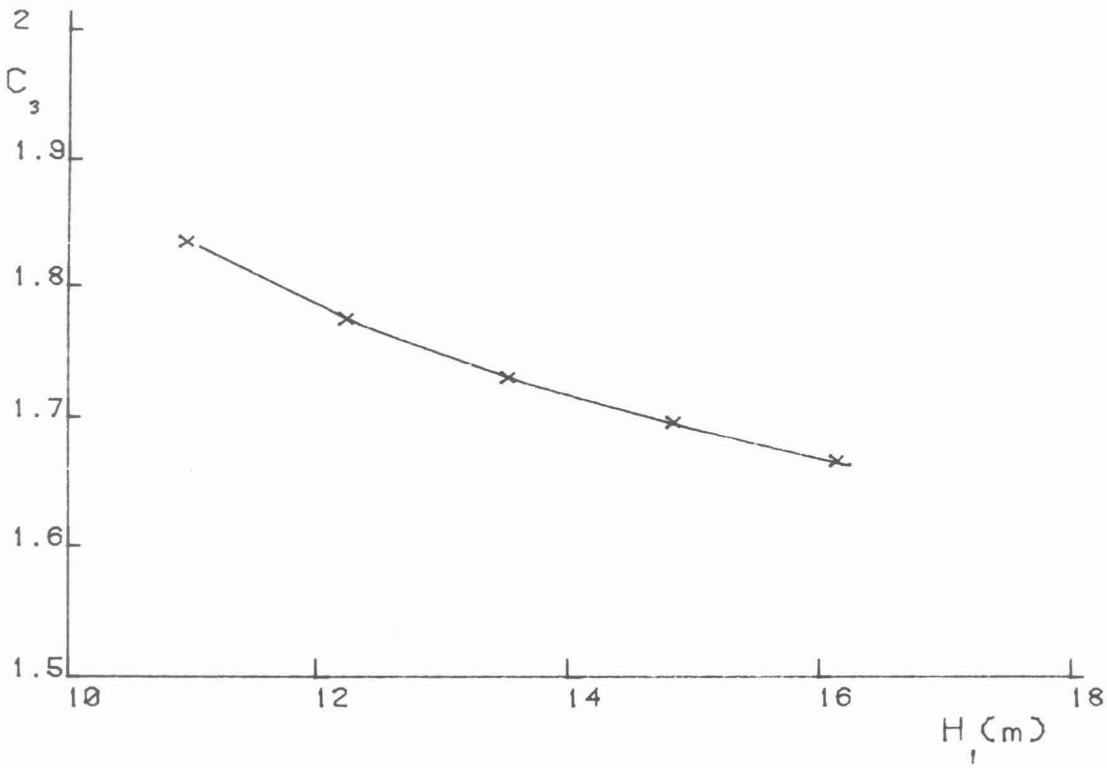

Figure 14. The relationship between C_3 and H_{50}.

tion (Griffin and Johnson 1980; Halaj 1978; Schütz and Badoux 1979; Franz 1971; Hradetsky 1972; Schmidt 1969).

The mathematical expression of growth in the balsam fir was established by means of Korf's function, which is expressed as follows:

$$H = C_1 \exp^{C_2/(1-C_3)T^{C_3-1}}$$

where

H is the height

C_1, C_2, C_3 are the parameters

and T is the age.

This function was used to adjust the relationship between height and age in five curves of the growth range. The parameters of the function are shown in Table 8, which also includes height calculated at 50 years (H_{50}). On the basis of the results obtained by adjusting the distributions by means of Korf's function, it is possible to conclude that the fitting was adequate and that the function itself is subtle enough to predict growth.

Before establishing the mathematical formulas for each curve of the family, we analyzed the relationships between parameters C_2 and C_3 and height calculated at 50 years (Table 8). The relationship between C_2 and H_{50} is shown in Figure 13. The best model for this relationship is:

$$C_2 = 2.94882 \exp^{21.18007/H_{50}}$$

with a determination coefficient R^2 of 0.998. Parameters A_1 = 2.94882 and A_2 = 21.18007 are used to further our understanding.

The relationship between parameter C_3 and height calculated at 50 years (H_{50}) is shown in Figure 14. Through the method of least squares, we find that the best algebraic expression is:

$$C_3 = A_3 + (A_4/H_{50})$$

where the values of the parameters are $A_3 = 1.30688$, $A_4 = 5.76418$, and the determination coefficient is 0.996.

The amplitude of the growth range at 50 years is from 11.06 to 16.24 m, suggesting that reference points for the growth curve at 50 years are from 11 to 17 m. We divided the growth curve into 1 m intervals. Through equations between parameters and height at 50 years, one can substitute these parameters in Korf's function to obtain a general formula that can be used to calculate height index curves.

$$H = I50 \exp \frac{A_1 \exp A_2/H_{50}}{1-A_3-(A_4/H_{50})} T^{1-A_3-(A_4/H_{50})} - 50^{1-A_3-(A_4/H_{50})}$$

where

H is the height that has been calculated

I50 is the site index

T is the age

A_1, A_2, A_3, and A_4 are the parameters defined above.

Figure 15 shows the site index curves. We have also established the height current increment curves (Figure 16). The shape of the curves (Figure 15 and 16) corresponds to the usual shape and this can be verified in the following comparisons.

