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## Balsam fir decay in central and northeastern Quebec

André Lavallée



Information Report LAU-X-70E  
Laurentian Forestry Centre



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Canadian Forestry Service

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## ABSTRACT

By analysing results from the dissection of 8 404 balsam fir trees from boreal and mixed hardwood forest the volume of decay was determined in relation to age and diameter. In undisturbed boreal forest, the net merchantable volume of balsam fir increases up to 120 years old. In mixed hardwood forest, fir trees grow better because of environmental conditions, but there is also more decay; however, the net merchantable volume increases until age 140. The percentage of merchantable volume infected by decay is also presented in relation to diameter of the fir trees studied. In general, butt rot is more frequent and varied than trunk rot. On the other hand, the latter produces decay that is three times more voluminous than butt rot. More trunk rot occurs among trees of the dominant storey, while the incidence of butt rot is greater among dominated trees. The identity and frequency of the principal fungi responsible for balsam fir rot are also discussed.

## RÉSUMÉ

L'analyse des résultats de dissection de 8 404 sapins baumiers de la forêt boréale ou de la forêt feuillue a permis de déterminer l'importance des caries en fonction de l'âge et du diamètre. En forêt boréale non perturbée, le volume marchand net du sapin progresse jusqu'à l'âge de 120 ans. Les conditions du milieu en forêt feuillue permettent des accroissements plus considérables du sapin et de ses caries, mais jusqu'à 140 ans, le volume marchand net continue de progresser. Le pourcentage du volume marchand affecté par les caries est aussi présenté en fonction du diamètre des sapins étudiés. En général, les caries du pied sont plus nombreuses et plus diversifiées que les caries du tronc. Par contre, ces dernières engendrent des caries trois fois plus volumineuses que les caries du pied. Une plus grande proportion d'arbres affectés de caries du tronc se rencontre chez les sapins de l'étage dominant tandis que les caries du pied sont plus fréquentes chez les arbres dominés. La fréquence et l'identité des principaux champignons de carie du sapin sont également considérées.

## INTRODUCTION

In Canada, as in the United States, many trees were dissected between 1940 and 1960 to distinguish the kinds of rot occurring in the main tree species of the natural forest. Researchers aimed at establishing reduction factors for measuring losses from rot according to the age of stands (Spaulding and Hansbrough 1944). The identity of the fungi causing the various kinds of rot and their importance according to site were also studied (Basham et al. 1953).

In Quebec, an early study (McCallum 1928) was published on balsam fir (*Abies balsamea* [L.] Mill.), based on data collected in the Lac St-Jean and Lower St. Lawrence regions. Between 1938 and 1957, several other regions in the province were studied but, with the exception of a description of the kinds of balsam fir rot (Pomerleau 1948), few quantitative results were published. Two unpublished internal reports<sup>1,2</sup> were, however, prepared for two of the six localities. Two published documents, one from Ontario (Morawski et al. 1958) and the other from the Maritimes (Davidson 1957), often had to be used to establish values applicable to Quebec.

In Quebec, the gross merchantable volume of balsam fir is estimated at 919 million m<sup>3</sup> in the commercial forest (MER 1984). This volume represents one third of the softwoods (Bonnor 1982), and more intensive management of balsam fir stands will require the use of all available information on decay. Earlier studies were meant as a guide for the forester who was trying to estimate more accurately his inventory when making management and logging plans. In particular, results were calculated using scaling regulations for pulpwood and timber in order to estimate "cull" according to the current use of the species being studied. Today, fir is often logged in one piece or in sections that are longer than the traditional 1.22 m (4 ft.) bolt. Information on the real volume of decay becomes as relevant as that calculated to estimate "cull" in relation to scaling. With this in mind, a data bank on conifer decay in natural stands was used as the basis for the analyses on balsam fir presented in this report. Results will therefore be presented from two points of view - "decay" and "cull" - thereby enabling the user to choose the information that is most relevant to his requirements.

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<sup>1</sup> Pomerleau, R. 1957. Studies on decay of balsam fir and red spruce in the eastern townships of Quebec. Interim Rep. 1957-1 and <sup>2</sup> Pomerleau, R.; Morin, L. 1959. Losses from decay in conifer stands in the Manicouagan watershed. Can. Dep. Agric., For. Biol. Lab. Qué., Interim Rep. 1959-1.

## METHODS

### Field procedure

The data collected under the direction of Dr. R. Pomerleau are the result of work done in the forest from 1940 to 1944 and from 1954 to 1957. Measurements were taken in the same way throughout the dissection sampling.

In the field, the two main criteria for selecting study sites were:

1. Homogeneity of the herbaceous ground cover determining forest type; and
2. tree growth and stand components representative of the adjacent forest. Stream banks, steep slopes, and shrub thickets were avoided. The main areas where balsam firs were dissected are illustrated in Figure 1. They are:

1. Baie-Comeau (the Manicouagan and Toulouste river basins) and Shelter Bay (the Ste-Marguerite river basin);
2. Eastern Townships (the St-François, Nicolet, and Au Saumon river basins);
3. Duchesnay and the Aux Pins river basin;
4. Laurentides Park (the Noire, Jacques-Cartier, Ste-Anne, Aux Écorces, and Malbaie river basins);

5. Charlevoix (the Du Gouffre river basin); and

6. L'Islet, Lac Ste-Anne.

Three of these areas (1, 4, and 5) are representative of the boreal forest (Rowe 1972), in the balsam fir and spruce climatic zones (Grandtner 1966). Black spruce dominates but balsam fir can be found in varying proportions under almost all types of canopy. The stands studied had not been recently disturbed by fire or spruce budworm (*Choristoneura fumifera* Clem.). The other three areas (2, 3, and 6) are mixed hardwood forest of the maple climatic zones.

In most sample plots, the stand was clearcut except at Baie-Comeau, where trees were cut selectively according to diameter for a given forest type. Most sample plots were rectangular, with an area of 0.1 ha (0.25 acres), and situated where there had been a minimum of previous intervention. A few sites were square, with an area of 0.04 ha (0.1 acres).

