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FRANK KAUFERT

INTRODUCTION

Balsam fir (*Abies balsamea,* Mill.) is just beginning to emerge from its status as an inferior species in the Lake States. It is being used in increasing quantities for pulpwood, boxboards, lumber, and lath. Altho somewhat inferior to spruce as a pulpwood, the shortage of spruce has forced paper mills in the region to accept larger and larger quantities of balsam.

Silviculturally, balsam fir has many desirable characteristics. It produces large quantities of seed at frequent intervals. It reproduces in dense shade, as seen by the reproduction under stands of aspen, Norway or white pine, and the hemlock-hardwood stands of Wisconsin. Because its tolerance permits it to grow under dense canopies without injury to its crown, it responds rapidly when released. If grown in short rotations, balsam fir grows more rapidly and yields more than spruce. Because of its aggressiveness and superior reproduction, balsam fir will no doubt be in greater demand than white or black spruce and will play a more important part in the management of much of the better forest land of the Lake States in the future.

The principal objections to balsam fir are its susceptibility to attack by the spruce budworm and wood-rotting fungi, principally those attacking the heart-wood of living trees. The damage in the Lake States done by the last spruce budworm epidemic has been described by Graham (3). Foresters and cruisers are well acquainted with the fact that many Lake States balsam fir stands are very defective, and that wind-breakage due to weakening of the trees by butt rot causes heavy losses. Hubert (4) has described the occurrence of a brown cubical butt rot, caused by *Polyporus balsameus* Pk. in balsam fir stands in the Lake States. The yellow stringy butt rot caused by *Poria subacida* (Pk.) Sacc. has also been found by several workers in this region. McCallum (5) and Spaulding and Hepting (9) have shown that this fungus causes serious losses in eastern balsam fir stands. The red rot caused by *Stereum*

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sanguinolentum Fr. has also been observed in the upper bole of overmature trees. The causal organism of this rot, which is so prevalent in stands of balsam fir in the Eastern United States and Canada, was first determined by Faull and Mounce (1).

OBJECTS OF THE STUDY

Altho there is observational evidence on losses caused by heart rot of balsam fir in the Lake States, a careful investigation of the extent and nature of these losses has never been made, and the object of this investigation was to obtain more precise information. Specifically, the objects were to obtain information on the following:

1. The actual volume of wood culled under present commercial culling practices because of rot.
2. The probable volume of cull under somewhat closer utilization practices.
3. The actual volume of rot and the pathologic rotation for balsam fir in the Lake States.
4. Whether a relationship exists between diameter and decay or between diameter and cull.
5. The influence of land type and rate of growth on the prevalence of decay and cull.
6. The reliability of external signs of decay as indications of heart rot.
7. The identity of the fungi causing most of the decay and cull losses and their points of entrance.

FIELD METHODS

The results of this study are based on data from about 1,170 sample trees of which more than 900 were of merchantable size, or would yield at least one 8-foot bolt with a minimum top diameter of 3.0 inches (inside bark). The trees were taken from 19 sample plots in Lake, St. Louis, Koochiching, Itasca, and Aitkin counties in Minnesota and Price and Sawyer counties in Wisconsin. Between 30 and 100 trees were cut from each sample plot. Some of the areas sampled were on the Superior, Chippewa, and Chequamegon national forests; some were on the George Washington and Cloquet Valley state forests; and some were on lands of the Northwest Paper Company and of the Minnesota and Ontario Paper Company.

Two methods of sampling were followed: (1) clear-cutting small areas; (2) cutting all trees within two feet on either side of a compass line run through the stand. When the trees in pulpwood operations were measured, all the merchantable trees cut by the loggers plus any small or obviously defective trees were taken. It is felt that these sampling methods should yield as near a representative sample as any known method. All types of stands were sampled. Some plots were on lowland; others were on ridges; some were in young rapidly growing stands; and some were in overmature balsam stands, growing as an understory in stands of white and Norway pine or hemlock and hardwood. Whenever possible, the largest samples were taken in the types most common in this region.

Since balsam fir grows on a wide range of sites and under such extremes of density, its size for a given age varies considerably. Even trees growing side by side are not alike. This great variability necessitated a larger sample than would have been required for more exacting species.

On pulpwood operations, the sections usually were eight feet long, the stump one foot high, and the top diameter three inches. Whenever possible, the age of each tree was determined on the stump. Because of the large amount of butt rot, however, the age of about 50 per cent of the trees had to be determined at points from 1 to 12 feet above the stump and then corrected for age at the ground.