The first comparison was made against some observed heights obtained through stem analysis (Figure 17). The slope and shape of the curves appear to be the same. The second comparison was made between height indices of 11, 14, and 17 and Ker's curves for 8 and 18 m; and between the first and Vézina's curves for the first and second class (Figure 18). The curves produced by other authors were obtained from normal yield tables. There is a similarity between Vézina's curves and ours. However, Ker's curves, especially those for the best classes, have a more pronounced sloped, indicating a more rapid growth; but the culmination of apical growth is also attained more rapidly.

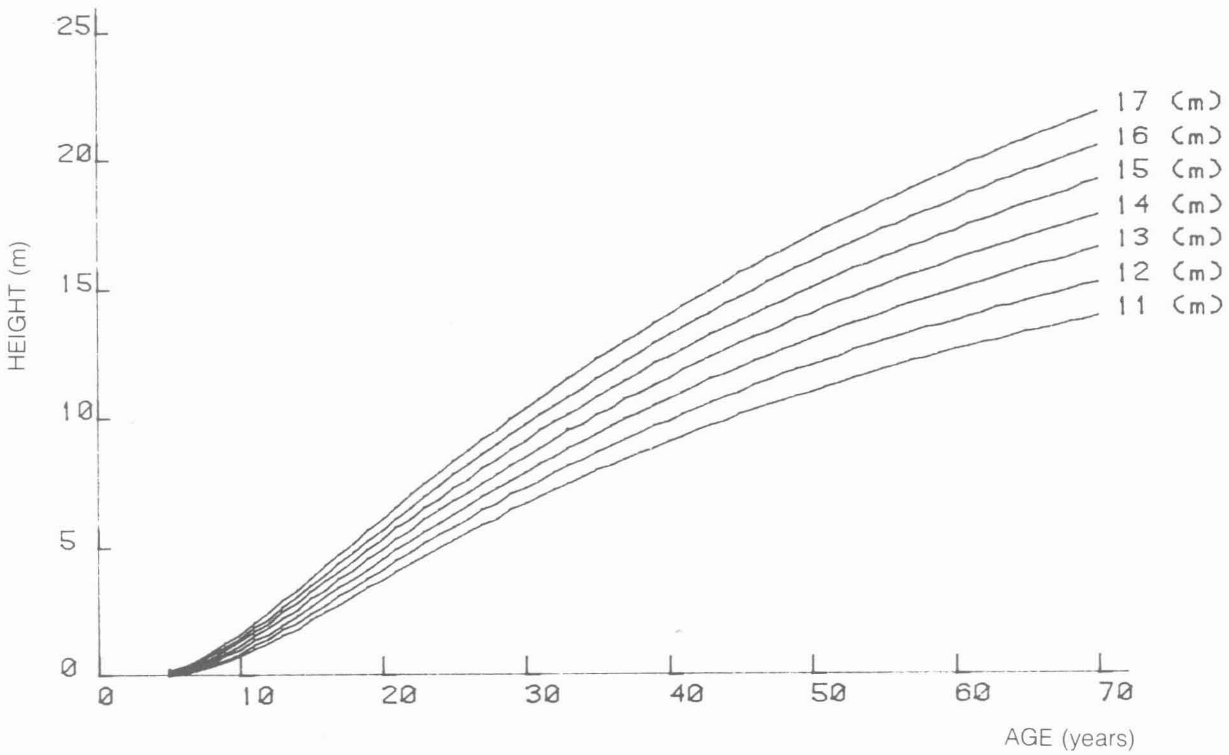

Figure 15. Site index curves for balsam fir.

