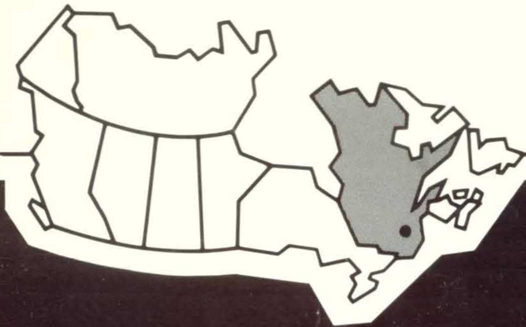
Government of Canada
Gouvernement du Canada

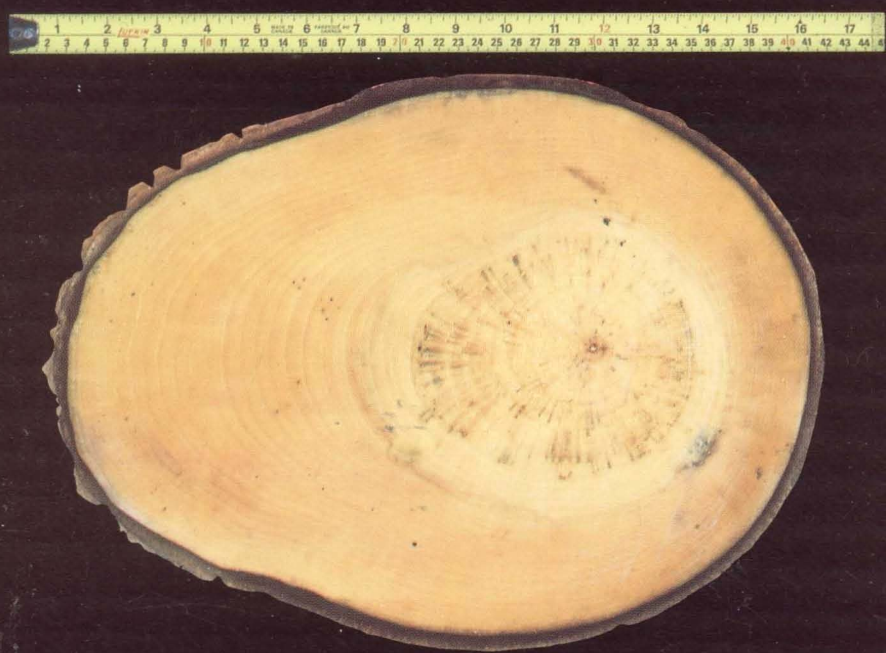
Canadian Forestry Service
Service canadien des forêts

Allometry, growth, yield, and prices for aspen in the Témiscouata region of Quebec

Richard Zarnovican and Denis Ouellet



Information Report LAU-X-78E
Laurentian Forestry Centre



CENTRE DE FORESTERIE DES LAURENTIDES

Le Centre de foresterie des Laurentides (CFL) est un des six établissements régionaux du Service canadien des forêts (SCF). Le Centre poursuit des travaux de recherche et de développement pour un aménagement et une utilisation plus rationnels des ressources forestières du Québec. En collaboration avec divers groupes et organismes québécois, les chercheurs du CFL visent à acquérir une meilleure compréhension du fonctionnement des écosystèmes forestiers en vue de contribuer à solutionner les problèmes majeurs en foresterie au Québec et à développer des méthodes acceptables pour l'amélioration et la sauvegarde de l'environnement forestier.

Au Québec, les activités du SCF portent sur trois éléments majeurs: la recherche dans le domaine des ressources forestières, la recherche dans le domaine de la protection et enfin, le développement forestier. La plupart des travaux sont entrepris pour répondre aux besoins des organismes intéressés à l'aménagement forestier, surtout dans le but d'améliorer la protection, la croissance et la qualité de la ressource forestière de la région. L'information est diffusée sous forme de rapports scientifiques, de feuillets techniques ou autres publications dans le but d'atteindre toutes les catégories d'utilisateurs des résultats de recherche.

LAURENTIAN FORESTRY CENTRE

The Laurentian Forestry Centre (LFC) is one of six regional establishments of the Canadian Forestry Service (CFS). The Centre's objective is to promote, through research and development, the most efficient and rational management and use of Quebec's forest. In cooperation with several Quebec agencies, scientists at LFC seek to acquire a better understanding of how the forest ecosystem works with a view to solving major forestry problems and develop methods to improve and to protect the forest environment.

In the province of Quebec, CFS's program consists of three major elements: forest resources research, forest protection research, and forest development. Most of the research is undertaken in response to the needs of forest management agencies, with the aim of improving the protection, growth, and quality of the region's forest resource. The results of this research are distributed to potential users through scientific and technical reports and other publications.

Allometry, growth, yield, and prices for aspen in the Témiscouata region of Quebec

Richard Zarnovican and Denis Ouellet

Information Report LAU-X-78E
1987

Laurentian Forestry Centre
Canadian Forestry Service

Copies are available free of charge from:
Laurentian Forestry Centre
Canadian Forestry Service
1055 du P.E.P.S.
P.O. Box 3800
Sainte-Foy, Quebec
G1V 4C7

Catalog No. Fo46-18/78E
ISSN 0835-1570
ISBN 0-662-15847-4

Aussi disponible en français sous le titre: <<Peuplier faux-tremble au Témiscouata: Allometrie, croissance, production et évolution des prix du bois>>.

Copies or microfiches of this publication may be purchased from: Micro Media Inc., Place du Portage, 165, Hôtel-de-Ville, Hull, Quebec J8X 3X2

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

Page

LIST OF TABLES

LIST OF TABLES (CONT'D)

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

RÉSUMÉ

La transformation des peuplements forestiers exige de l'aménagiste une connaissance approfondie de différents aspects concernant la production, la sylviculture, les conditions des prix du marché pour les assortiments à produire et ceci, aussi bien pour l'essence actuelle que pour l'essence future.

Dans cette optique, le présent rapport d'information analyse un certain nombre de questions que soulève la transformation des peuplements de peuplier faux-tremble, *Populus tremuloïdes* Michx., dans les forêts privées du Bas-Saint-Laurent et particulièrement dans la région du Témiscouata.

L'étude de la production de cette essence fut concentrée à l'analyse de relations allométriques et temporelles pour évaluer la croissance en principales grandeurs dendrométriques, les tarifs de cubage, la structure des peuplements et la morphologie des arbres d'une part et d'autre part pour apprécier la production de différents assortiments selon les normes actuelles de transformation. Le dernier aspect de cette analyse, à savoir la production des assortiments en relation avec les résultats sur l'évolution des prix permettront d'apprécier

ABSTRACT

Conversion of forest stands oblige the forest manager to have a thorough knowledge of several aspects concerning yield, silvicultural practices, and market prices of wood products for both existing species and those of the future.

This report deals with problems raised by the conversion of private aspen-forest, *Populus tremuloides* Michx., lands in the Lower St. Lawrence, and specifically the Témiscouata region.

This study focused on allometric and temporal relationships, the purpose being to track the principal growth-related parameters over time, establish volume tables, stand structure and tree morphology, and determine the yield of wood that is suitable, according to current standards, for various purposes. These latter findings, concerning assortment, are related to price changes affecting activity on private forest lands.

The report concludes with a brief look at tree defects that might lead to volume losses.

l'intensité de la sylviculture dans les peupleraies privées du Témiscouata.

Enfin, le rapport est complété par un examen rapide des défauts susceptibles d'engendrer des pertes en volume chez le peuplier faux-tremble.

INTRODUCTION

A direct consequence of the reforestation program of the Quebec Ministère de l'Énergie et des Ressources (MER) has been an increase in the conversion of aspen forests in the Lower St. Lawrence region and the Gaspé Peninsula.

Conversion was carried out by clear-cutting, which led to a rapid saturation of the market for this species, a drop in prices, and often a complete stoppage of work by forest cooperatives and private woodlot owners. Much of the work, often undertaken on highly productive sites, has been motivated more by reforestation grants than by an adequate knowledge of aspen growth. To provide assistance in conversion efforts, we undertook a study of aspen at Lake Squatec, in cooperation with the Groupement forestier de l'Est du Lac Témiscouata (Eastern lake Temiscouata forest group venture). This particular area was selected because of the forest composition: the upper story is dominated by aspen *Populus tremuloides Michx.* and most of the trees have reached commercial size.

The main goal of the study was to analyse the various aspects of aspen growth. This involved first a study of allometric relationships (volume tables, assortment tables, diameter distribution in the forest) and second a study of temporal relationships (tracking the various growth-related parameters over time).

The report also contains a brief look at the extent of aspen pathology in the area, as well as statistics on volumes cut and on price fluctuations for various aspen products.

DESCRIPTION OF REGION

Location

The aspen stand studied is a part of the JAL experimental forest in Témiscouata County (Rouillard township). It is situated 6 km east of the village of Auclair and belongs to the Groupement forestier de l'Est du Lac Témiscouata. The Laurentian Forestry Centre, Canadian Forestry Service (CFS) signed an agreement with this cooperative, giving the CFS the right to carry out research on the intensive management of deciduous forests.

The area is elongated and covers about 7 ha. It is on the upper part of a rounded hill having a 12 percent slope and a southern exposure. The geographical coordinates are 47°43' latitude north and 68°34' longitude west: the altitude is 325 m above sea level.

Climate

The climate is the temperate continental type (Villeneuve 1959). According to Wilson (1971), the mean annual temperature is about 2.5°C, the mean length of the growing season is between 160 and 170 days, and the mean annual precipitation is 1 000 mm, a third of which is in the form of snow.

Soil

According to Lespérance and Greiner (1969), the Lake Squatec region belongs to the Témiscouata (Devonian) geological region and is characterized by siltstone and slaty schists (Gerardin 1985). The soils belong to the Glassville series (Rochefort 1981)--well drained and relatively thin, with the solum not exceeding 75 cm. The texture is fairly fine, with a predominance of loams. Stoniness increases with depth. The base saturation rate is very high: 80 percent for the humus and 70 percent for Horizon B. The C/N ratio, 17 for the humus and 12 for Horizon B, indicates rapid decomposition of organic matter.

Given these physical and chemical charactersitics, the soils compare favorably with the best sites observed by Blouin and Grandtner (1971) and Gagnon et al. (1978) in the Lower St. Lawrence. However the thinness of the soil and the presence of porous parent rock result in a water deficit during dry summers (Gerardin 1985).

Vegetation

The immediate area belongs to the sugar maple yellow birch climax described by Grandtner (1966), as is characteristic of mesic sites. The forest is in section L6 (Témiscouata - Restigouche) of the Great Lakes - St. Lawrence forest region (Rowe 1972).

There has been considerable human impact on the vegetation in the area. Lavoie (1984) points out that as far back as the early 19th century private companies held vast concessions here, and excessive harvesting led to the disappearance of several species such as white pine and elm. It frequently happened that climax forests were replaced by others, especially aspen.

The predominant tree in the forest is trembling aspen, accompanied by sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britton). There is also a shrub story here and there, composed of mountain maple (*Acer spicatum* Lam.), stripped maple (*Acer pensylvanicum* L.), and red-berried elder (*Sambucus pubens* Michx.). There is almost no moss because the canopy is closed.

EXPERIMENTAL DESIGN AND DATA GATHERING

A rectangle 200 by 140 m was selected in the middle of the forest and divided into 70 plots measuring 20 m on each side. The trees in each plot were counted by species and by dbh class, beginning at 4 cm. The results were used to determine the structure of the plots, in terms of diameter and density, with a view to their experimental conversion into a regular forest of white pine (*Pinus strobus* L.) and Norway spruce (*Picea abies* [L.] Karst.).

Aspen growth was examined on the basis of an analysis of 30 dominant trees. The criteria for selection were that there be no visible defect on crown or trunk, and that the dbh of the tree be as near as possible to the dbh at the 95th percentile on the cumulative frequency curve of the trees in its plot.

The 30 trees were analyzed by the method described in Zarnovican (1985), which gives a reconstruction of tree growth over time in terms of various growth-related parameters. Table 1 shows the results for dbh, height, age, and volume classes. It will be seen that the distribution of the trees is almost normal for dbh, volume, and height, but that the distribution for age is bimodal, with the maximums in the 35- and 50-year classes.

RESULTS AND DISCUSSION

Structure of aspen stands

Aspen is a heliophyte, therefore an aspen stand consists of a single story with a simple vertical structure and diameter distribution. However when other species--especially sciophytes--are present, the stand will have several storys and a more complex structure. Because it is difficult for aspen to regenerate naturally from seed in a shaded environment, aspen stands tend to turn into stands of shade-tolerant species.

Reconstructing growth and development over time requires a knowledge of diameter distribution in aspen stands, and some idea of how they change into other types of stands. For this purpose, observations were made of the Lake Squatec forest and of stands in the Lake Matagami region.

Figure 1 shows the diameter distribution for plot 52 at Lake Squatec, in terms of trees per hectare and dbh class for three species: sugar maple (SM), yellow birch (YB), and trembling aspen (TA). Aspen forms the dominant story,

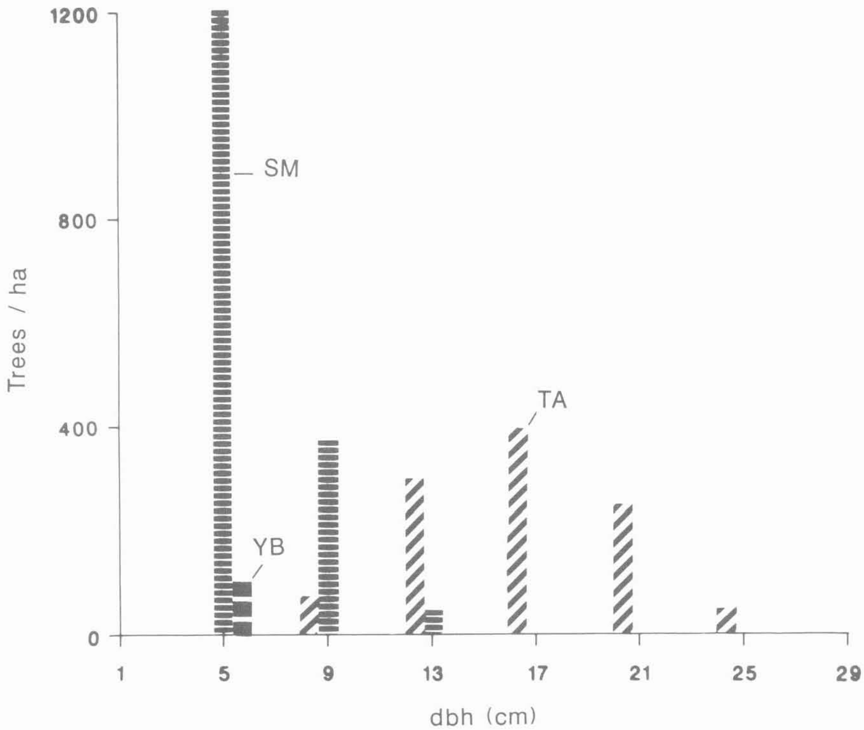


Figure 1. Number of trees per hectare by dbh class for Lake Squatec: plot 52.