General notes on location, ground cover, forest type, site quality, associated species, etc., were taken for each plot. In addition, the following data were obtained for each sample tree:

- DBH (outside bark to nearest 1/10 inch)
- Crown class
- Local land type
- Total height
- Condition of tree
- Age at stump, where this could be obtained, or higher when butt rot was present
- Wounds (type, location, size, etc.)
- Insect damage
- Type of decay
- Location of decay
- Causal organism (where decay was so typical as to be readily recognized)
- Avenue of entrance of causal organism
- Top diameter of stump inside bark
- Bottom and top diameter of each bolt (inside bark to the nearest 1/10 inch)
- Length of top (to nearest foot)
- Length and diameter of butt and top rot (at four-foot intervals)
- Length and diameter at small and large ends of bolts culled according to present culling practices
- Length and diameter at small and large ends of bolts containing top or butt rot (theoretical cull)

CULLING PRACTICES

The question of how to cull is a difficult one. As pointed out by Schmitz and Jackson (7), utilization standards change continually, and, as they change, culling practices change also. What is cull today may not be cull tomorrow. For this reason two culling standards were arbitrarily adopted in this study, and two sets of figures were obtained for cull losses, in addition to those on the actual volume of rot. The present culling practice used in pulpwood operations in Northern Minnesota was adopted as one method. Altho practices of various companies and even individual pulpwood cutters differ, the same general principles are followed by both. In general, sections less than eight feet long and those with butt rot or with the advanced stages of red top rot are discarded and left in the woods. In some cases the short sections are discarded because of excessive knots or sweep, but more often because rot is present. This type of cull is termed commercial or *actual cull.*

The second method adopted was the method used by McCallum (5) and by Spaulding and Hepting (9). In this method only those sections of the merchantable portion of the tree having either top or butt rot were culled. All sound short sections and sections that would be considered unmerchantable under present woods practices were considered merchantable. This type of cull is termed probable or *theoretical cull.*

The cull loss according to present utilization practices is of greatest immediate value to the forester and private timber owner, altho data on probable or theoretical cull may be of more value in the future when economic conditions make closer utilization possible and other than 4-, 8-, and 12-foot sections are accepted. Because wood is now culled that in the future will perhaps be utilized, the figures for actual cull are higher than those for theoretical or probable cull.

METHOD OF COMPILATION

The method of compilation outlined by Schmitz and Jackson (7) was followed. All volumes were computed in cubic feet inside the bark. The stump was considered a cylinder with a diameter equal to the top of the stump. The volume of each section was computed by Smalian's formula and the volume of the top by the formula for the volume of a cone. Both total and merchantable volume were computed. The merchantable volume included only the wood from stump height to a three-inch top; total cubic volume included, in addition, the volumes of the stump and top. The volume of butt and top rot and the volumes of culled bolts were also computed by Smalian's formula.

A single mimeographed sheet, on which all the field information and office computations were recorded, was used for each tree. This arrangement eliminated copying of the data and speeded up the computations, checking, and analysis.

Since the age of each tree was determined either at stump height or from 1 to 12 feet above ground, a correction for age at the ground was necessary to obtain the total age of the tree. This was done by cutting a number of young trees, from 10 to 30 years old, on each plot and determining their age at the ground and at intervals of one foot up to 13 feet above ground. In all, 80 saplings were cut. The ages at one foot above ground, two feet above ground, etc., were averaged and the averages curved over height. The ages at various heights above ground, which were used in correcting the ages of the trees, are given in Table 1, which shows the effect of suppression on the height growth of balsam fir in the early part of its life.

Table 1.—Age of Balsam Fir at Different Heights Above Ground

Height above ground	Average age	Height above ground	Average age
feet	years	feet	years
1	7	8	23
2	11	9	24
3	14	10	25
4	16	11	26
5	18	12	27
6	20	13	28
7	22		

DECAY AND CULL OF BALSAM FIR IN RELATION TO AGE

The relationship between age, decay, and cull was determined from an analysis of the sample trees. To determine accurately the effect of decay on the rotation, the stand rather than the individual tree should be used as a basis. Because of mortality losses, the mean annual growth of the stand culminates before that of individual trees. However, since balsam fir rarely occurs in pure and even-aged stands, a sufficiently large sample could not be obtained for stand data. When the data from individual trees are applied to stands, therefore, it is done with the realization that a certain selection has been practiced and that the culmination of growth for stands may come earlier than is indicated by the data for individual trees.

In order to arrive at a pathologic rotation for balsam fir, several factors must be considered:

1. The percentage of trees with decay. The higher this percentage, the greater are the chances of wind-breakage, an important source of loss in balsam fir stands at present (Figs. 1 and 2).

2. The relationship between total periodic increment and periodic decay decrement. The point where the net increment curve begins to drop rapidly is the point at which decay becomes important and largely determines the pathologic rotation (6).

3. The relationship between periodic merchantable increment and periodic cull losses. Since decay is usually closely correlated with cull, this also aids in determining the correct pathologic cutting cycle.