The tree's storey, signs indicating the infection courts of decay, and health were noted. Trees over 9 cm (3.5 in.) in diameter at breast height (dbh, at 1.3 m from the ground) were cut 15 cm from the ground and sectioned into lengths of 1.2 m (4 ft.). The following

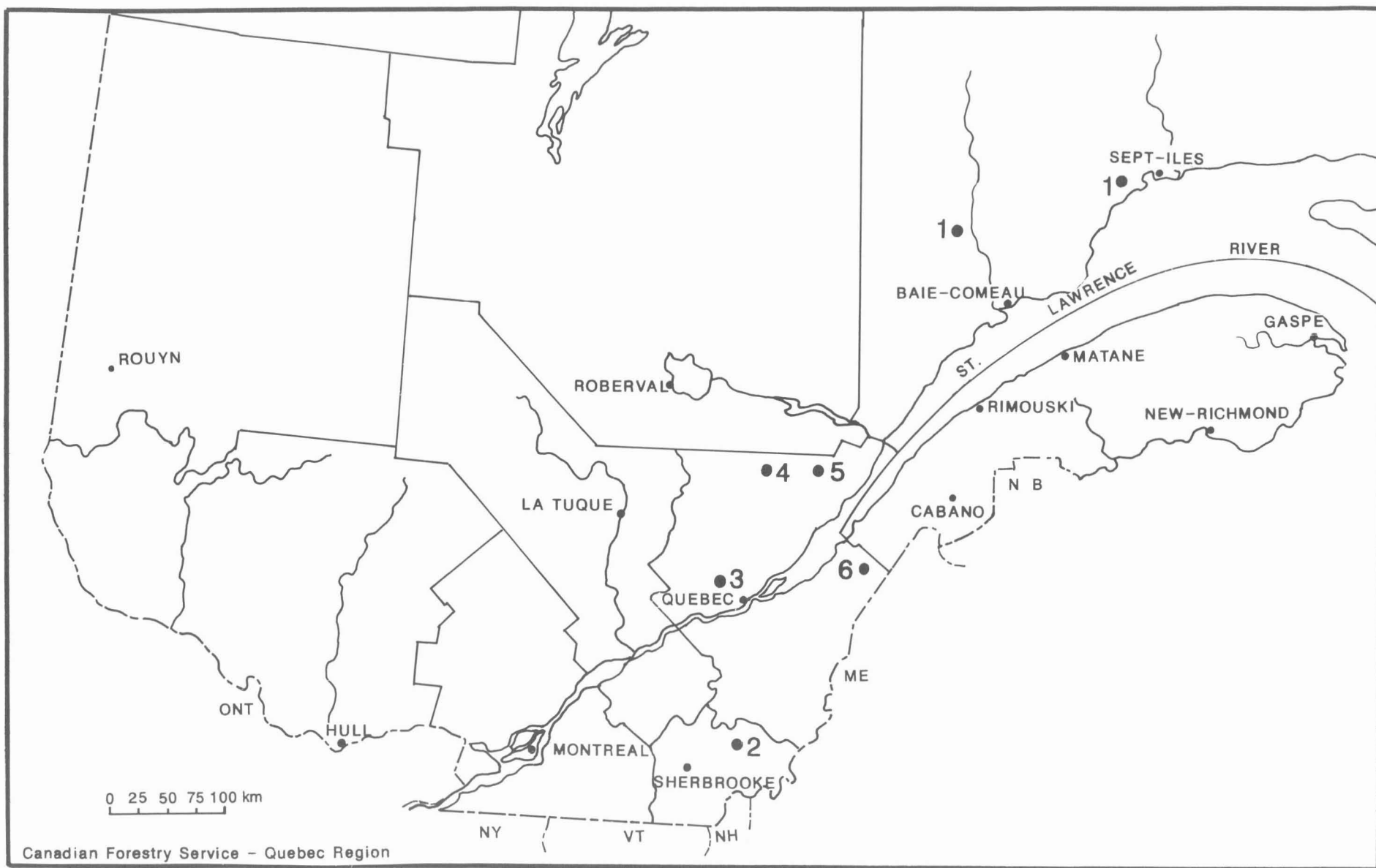


Figure 1. Location of balsam fir decay study sites.

measurements were taken: total length, diameter at half tree height in order to calculate the form-class, merchantable length (to a diameter of 7.6 cm (3 in.)), and diameter outside and inside the bark at each end of the bolt. The age of the tree was determined by the number of annual rings at breast height.

When rot was present, its diameter was noted at the ends of the bolts and, if necessary, the bolt was cut lengthwise to obtain the exact extent of the rot column. The decay was subsequently quantified as "cull" according to the Quebec Department of Lands and Forests scaling regulations in effect in 1955-1957. A sample of each rot was collected and sent to the laboratory for culturing and identification.

A survey of the vegetation and of the soil structure at each horizon was done within each area studied. The percentage of sand, clay, and silt in the soils was found by dry sifting. The pH and moisture equivalent were also obtained for each sample.

## Data analysis

### Compilations

The total volume of the tree was obtained by adding the butt volume (formula for a cylinder), the volume of the non-merchantable part of the trunk (diameter less than 9 cm (formula for a cone)), and finally the volume of the merchantable part of the trunk. The latter was calculated using Newton's formula for each 1.2 m bolt.

$$V = (B + 4B\frac{1}{2} + b) \frac{L}{6}$$

where V = volume; L = length and B, b = cross sectional area at the large and small end of the bole.

Decay volumes were calculated using the same method (the formula for a cone and Newton's formula) since the exact length and diameter of decay were known for each bolt.

The results give the basic data (Tables 2 and 5) and values calculated from the curves (Tables 3, 4, 6, and 7). Age-volume curves were determined using the Régnière and Beilhartz<sup>3</sup> method for non-linear functions. The correlation coefficients ( $R^2$ ) varied between 0.92 and 0.99.

<sup>3</sup> Régnière, J.; Beilhartz, D.W. 1983. Search, a user's manual. Non linear regression analysis: a handbook to commonly used equations, and initial parameter estimation. Environ. Can., Can. For. Serv. Great Lakes For. Res. Cent., Sault Ste. Marie, Ontario, Mimeo. Rep.

### . Boreal forest

$$GMV = \frac{240.7}{\left(1 + e^{-.1225 (\text{age} - 92.2)}\right)^{0.23}}$$

$$TV = 9.599 + 1.008 \text{ GMV}$$

$$\% \text{ decay} = 0.725 + 0.674 (\text{age})$$

$$\% \text{ cull} = 4.17 + 1.33 (\% \text{ decay})$$

$$DV = \% \text{ decay}/100 \times \text{GMV}$$

$$CV = \% \text{ cull}/100 \times \text{GMV}$$

### . Mixed hardwood forest

$$GMV = \frac{566.34}{\left(1 + e^{-.04 (\text{age} - 92.6)}\right)^{0.85}}$$

$$TV = 9.401 + 1.018 \text{ GMV}$$

$$\% \text{ decay} = -2.41 + 1.229 (\text{age})$$

$$\% \text{ cull} = 3.70 + 1.41 (\% \text{ decay})$$

Curves in relation to dbh were obtained using polynomial or power-law equations:

### . Boreal forest

$$GMV = 91.7 - 17.677X_1 + 1.2116X_2$$

$$TV = 104.47 + 18.518X_1 + 1.248X_2$$

$$DV = 0.00036X_1^{3.5535}$$

$$CV = 0.00328X_1^{3.0389}$$

### . Mixed hardwood forest

$$GMV = 144.27 - 22.730X_1 + 1.2802X_2$$

$$TV = 156.22 + 23.152X_1 + 1.305X_2$$

$$DV = 0.00041X_1^{3.4060}$$

$$CV = 0.00391X_1^{2.8908}$$

### Variables

The data were first analysed in relation to forest types. These were determined by examining the vegetation and were classified according to Bellefeuille (1932), Heimbürger (1934), Ray (1941), Lafond (1956), or Linteau (1955), depending on what date the work was done. A few tendencies were detected when the study areas were analyzed at that level of subdivision. However, it was felt that there were not enough repetitions to conclude significant differences in forest type at one given locality or from one locality to another. The results were therefore presented simply for boreal forest and for mixed hardwood forest, with some additional tendencies being noted in relation to soil fertility and drainage class.