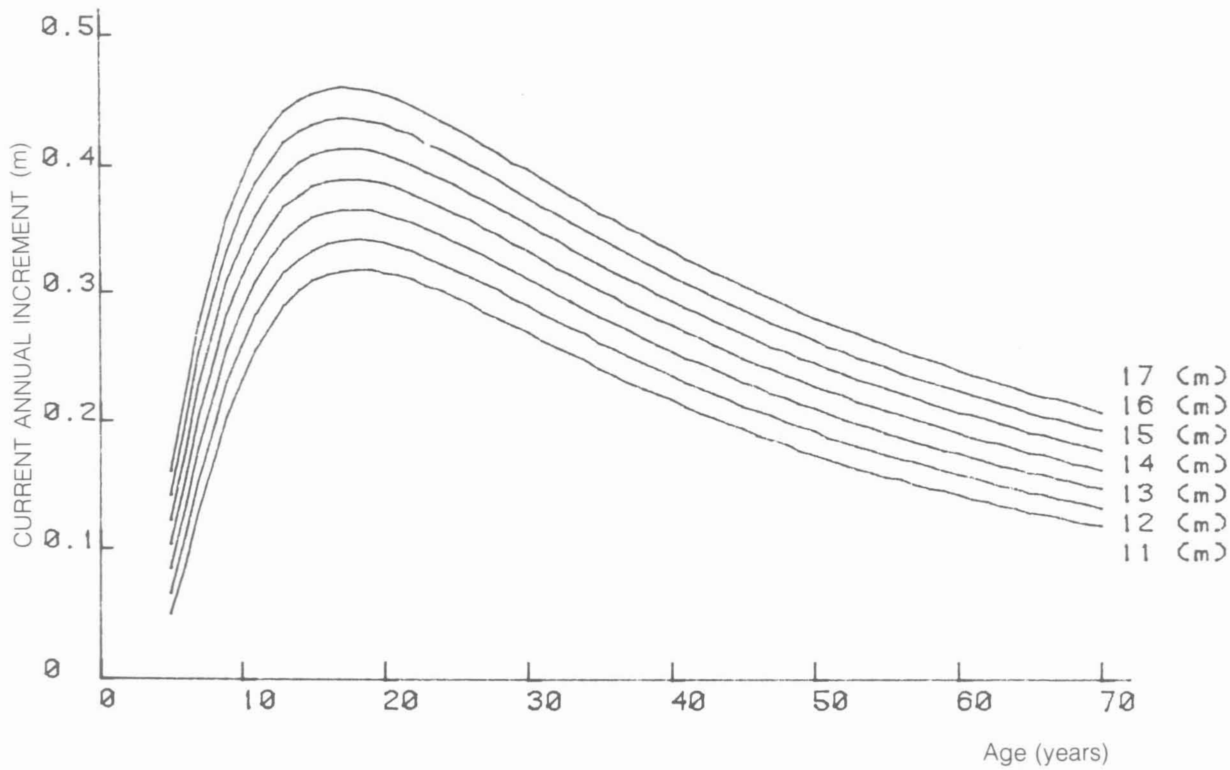

Figure 16. Current annual height growth curves for balsam fir.

Table 8. Parameters in Korf's function for 5 height growth curves in the balsam fir

Curve	Parameters C_1	C_2	C_3	R^2	H_{50} (m)	Residual sum of squares	Culmination CAI (years)	age for MAI (years)
H_m+2s_x	55.42569	10.95927	1.66423	0.998	16.24	4.43	17	37
H_m+s_x	48.14231	12.17426	1.69262	0.999	14.94	1.72	17	37
H_m	41.21879	13.82545	1.72710	0.999	13.64	0.28	18	37
$H_m - s_x$	34.64386	16.23897	1.77092	0.999	12.34	0.14	18	37
$H_m -2s_x$	28.39325	20.24318	1.83117	0.999	11.06	1.61	18	37

Finally, the last comparison concerned apical growth in relation to the coenological groups. This was done to verify the significance of these groups relative to height growth and, consequently, to yield. Height data was regrouped in age categories of 5 years for trees taken from stands with typical or dominant coenological group by the method previously used for the definition of height growth range. Tables 9, 10, and 11 show the means and standard deviations of the results obtained concerning apical growth and ground cover groups. Figure 19 illustrates this growth in terms of ground cover groups in the following order: 1st, 3rd, and 5th groups. Apical growth is almost identical in all three groups and statistically significant differences are absent.

To verify this result we also compared the specific weights of wood obtained from balsam fir, because stand influence on the quality of wood has been generally recognized. Our comparisons did not take into account the effects of anisotropy, which in balsam fir can be explained on the one hand in terms of juvenile growth and on the other by prevailing winds. However, the effects of anisotropy become less significant once a tree grows over 2 m tall.

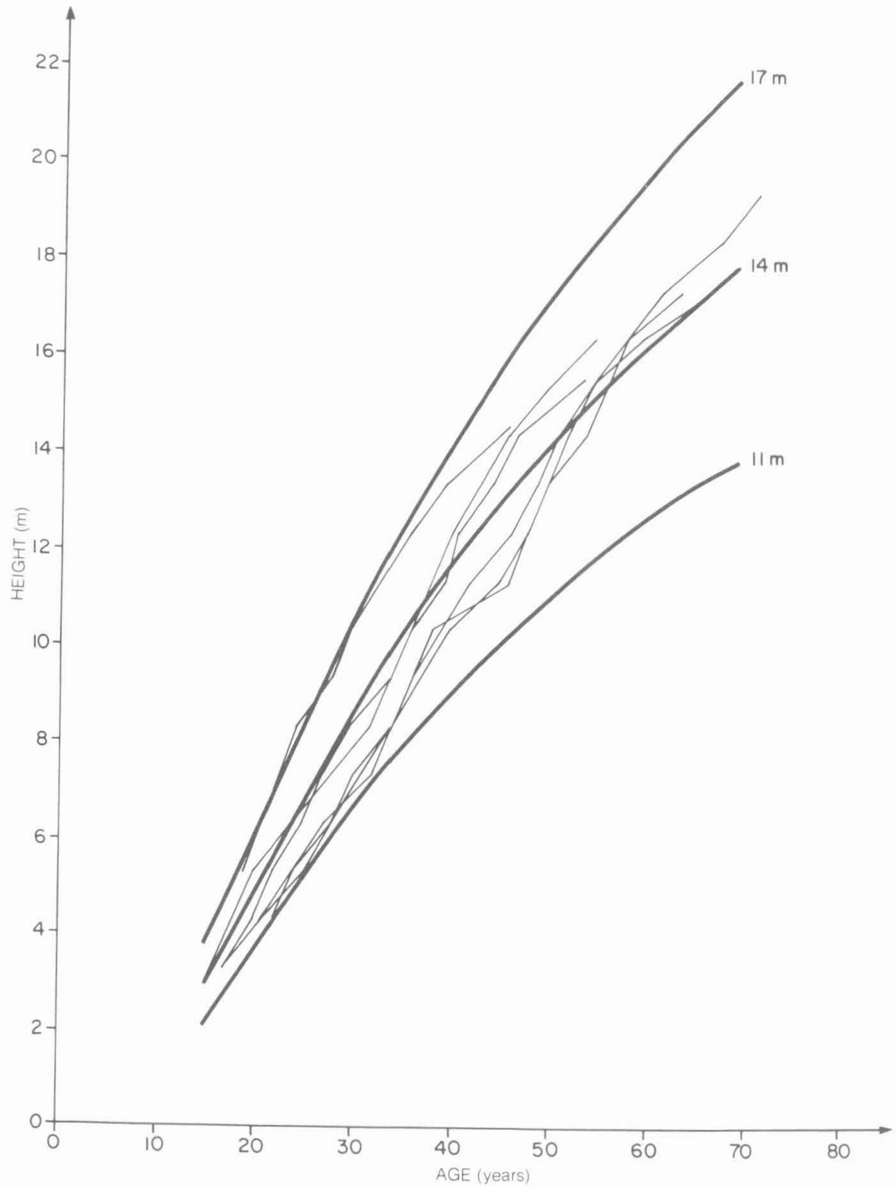

Figure 17. Comparison of site index curves with some heights established by stem analysis.