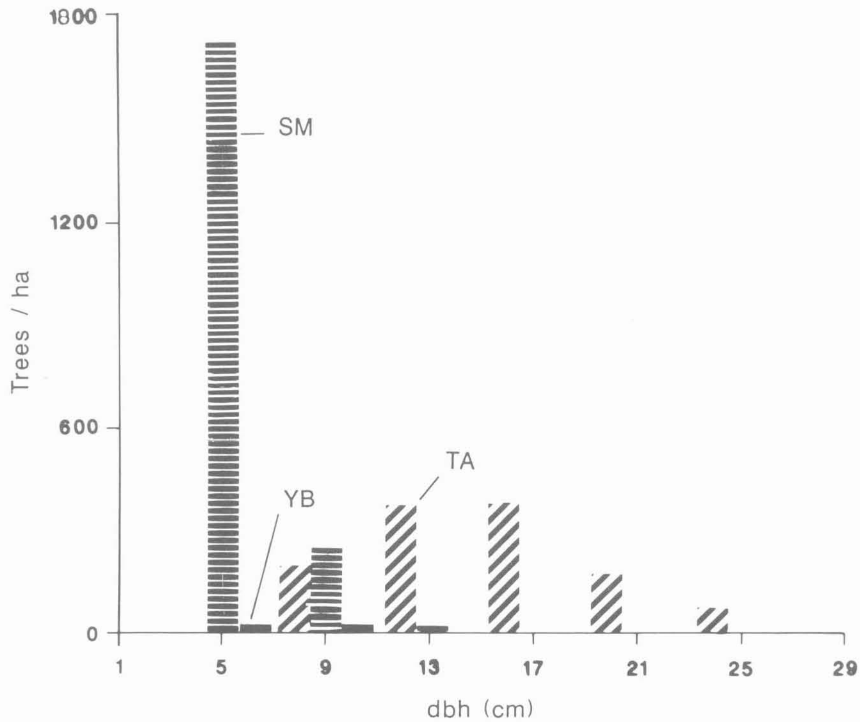


Figure 2. Number of trees par hectare by dbh class for Lake Squatec: plot 4.

Table 1. Number of trees by dbh class, height class, age class, and volume class, for 30 dominant aspen at Lake Squatec

Dbh (cm)	Height (m)			Age (yrs)				Volume (inside bark)(dm³)						Σ
	20	22	24	35	40	45	50	550	650	750	850	950	1050+	
26	1	3		2	2			4						4
28		3	2	3			2		5					5
30	1	3	3	2			5			6	1			7
32	3	5	1	4	1	1	3			4	5			9
34			3			1	2					2	1	3
36		1					1				1			1
38														
40			1				1						1	1
Σ	5	15	10	11	3	2	14	4	5	10	7	2	2	30

and has a near-normal distribution. Yellow birch and sugar maple form the lower story, and their distribution is highly asymmetric (skewed to the right). The same situation is found at Lake Squatec plot 4 (Figure 2).

Figures 3 and 4 show the distribution of black spruce (BS) (*Picea mariana* [Mill.] BSP) and trembling aspen (TA). It will be seen that aspen forms the upper story, while spruce, being shade-tolerant, forms the lower story. As a result, this aspen stand will be transformed with time into a black spruce stand.

The aspen distribution shown in Figure 3 is normal, while the spruce distribution both there and in Figure 4 is approaching normal.

Figure 5 shows how, on productive sites, an aspen forest can be transformed through the appearance of complex, multi-storyed structures. This site at Lake Matagami has three storys: a dominant

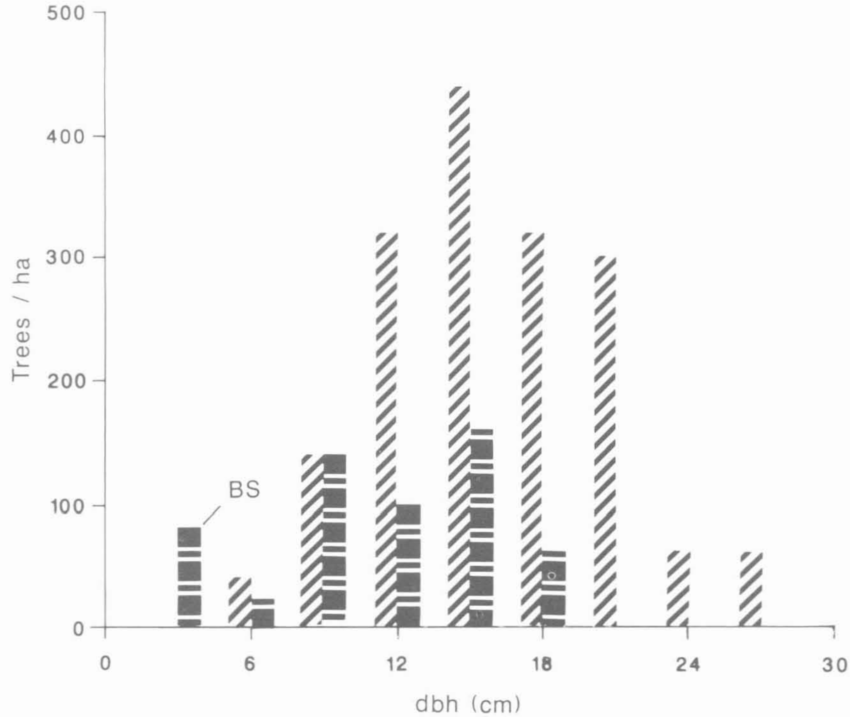


Figure 3. Number of trees per hectare by dbh class for Lake Matagami: plot 264.

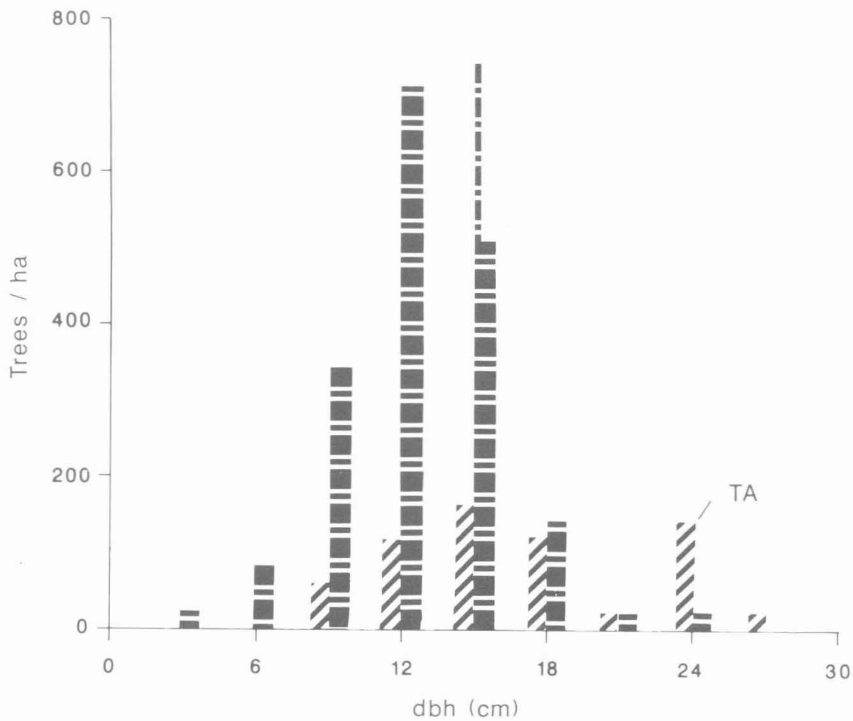


Figure 4. Number of trees per hectare by dbh class for Lake Matagami: plot 632.

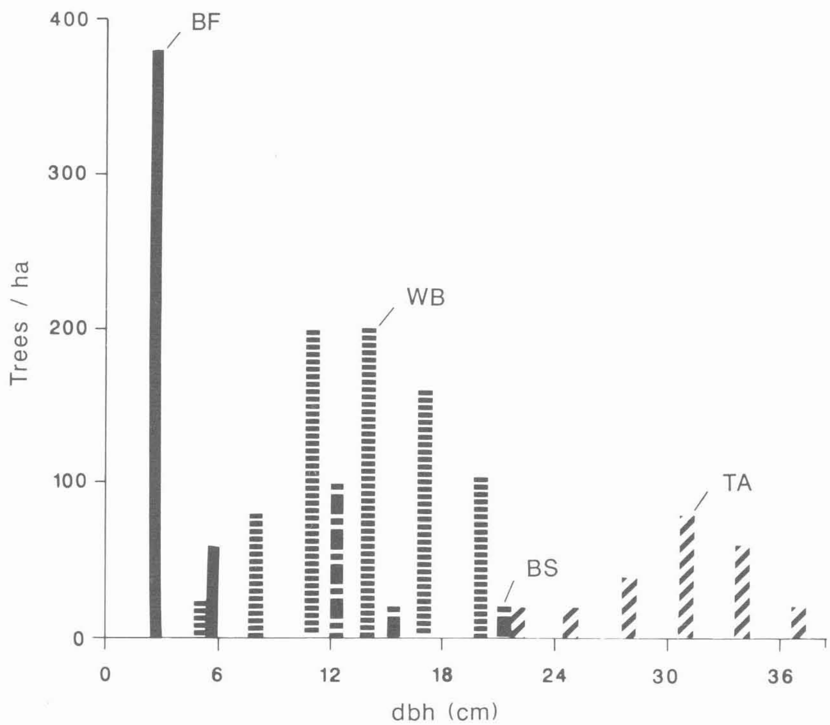


Figure 5. Number of trees per hectare by dbh class for Lake Matagami: plot 654.

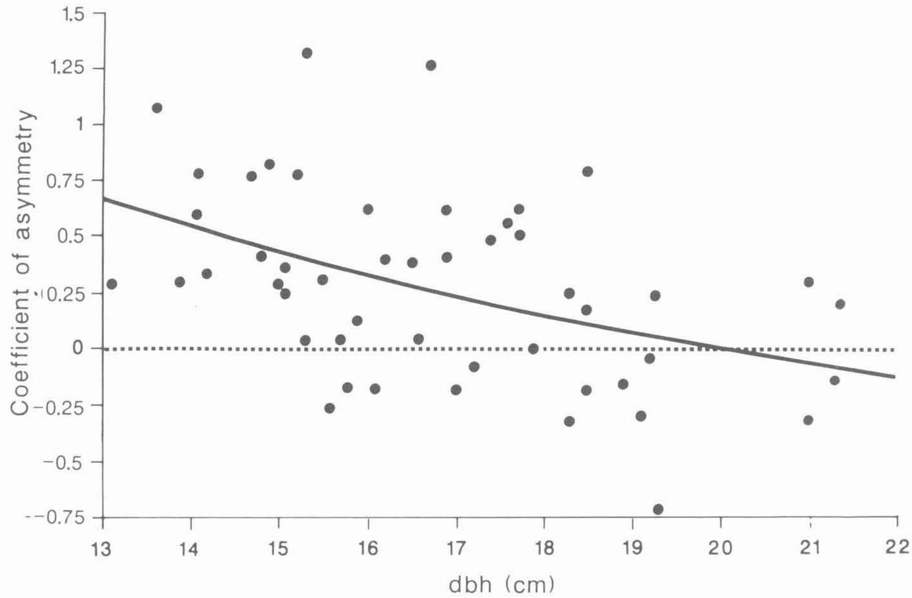


Figure 6. Mean dbh vs coefficient of asymmetry for 50 aspen plots at Lake Squatec.

aspen story, an intermediate story of white birch (WB) (*Betula papyrifera* Marsh.) and black spruce, and a lower story of balsam fir (BF) (*Abies balsamea* [L.] Mill.). The distribution in the upper storys is near-normal while in the lower story it is asymmetric.

This situation is indicative of a gradual natural transformation involving sciophytes and hemisciophytes. The result is better use of space and an increase in yield.

Figure 6 shows the relationship, for 50 plots at Lake Squatec, between the mean dbh of aspen in each plot and the coefficient of asymmetry of the dbh distribution within that plot. The results demonstrate that the distribution of diameters in an aspen forest shifts over time from right-skewed to normal. This normalizing tendency justifies the assumption of a mean regional yield and makes it possible to construct predictive models for changes in aspen forests over time.

Allometry of aspen

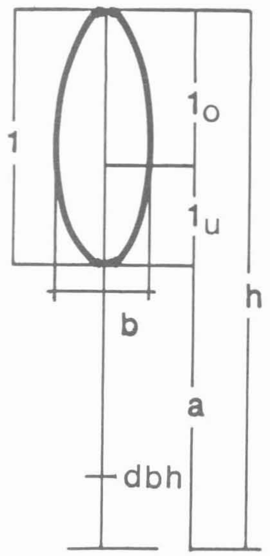
Morphology

Modern silviculture rests in large part on an understanding of tree morphology and stand architecture. Anyone undertaking work to increase forest quality and yield needs morphological data to determine the setup mixture and regulate the growing space of the best trees.

In view of this, certain aspects of tree morphology were examined (Figure 7), using as a basis the work of Burger (1939), Assmann (1961), and (Zarnovican 1982).

From the parameters of Figure 7, the following further parameters can be determined: l/h = the crown ratio; l_o/l = part of the crown exposed to sunlight; l_u/l = the shaded part of the crown; b/n = the crown-width to tree-height ratio; b/h = (the degree of spread of the crown); b/l = the crown taper; l/b = the crown fullness ratio, its reciprocal value has also been used as the crown index; b/dbh = the growing-space factor; and h/dbh = the tree taper. The study was on the morphology of 30 dominant trees in the wooded massif of Lake Squatec in Témiscouata. The measurements (Figure 7) were taken from trees felled and the main statistics on the morphology of these trees are shown in Table 2.

The morphological characteristics (Figure 8) make it possible for us to give the following description for aspen: for a dbh of 30.4 cm and a height of 22.4 m, the height of the crown (l) and the bole correspond to an average of 52



h = tree height
l = crown length (including living branches only)
l_o = part of crown exposed to sunlight
l_u = shaded part of crown
a = height of the base of the crown
b = crown width
dhb = diameter at 1.3 m

Figure 7. Tree morphology parameters.

and 48 percent of the total height respectively. The relationship between h/dbh varies from 60 to 85 for an average of 74. While the relationship between the width of the crown and the dbh varies from 12 to 22. Diameter of the growth space is an average of 17 times larger than the dbh of the tree. Therefore, the average crown area is about 300 times larger than the mean basal area of the studied trees.

The part of the crown (l_o) exposed to sunlight represents 44 percent of the length of the crown. The degree of expansion of the crown (b/h) is 23 percent, relatively weak. Finally, the exposure of the crown (b/l) is fairly important, that is 44 percent in relationship to the height of the crown.

The crown of this average aspen (with a dbh of 30.4 cm) has the form of an ellipsoid, a volume of about 165 m^3, and an area of 210 m^2.

Volumes

a) Data acquisition

To construct general volume tables, measurements are normally taken from a certain number of felled trees. However this requires a considerable amount of field work and a large number of trees ranging over all the sizes involved. Given our limited human and financial resources, we used stem analysis instead, and this yielded a true and precise picture of tree growth and development.