---

$e = 2.718$ ; GMV = gross merchantable volume; TV = total volume; DV = decay volume; CV = cull volume;  $X_1$  and  $X_2$  = dbh and dbh<sup>2</sup>

Balsam fir was a component in 122 sample plots. Table 1 shows the distribution of trunk studies according to forest type and locality. In several cases, it can be seen that the sampling does not permit comparisons in all categories.

Finally, since all measurements were taken in British units, calculations were done on that basis and results converted to metric units.

## RESULTS

### Volumetric data

#### Boreal forest region

When the trees were dissected, more than half the area was overmature forest. The volumetric data obtained must therefore be interpreted accordingly; a pure balsam fir commercial forest might produce different results. On the other hand, the data give a good picture of conditions in an unmanaged virgin forest in Quebec.

Table 2 summarizes field data according to age class for balsam fir in the boreal forest. These figures were used to construct the curves in Figure 2 and arrive at estimated values for the average tree in each ten-year age class. The estimated values are presented in Table 3.

Table 3 shows the direct relationship between the percentage of decay or cull and the age of the tree. Until the tree is 120 years old, the net merchantable volume continues to increase; afterwards, the proportion of decay or cull rises, causing the net merchantable volume curve to drop. At this age, it can also be seen that the total volume, average height, and average diameter reach a ceiling. Since dissections were done on living trees only, the proportion of fir trees killed by decay cannot be evaluated in these stands. On the other hand, the average heights and diameters of these trees show that they reached maturity in this area at between 90 and 110 of age.

The volume and percentage of decay in relation to diameter (dbh) of the tree are presented in Figure 3 and Table 4. Trees of 23 cm or less had an average decay volume of approximately 6 percent of the gross merchantable volume; for trees of 24 to 30 cm this percentage is closer to 9 percent. On the other hand, the cull volume is between 12 and 15 percent of the gross merchantable volume for trees 12 to 28 cm dbh.

**Table 1.** Distribution of number of balsam fir trees measured and dissected at each locality according to forest type, soil fertility, and drainage class

Forest type	Fertility*	Drainage**	Number of trees					
			Boreal forest localities			Mixed hardwood forest localities		Total
			1	4	5	2	3	6
<i>Cornus-oxalis</i>	I	G						272
<i>Dryopteris-oxalis</i>	I	M				494	596	1090
<i>Aralia-Cornus</i>	I	M	224					224
<i>Aralia-Diervilla</i>	I	M	192					192
<i>Calliargon-Oxalis</i>	II	G		297			494	791
<i>Calliargon-Vaccinium</i>	II	G	8	85			18	111
<i>Kalmia-Vaccinium</i>	II	G	3					3
<i>Hypnum</i>	II	G				47		47
<i>Hylocomium-Oxalis</i>	II	M	791	561	894	1134	60	3440
<i>Hypnum-Cornus</i>	II	M		110				110
<i>Hypnum-Hylocomium</i>	II	M		381				381
<i>Hylocomium-Cornus</i>	II	M	667		273			940
<i>Calliargon</i>	II	M	21					21
<i>Sphagnum-Oxalis</i>	II	P		637				637
<i>Bazzania-Oxalis</i>	III	M				145		145
Total			1906	2071	1167	1820	1168	272
								8404

\* Fertility I to III from very good to poor.

\*\* Drainage: good (G), moderately good (M), poor (P).

**Table 2.** Volume compiled from basic field data collected during dissections of balsam fir in the boreal forest

Age class	Number of trees examined	Average age	Average height (m)	Average dbh* (cm)	Volume (m <sup>3</sup> )						Percentage of gross merchantable volume	
					Total	Gross merchantable**	Decay	Cull	Net merchantable (minus decay)	Net merchantable (minus cull)	Decay	Cull
1-20	68	18	8.0	9.7	2.0	1.4	0.0	0.1	1.4	1.3	0.1	7.1
21-40	418	31	9.9	11.4	23.0	18.9	0.3	1.2	18.6	17.5	1.5	6.3
41-60	1083	52	11.8	12.4	91.4	80.9	4.5	9.1	76.4	71.8	5.6	11.2
61-80	1228	71	14.1	15.0	172.3	159.5	7.6	15.0	151.9	144.5	4.8	9.4
81-100	1274	90	15.2	17.5	259.8	245.6	17.1	32.1	228.5	213.5	7.0	13.1
101-120	602	109	15.6	19.3	152.9	145.7	13.6	24.0	132.1	121.7	9.3	16.5
121-140	262	129	15.4	19.3	67.2	64.1	7.5	13.0	56.6	51.1	11.7	20.2
141-160	139	149	15.5	19.3	33.4	32.0	2.7	5.0	29.3	27.0	8.4	15.6
161+	70	175	16.2	20.3	17.9	17.1	1.7	3.1	15.4	14.0	9.9	18.1
Total	5144				819.9	765.2	55.0	102.6	710.2	662.6		
Average											7.3	13.5

\* Diameter at breast height, at 1.3 m from the ground.

\*\* Minus the butt and non-merchantable part of the trunk.

Table 3. Average volume ( $\text{dm}^3$ ) per tree and percentage decay and cull in relation to age class for balsam fir in the boreal forest (estimated values)

Age class	Number of trees examined	Average height (m)	Average dbh (cm)	Volume ( $\text{dm}^3$ ) per tree						Percentage of gross merchantable volume	
				Total	Gross merchantable	Decay	Cull	Net merchantable (decay)	Net merchantable (cull)	Decay	Cull
20	137	8.3	10.2	41.3	31.5	0.7	2.2	30.8	29.3	2.1	6.9
30	211	10.2	11.0	51.6	41.7	1.2	3.3	40.5	38.4	2.8	7.8
40	325	10.6	11.4	65.3	55.2	1.9	4.8	53.3	50.4	3.4	8.7
50	583	11.9	12.4	83.3	73.2	3.0	7.0	70.2	66.2	4.1	9.6
60	604	12.9	13.5	107.0	96.7	4.6	10.2	92.1	86.5	4.7	10.5
70	609	14.0	14.7	137.4	128.9	6.9	14.5	114.4	114.4	5.4	11.4
80	658	14.5	16.3	173.7	162.8	10.0	20.0	152.8	142.8	6.1	12.3
90	668	15.2	17.5	209.7	198.4	13.5	26.2	184.9	172.2	6.8	13.2
100	462	15.5	18.3	234.6	223.2	16.7	31.5	206.5	191.7	7.5	14.1
110	310	15.8	19.2	246.2	234.7	19.1	35.2	215.6	199.5	8.1	15.0
120	191	15.8	19.5	250.3	238.7	21.1	38.0	217.6	200.7	8.8	15.9
130	122	15.8	19.5	251.5	240.0	22.8	40.3	217.2	199.7	9.5	16.8
140	94	15.9	19.8	251.9	240.4	24.4	42.5	216.0	197.9	10.2	17.7
150	64	15.9	19.8	252.0	240.5	26.1	44.7	214.4	195.8	10.8	18.6
160+	99	15.9	20.1	252.1	240.6	27.7	46.8	212.9	193.8	11.5	19.5