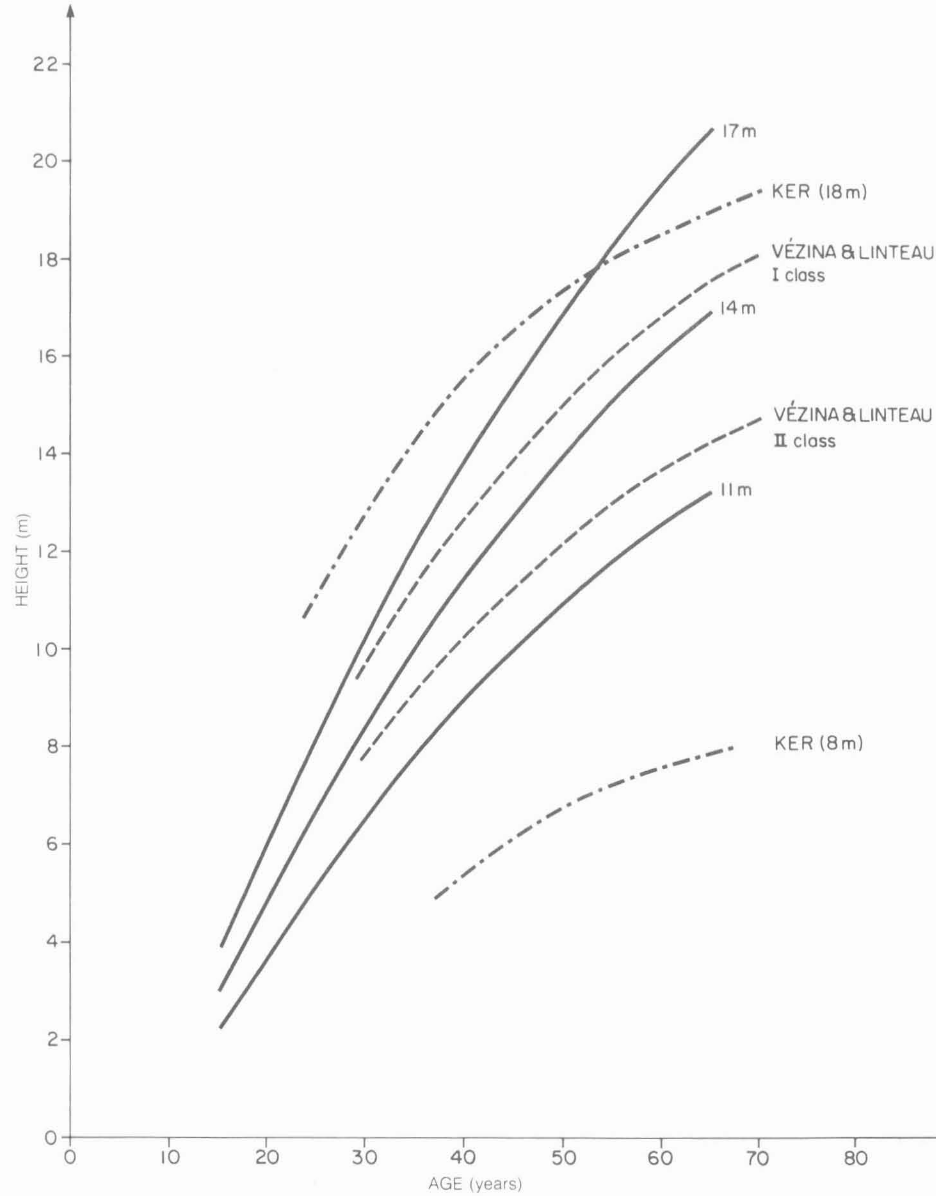

Figure 18. Comparison of site index curves with data published by Ker (1976) and by Vézina and Linteau (1968).

Table 9. Height growth in balsam fir in typical stands or those dominated by the first vegetation group, expressed in terms of mean height according to age class by intervals of 5 years

Age class (years)	Mean height (m)	Standard deviation (m)	Number of observations
15	2.71	0.50	37
20	4.36	0.67	36
25	5.98	0.78	37
30	7.58	0.81	32
35	8.86	0.80	27
40	10.36	0.92	34
45	11.62	0.95	25
50	12.85	1.08	23
55	13.70	1.19	21
60	15.07	0.75	16
		Total	288

Table 10. Height growth in balsam fir in typical stands of those dominated by the third vegetation group, expressed in terms of mean height according to age class by intervals of 5 years