Table 2. Statistics on tree morphology parameters for 30 dominant aspen at Lake Squatec

Dbh (cm)	h (m)	a (m)	l (m)	b (m)	l_0 (m)	l_u (m)	h/dbh	l/h (%)	l_0/l (%)	l_u/l (%)	b/l (%)	b/h (%)	b/dbh (%)	
30.4	22.4	10.6	11.7	5.2	5.2	6.6	74	52	44	56	44	23	17	[1]
3.1	1.3	1.6	1.7	1.0	1.3	1.5	7	7	9	9	7	4	3	[2]
25.5	19.6	7.9	8.3	3.6	3.5	3.5	60	38	30	36	30	15	12	[3]
40.5	24.9	13.8	16.5	7.6	7.8	9.1	85	68	65	70	57	31	22	[4]

[1] mean; [2] coefficient of variation; [3] minimum; [4] maximum

Parameters:

l/h= 52 % l_0/l= 44 %

b/h= 23 %   b/l= 44 %

b/dbh= 17   h/dbh= 74.2

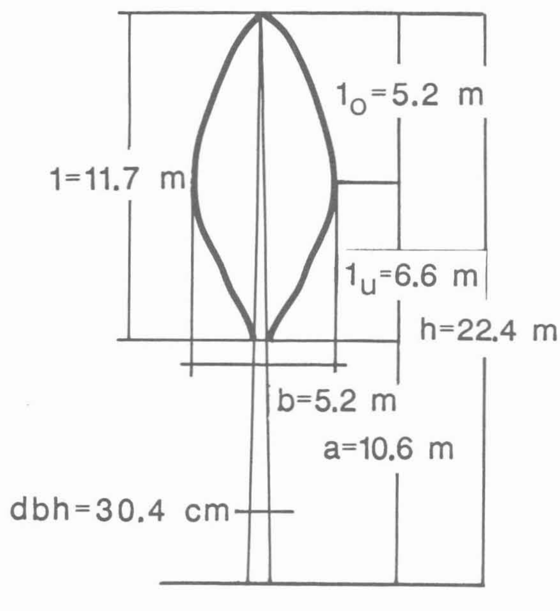


Figure 8. Morphology of typical aspen.

Table 3. Results of stem analysis for tree #SQ0100118 at Lake Squatec

AGE AT 0.4 METRE= 0

AGE	DBH -	ANNUAL INCREMENT CURRENT	MEAN	BASAL AREA	ANNUAL INCREMENT CURRENT	MEAN	VOL -	ANNUAL INCREMENT CURRENT	MEAN	HEIGHT-	ANNUAL INCREMENT CURRENT	MEAN	FORM FACTOR	FORM HEIGHT
2	0.00		0.000	0.00		0.00	0.05		0.026	1.30		0.650	0.000	0.00
		0.392			0.24			0.105			0.333			
4	0.78		0.196	0.48		0.12	0.26		0.065	1.97		0.492	2.747	5.40
		0.813			2.04			0.483			0.917			
6	2.41		0.402	4.57		0.76	1.23		0.204	3.80		0.633	0.707	2.69
		1.215			6.92			1.837			0.750			
8	4.84		0.605	18.41		2.30	4.90		0.613	5.30		0.663	0.502	2.66
		0.921			8.34			3.172			1.000			
10	6.68		0.668	35.08		3.51	11.25		1.125	7.30		0.730	0.439	3.21
		0.916			10.93			5.539			1.000			
12	8.51		0.710	56.95		4.75	22.32		1.860	9.30		0.775	0.422	3.92
		0.915			13.56			8.452			0.500			
14	10.35		0.739	84.06		6.00	39.23		2.802	10.30		0.736	0.453	4.67
		0.904			15.98			10.381			0.500			
16	12.15		0.760	116.01		7.25	60.39		3.774	11.30		0.706	0.461	5.21
		0.909			18.65			12.332			0.333			
18	13.97		0.776	153.32		8.52	85.05		4.725	11.97		0.665	0.464	5.55
		0.652			14.98			13.122			0.667			
20	15.28		0.764	183.28		9.16	111.30		5.565	13.30		0.665	0.457	6.07
		0.821			20.77			15.266			0.333			
22	16.92		0.769	224.82		10.22	141.83		6.447	13.97		0.635	0.452	6.31
		0.938			26.32			20.236			0.667			
24	18.80		0.783	277.46		11.56	182.30		7.596	15.30		0.637	0.429	6.57
		0.469			14.20			14.465			0.250			
26	19.73		0.759	305.86		11.76	211.23		8.124	15.80		0.608	0.437	6.91
		0.427			13.51			16.094			0.250			
28	20.59		0.735	332.87		11.89	243.42		8.694	16.30		0.582	0.449	7.31
		0.588			19.55			20.671			0.250			
30	21.76		0.725	371.98		12.40	284.76		9.492	16.80		0.560	0.456	7.66
		0.528			18.50			19.143			0.250			
32	22.82		0.713	408.97		12.78	323.05		10.095	17.30		0.541	0.457	7.90
		0.439			16.04			18.165			0.200			
34	23.70		0.697	441.05		12.97	359.38		10.570	17.70		0.521	0.460	8.15
		0.472			17.92			20.981			0.200			

Table 3. (cont'd)

AGE	DBH -	ANNUAL INCREMENT CURRENT	MEAN	BASAL AREA	ANNUAL INCREMENT CURRENT	MEAN	VOL -	ANNUAL INCREMENT CURRENT	MEAN	HEIGHT-	ANNUAL INCREMENT CURRENT	MEAN	FORM FACTOR	FORM HEIGHT
36	24.64		0.684	476.88		13.25	401.34		11.148	18.10		0.503	0.465	8.42
		0.472			18.62			20.661			0.600			
38	25.58		0.673	514.11		13.53	442.66		11.649	19.30		0.508	0.446	8.61
		0.563			23.14			28.512			0.586			
40	26.71		0.668	560.39		14.01	499.69		12.492	20.47		0.512	0.436	8.92
		0.448			19.10			25.196			0.173			
42	27.61		0.657	598.59		14.25	550.08		13.097	20.82		0.496	0.441	9.19
		0.379			16.66			26.073			0.173			
44	28.37		0.645	631.91		14.36	602.22		13.687	21.16		0.481	0.450	9.53
		0.486			22.00			31.762			0.173			
46	29.34		0.638	675.92		14.69	665.75		14.473	21.51		0.468	0.458	9.85
		0.179			8.28			13.893			0.173			
48	29.69		0.619	692.49		14.43	693.53		14.449	21.85		0.455	0.458	10.02
		0.466			22.07			29.632			0.173			
50	30.63		0.613	736.63		14.73	752.80		15.056	22.20		0.444	0.460	10.22
WITH BARK														
50	32.76			843.02			850.91			22.20			0.455	10.09

DBH (cm); ba (cm²); Vol (dm³); tree height and form height (m)

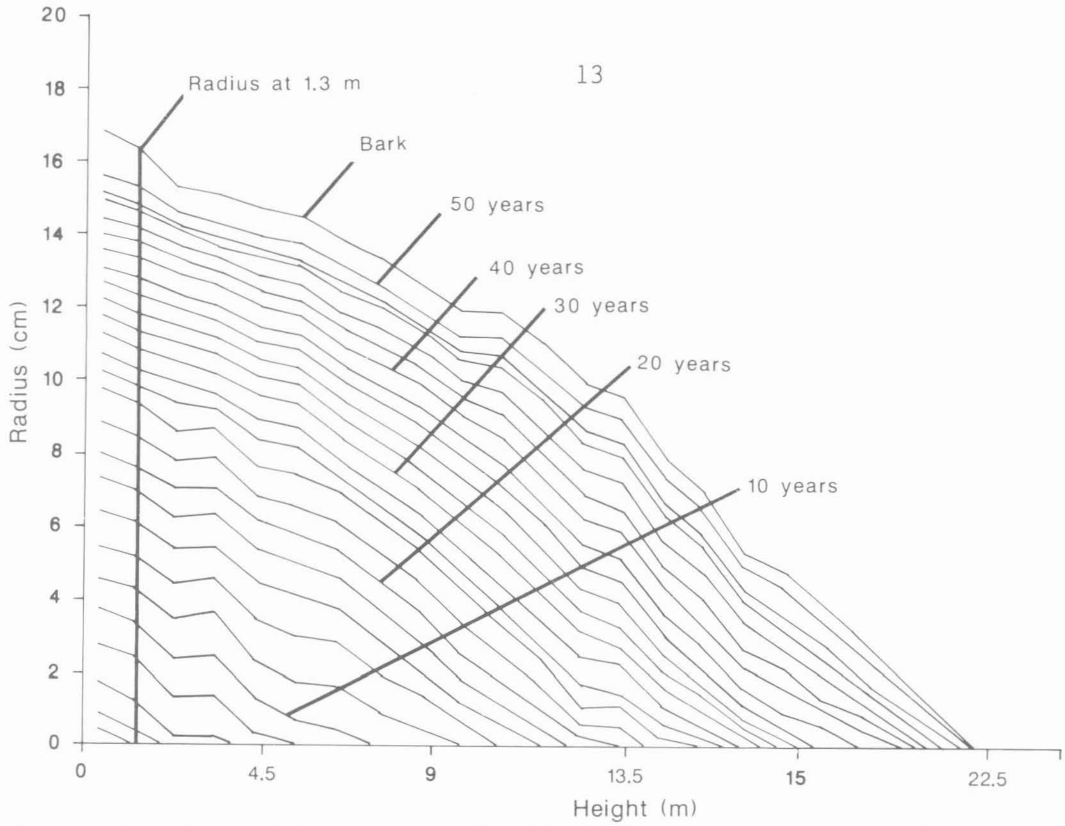


Figure 9. Radius by height on tree #SQ0100118 at 2-year intervals.

Table 3 shows the results of stem analysis for tree #SQ0100118 at Lake Squatec. Figure 9 shows the radius by height on the tree at 2-year intervals from 1935 to 1985, when this particular tree was felled. The main allometric and temporal relationships established for the aspen are based on such stem analyses.

On the whole, 636 trees were analyzed for dbh, height and volume, and their increments. Bear in mind that the diameter, volume, and increment data refer to the tree inside bark.

b) Volume tables

The relative homogeneity of the measurements shown in Table 4 reflects the uniformity of the site conditions, and justifies the use of single-entry volume tables based on dbh. This table shows that while there were few trees with a dbh over 32 cm, other sizes are well represented.

c) Height vs diameter

Figure 10 shows the relationship between total tree height and dbh to be parabolic in form or polynomial. The fit of the data in Table 4 to a second-degree polynomial distribution is quite good. Using the least squares method, with a height of 1.3 m for dbh = 0, R-squared 0.997, and the standard error of estimate for the mean height is 8.2 percent. For practical purposes, confidence intervals were established, at the 99 percent level

Table 4. Number of trees by dbh and height for 636 aspen at Lake Squatec

	Height												
Dbh (cm)	2	4	6	8	10	12	14	16	18	20	22	24	Σ
2	54	30											84
4		9	24	1									34
6			7	21									28
8			1	13	13								27
10				2	22	7							31
12					7	20	2						29
14					1	18	12						31
16					1	5	24	7					37
18						1	14	15	5				35
20							5	21	11				38
22							1	10	21	12			44
24								4	17	18	5		44
26								1	13	22	22		58
28									5	15	16	5	41
30									1	8	26	7	42
32										4	12	6	22
34											2	4	6
36											1		1
38												2	2
40												2	2
Σ	54	39	32	37	44	51	58	58	73	80	84	26	636

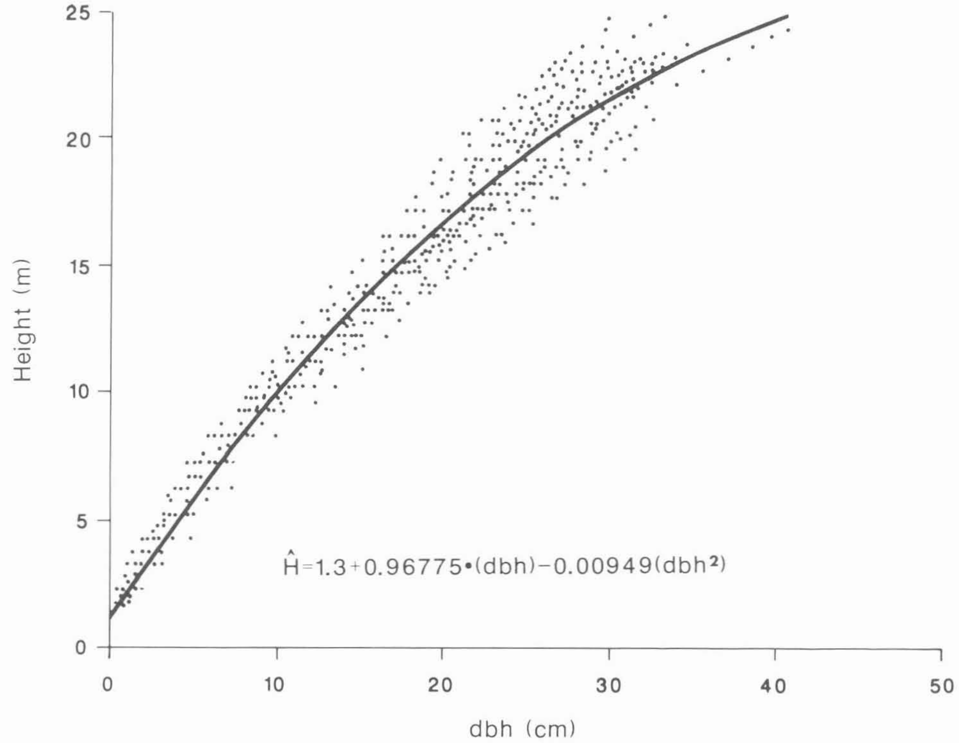


Figure 10. Tree height vs dbh (inside bark).

Table 5. Tree height and diameter statistics for trees with dbh of 10-32 cm

Dbh (cm)	n	Mean height (m)	Standard deviation (m)	Limits of confidence interval (m)	
				lower	upper
10	32	10.3	0.9	9.8	10.8
12	30	11.5	0.9	11.1	11.9
14	32	12.9	1.0	12.4	13.4
16	37	13.9	1.2	13.4	14.4
18	36	15.4	1.2	14.9	15.9
20	49	16.5	1.4	15.9	17.1
22	45	17.9	1.5	17.3	18.5
24	46	19.2	1.6	18.6	19.8
26	60	20.3	1.6	19.8	20.8
28	43	21.0	1.5	20.4	21.6
30	44	21.8	1.3	21.3	22.3
32	24	22.3	1.2	21.6	23.0

for the mean height of each dbh class. Since the diameters are normally distributed, and the mean dbh represents the trees of the dominant story, the confidence intervals shown on Table 5 can be considered an objective measure of spatial validity of the volume table.

Given the number of trees per dbh class between 10 and 32 cm, together with the variability (Table 5), it can be shown that at least 11 dominant aspen must be measured in order to determine the mean height with a precision of 5 percent at the 95 percent level.

d) Volume vs dbh

The relation between the dbh and the volume of the trunk inside bark is exponential in form (Figure 11). The distribution of data on the 636 trees fit an allometric model whose parameters were established using the P3R program of Biomedical Computer Programs (Dixon 1985). The standard estimate of error for the mean volume is 15.5 percent. Note that the regression of Figure 11 is heteroscedastic: the variance of the residuals increases with dbh. For practical purposes we would suggest using the local volume table (Table 6) to establish volumes for diameters between 10 and 32 cm. The last column gives the error to be expected (at the 95 percent level) when using the table to establish plot volumes.