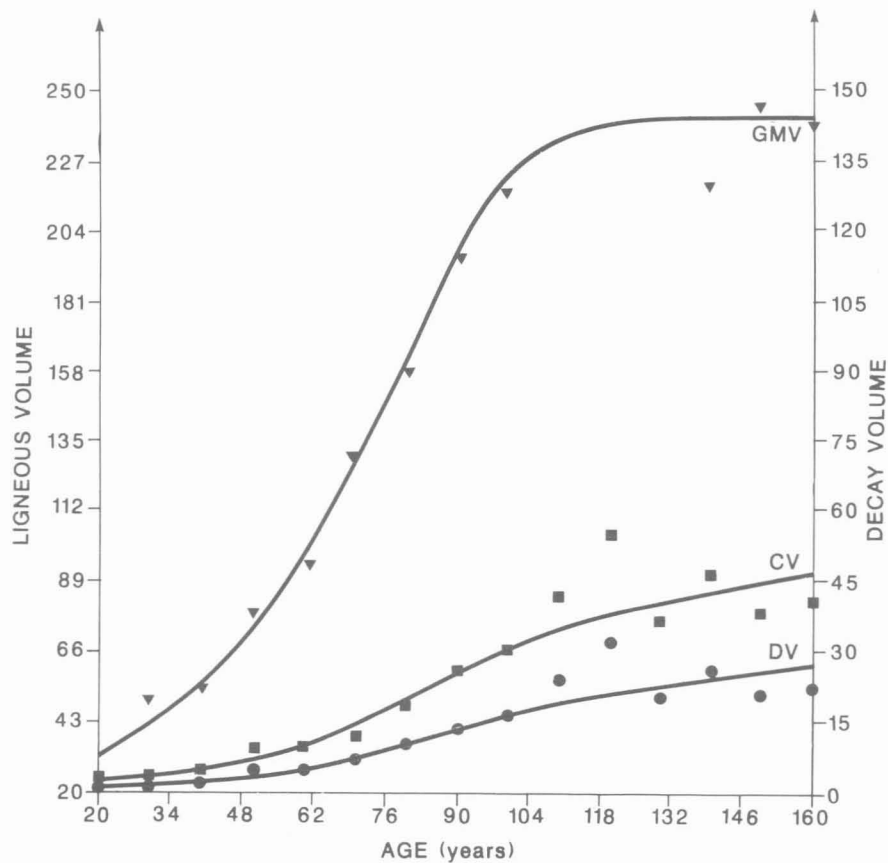


Figure 2. Average volume ( $\text{dm}^3$ ) per tree in relation to age for balsam fir in the boreal forest. Gross merchantable volume (GMV), decay volume (DV), and cull volume (CV).

Table 4. Average volume ( $\text{dm}^3$ ) per tree and percentage decay and cull in relation to diameter class for balsam fir in the boreal forest (estimated values)

dbh (cm)	Number of trees	Average height (m)	Average age	Volume ( $\text{dm}^3$ ) per tree						Percentage of gross merchantable volume	
				Total	Gross merchantable	Decay	Cull	Net merchantable (decay)	Net merchantable (cull)	Decay	Cull
-9.0	444	7.6	52.0	22.0	13.3	0.6	1.9	12.7	11.4	4.5	14.2
10.2	863	9.5	61.5	38.5	29.8	1.4	3.8	28.4	26.0	4.7	12.7
12.7	877	12.2	71.6	71.3	62.1	3.0	7.4	59.1	54.7	4.8	11.7
15.2	841	14.0	80.0	111.6	107.9	5.7	12.8	102.2	97.1	5.3	11.9
17.8	803	15.8	87.0	179.6	169.0	10.0	20.7	159.0	148.3	5.9	12.2
20.3	580	17.1	92.2	251.8	240.1	16.0	30.8	224.1	209.3	6.6	12.8
22.9	342	18.2	97.2	339.5	326.2	24.6	44.4	301.6	281.8	7.5	13.6
25.4	179	19.2	103.2	435.2	420.1	35.5	60.8	384.6	359.3	8.5	14.5
27.9	115	20.6	110.6	541.5	524.3	49.6	80.8	474.7	443.5	9.5	15.4
30.5	66	22.0	113.3	662.6	642.9	68.1	105.9	574.8	537.0	10.6	16.4
31.8+	27	21.8	116.8	820.3	796.9	96.2	142.1	700.7	654.8	12.1	17.8

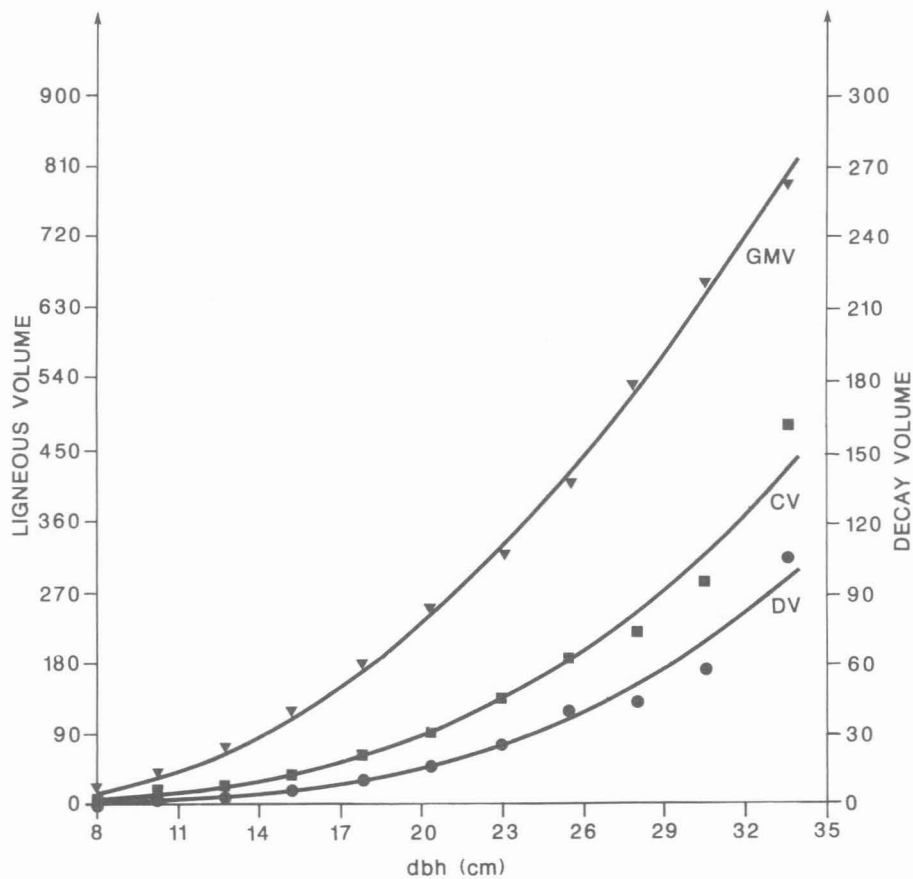


Figure 3. Average volume ( $\text{dm}^3$ ) per tree in relation to diameter (dbh) for balsam fir in boreal forest. Gross merchantable volume (GMV), decay volume (DV), and cull volume (CV).