Age class (years)	Mean height (m)	Standard deviation (m)	Number of observations
15	2.78	0.65	25
20	4.26	0.96	26
25	5.63	1.14	27
30	7.30	1.29	31
35	8.94	1.45	33
40	10.78	1.48	27
45	11.68	1.32	21
50	12.93	1.20	17
55	13.95	1.25	13
60	14.22	1.00	12
		Total	232

Table 11. Height growth in balsam fir in typical stands or those dominated by the fifth vegetation group, expressed in terms of mean height according to age class by intervals of 5 years

Age class (years)	Mean height (m)	Standard deviation (m)	Number of observations
15	2.66	0.49	28
20	4.44	0.80	36
25	6.23	0.96	29
30	7.82	1.03	30
35	9.52	1.14	30
40	11.30	1.17	20
45	12.49	1.18	16
50	13.59	1.06	14
55	14.39	1.32	10
60	15.80	1.41	8
		Total	221

Table 12. Wood density in balsam fir according to ground cover

Coenological group	Number of observations	Wood density (g per cm^2)		Coefficient of variation (%)
		Mean	Standard deviation	
1st group	87	0.359	0.041	11.4
3rd group	57	0.350	0.032	9.1
5th group	51	0.346	0.028	8.1

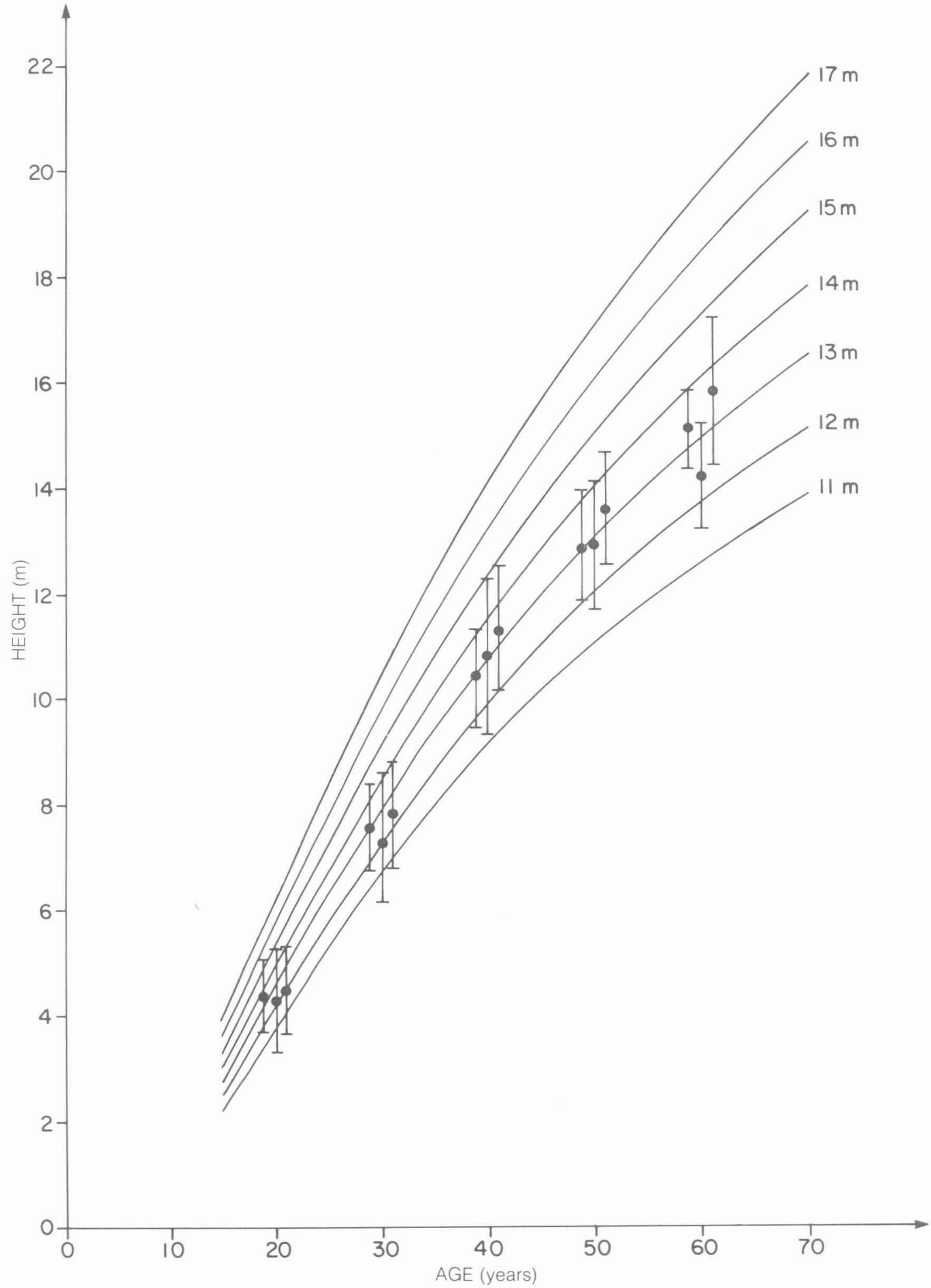

Figure 19. Height growth according to site index curves of coenological groups 1, 3 and 5 depending on age.