In our view, the regression of Figure 11 could be used profitably to calculate the volume of aspen having a dbh inside bark of more than 32 cm.

e) Bark volume

The volume of a standing tree is made up of the volume of the wood and the volume of the bark. While the bark is an integral part of the tree, its volume must be quantified separately because its presence poses numerous problems at the mill. Several studies (Meyer 1946; Loetsch 1950; Korsun 1955; Smelko 1962; Kozak and Yang 1981) have shown that the volume of the bark depends on the species, the region, and most of all on the diameter of the tree. Using data on the bark and on tree height and diameter, Bélanger and Dumont (1974) showed that the thickness of the bark is independent of the height of the tree. The bark portion of a tree's volume is often estimated using the "k" factor (Meyer 1946), which is based on a linear relation between dbh outside bark (o.b.) and dbh inside bark (i.b.). However according to Korsun (1955), Wolf (1962) and Smelko (1962), there is no simple ratio ($dbh_{o.b.}$/ $dbh_{i.b.}$) between the two diameters, because the straight line

Table 6. Volume table for trees with dbh of 10-32 cm

Dbh (cm)	Volume inside bark (dm^3)	Standard deviation (dm^3)	Error at 95% level
10	37.8	8.1	7.8
12	59.7	9.1	5.9
14	89.5	13.5	5.5
16	128.0	22.1	5.8
18	175.1	25.2	5.0
20	228.2	30.8	4.4
22	300.9	39.8	4.0
24	389.6	54.9	4.3
26	490.6	71.4	3.8
28	582.7	71.0	3.8
30	696.2	66.2	3.0
32	798.8	80.9	4.5

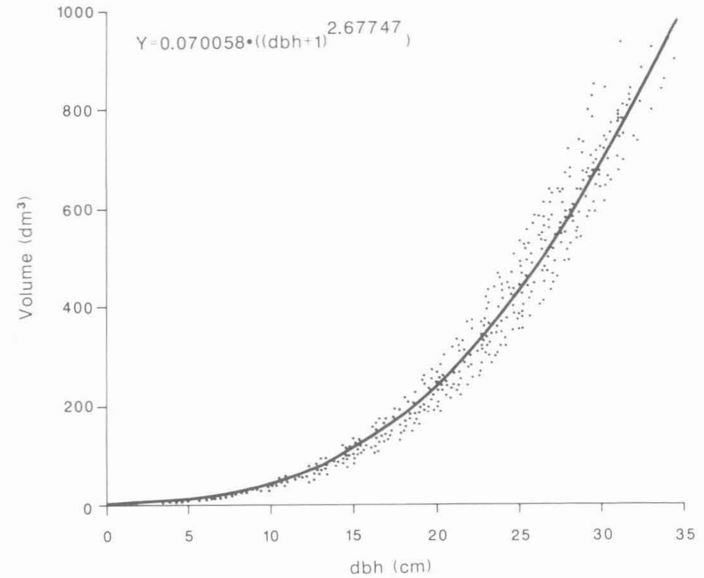


Figure 11. Volume (inside bark) vs dbh (inside bark).

Table 7. Statistics on bark of aspen

DBH (cm)	Number of observations	Thickness (cm)	s.d. of thickness	Bark as % of volume	s.d. bark as % of volume	"k" factor
10	83	0.88	0.20	20.4	5.3	1.09708
12	80	1.02	0.25	19.7	5.5	1.09363
14	100	1.14	0.22	18.5	4.3	1.08838
16	99	1.19	0.25	16.8	3.8	1.08053
18	119	1.30	0.24	16.3	3.5	1.07812
20	143	1.32	0.25	14.8	3.2	1.07123
22	164	1.41	0.36	14.3	4.0	1.06898
24	202	1.41	0.34	13.0	3.5	1.06282
26	225	1.51	0.36	12.8	3.5	1.06181
28	201	1.57	0.41	12.3	3.5	1.05982
30	173	1.62	0.40	11.8	3.1	1.05727
32	129	1.74	0.48	11.9	3.6	1.05762
34	74	1.82	0.52	11.7	3.6	1.05671

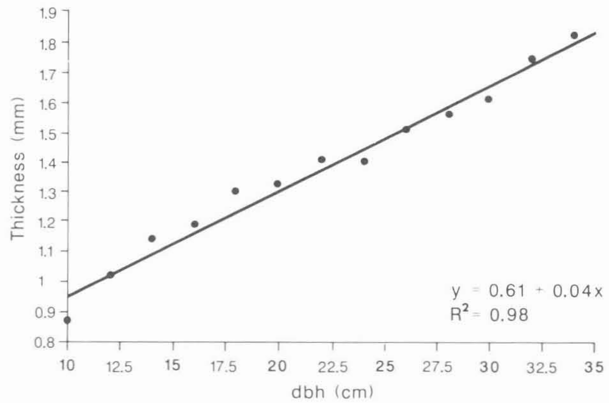


Figure 12. Bark thickness vs dbh for aspen

Table 8. Regression statistics for bark thickness vs dbh

Y: Bark thickness (cm); X: DBH (cm)

N.D.F.	R^2	Absolute s.e. (cm)	Relative s.e. (%)
12	0.98	0.04	2.87

Regression Coefficients

Parameter:	Value:	Std. Err.:	Variance:	T Value
B_0	0.61	0.03	0.00116	17.73
B_1	0.04	0.00147	0.00000216	23.97

Analysis of variance table

Source	N.D.F.	Sum of squares	Mean square	F test
REGRESSION	1	0.9	0.9	574.44
RESIDUAL	11	0.02	0.00157	$p \leq 0.0001$
TOTAL	12	0.92		

Residual information table

SS[e(i)-e(i-1)]:	e≥0:	e≤0:	Dw Test
0.02	7	6	1.22

representing the relationship does not pass through the origin: the equation has to be of the form $k = a+b.dbh_{o.b.}$ Also, according to Kozak and Yang (1981), the "k" factor is a highly variable and biased estimator; they say that in order to use it to estimate bark thickness, it is necessary to have observations of at least 11 different cross-sections.

For the present study, 1 718 measurements of radii outside and inside bark were used. They represent various cross-sections of the tree. For each dbh class, Table 7 gives the number of observations, the mean thickness of the bark and the corresponding standard deviation, the mean percentage volume represented by the bark and the corresponding standard deviation, and the mean value of the "k" factor.

The relation between bark thickness and dbh is linear, as seen in Figure 12. Table 8 gives the results of the regression analysis.

The Y-intercept test for the regression equation gives a t_c value of 17.73 with 11 degrees of freedom, which is several times the threshold value (4.427 at the 99.9 percent level). This confirms that there is no simple ratio between the dbh outside and inside bark.

The relationship between the dbh outside bark and the bark volume as a percentage of total volume has the form of a decreasing second-degree polynomial (Figure 13). As the variance analysis of Table 9 shows, the equation provides a very good representation of the relationship.

Thus aspen bark varies in thickness from 10 mm, for a $dbh_{o.b.}$ of 10 cm, up to 19 mm for a $dbh_{o.b.}$ of 32 cm. And the bark volume as a percentage of total volume varies from 20 percent, for a $dbh_{o.b.}$ of 10 cm, down to 12 percent for a $dbh_{o.b.}$ of 32 cm.

f) Assortment volumes

The calculation of assortment volumes is generally based on a mathematical description of tree form: a solid of revolution is generated from the taper curve representing the shape of the tree (Désaulnier 1980). However with this approach a problem arises in selecting the regression equation, which has to express observed radii or diameters as a function of height (Hradetzky 1981).

It is quite difficult to find the appropriate equation if great precision is required, and this has led to the alternative approach of dividing up the bole into a number of characteristic

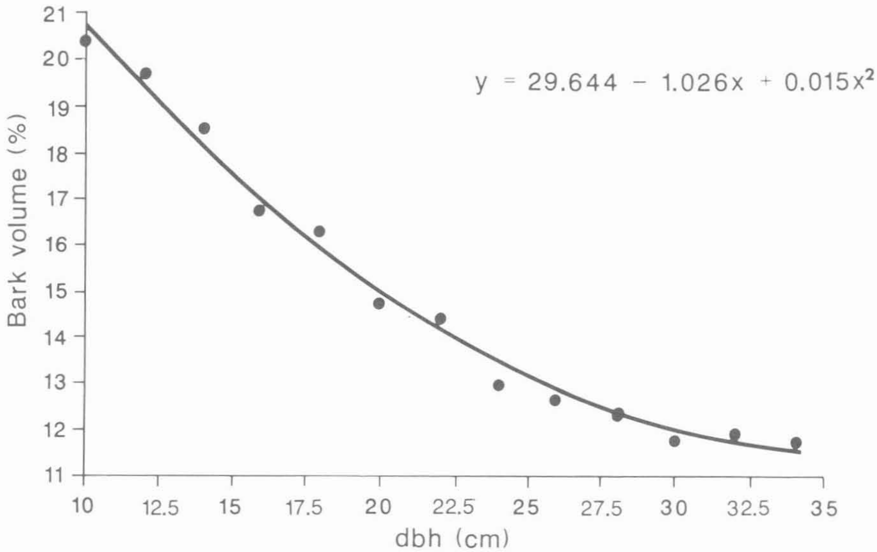


Figure 13. Dbh vs bark volume as percentage of total volume.

Table 9. Regression statistics for dbh vs bark volume as percentage of total volume

Bark volume/total volume X 100 X: DBH (cm)

N.D.F.	R^2	Absolute std. error	Relative std. error
12	0.99	0.29	1.92

Analysis of variance table

Source	N.D.F.	Sum of squares	Mean square	F test
REGRESSION	2	114.68	57.34	694.96
RESIDUAL	10	0.83	0.08	$p \leq 0.0001$
TOTAL	12	115.51		

Regression coefficients

Parameter	Value	S.E.	T - Value	Partiel F-test
B_0	29.64	0.73	40.6	
B_1	-1.03	0.07	-14.37	206.5
B_2	0.01	0.0016	9.08	82.47

segments, and describing these by simple functions (Schopfer 1972; Roiko-Jokela 1976). With this approach, however, there are problems of continuity at the segment boundaries.

Given the difficulties, it was decided to use a spline function to fit the morphological curves. In this approach, the tree height is divided into a number of intervals and third-degree polynomial is used to provide continuity for the tree-form curves at the points corresponding to the interval boundaries. The degree of the polynomial provides that there are no jumps and due to its second derivate, the spline curve is continous (Hradetzky 1981). With our spline function, we were able to identify radii corresponding to market sizes[1].

A program was written that establishes lengths available for each use, in terms of minimum diameter at the small end (10 cm for pulpwood, 20 cm for sawlogs, 28 cm for veneer logs) and divides these lengths into standard units (1.22 m for pulpwood, 2.5 m for sawlogs, 2.7 m for veneer logs). Assortment volumes were established by the section volume method, with lengths of 0.61 m for pulpwood, 0.5 m for saw timber, and 0.675 m for veneer logs and the stem shape was interpreted as the frustum of a cone. The merchantable volume is the volume corresponding to the minimum diameter greater than 7 cm at the small end.

Table 10 gives the resulting volumes for Lake Squatec aspen, by dbh class and height. Total volume is given in dm^3, while merchantable volume, pulpwood volume, sawlog volume and veneer log volume are given as percentages of total volume. Note how the pulp volume percentage increases very rapidly in small trees. Sawmill class volumes appear when dbh reaches 21 cm and height 16 m, while veneer class volumes appear when dbh reaches 29 cm and height 18 m.

Figures 14 and 15 show assortment volumes for a typical aspen as a function of age. Figure 14 shows the volumes in dm^3; figure 15 shows the volumes as a percentage of total volume. It will be seen that at age 20, 80 percent of total volume is made up of pulpwood; not until age 50 is 80 percent sawlog grade. As for veneer, there is nothing until age

---

1 Rousseau, D.; Tremblay, N. 1986. Information statistique sur les volumes coupés et les prix de vente du peuplier faux-tremble au Québec. Government of Canada. Department of Agriculture. Canadian Forestry Service. Internal report, 52 p.

Table 10. Assortment volumes for Lake Squatec aspen

DBH (cm)	Height (m)	Volume (dm^3)	Merchantable volume %	USES Pulp %	Lumber %	Veneer %
9	8	17.00	24	0	0	0
9	10	37.77	76	26	0	0
9	12	50.63	83	37	0	0
13	10	57.00	86	52	0	0
13	12	76.44	91	60	0	0
13	14	104.10	92	74	0	0
13	16	133.50	94	81	0	0
17	14	148.91	95	85	0	0
17	16	182.14	96	86	0	0
17	18	203.70	96	88	0	0
21	14	190.63	97	87	0	0
21	16	233.41	97	89	11	0
21	18	290.34	98	91	27	0
21	20	335.76	98	93	34	0
25	14	231.50	97	92	0	0
25	16	307.43	98	94	35	0
25	18	385.32	98	94	54	0
25	20	465.64	99	95	56	0
25	22	552.59	99	96	62	0
29	16	320.90	98	94	42	0
29	18	487.47	99	96	62	8
29	20	596.55	99	96	70	8
29	22	658.00	99	97	75	8
29	24	746.82	99	97	75	18
33	20	685.24	99	97	82	28
33	22	778.89	99	97	79	35
33	24	919.80	99	97	84	41
37	22	917.80	99	98	80	51
37	24	1 235.60	99	99	88	66

Note: Merchantable volumes and volumes for specific uses are expressed as percentages of total volume.

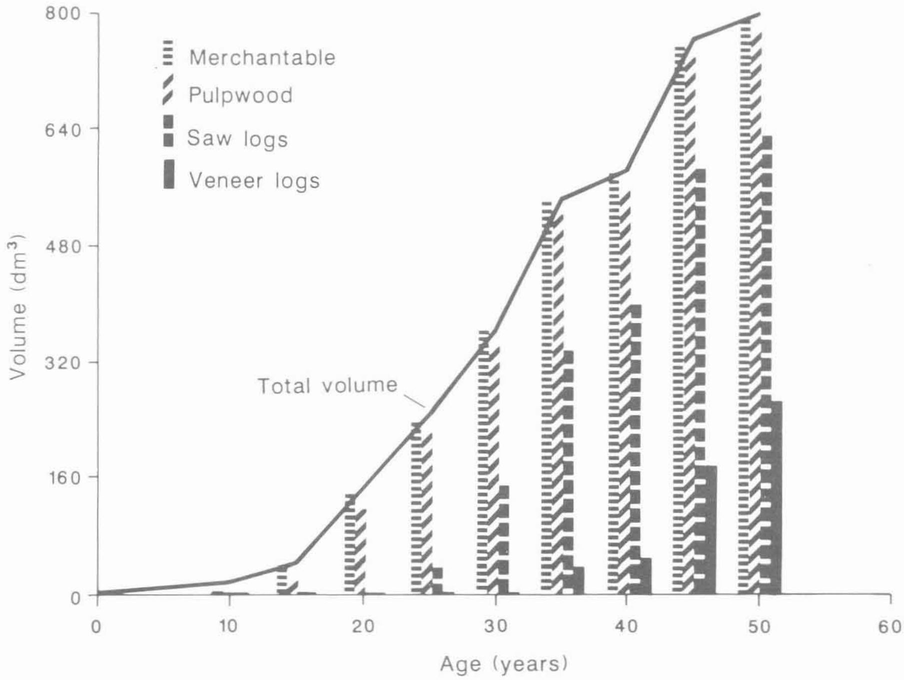


Figure 14. Assortment volumes (dm³) of an average aspen by age.