### Mixed hardwood forest region

In this type of forest, balsam fir is frequently found together with several other species. In the three localities representing this forest type, 3 260 trees were studied. A milder climate and more fertile soil support more productive forest in this area of southeastern Quebec. One of the differences between this area and the boreal forest region is that virgin stands were almost non-existent. This area had undergone at least one cutting by the end of the nineteenth century, so in 1955, the proportion of trees 80 years of age and over was much lower than in the boreal forest (Table 5).

The merchantable volumes from the mixed hardwood forest of southern Quebec are practically double those seen in boreal forest at comparable ages (Figure 4). Whether in terms of decay or cull, the net merchantable volume of balsam fir in mixed hardwood forest continues to increase significantly until age 140 (Table 6). Subsequently, it seems to reach a ceiling, without decreasing in absolute value. However, in mixed hardwood forest the percentage of decay in relation to gross merchantable volume (Table 6) seems higher than in boreal forest after age 60.

Table 5. Volume compilations from basic field data collected during dissections of balsam fir trees in mixed hardwood forest

Age class	Number of trees examined	Average age	Average height (m)	Average dbh* (cm)	Volume (m <sup>3</sup> )						Percentage of gross merchantable volume	
					Total	Gross merchantable**	Decay	Cull	Net merchantable (minus decay)	Net merchantable (minus cull)	Decay	Cull
1-20	22	19	6.7	8.6	0.4	0.3	0.0	0.03	0.3	0.3	0.0	10.0
21-40	441	33	10.4	11.4	27.3	23.0	0.2	1.2	22.8	21.8	0.9	5.2
41-60	1609	52	13.8	15.7	247.3	226.6	6.4	13.9	220.2	212.7	2.8	6.1
61-80	701	68	15.1	18.3	150.8	141.3	9.4	17.3	131.9	124.0	6.7	12.2
81-100	254	89	15.2	21.1	73.4	70.1	7.6	13.2	62.5	56.9	10.8	18.8
101-120	155	109	17.0	24.9	64.7	60.1	6.8	11.3	53.3	48.8	11.3	18.8
121-140	65	128	18.1	27.9	33.6	32.3	3.7	5.9	28.6	26.4	11.5	18.2
141-160	12	147	18.4	31.0	7.5	7.3	1.0	1.6	6.3	5.7	13.7	21.9
161+	1	170	17.4	32.0	0.6	0.5	0.1	0.2	0.4	0.3	20.0	40.0
Total	3260				605.6	561.5	35.2	64.7	526.3	496.8		
Average											6.3	11.5

\* Diameter at breast height, at 1.3 m from the ground.

\*\* Minus the butt and the non-merchantable part of the trunk.

Table 6. Average volume (dm<sup>3</sup>) per tree and percentage decay and cull in relation to age for balsam fir in mixed hardwood forest (estimated values)

Age class	Number of trees	Average height (m)	Average dbh (cm)	Volume (dm <sup>3</sup> ) per tree						Percentage of gross merchantable volume	
				Total	Gross merchantable	Decay	Cull	Net merchantable (decay)	Net merchantable (cull)	Decay	Cull
20	81	7.7	9.1	56.0	45.8	0.1	1.7	45.7	44.1	0.1	3.8
30	208	10.2	10.9	73.3	63.0	0.8	3.4	62.2	59.6	1.3	5.5
40	434	12.0	13.5	96.8	85.8	2.1	6.2	83.7	79.6	2.5	7.2
50	810	13.6	15.7	126.8	115.4	4.3	10.4	111.1	105.0	3.7	9.0
60	836	14.9	17.0	164.5	152.3	7.6	16.3	144.7	136.0	5.0	10.7
70	321	15.2	18.5	209.5	196.6	12.2	24.4	184.4	172.2	6.2	12.4
80	156	15.4	20.3	260.6	246.8	18.3	34.9	222.5	211.9	7.4	14.2
90	138	15.4	20.9	314.9	300.1	25.9	47.7	274.2	252.4	8.7	15.9
100	91	15.5	22.1	368.5	352.8	34.9	62.2	317.9	290.6	9.9	17.6
110	81	16.7	25.4	417.9	401.3	44.6	77.7	356.7	323.6	11.1	19.4
120	48	17.7	25.9	460.3	443.0	54.6	94.4	388.4	348.6	12.3	21.1
130	37	17.8	27.9	494.6	476.7	64.7	108.8	412.0	367.9	13.6	22.8
140	14	17.9	28.7	521.0	502.6	74.3	123.4	428.3	379.2	14.8	24.6
150	2	17.9	33.0	540.5	521.7	83.6	137.2	438.1	384.5	16.0	26.3
160+	3	18.2	34.8	554.5	535.4	92.4	150.1	443.0	385.3	17.2	28.0