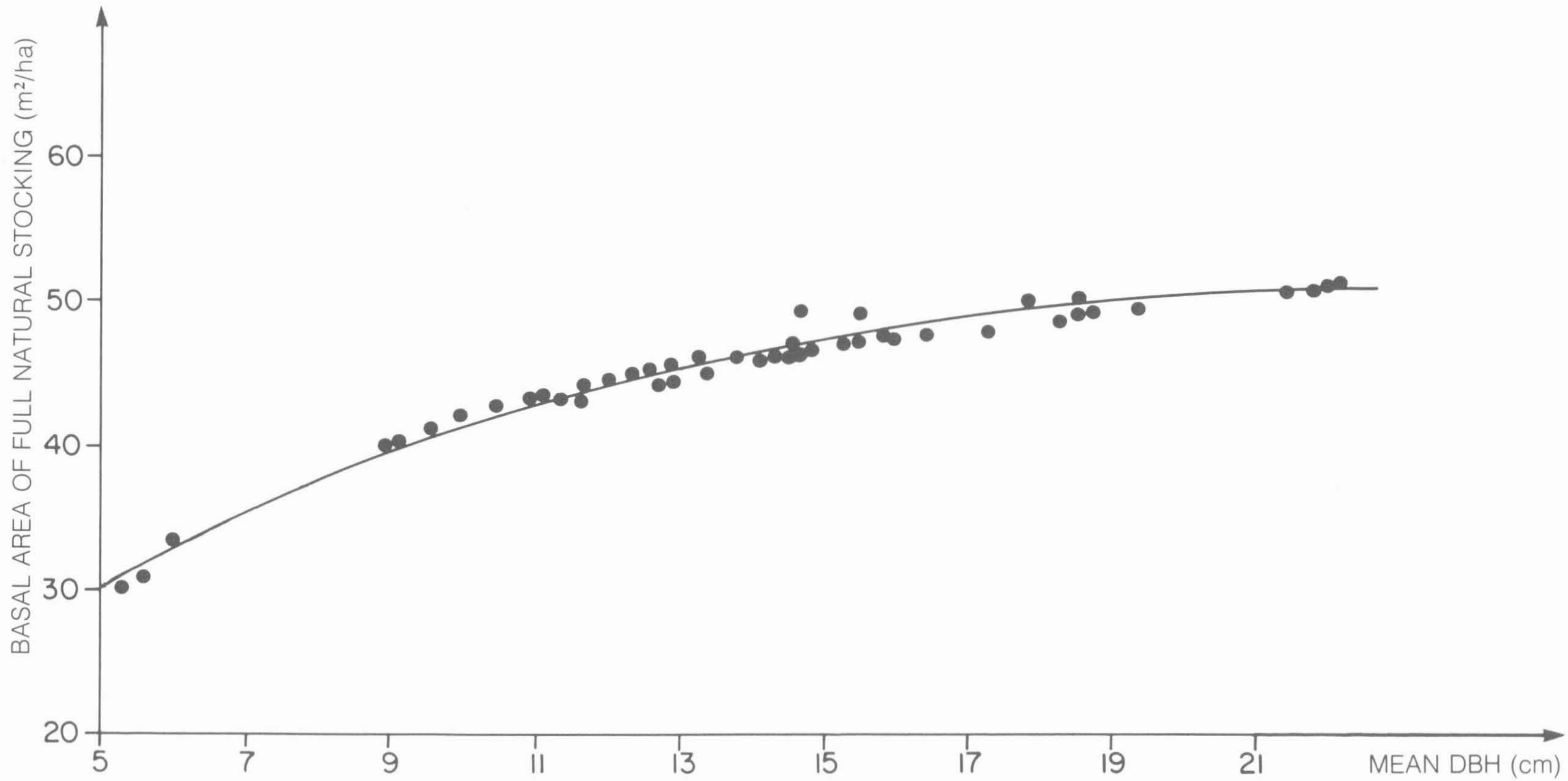

Figure 20. Yield level of fully stocked stands expressed as basal area per hectare according to the mean dbh of the stands.

Table 12 shows data obtained on balsam fir wood densities, expressed in terms of means and standard deviations per floristic group. It also shows that the wood density of balsam firs is practically the same from one ground cover group to the other. The same would probably also be true for the effects of stand ecological factors on the growth of balsam fir. Finally, the last check on the validity of the site indices established above refers to the comparison of yield in the 52 research stands located in the Lake Joffre area. It is important to remember that yield has been defined in terms of basal area in hectares for a stand providing full natural stocking, in relation to the average dbh of the stand. Figure 20 shows the order of the 52 stands according to these two criteria. It is easy to see that they line up perfectly, evidence of single level of production and, in my opinion, of the same level of stand quality.

CONCLUSION

An examination of the main characteristics of the 52 stands leads to the conclusion that they represent a single growth serie. The diametral structure of the research stands indicates that balsam fir populations tend to regularize themselves over time and to achieve practically normal distribution. The comparison between results presented in this paper on balsam fir and those obtained by Vézina and Linteau (1968) and Ker (1976) reveal a remarkable similarity. However, there are significant differences between our results and data reported by Boudoux (1978). The social position of the tree, has a greater influence on the height growth of balsam fir which is reflected in the length of the juvenile period and the physical age of the tree. Furthermore, we have found that insect outbreaks, though difficult to quantify, have a determining influence on height growth.

Because height growth appears the same for all ground cover groups, they cannot be used for forecasting stand yield. Comparisons of wood density confirmed these results. On the basis of the synecology of the three groups studied, we can only say that, at least for the region under consideration, these groups represent nothing more than normal phases in the evolution of a balsam fir stand over time.