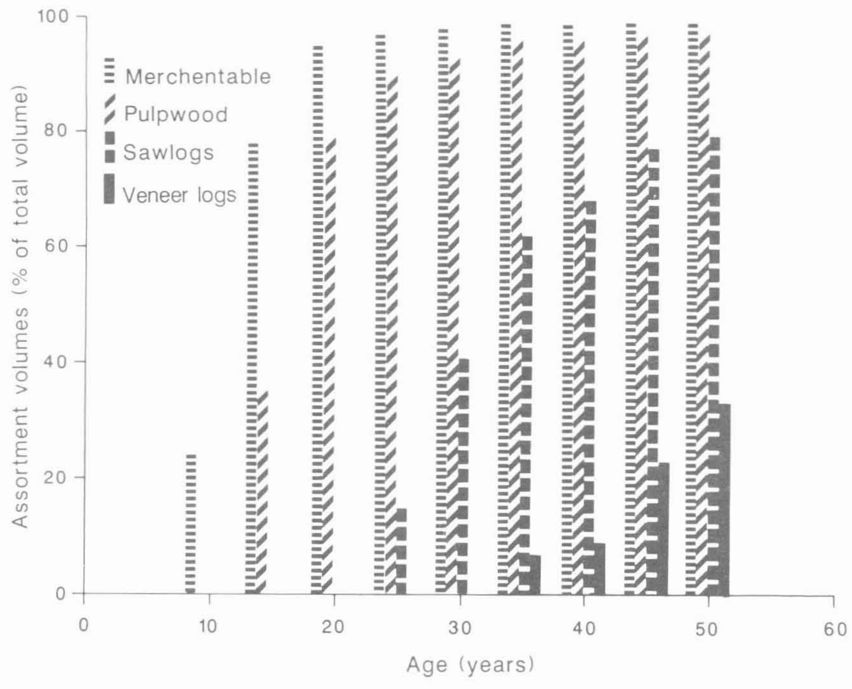


Figure 15. Assortment volumes (as percentage of total volume) by age.

35, and it would appear that our typical tree must be 70 years old before 80 percent is suitable for this purpose.

g) Basic density

Basic density was determined from four disks taken from each tree. The disks were as close as possible to 0.2, 0.4, 0.6, and 0.8 of the tree height. Each disk was divided into quadrants, and two cylindrical samples were taken--each 19.3 mm in diameter--at points one-quarter and three-quarters of the way along the line bifurcating the first and third quadrants.

On each sample, an electronic caliper was used to measure, to the nearest 100th of a millimeter, two diameters and two heights at right angles to each other. This gave the green volume. Then the samples were oven-dried at 105° until they reached a constant weight, and they were weighed to the nearest 1000th of a gram, giving the overdry weight, and then the basic density (ratio of green volume and overdry weight).

Table 11 gives the basic density data obtained. Note that the mean density of the 8 samples for each tree varies between 0.320 and 0.457 g/cm^3, the average for all 30 trees being 0.390 g/cm^3. By way of comparison, Jessome (1977) found an average of 0.374 g/cm^2 for a sample of 20 aspen. Internal variability among the samples for a tree ranges between 1.5 and 15.5 percent of the mean for that tree, the average for the 30 trees being only 6.5 percent.

Table 12 and Figure 16 show the relationship between basic density and the relative height from which the sample was taken. It will be seen that the density increases slightly with height, but in view of the associated variabilities, the differences are not significant.

Growth of aspen

Compared to other Quebec forest species, aspen grows quickly. Figure 17 compares height growth of several Quebec heliophytes, and it shows that the speed of growth of the aspen is comparable to that of black cherry (*Prunus serotina* Ehrh.) and pin cherry (*Prunus pensylvanica* L.F.) and faster than that of tamarack (*Larix laricina* (Du Roi) K.Rock), red pine (*Pinus resinosa* Ait.), and jack pine (*Pinus banksiana* Lamb.).

However for a proper appreciation of growth in a forest, it is necessary to check whether the diameters are normally distributed and whether growing conditions have been homogeneous over time, as results already presented tend to show.

Table 11. Basic density of 30 dominant aspen at Lake Squatec.

Tree #	Number of samples	Mean basic density (g/cm³)	Standard deviation (g/cm³)
2	8	0.388	0.021
3	8	0.389	0.028
4	8	0.380	0.032
5	8	0.433	0.016
6	8	0.383	0.019
7	8	0.391	0.006
8	8	0.401	0.020
9	8	0.431	0.023
10	8	0.409	0.011
11	8	0.376	0.017
12	8	0.342	0.053
13	8	0.457	0.029
14	8	0.348	0.025
15	8	0.364	0.030
16	8	0.320	0.018
17	8	0.389	0.036
18	8	0.410	0.013
19	8	0.412	0.007
20	8	0.425	0.024
21	8	0.446	0.011
22	8	0.420	0.028
23	8	0.449	0.026
24	8	0.421	0.016
25	8	0.361	0.027
26	8	0.358	0.023
27	8	0.350	0.022
28	8	0.340	0.012
29	8	0.367	0.030
30	8	0.398	0.018
31	8	0.348	0.021

Table 12. Basic density by height on tree for aspen

Height on tree (as fraction of total tree height)	Number of trees	Mean basic density (g/cm³)	Standard deviation (g/cm³)
0.2	30	0.381	0.045
0.4	30	0.383	0.040
0.6	30	0.396	0.043
0.8	30	0.402	0.035

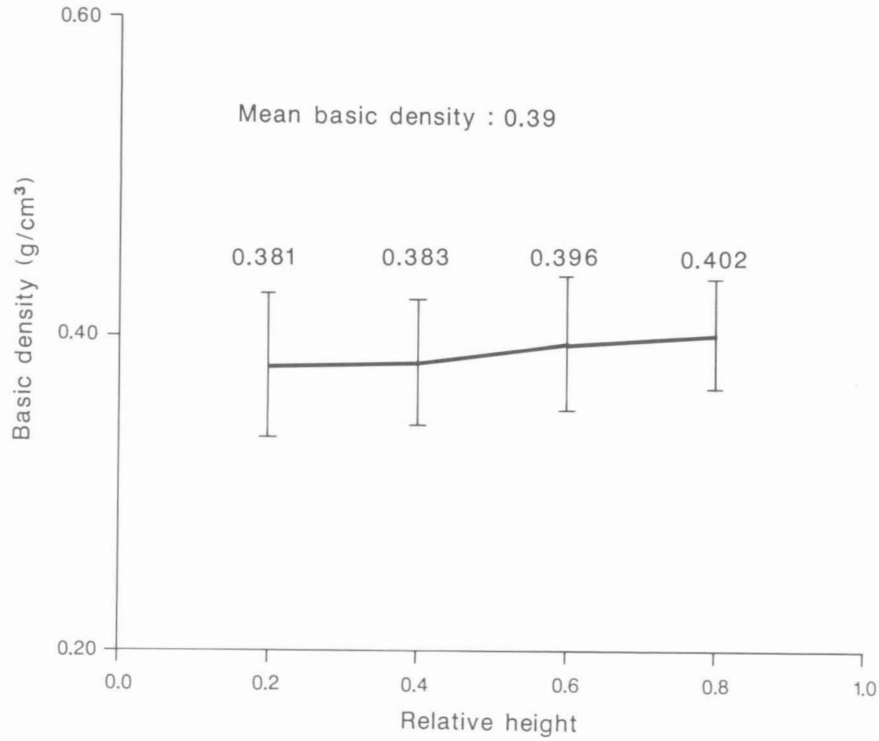


Figure 16. Basic density by height on aspen.

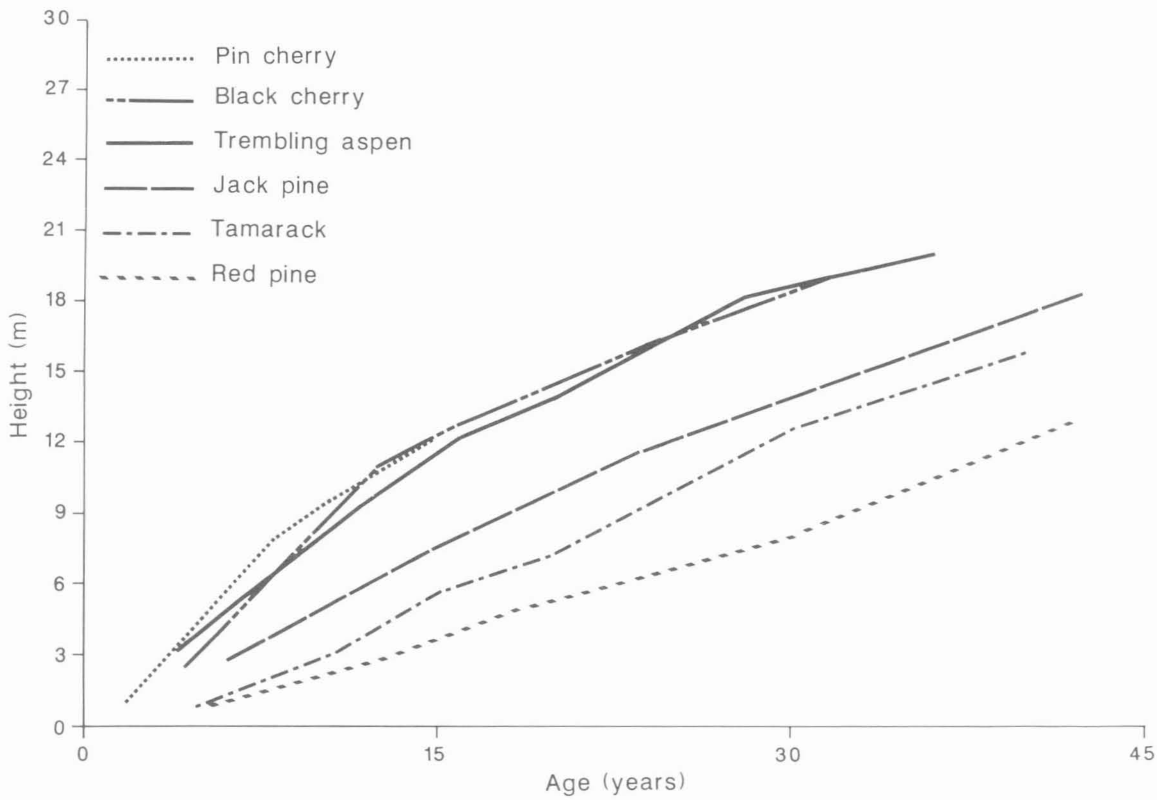


Figure 17. Comparison of height growth in some Quebec heliophytes.

Table 13. Means and standard deviations for dbh, height, volume, and volume increment by age class for Group I aspen

Age	n	dbh	S_d	i_d	S_{i_d}	P_d	S_{P_d}	h	S_h	i_h	S_{i_h}	P_h	S_{P_h}	v	s_v	i_v	S_{i_v}	P_v	S_{P_v}
(ans)		(cm)	(cm)	(cm)	(cm)	(%)	(%)	(m)	(m)	(m)	(m)	(%)	(%)	(dm^3)	(dm^3)	(dm^3)	(dm^3)	(%)	(%)
11	16	7.0	1.7	1.06	0.26	15.8	5.0	7.8	1.4	1.02	0.34	13.5	5.2	14.9	6.0	5.4	2.1	38.2	8.6
13	16	9.0	1.9	1.01	0.19	11.5	3.1	9.4	1.3	0.62	0.18	6.9	3.1	28.6	10.2	8.2	2.6	30.2	6.2
15	16	11.0	2.0	0.91	0.20	8.4	1.9	10.5	1.1	0.46	0.17	4.5	1.8	46.3	15.0	9.5	2.8	21.1	3.4
17	16	12.8	2.1	0.94	0.23	7.5	2.0	11.5	1.1	0.54	0.30	4.7	2.5	67.5	19.6	11.7	3.0	18.1	4.1
19	16	14.6	2.1	0.83	0.21	5.9	2.0	12.5	1.1	0.47	0.20	3.8	1.7	92.6	24.1	13.4	4.4	15.0	4.7
21	16	16.3	2.1	0.86	0.20	5.4	1.6	13.5	1.2	0.49	0.23	3.6	1.7	122.0	28.8	16.1	3.8	13.6	3.3
23	16	18.0	2.1	0.90	0.19	5.1	1.2	14.4	1.2	0.45	0.20	3.2	1.5	157.7	34.2	19.7	4.5	12.7	2.7
25	16	19.6	2.2	0.66	0.20	3.4	0.9	15.2	1.2	0.37	0.19	2.4	1.3	195.1	41.9	17.8	5.8	9.1	1.9
27	16	20.9	2.3	0.70	0.19	3.3	0.9	16.1	1.1	0.49	0.19	3.11	1.3	234.2	50.1	21.3	5.8	9.2	2.3
29	16	22.3	2.4	0.69	0.16	3.1	0.7	17.0	1.1	0.37	0.13	2.2	0.8	279.5	57.7	24.0	5.6	8.7	1.5
31	16	23.6	2.5	0.59	0.16	2.5	0.7	17.6	1.1	0.28	0.10	1.6	0.6	327.2	66.4	23.8	6.5	7.3	1.4
33	16	24.7	2.5	0.48	0.14	2.0	0.6	18.3	1.2	0.38	0.23	2.1	1.2	375.4	77.5	24.4	8.0	6.4	1.4
35	16	25.7	2.6	0.50	0.16	2.0	0.6	19.0	1.3	0.35	0.10	1.9	0.5	426.4	91.8	26.7	9.1	6.2	1.2
37	16	26.6	2.7	0.48	0.20	1.8	0.7	19.8	1.3	0.48	0.21	2.5	1.1	481.2	108.0	28.1	10.3	5.8	1.3
39	16	27.6	2.7	0.52	0.16	1.9	0.6	20.7	1.2	0.35	0.15	1.7	0.8	540.5	121.3	31.3	8.4	5.9	1.2
41	16	28.6	2.8	0.47	0.16	1.6	0.5	21.2	1.1	0.21	0.07	1.0	0.4	602.5	133.1	30.6	11.5	5.1	1.3
43	16	29.5	2.9	0.42	0.17	1.4	0.5	21.6	1.1	0.18	0.05	0.9	0.2	664.4	148.6	31.3	12.1	4.7	1.1
45	14	30.1	3.1	0.41	0.12	1.4	0.3	21.9	1.1	0.19	0.05	0.9	0.2	705.7	166.4	30.1	10.9	4.2	0.8

dbh = diameter at 1.3 m; h = tree height; v = volume i.b.
n = number of observations
S_x = standard deviation
i_x = current annual increment
P_x = increment percentage

However classification of the tree diameters by age suggests the presence of two groups, and the question arises whether their growth patterns are similar. For instance, Figure 18 shows volume increases for three aspen from plot 34 (tree 11, age 45; tree 12, age 37; and tree 13, age 50). Note that tree 13, did not grow at the same rate as trees 11 and 12. This would indicate that growing conditions changed over time, and that the growth of the forest must be analysed in terms of two separate groups.

Growth data on our 30 dominant trees are given on Tables 13 (Group I) and 14 (Group II). Group I has 16 trees with an average age of 49 years; Group II has 14 trees with an average age of 36 years.

Let us first check for statistical differences between the two groups as regards dbh, height, and volume growth. Figures 19, 20, and 21 show the 95 percent confidence intervals (broken lines) for the average values (solid lines) of these parameters. The difference between the two groups is considered significantly different when the confidence intervals do not overlap. Thus the differences in dbh growth (Figure 19) are not significant. But Figures 20 and 21 show that after the age of 25, average height growth and average volume growth are greater in Group 11.

Our comparison suggests that growing conditions changed over time to the point where the younger trees of Group II grew faster in height and volume than the older trees of Group I. The difference may be a result of greater competition which activates height and volume growth.

Comparison of observed growth with yield tables

In this section, we compare the growth of the Lake Squatec aspen with growth data from the yield tables established by Le Goff et al. (1976). The parameters considered are mean diameter, height, volume and volume, increment by age. The two groups at Lake Squatec are compared to the dominant and co-dominant trees of yield tables for site index (SI) of 22 and 19 m.