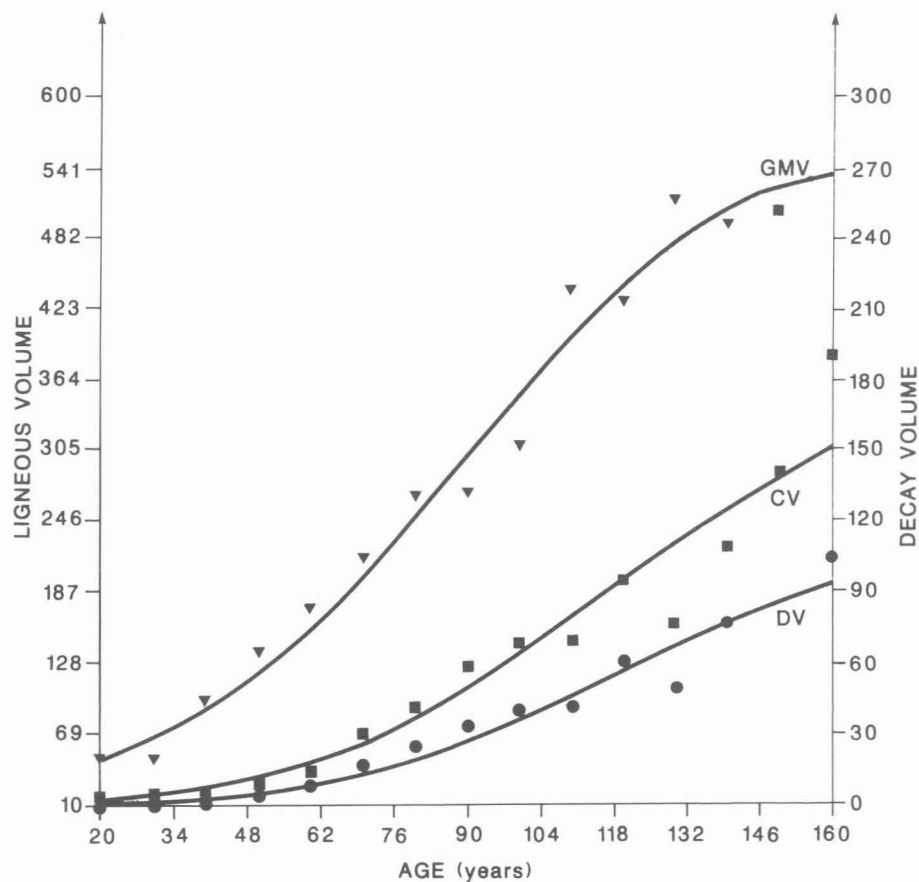


Figure 4. Average volume (dm<sup>3</sup>) per tree in relation to age for balsam fir in mixed hardwood forest. Gross merchantable volume (GMV), decay volume (DV), and cull volume (CV).

Table 7. Average volume ( $\text{dm}^3$ ) per tree and percentage decay and cull in relation to diameter class for balsam fir in mixed hardwood forest (estimated values)

dbh (cm)	Number of trees	Average height (m)	Average age	Volume ( $\text{dm}^3$ ) per tree						Percentage of gross merchantable volume	
				Total	Gross merchantable	Decay	Cull	Net merchantable (decay)	Net merchantable (cull)	Decay	Cull
9.0	150	7.6	37.1	22.2	12.8	0.5	1.6	12.3	11.2	3.9	12.5
10.2	529	9.9	46.0	40.3	30.4	1.1	3.2	29.3	27.2	3.6	10.5
12.7	598	12.1	54.7	72.7	62.0	2.4	6.1	59.6	55.9	3.9	9.8
15.2	527	14.0	58.3	116.4	104.8	4.4	10.2	100.4	94.6	4.2	9.7
17.8	407	15.1	62.1	173.3	160.5	7.5	16.1	152.5	144.4	4.7	10.0
20.3	332	16.2	66.1	238.5	224.4	11.7	23.5	212.7	200.7	5.2	10.4
22.9	253	17.2	68.7	316.6	301.0	17.6	33.3	283.4	267.7	5.8	11.1
25.4	193	17.9	74.6	401.1	383.8	25.1	44.9	358.7	337.9	6.5	11.7
27.9	114	18.5	79.7	494.3	475.2	34.4	59.0	440.6	416.2	7.2	12.4
30.5	73	19.1	93.3	599.9	578.6	46.5	76.3	532.1	502.3	8.6	13.2
31.8+	84	20.2	101.7	816.0	790.2	76.3	116.5	713.9	673.7	9.7	14.7

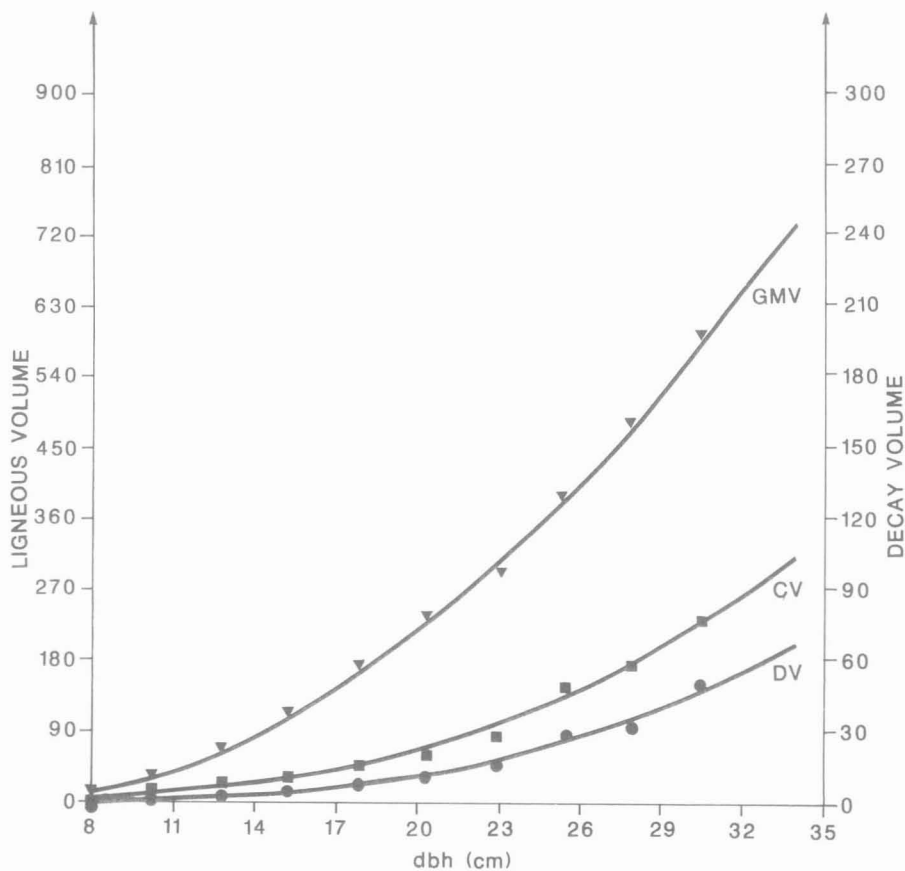


Figure 5. Average volume ( $\text{dm}^3$ ) per tree in relation to diameter (dbh) for balsam fir in mixed hardwood forest. Gross merchantable volume (GMV), decay volume (DV), and cull volume (CV).

The extent of decay in relation to dbh for balsam fir in mixed hardwood forest is illustrated in Figure 5. Trees smaller than 15 cm dbh show about 4 percent decay in terms of gross merchantable volume; this is equivalent to 10 percent cull (Table 7). For trees with a diameter of 18 to 30 cm, decay and cull vary from 5 to 8 percent and from 10 to 13 percent respectively.

#### Principal fungi causing balsam fir decay

By culturing each rot found during dissection, it was possible to identify the principal fungi that infect the trunk or butt of balsam fir in natural forest.

#### Location and frequency

Table 8 indicates the relative importance of rot-causing fungi for the various localities studied. Whether in boreal forest (localities 1, 4, and 5) or in mixed hardwood forest (localities 2, 3, and 6), *Stereum sanguinolentum* (Alb. and Schw. ex Fr.) Fr., subsequently known as *Haematostereum sanguinolentum* (Fr.) Pouzar, is responsible for virtually all trunk rot in balsam fir. This red rot also causes the greatest loss by volume.