It seems that the approach used to establish height growth patterns and site index is logical and relatively simple. On the basis of the results obtained, it appears that Korf's function is flexible enough to be used as a predictive model for height growth process. Even though the range of height growth at 50 years was sufficiently large to reflect several yield classes, the comparison of height growth between the main vegetation groups and the comparison of wood densities did not confirm these results. Furthermore, an examination of yield and form height in the 52 research stands indicates that stand quality is practically the same for the group of balsam fir sites studied and that site indices reflect nothing more than variations in height growth which can probably be explained by the effects of repeated spruce budworm outbreaks.

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REFERENCES

Assmann, E. 1955. Die Bedeutung des "erweiterten Eichhornschen Gesetzes" für die Konstruktion von Fichten-Ertragstafeln. Forstwiss. Cbl., 74:321-330.

Assmann, E. 1961. Waldertragskunde. BLV München, 490 p.

Assmann, E. 1965. Die Schätzung jetziger und künftiger Ertragsleistungen. Forstwiss. Cbl., 85:355-371.

Assmann, E. 1974. Zum Begriff "Ertragsniveau". Forstwiss. Cbl., 93:177-179.

Assmann, E.; Franz, F. 1963. Vorläufige Fichten-Ertragstafel für Bayern. München, Institut für Ertragskunde der Forstlichen Forschungsanstalt, 104 p.

Badoux, E. 1969. Les tables de production. La Forêt. 232:30-35.

Beck, D.E. 1971. Height-growth patterns and site index of white pine in the southern Appalachians. For. Sci. 17:252-260.

Blais, J.R. 1961. Spruce budworm outbreaks in the Lower St. Lawrence and Gaspé Regions. For. Chron. 37:192-202.

Blais, J.R.; Martineau, R. 1960. A recent spruce budworm outbreak in the Lower St.Lawrence and Gaspé with reference to aerial spraying operation. For. Chron. 36:209-224.

Bolghari, H.A. 1977. Hauteur dominante et indices de qualité des stations dans les plantations d'épinette blanche et de Norvège. Nat. Can. 104:475-484.

Bolghari, H.A.; Vézina, P.-E. 1974. Estimation de l'accroissement et de la production des sapinières de diverses densités. Qué. Minist. Terres For., Serv. Rech. Mém. n° 18.

Bolghari, H.A.; Vézina, P.-E. 1975. L'influence de quelques caractéristiques du peuplement et du milieu sur la croissance en volume du sapin baumier et de l'épinette noire au Québec. Nat. Can. 102:339-352.

Boudoux, M. 1978. Tables de rendement empirique pour l'épinette noire, le sapin baumier et le pin gris du Québec. Qué. Minist. Terres For., Serv. Inf. 101 p.

Boudoux, M.; Bonenfant, F. 1979. SACADOS. Système automatique conversationnel d'analyse de données Statistiques. Environ. Can., Serv. Can. For., Cent. Rech. For. Laurentides, Sainte-Foy, Qué. Rapp. Inf. LAU-X-39. 22 p.

Bradley, R.T.; Christie, J.M.; Johnson, D.R. 1966. Forest Management Tables. Booklet 16, For. Comm., London, 218 p.

Bruce, D.; Schumacher, F. 1950. Forest mensuration. McGraw-Hill. New York, 483 p.

Busby, J.R.; Bliss, L.C.; Hamilton C.D. 1978. Microclimate control of growth rates and habitats of the boreal mosses, *Tomenthypmum nitens* and *Hylocomium splendens*. Ecological Monographs 48: 95-110.

Cantiani, M. 1964. Tavola alsometrica delle pinete de laricio dell'Etna. [Production tables for Corsican pine at Etnap]. [In Italien]. L'Ital. For. e Montana, 1:98-115.

Carmean, W.H. 1979. A comparison of site curves for northern hardwood species. U.S. Dept. Agric. For. Serv., North Cent. For. Exp. Stn., St.Paul, Minnesota. Res. Pap. NC-167, 12 p.

Commission Canadienne de Pédologie, Comité de la classification des sols. 1978. Le système canadien de classification des sols. Can. Minist. Agric. publ. n° 1646. 170 p.

Curtis, R.O. 1964. A Stem-Analysis approach to site-index curves. For. Sci. 10: 241-256.

Decourt, N. 1965. Le Pin sylvestre et le Pin laricio de Corse en Sologne. Tables de production provisoires et méthodes utilisées pour les construire. Ann. Sci. forest., 22:257-318.

Decourt, N. 1973. Production primaire, production utile: Méthodes d'évaluation, indices de productivité. Ann. Sci. forest., 30:219-238.

Dixon, W.T. 1977. BMDP, Biomedical Computer Programs, P-Series, Univ. Calif. Press, Berkeley, Calif.

Duchovnikov, J. 1972. Tablici za bonitirane na belborovi nasazdenia po gospod-stvuvascata visocina. [Site index evaluation tables, according to height, for pine stands]. [In Bulgarian] Gorsko stopanstvo 28:24-28.

Franz, F. 1971. Grundlagen und Verfahren standortbezogener Leistungsschätzung. Forstl. Forschungsanstalt, München, Nr. 2, 316 p.

Gagnon, R.M. 1970. Climat des Chic-Chocs. Qué. Minist. Rich. Nat. 103 p.

Gobeil, A.R. 1938. Dommages causés aux forêts de la Gaspésie par les insectes. Qué. Minist. Terres For., Serv. Ent. Bull. n° 2. 16 p.