Figure 22 deals with dbh growth and reveals considerable differences between the Lake Squatec observations and the yield tables. We have no explanation for the difference, though it may in part be caused by the methodology used in constructing the tables. The same seems to apply to height growth (Figure 23): Lake

Table 14. Means and standard deviations for dbh, height, volume, and volume increment by age class for Group II aspen

Age (yrs)	n	dbh (cm)	S_d (cm)	i_d (cm)	S_{i_d} (cm)	P_d (%)	S_{P_d} (%)	h (m)	S_h (m)	i_h (m)	S_{i_h} (m)	P_h (%)	S_{P_h} (%)	v (dm^3)	s_v (dm^3)	i_v (dm^3)	S_{i_v} (dm^3)	P_v (%)	S_{P_v} (%)
11	14	7.5	1.5	1.06	0.11	14.6	2.5	8.4	1.2	0.72	0.24	8.8	3.4	20.3	9.6	6.9	2.7	35.9	5.2
13	14	9.4	1.6	0.90	0.18	9.7	2.4	9.8	1.2	0.63	0.27	6.5	3.0	35.5	14.6	8.3	2.7	24.4	5.0
15	14	11.3	1.7	1.02	0.16	9.1	1.4	11.4	1.2	0.97	0.27	8.6	2.3	56.9	20.8	13.2	4.2	23.8	3.7
17	14	13.3	1.9	0.98	0.10	7.5	1.1	12.9	1.3	0.54	0.19	4.3	1.6	86.7	28.5	16.6	4.1	19.7	2.7
19	14	15.3	1.9	0.93	0.13	6.2	1.4	13.9	1.3	0.44	0.21	3.1	1.4	122.9	35.2	19.6	3.5	16.6	3.0
21	14	17.0	1.8	0.86	0.13	5.1	1.0	15.0	1.4	0.65	0.13	4.4	1.0	164.0	41.1	21.5	3.8	13.5	2.1
23	14	18.7	1.8	0.78	0.10	4.2	0.7	16.2	1.4	0.55	0.17	3.4	0.9	209.9	47.6	24.4	4.1	11.9	1.5
25	14	20.3	1.8	0.89	0.14	4.4	0.7	17.4	1.5	0.70	0.26	4.1	1.6	264.5	56.5	30.2	6.2	11.5	1.4
27	14	22.1	1.9	0.83	0.13	3.8	0.6	18.7	1.4	0.54	0.20	2.9	1.13	328.2	66.0	33.4	5.3	10.4	1.5
29	14	23.7	2.0	0.79	0.12	3.3	0.4	19.6	1.4	0.36	0.13	1.9	0.72	398.7	76.3	37.1	7.2	9.4	1.0
31	14	25.2	2.1	0.75	0.11	3.0	0.4	20.2	1.4	0.30	0.10	1.5	0.54	475.1	87.9	39.3	7.4	8.4	1.1
33	14	26.5	2.2	0.56	0.14	2.1	0.5	20.8	1.4	0.30	0.09	1.4	0.45	546.2	97.5	31.8	6.9	5.9	1.1
35	14	27.7	2.4	0.44	0.18	1.6	0.6	21.5	1.4	0.28	0.07	1.3	0.31	615.6	101.2	28.6	10.0	4.7	1.6

dbh = diamèter at 1.3 m, h = tree height,v = volume i,b,.
n = number of observations
S_x = standard deviation
i_x = current annual increment
P_x = increment percentage

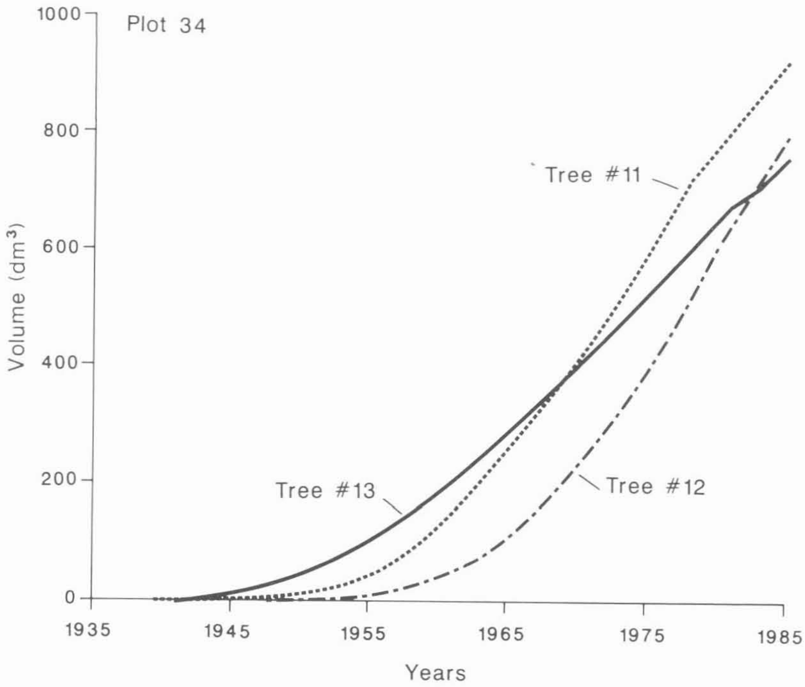


Figure 18. Volume growth in 3 aspens from plot 34.

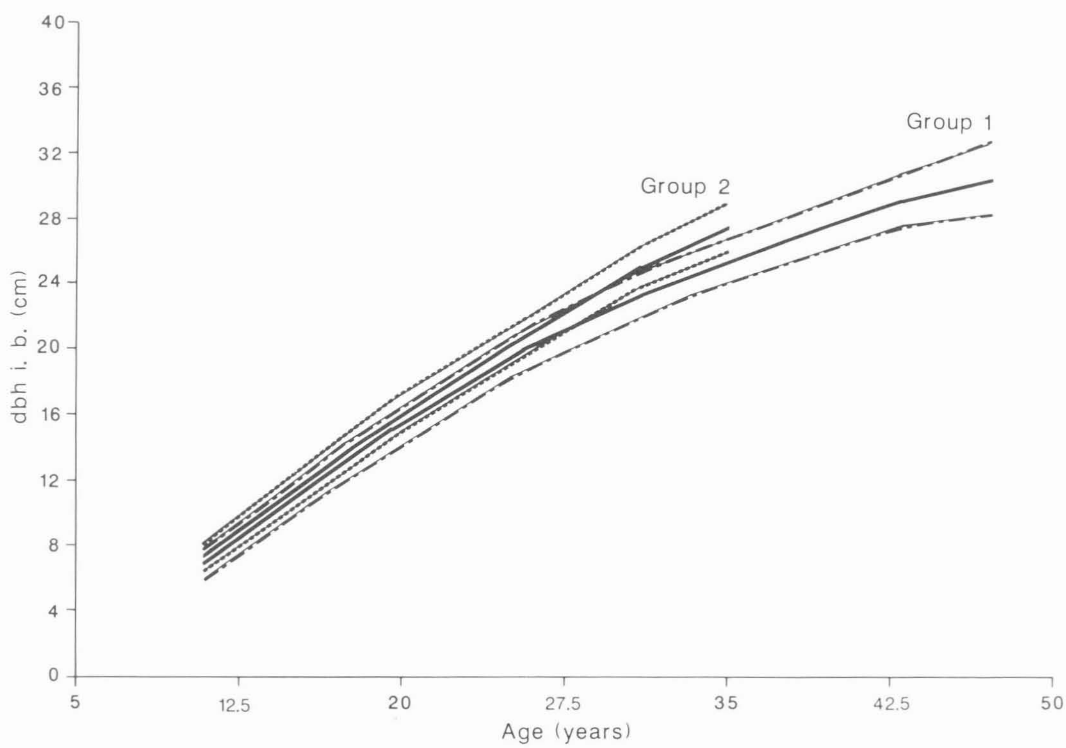


Figure 19. Differences in dbh growth between two groups of aspen, and 95 percent confidence intervals (broken lines).

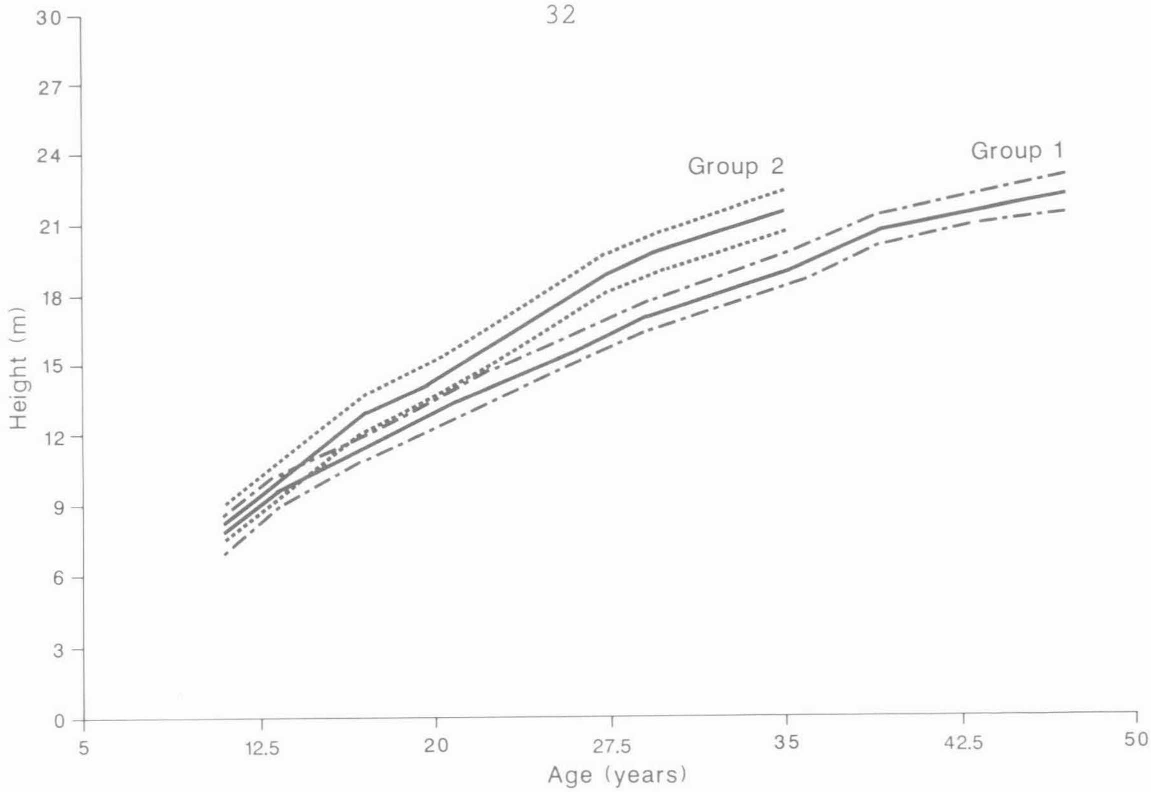


Figure 20. Differences in height growth between two groups of aspen, and 95 percent confidence intervals (broken lines).

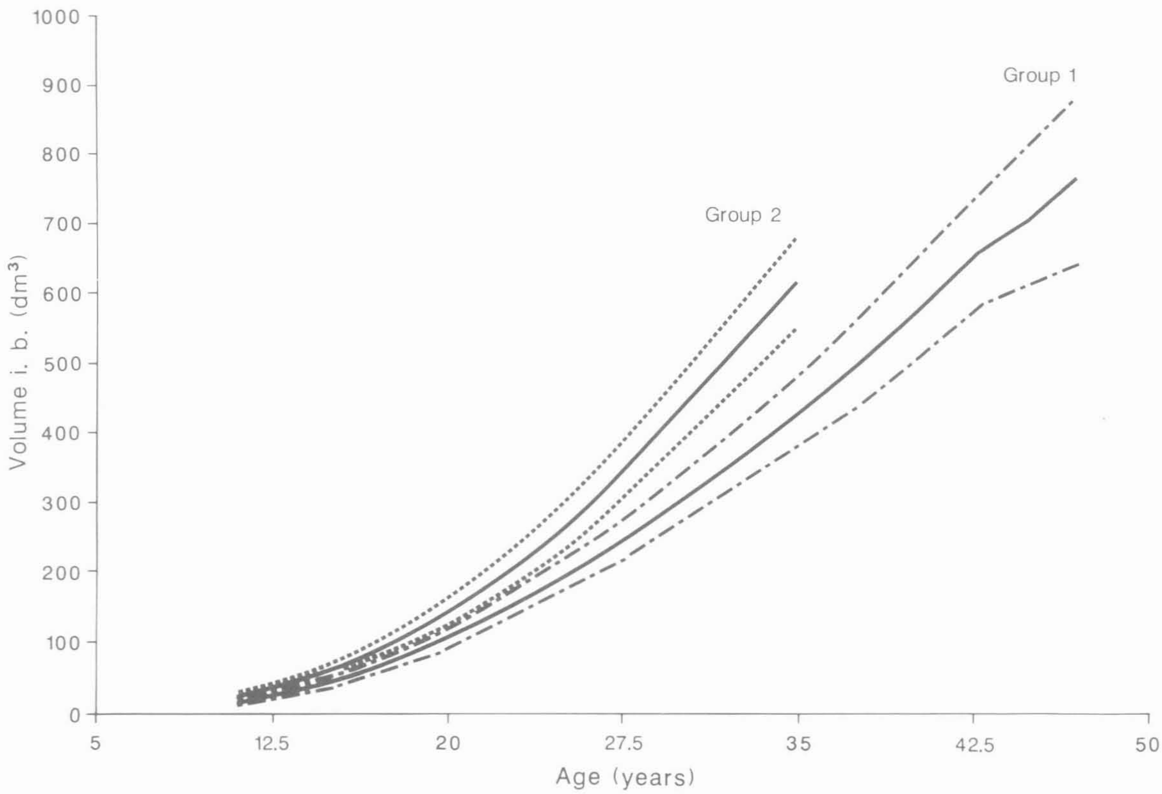


Figure 21. Differences in volume growth between two groups of aspen, and 95 percent confidence intervals (broken lines).