Butt rot is more frequent than trunk rot but the volume of decay is much less. In addition, butt rot is caused by

a greater variety of organisms. *Poria subacida* (Pk.) Sacc. can infect both hardwoods and softwoods and it is found on balsam fir at all localities studied. Because *Corticium galactinum* (Fr.) Burt. and *Poria subacida* (Peck.) Saccardo may have been misidentified in culture when the dissections were being done (White 1951), it is not possible to comment on their distribution. *Polyporus balsameus* Pk., causing a brown cubical butt rot, is the only other fungus found at all localities.

The low proportion of other fungi identified and their scattered distribution makes it impossible to identify mycoflora specific to boreal or mixed hardwood forest. None the less, it should be noted that *Armillaria mellea* (Vahl ex Fr.) Kumm., an ubiquitous forest pathogen, seems to infect balsam fir more frequently in mixed hardwood forest.

#### Infection courts

The only two trunk rot fungi considered for this analysis were *H. sanguinolentum* and *Fomes pinicola* (Sw ex Fr.) Cke. For the former, branch stubs served as the point of entry into the trunk in 67 percent of cases; other infection courts were mechanical wounds (16%), frost cracks (4%), split crotches (3%), and broken tops. *F. pinicola*, responsible for less than 1 percent of

trunk rot, entered mainly through mechanical wounds or dead or broken branches.

For the five main types of butt rot, the greatest majority of infection courts (97%) are at root level; there were no visible signs above ground level. Mechanical wounds and frost cracks were identified as the other types of infection courts. The absence of external signs of butt rot confirms that the study

sites were not located in old burns and that no recent cutting or hauling had taken place in these stands.

It seems that balsam fir decay fungi generally used similar points of entry, irrespective of the locality, and it was not possible to detect any difference in evolution from one stand to another based on external signs of decay.

Table 8. Distribution and frequency of fungi causing balsam fir decay

Decayed part and fungus	Frequency in % by locality						Percentage of total All localities
	Boreal forest locality			Mixed hardwood forest locality			
	1	4	5	2	3	6	
<u>Trunk rot</u>							
<i>Stereum sanguinolentum</i>	49.0	44.0	33.4	34.4	43.5	38.1	41.0
<i>Fomes pinicola</i>	0.2	1.2	-	0.7	0.9	0.5	0.6
<i>Fomes pini*</i>	-	0.1	-	0.8	0.4	-	0.3
<u>Butt rot</u>							
<i>Poria subacida</i> and/or	41.9	50.3	42.1	42.4	45.5	56.4	44.8
<i>Corticium galactinum**</i>	-	-	-	-	-	-	-
<i>Polyporus balsameus</i>	2.8	3.5	6.3	3.7	8.4	0.5	4.3
<i>Coniophora puteana</i>	1.2	-	3.4	5.0	-	-	1.8
<i>Odontia bicolor</i>	0.9	-	-	2.6	-	-	0.7
<i>Armillaria mellea</i>	0.1	0.1	-	0.5	0.6	-	0.2
<i>Merulius himantioides</i>	0.2	-	-	2.1	-	-	0.5
<i>Polyporus tomentosus</i>	-	0.3	0.2	0.1	-	-	0.3
<i>Polyporus schweinitzii</i>	0.1	-	0.1	0.4	-	-	0.1
<i>Polyporus abietinus</i>	-	0.1	-	-	0.4	-	0.1
<u>Unidentified basidio - mycetes</u>							
	3.6	0.4	14.5	7.3	0.3	4.5	5.3
Total	100	100	100	100	100	100	

\* Occasionally butt rot.

\*\* There may have been confusion between the two species over the course of the study.

### Storey of infected trees

The proportion of infected trees at each storey of the stand as well as the relative volume and proportion of butt and trunk rot in relation to storey were studied. No particular tendency was evident when the data were reviewed in relation to locality or ecological type. The analysis therefore deals with the localities taken as a group.

Table 9 shows that 48 percent of the trees studied had no decay. The percentage of rot-free trees is greater at the intermediate and suppressed storeys in each locality. The proportion of trees infected with butt rot increases from the dominant storey to the suppressed storey, whereas the reverse is true for the proportion of trees infected with trunk rot. In contrast, the volumes of both categories of decay decrease from the dominant storey to the suppressed storey. For a given storey, the average volume of trunk rot is five times greater than the volume of butt rot for the two higher storeys; this ratio is about 3:1 for the two lower storeys. The total of decay volumes from Table 9 does not correspond exactly to the total from the first part of this work because some cases of butt rot and trunk rot could not be assigned to one particular category and were omitted.

### Some site characteristics

The frequency and volume of butt rot and trunk rot from one locality to another revealed differences which cannot be attributed to the number of trees studied or to the number of trees with rot (Table 10). For example, in the Baie-Comeau forest (locality 1) the average volume of trunk rot was higher than in Laurentides Park (locality 4), although the number of trees with decay was the same in both places. Unverifiable factors such as climate, topography, or the history of the stand probably explain these variations. To reduce the influence of such factors from one locality to another, an attempt was made to compare types of decay within a given locality and to report the number of localities where a given phenomenon was observed. The number of comparisons becomes so limited that we will simply summarize our findings below, rather than illustrate them with a very incomplete chart.

As mentioned earlier, butt rot is generally more frequent than trunk rot. One exception was noted in the fertility I class sites at Baie-Comeau (locality 1), where butt rot was twice as infrequent as trunk rot. Consequently, decay volumes for trunk rot are approximately three times greater than

**Table 9.** Breakdown of decay categories according to storey of balsam fir tree in stand (all localities)

Storey	Number of trees		Incidence of decay and percentage of trees infected by decay				Decay volume in m <sup>3</sup> and as percentage of total decay volume				Average volume (dm <sup>3</sup> )*	
			Butt		Trunk		Butt		Trunk		Butt	Trunk
	Total	Decay-free (%)	No	%	No	%	m <sup>3</sup>	%	m <sup>3</sup>	%		
Dominant	1401	484 (34)	654	71.3	587	71.8	8.3	8.1	36.7	35.9	11.7	56.7
Co-dominant	2758	1148 (42)	1157	71.8	875	54.3	8.6	8.4	32.1	31.4	7.0	34.3
Intermediate	2450	1320 (54)	820	72.5	520	46.0	3.6	3.5	8.2	8.1	4.2	14.9
Suppressed	1795	1048 (58)	563	75.3	317	42.4	1.7	1.6	3.1	3.0	2.8	9.5
Total	8404	4000 (48)	3284		2299		22.1	21.6	80.1	78.4	6.5	32.7

\* Average volume = decay volume ÷ incidence of decay.