Griffin, R.H.; Johnson, J.E. 1980. Polymorphic site index curves for spruce and balsam fir growing in even-aged stands in Northern Maine. Life Sci. Agric. Exp. Stn., School For. Resour., Univ. Gutte Maine, Orono, Me. Bull. 765.

Guttenberg, A.R. 1915. Wachstum und Ertrag der Fichte im Hochgebirge. Franz Deuticke, Wien und Leipzig, 156 p.

Halaj, J. 1978. Vyskovy rast a struktura porastov. [Height growth and structure of stands]. [In Slovak]. Slov. Akad. Vied, Bratislava 284 p.

Hamilton, G.J.; Christie, J.M. 1973. Forest Management Tables. Booklet 34, For. Comm. London. Booklet 34. 201 p.

Heger, L. 1968. A method of constructing site index curves from stem analysis. For. Chron. 44:11-15.

Hradetzky, J. 1972. Modell eines integrierten Ertragstafel-Systems in modularer Form. Inaugural-Dissertation, Freiburg i. Br. 172 p.

Jurdant, M. 1964. Carte phytosociologique et forestière de la Forêt expérimentale de Montmorency. Can. Minist. For. Publ. 1946. 73 p.

Ker, M.F. 1976. Metric yield tables for the major forest cover types of Newfoundland. Environ. Can., Can. For. Serv., Nfld. For. Res. Cent., Inf. Rep. N-X-141.

Korf, V. 1953. Dendrometrie. [Forest mensuration]. [In Czech]. Stat. zem. nakl., Praha, 327 p.

Lafond, A. 1967. Notes pour l'identification des types forestiers des concessions de la Québec North Shore, Paper Co., 3e édition. Imprimerie Laize Ltée., Hauterive, Qué. 93 p.

Lebuis, J.; David, P.P. 1977. La stratigraphie et les événements du quaternaire de la partie occidentale de la Gaspésie, Québec. Géogr. Phys. Quat. 21:275-296.

Linteau, A. 1957. Classification des stations forestières de la Section des Conifères du Nord-Est, Région des Forêts Boréales, Québec. Can. Dep. North. Aff. Nat. Resour., For. Br., Bull. No. 118. 85 p.

Logan, K.T. 1969. Growth of trees seedlings as affected by light intensity. IV. Black spruce, White spruce, Balsam fir, and Eastern White cedar. Dep. Fish. For., Can. For. Serv., Publ. No. 1256. 12 p.

Martineau, R. 1943. Population studies of the European spruce sawfly (*Gilpinia hercyniae* Htg.) in Québec. For. Chron. 19:87-107.

McKeague, J.A. 1977. Manuel de méthodes d'échantillonnage et d'analyse des sols, Sous-comité des méthodes d'analyse, Comission canadienne de pédologie, 223 p.

Panek, F. 1976. Construction of the site class curves by means of Korf's equation. Les. Cas. 22:129-139.

Piene, H. 1978. Effects of increased spacing on carbon mineralisation rates and temperature in a stand of young balsam fir. Can. J. For. Res. 8:398-406.

Popovich, S. 1974. Volume par unité de surface terrière, comme moyen d'évaluer la productivité de stations et la production des plantations d'épinette blanche au Québec. Can. J. For. Res. 4:127-137.

Robinson, J.F., Thor, E. 1969. Natural variation in Abies of the Southern Appalachians. For. Sci. 15:239-245.

Rowe, J. 1972. Forest Regions of Canada, Can. Dep. Environ., Can. For. Serv., Publ. No. 1300, 172 p.

Schmidt, A. 1969. Der Verlauf des Höhenwachstums von Kiefern auf einigen Standorten der Oberfalz. Forstwiss. Centralbl. 88:33-40.

Schütz, J.-Ph.; Badoux, E. 1979. Production de jeunes peuplements de chênes en relation avec la station. Mitt. schweiz. Centralanst.

Schwappach, A. 1902. Unterschungen über Wachstum und Ertrag normaler Fichtenbeständes in Preussen. Neudamm Verlag, Berlin. 199 p.

Tesch, S.D. 1981. The evolution of forest yield determination and site classification. For. Ecol. Manage. 3:169-182.

Tveite, B. 1969. A method for construction of site-index curves. Medd. Nor. Skogforsoksves. 97:132-159.

Veuilleux, J.-M.; Sheedy, G. 1978. Projet interprovincial de fertilisation des forêts naturelles. I-Effets de la fertilisation sur quelques caractéristiques de sept sapinières en Gaspésie. Qué. Minist. Terres For. Serv. Rech. Mém. n° 45.

Vézina, P.-E.; Linteau, A. 1968. Growth and yield of balsam fir and black spruce in Quebec. Can. For. Res. Lab. Inf. rep. Q-X-2.

Villeneuve, P. 1971. Calcul de l'erreur d'échantillonnage. Qué. Min. Terres For. Serv. Rech. Mém. n° 5.

Zarnovican, R. 1979. Fonction de la croissance de Korf. For. Chron. 55:194-197.

Zarnovican, R. 1981. A propos de l'âge du sapin baumier et de sa détermination. Can. J. For. Res. 11:805-811.

Zarnovican, R. 1982. Examen de quelques relations allométriques chez le sapin baumier et l'épinette blanche. Can. J. For. Res. 12:171-180.

Zarnovican, R.; Gerardin, V.; Ducruc, J.P.; Jurdant, M; Audet, G. 1976. Les régions écologiques du territoire de la Baie James. Environ. Can. Rapp. ETBJ n°, 28, Env. Can.-SDBJ. 12. p.

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