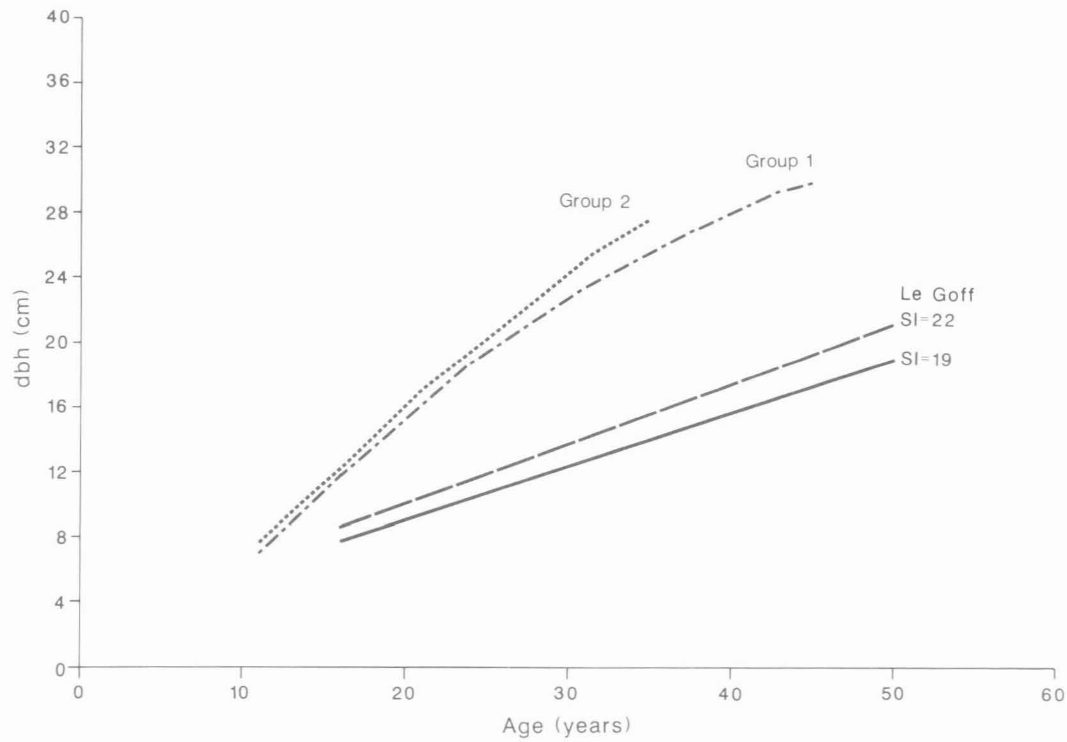


Figure 22. Differences between Lake Squatec observations, and LeGoff's yield tables for dbh (inside bark) growth of aspen

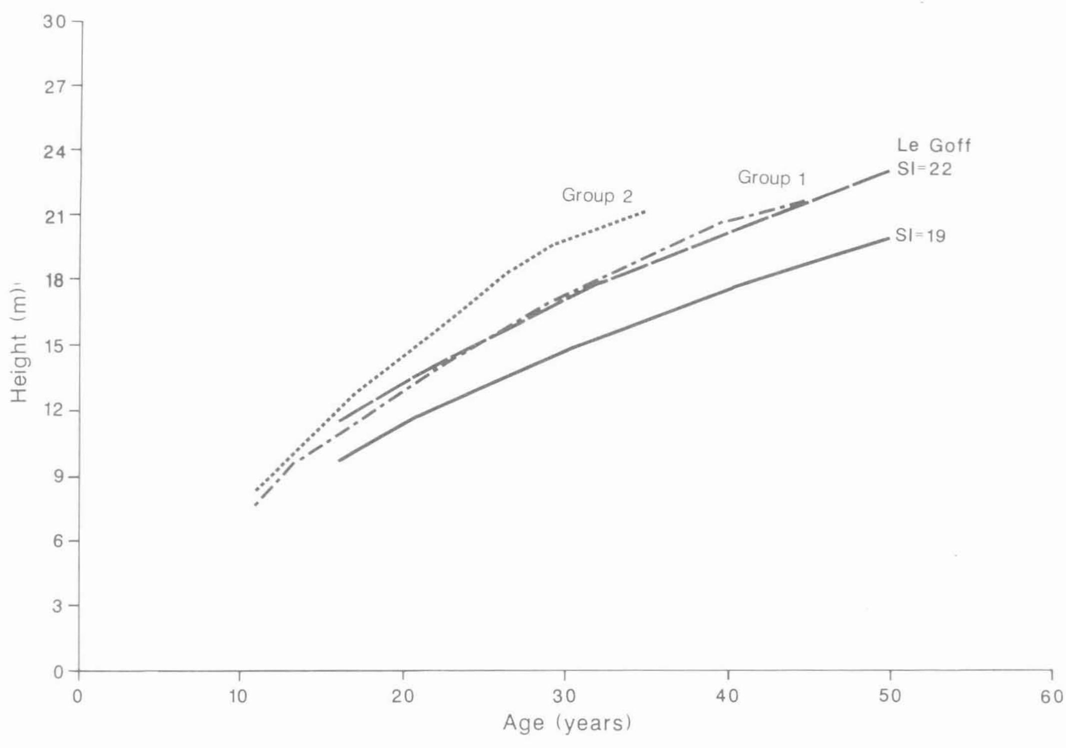


Figure 23. Differences between Lake Squatec and LeGoff's yield tables for height growth of aspen.

Squatec Group I is very similar to SI22, while Group II saw much greater growth than either of the yield table groups.

The differences appear again when volume growths are compared. Indeed, they are even more pronounced (Figures 24).

Figure 25, finally, shows the Lake Squatec volume increments to be much greater than the yield table increments. Before the insect infestations and resulting defoliation around 1981-82, the annual volume increments among the Group II trees were 65 percent of the increments among the Group I trees, but they were 5 times greater than increments among the SI22 trees.

Volume cut and price statistics

Statistics on volumes cut and selling prices are given by Rousseau and Tremblay of the Laurentian Forestry Centre (Canadian Forestry Service, Forest Development Branch).

Uses for aspen

Aspen is used for pulp, lumber, veneer, board, and chemicals. Table 15 compares the uses of trees from public and private forests in 1980 and 1984. About three-quarters of the pulp comes from the private forests, while lumber and veneer come from the public forests. In 1984, the percentage of aspen devoted to board and chemicals was three times what it was in 1980.

Volumes cut

Figure 26 shows the volumes of aspen cut in private and public forests during the period 1970-1984. It shows that the harvest from private forests has been relatively stable, especially since 1978, whereas the harvest from public forests has been growing continuously (77 000 m³ in 1978; 1 626 000 m³ in 1984).

Figure 27 shows the volumes cut in each of Quebec's administrative regions during 1970-84. It shows that there are two main sources: region 01 (Lower St. Lawrence and Gaspé Peninsula) and region 08 (Abitibi-Temiscamingue), in both of which an average of 230 000 m³ was cut each year. The difference between the two regions is that in region 08, the wood comes from public forests whereas in region 01 it comes mainly from private forests. In other regions, volumes harvested are either negligible (region 09), small (regions 05 and 06), or at the 100 000 m³ per year level (regions 02, 03, 04, and 07).

Price fluctuations

It is almost impossible to obtain price data for public forests since operators pay only stumpage fees to the provincial government. Thus our price

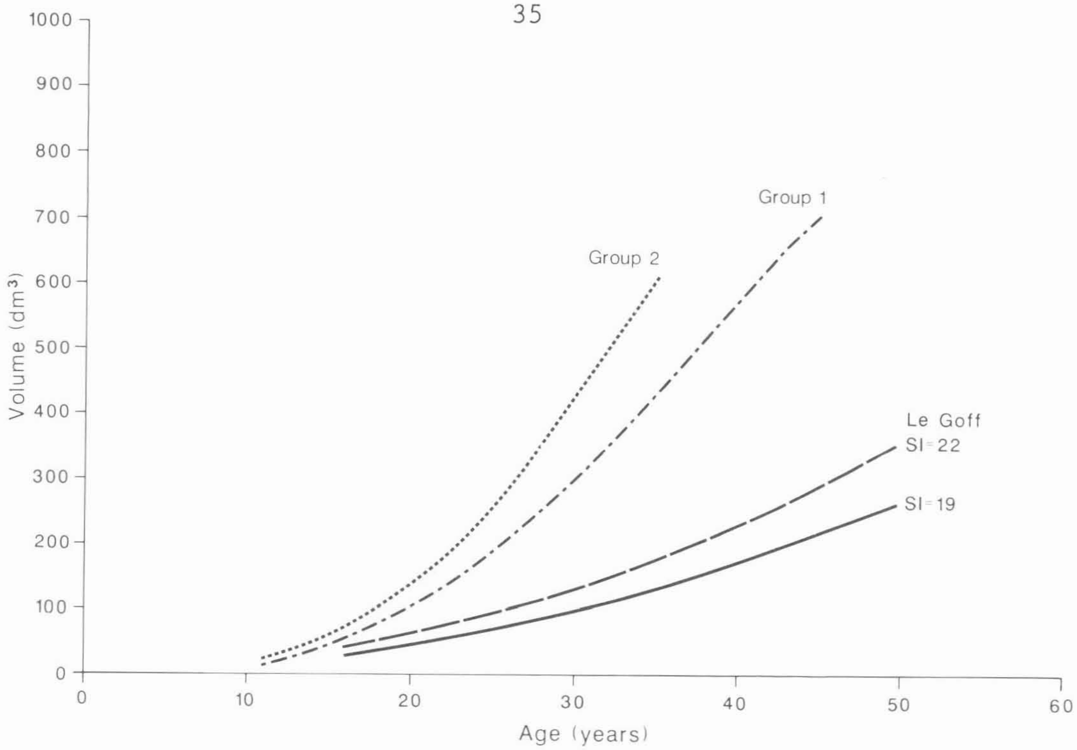


Figure 24. Differences between Lake Squatec observations and Le Goff's yield tables for volume (inside bark) growth of aspen.

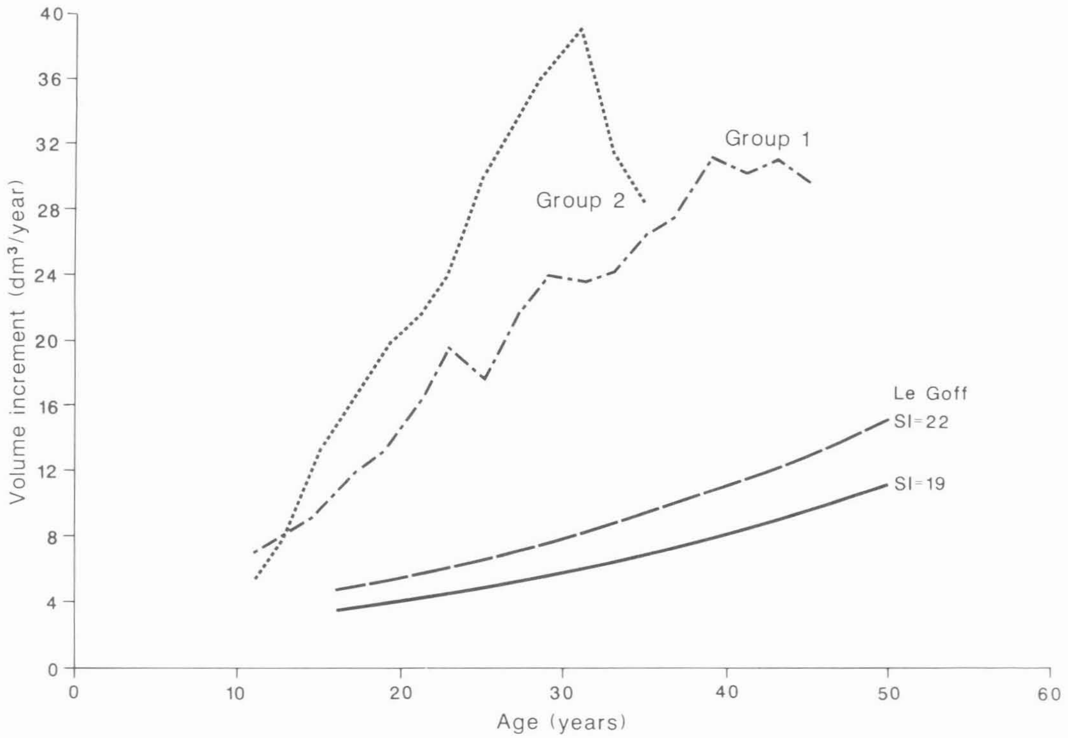


Figure 25. Differences between Lake Squatec observations and Le Goff's yield tables for annual volume (inside bark) increments.

Table 15. Percentages of aspen used for various purposes

USE	Percentages used by year					
	1980			1984		
	Public forest	Private forest	Total	Public forest	Private forest	Total
Pulp	18	80	59	8	72	29
Lumber and veneer	81	1	29	53	6	38
Board and chemicals	1	19	12	39	22	33

data come solely from private forest operations. They were provided by the wood producers' associations in the various regions.

Table 16 shows average prices by use for the whole of Quebec, in 1970 constant dollars (based on the consumer price index).

It shows both the price after milling and the price paid to the producer of the raw material. Figure 28 shows the mill prices by use in graph form. It will be seen that the price for pulpwood is the most stable. The price for saw timber dropped from $8.00 in 1974 to $5.00 in 1978 and has remained constant around $4.50 since then. The price for veneer logs has fluctuated between $5.00 and $7.50; the trend has been downward, but the price for board dropped sharply between 1980 and 1983 but then rose slightly above pulpwood in 1984. The fluctuations in average price for one use do not appear to be related to the fluctuations for other uses. Finally we may note that, taking inflation into account, there has been no increase in the value of aspen.

Defects

Our analysis would not be complete without a look at the defects that may lead to volume losses (of varying extent, depending on the use to which the wood is

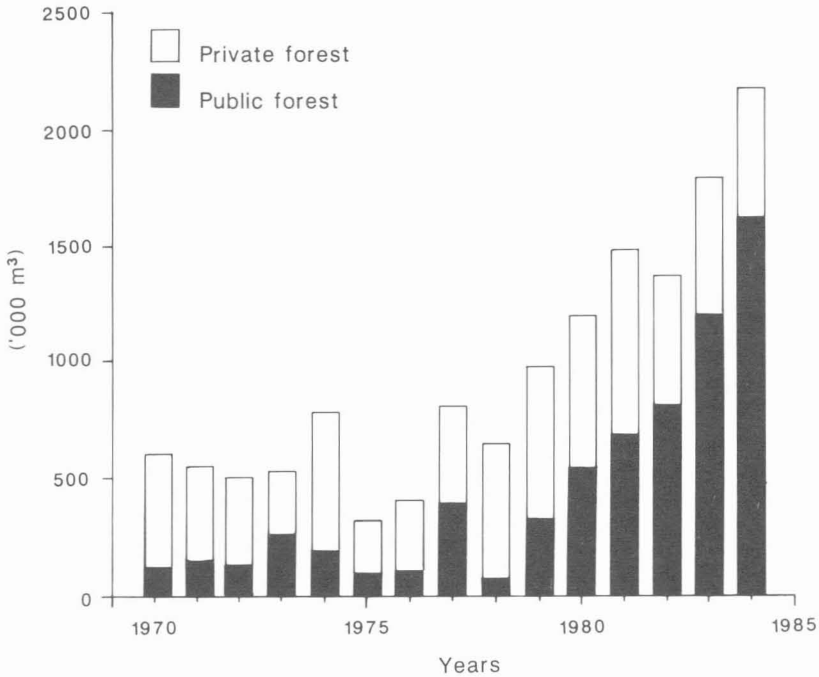


Figure 26. Approximate volume of aspen cut in Quebec.

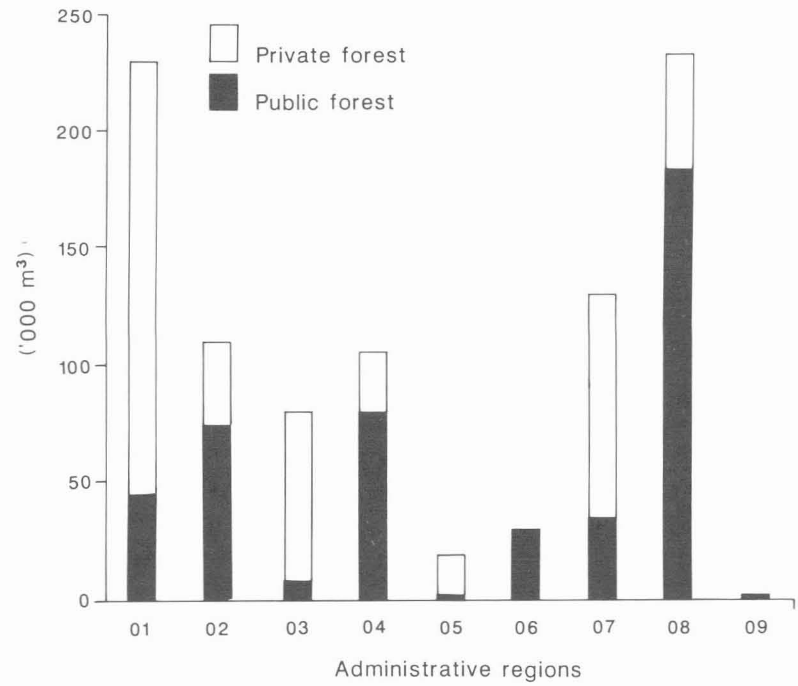


Figure 27. Approximate mean annual volume cut in Quebec, 1970-1984, by administrative region.