**Table 10.** Frequency and volume of balsam fir decay according to locality

Locality	Number of trees		Incidence of decay		Total decay volume (m <sup>3</sup> )		Average decay volume (dm <sup>3</sup> )*		
	Total	With decay	Butt	Trunk					
					Butt	Trunk	Butt	Trunk	
<u>Boreal forest</u>									
1	1906	940	631	607	3.5	25.4	5.5	41.8	
4	2071	1176	860	700	5.1	18.6	5.9	26.6	
5	1167	660	623	303	3.5	9.2	5.6	30.4	
<u>Mixed hardwood forest</u>									
2	1820	944	748	427	5.2	14.3	6.9	33.5	
3	1168	509	376	303	4.3	11.5	11.4	37.9	
6	272	175	134	84	0.5	1.1	3.7	13.1	

\* Average volume = decay volume ÷ incidence of decay

those for butt rot in all localities except Baie-Comeau, where the ratio is 14:1.

In the fertility II class, the highest percentage of rot in terms of volume is found in forest type *Hylocomium-Oxalis* for three of four localities where it was encountered, the second highest being in type *Hylocomium-Cornus*. Forest type *Calliargon-Vaccinium* yielded the least rot in each of the three localities where it was studied, whether in boreal forest or in mixed hardwood forest. Mixed hardwood forest type *Dryopteris-Oxalis* also exhibited less decay than the others.

The only data suitable for use in comparing the three soil drainage classes is that collected in Laurentides Park (locality 4). Although the differences are not very significant, it should be pointed out that, here, the average volume and frequency of butt rot increases as one moves from well drained sites (5.2 dm<sup>3</sup>/rot) to poorly drained sites (5.9 dm<sup>3</sup>/rot); the frequency of butt rot is 2.5 times greater on poorly drained sites than on well drained sites. The ratio is the same for trunk rot but the differences among the three drainage classes are smaller. Comparisons in the other localities, between well drained sites and moderately well drained sites,

showed nothing of interest. The one point we should mention is that in boreal forest type *Hypnum-Hylocomium* seemed more infected by rot than type *Hylocomium-Oxalis* in locality 4.

## DISCUSSION AND CONCLUSIONS

Most previously published studies on decay show a correlation between decay and age of the tree. Decay volume generally increases with the age of the tree and is influenced by many factors in the environment. The diameter-decay relationship can be considered in some cases, but we know that diameter is greatly influenced by the quality of the site in a given region. The data was therefore analysed mainly in relation to age, but in order to allow practical application, it was also presented in relation to diameter, even though there was less of a correlation at times.

With respect to ecological differentiation of volumetric data, the only distinction we could make in our analyses was between boreal forest and mixed hardwood forest in southern Quebec. The results from the decay studies done in different locations in the province can be used for general information, but they will have to be completed on a local basis if an improved level of accuracy is

desired. Since the data come from studies of individual trees taken from different stands of varying composition and density, it should not be used for extrapolations on the basis of area.

The volumetric figures on total and merchantable volume for trees in the boreal forest are somewhat lower than those of McCallum (1928), closer to those of Davidson (1957), and higher than those of Morawski et al. (1958). On the other hand, the percentages of decay or cull volume given by Morawski et al. (1958) compare closely with our data for mixed hardwood forest; the other studies mentioned report a higher percentage of cull, particularly among trees 100 years of age and over. Given the variety of sites studied and differences in scaling regulations for calculating cull, the values that we obtained are, on the whole, comparable to those published previously.

Results obtained from boreal forest are different from those for mixed hardwood forest and reflect significant differences in growing conditions. In the boreal forest, where balsam fir often co-exists with black spruce, a virgin stand, apparently, undisturbed by fire or insects, reaches maturity at about 120 years. At that point, almost 10 percent of the merchantable volume of living

trees is decayed; scaled for pulpwood, this translates into approximately 18 percent cull. Beyond 120 years, it appears from the basic data that decay works cyclically; some trees, generally the most rotten, fall, and the decay volume of the remaining trees decreases only to increase again later. Type *Hylocomium-Cornus* which has the most decay, was often found in this kind of overmature forest.

In mixed hardwood forest, the net merchantable volume increases until about 140 years. In contrast, an analysis of some of this data puts pathological maturity at between 110 and 140 years, depending on forest type (Pomerleau 1957)<sup>1</sup>; Pomerleau also points out that maturity can occur at between 70 and 100 years according to average annual growth and periodic net growth. In the 140-year-old mixed hardwood forest, the proportions of decay and cull for pulp are, respectively, 15 and 25 percent of merchantable volume, which is itself double that for boreal forest. Environmental conditions in mixed hardwood forest seem, then, to encourage better growth both of the tree and of its decay pathogens.

Moreover, if cull had been calculated in terms of milling, it would have been necessary to add about 4

percent to the cull volume given in the results (Pomerleau 1957)<sup>1</sup>. As already noted (McCallum 1928), volumetric data and data related to the storey of the trees seem to indicate that fast-growing trees show a higher percentage of decay. On the other hand, for a given period, such trees yield a greater net volume of ligneous matter than slow-growing trees.

The identities, modes of entry, and relative importance of the balsam fir decay fungi correspond to what was reported previously (Basham et al. 1953; McCallum 1928; Spaulding and Hansbrough 1944). These studies point out that decay can result from the successive action of a number of fungi, of which some would be of secondary importance. However, the cumulative frequencies of rot fungi cultures obtained by various researchers in different places indicate to us that the relative importance of at least the six major pathogens is the same. More detailed studies in Quebec and elsewhere have already been done on the importance and mode of entry of the principal trunk rot fungus *H. sanguinolentum* (Davidson and Etheridge 1963).

Trunk rot produces a much greater volume of decay than butt rot. It is possible that several infection courts on a given trunk feed a given

decay column at different levels on the tree. In a second or third growth stand, or in a forest where hardwood trees have been cut by diameter limit, more decay in the trees at all storeys would be expected. Lortie (1968) illustrates and describes the great variety of infection courts that can be found in a forest more frequently disturbed, although younger, than those studied here. Our results indicate a higher proportion of decay-free trees at the lower storeys because at the time the areas were being studied, they were relatively undisturbed.

Comparisons between butt rot and trunk rot at a given locality are possible because the same trees are being considered in relation to the age and history of the stand. No major fungus was limited to a single locality. The relationship between the extent of decay and soil drainage in locality 4 corresponds to what Morawski et al. (1958) observed for balsam fir trees less than 100 years of age. However, this is the reverse of the relationship established by Whitney (1974) for a softwood stand in Ontario. More specific studies are needed to increase our knowledge about the frequency and rate of progression of decay in a particular type of forest. One point that should be the subject of future study has already been

mentioned, that is that butt rot is more frequent on well drained lands of mixed hardwood forest than on flat, less well drained lands of softwood forest (Heimbürger and McCallum 1940, Basham et al. 1953).

These results should serve as a supplement to forest inventories, particularly when net merchantable volumes in relation to balsam fir decay must be determined. It is obvious that at the local level certain factors governing loss from rot will be different; consequently, additional samplings will be required if greater accuracy is to be obtained.

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