Table 16. Aspen prices for Quebec private forests in 1970 constant dollars ($\$/m^3$ app.)

	1970		1971		1972		1973		1974	
	PRICE		PRICE		PRICE		PRICE		PRICE	
Use	After milling	Producer	After milling	Producer	After milling	Producer	After milling	Producer	After milling	Producer
Pulp	5.12	3.22	5.07	3.22	4.76	2.89	5.81	3.72	6.51	4.35
Veneer	—	—	—	—	—	—	7.98	5.26	—	—
Lumber	—	—	—	—	—	—	—	—	8.04	6.96
Board	—	—	—	—	—	—	—	—	—	—
Chemicals	—	—	—	—	—	—	—	—	—	—

	1975		1976		1977		1978		1979	
	PRICE		PRICE		PRICE		PRICE		PRICE	
Use	After milling	Producer	After milling	Producer	After milling	Producer	After milling	Producer	After milling	Producer
Pulp	6.05	4.08	6.00	4.07	6.02	3.97	5.63	3.46	5.53	3.54
Veneer	—	—	—	—	—	—	7.65	3.70	6.00	2.86
Lumber	—	—	—	—	—	—	4.74	2.29	4.12	1.96
Board	—	—	—	—	—	—	—	—	—	—
Chemicals	—	—	—	—	—	—	—	—	—	—

	1980		1981		1982		1983		1984	
	PRICE		PRICE		PRICE		PRICE		PRICE	
USE	After milling	Producer	After milling	Producer	After milling	Producer	After milling	Producer	After milling	Producer
Pulp	5.64	3.73	5.57	3.56	5.48	3.22	5.14	2.91	5.53	3.13
Veneer	5.03	2.64	5.91	3.10	7.43	4.83	5.72	3.28	6.45	4.45
Lumber	4.62	2.60	4.53	2.38	4.35	2.85	4.61	2.61	4.45	3.07
Board	7.51	5.10	4.12	2.37	4.94	2.90	4.55	2.48	5.95	3.29
Chemicals	—	—	—	—	5.67	3.16	4.89	2.89	5.04	2.94

to be put). The following is based on defects found in the disks used for stem analysis.

A study of this matter is currently underway at the Laurentian Forestry Centre. It has revealed two main types of rot. The first--which accounts for 10 percent of the cases of rot--is yellowish white and often surrounded by a black line. Depending on the stage to which the rot has developed, the texture may be anywhere from firm to spongy. This type of rot is generally caused by *Fomes ignarius* var. *populinus* (Neu.) Campb. The second type of rot is yellow or yellowish brown, anywhere from firm to stringy in texture, and rarely found at the base of the trunk. It is caused mainly by *Corticium polygonium* Pers. In trees under 70 years of age, 70 percent of the cases of rot are of this type. About 20 percent of the cases of rot are at stump level and may be attributable to *Armillaria mellea* (Vahl. exFr.) Kummer, or other fungi that cause rot in this part of a tree. Nine of the 30 trees analysed had stump-level rot, and of these, 8 were between the ages of 48 and 50.

The average volume of the aspen tree affected by defects is 3.9 percent of the total. In most cases, the volume affected by discoloration is greater than the volume affected by rot, which represents less than 1 percent of the tree volume. Among the trees 45 years

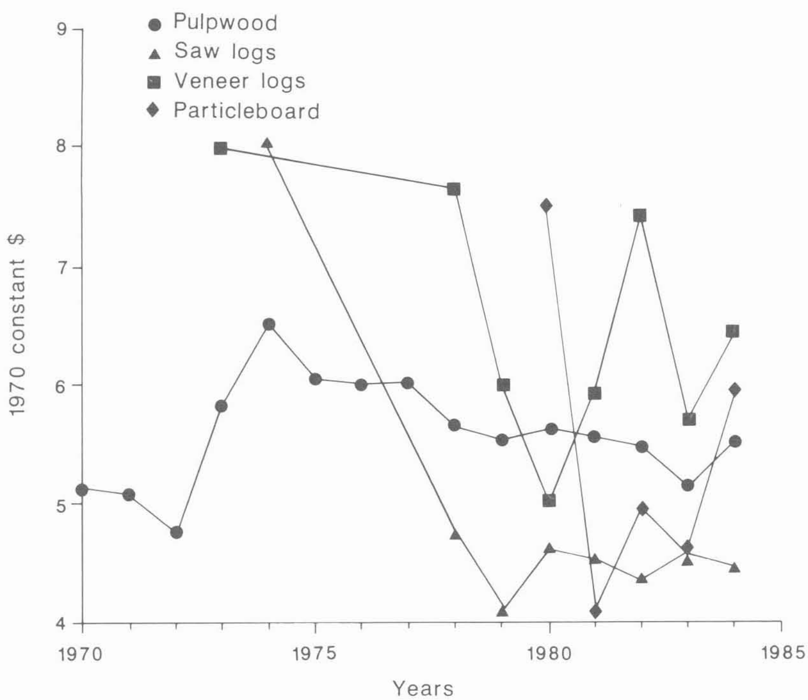


Figure 28. Changes in aspen prices for Quebec private forests, 1970-1984.

of age or over, the mean volume affected by rot and discoloration is 5.4 percent with a standard deviation of 4.3 while for the trees 36 to 38 years of age, the mean is 2.1 percent with a standard deviation of 1.9.

Thus aspen can be maintained for at least 10 to 15 years without any great losses due to rot. Also, since most of the aspen cut in the Témiscouata area is used for pulp, and most of the defects take the form of discoloration, they can essentially be ignored.

CONCLUSION

Allometry

Trembling aspen is a heliophyte that initially gives single-story forests with a simple vertical and horizontal structure. However the forests become multistoryed and more complex in structure once sciophytes appear.

To understand the growth and development of aspen forests, it is necessary to know the distribution of tree diameters. Observations of aspen at Lake Squatec and in the Matagami region show that the aspen forming the dominant stratum have a near-normal diameter distribution. The lower storys, composed of shade-tolerant species, have a more or less asymmetric distribution (skewed to the light), but tend toward a normal distribution as the mean diameter increases. The forests may change gradually through the action of sciophytes and hemisciophytes; this leads to a better use of space and increases yield.

Analysis of the Lake Squatec aspen forest shows that over time, the diameter distribution shifts from a left-skewed asymmetric one to normal. This justifies the assumption of a mean regional yield and makes it possible to construct predictive models for changes in aspen forests over time.

Knowledge of tree morphology and forest structure is essential to silvicultural operations if setup mixtures are to be properly determined and growing space regulated. A typical aspen, which has a breast-height diameter of 30.4 cm will have a total height of 22.4 m. The crown length is 52 percent of the tree height. The ratio of the crown width to the dbh varies from 12 to 22, so that on average the diameter of the growing space is 17 times the dbh, which corresponds to a projection of the crown that is about 300 times the basal area. The part of the crown exposed to sunlight is

44 percent of the crown length. The width of the crown is 23 percent of the tree height. The taper of the crown is considerable: its width is 44 percent of its height.

The relative homogeneity of the height and dbh data on the 30 trees considered reflects the fact that the site conditions are fairly uniform. Thus single-entry volume tables based on the dbh can be used. The height-to-diameter ratio is parabolic in form; the fit of the data to a second-degree polynomial distribution is quite good. For practical purposes, confidence intervals were established, at the 99 percent level, for the mean height of each dbh class, so as to obtain an objective measure of the validity of the volume table for the forest as a whole. At least 11 dominant aspen must be measured in order to determine the mean height with a precision of 5 percent at the 95 percent level.

The relation between the bark thickness and the dbh is linear. The Y-intercept test for the corresponding regression equation shows that the intercept is significantly different from 0 at the 99.9 percent level. This confirms that there is no simple ratio between the dbh outside and inside bark. The bark volume as a percentage of total volume varies from 20 percent for a $dbh_{o.b.}$ of 10 cm down to 12 percent for a $dbh_{o.b.}$ of 32 cm.

Calculation of assortment volumes shows that in small trees the percentage of volume suitable for pulp increases very rapidly with an increase in height. Volumes suitable for lumber appear when dbh reaches 21 cm and height 16 m, while volumes suitable for veneer appear when dbh reaches 29 cm and height 18 m. At age 20, 80 percent of total volume is suitable for pulp; not until age 50 is 80 percent suitable for lumber, while for veneer there is nothing suitable until age 35 and it would appear that the tree must be 70 years old before 80 percent is suitable for this purpose.

The mean basic density for samples from a single tree varies from 0.320 to 0.457 g/cm³, while the average for all 30 trees is 0.390 g/cm³. Differences between densities at different heights on a tree are not significant.

Growth

Classification of the tree diameters by age reveals the presence of two age groups, one with an average age of 49 years and one with an average age of 36 years. The groups do not differ in dbh growth but there is a significant difference as regards growth in height and volume. The difference may be attributable to competition from the older group over the younger one, which may trigger greater height and volume increases in the younger group.

Comparison of growth observed at Lake Squatec with growth data from the yield tables established by LeGoff et al. (1976) reveals considerable differences in dbh and volume growth and in annual volume increments. The differences may arise from the methodology used in construction of the tables.

Yield and prices

In Quebec, about 75 percent of the aspen yield from private forests goes into pulp production. Lumber and veneer are made essentially out of wood from public forests.

The yield from private forests has been fairly stable at about 600 000 m^3 a year. The yield from public forests has been continually on the increase, reaching 1 626 000 m^3 in 1984. The main administrative regions of Quebec that produce aspen are region 01 (Lower St. Lawrence and Gaspé Peninsula) and region 08 (Abitibi-Temiscaming). The main difference is that aspen from region 01 comes from private forests while aspen from region 08 comes from public forests.

Data on price changes for aspen from private forests indicate that the price for pulpwood has been stable. It has been higher than the price for saw timber and slightly lower than the price for veneer logs.

Given the current market for aspen in Quebec, silvicultural work to produce a high-quality assortment would not be worthwhile. In the Témiscouata region, aspen should be eliminated from the age of 20, when 80 percent of its volume is already going for pulp (a figure which rises to 90 percent by age 30). Nevertheless it should be remembered that market conditions may change.

REFERENCES

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

Bélanger, J.; Dumont, J.-M. 1974. Variation de l'épaisseur de l'écorce. Qué. Minist. Terres Forêts Québec, Serv. invent. for., Mem. 30 p.

Blouin, J.-L.; Grandtner, M.M. 1971. Étude écologique et cartographie de la végétation du comté de Rivière-du-Loup. Qué. Minst. Terres For. Serv. rech., Mém. No. 6, 371 p.

Burger, H. 1939. Baumkrone und Zuwachs in sweihiersreifen Fichtenbestanden. Mitt. Schweiz. Anstalt. Forstl. Versuchsw., 21: 147-176.

Désaulniers, G. 1980. Équation de défilement d'un tronçon: fondement du cubage des arbres en vue du débitage. Qué. Minist. Énerg. Ressour. Serv. Rech. for. Mém. 69. XV+91 p.

Dixon, W.J. 1985. BMDP. Statistical software, Univ. Calif. Press, Berkeley, Calif. 734 p.

Gagnon, G.; Carrier, L.; Thomas, J. 1978. Recherche et développement sur le peuplier dans la région de l'Est du Québec. X- Classification écologique des peupleraies naturelles des compés de Montmagny à Rimouski. Qué. Minst. Terres For. Serv. Rech., Mém. no. 42, 87 p.

Gerardin, V. 1985. Caractéristiques écologique de trois blocs forestiers expérimentaux des environs du Lac Squatec, comté de Témiscouata. Qué. Minist. Environ. Div. invent. écol., vol. 21, 25 p.

Grandtner, M.M. 1966. La végétation forestière du Québec méridional. Presses Univ. Laval, Québec, Qué. 216 p.

Hradetzky, J. 1981. Spline-Funktionen und ihre Anwendung in der forstlichen Forschung. Forstw. Cbl. 100:45-59.

Jessome, A. P. 1977. Strength and related properties of woods grwn in Canada. East. For. Prod. Lab., Ottawa, For. Tech. Rep. 21, 37 p.

Korsun, F. 1955. bark thickness as a function of stem diameter. Les. 2: 51-54.

Kozak, A.; Yang, R. C. 1981. Equations for estimating bark volume and thickness of commercial trees in British Columbia. For. Chron. 6: 112-115.

Lavoie, G. 1984. La flore vasculaire du comté de Témiscouata. Provancheria 16, 131 p.

LeGoff, N.; Ménard, M.; Richard, Y. 1976. Recherche et développement sur le peuplier dans la région de l'Est du Québec. VIII - Tables de rendement pour les peupleraies naturelles dans comptés de Montmagny à Rimouski. Que. Minist. Terres Forêts, Serv. rech., Mém. 32, 78 p.

Lespérance, P.-J.; Greiner, H.R. 1969. Région de Squatec. Cabano. Comtés de Rimouski, Rivière-du-Loup, Témiscouata. Que. Minist. Rich. nat. R.G. 128, 122 p.

Loetsch, F. 1950. Uber die Abhangigkeit der Kiefernrindenstarke von Durchmesser und Alter. Allg. Forst. V. J. Ztg. 122:58-61.

Meyer, H. A. 1946. Bark volume determination in trees. J. For. 44:1067-1070.

Rochefort, B. 1981. Étude pédologique du comté de Témiscouata (Québec). Qué. Minist. Agric. Pêch. Aliment. Serv. rech. sols, 120 p.

Roiko-Jokela, P. 1976. Die Schaftfunktionen der Fichte. Mitt. D/tsch. Eidgen. Anst. Forstl. Versuchwesen, H. 52.

Rowe, J. S. 1972. Forest Regions of Canada, Can. Dep. Environ., Can. For. Serv. Publ. No. 130

Smelko, S. 1962. Prispevok k stanoveniu kowficientu kroy [Contribution à la définition du coefficient d'écorce] [In Slovak]. Lesnictvi 8: 452-455.

Schopfer, W. 1972. Zur Konstruktion von Sektionstabellen fur Nadelbaumarten. Aug. Forstz. 42:815-817.

Villeneuve, G.O. 1959. Bref aperçu climatique du Québec méridional. Cah. géogr. Québec, 3:153-162.

Wilson, C. 1971. The Climate of Quebec. Part I: Climatic Atlas. Environ. Can. Atm. Env. Serv., Climatoligical Studies II.

Wolf, J. 1962. Problematika stanoveni hodnot faktoru kury. [Problématique de la détermination du coefficient] [In Slovak]. Lesnictvi, 8:445-452.

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. 1985. Analyse de tiges: une méthode à redécouvrir. Naturaliste can. 112:253-260.

Canada