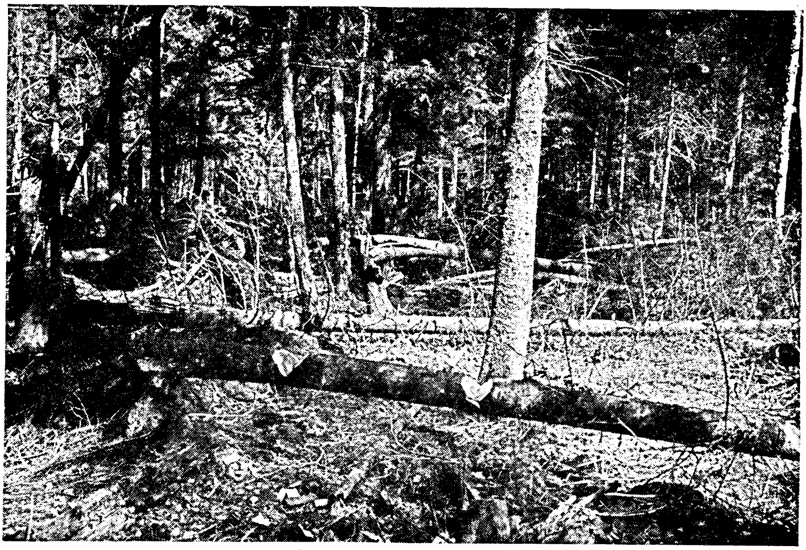

Fig. 1. A Stand of Balsam Fir, on the Chequamegon National Forest, Wisconsin, Which Has Suffered Severe Losses Owing to Wind-Breakage of Butt-Rotted Trees

The trees in this stand are from 60 to 110 years old. Most of the breaks are within a few feet of the ground, where weakening by butt rot is greatest.

Fig. 2. Wind-Breakage in an 80- to 120-Year-Old Balsam Fir Stand in the George Washington State Forest, Minnesota

Butt rot is the principal cause of such losses. This is the condition of many overmature stands of balsam fir growing as an understory in mature Norway and white pine.

The Percentage of Trees with Decay

The percentage of trees with decay is shown in Figure 3. Up to 40 years very few trees contain decay. During the following 40 years, however, the percentage of decayed trees increases rapidly. Of particular interest are the figures for butt rot. At 70 years approximately 60 per cent of the trees are infected with butt rot. Altho much of this rot does not extend far up the bole, it usually occupies enough of the stump cross section to weaken the trees and make them subject to wind-breakage (Fig. 8). Figure 3 also shows that the percentage of trees with butt rot increases rapidly after 70 years and that at 130 years practically every tree is infected. The organism causing top rot, how-

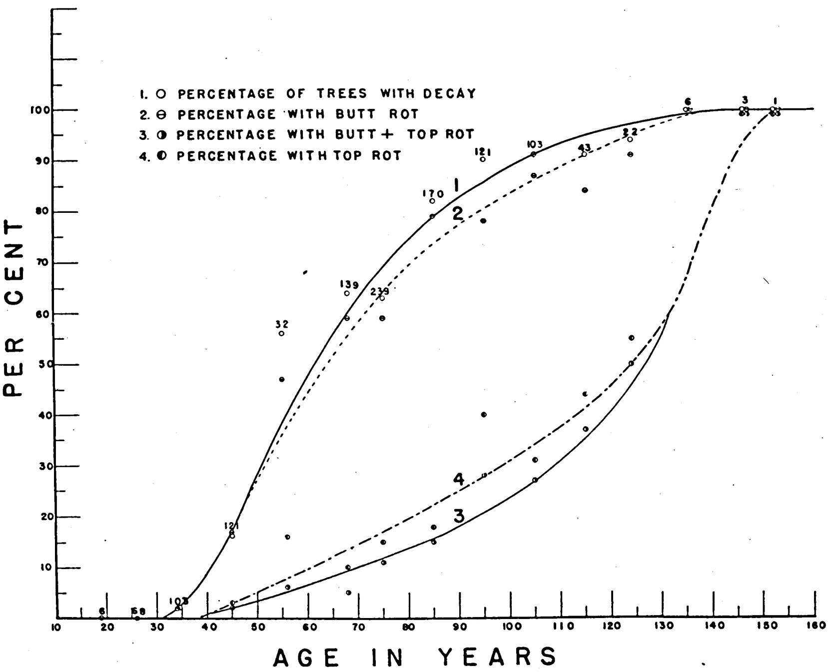

Fig. 3. Percentage of the Total Number of Trees Infected With Decay, by Age Classes

ever, apparently does not attack trees until they are somewhat older and larger. Until an age of 140 to 150 years is reached, the percentage of trees with top rot is much lower than the percentage with butt rot. At that age practically every tree has both top and butt rot. Since top rot is important only as a cause of cull and is not a cause of wind-breakage, the percentage of trees infected is not so important.

The Volume of Decay in Trees of Different Ages

The amount of rot in trees of different ages is given in Table 2 and Figure 4. The total cubic volume curve rises slowly until 50 years, after which it increases rapidly to an age of 100 years. Up to 60 years rot

Table 2.—Average Gross and Net Cubic Volume of Balsam Fir Trees, by Age Classes

Age	Total stem volume without bark*	Volume of rot per tree	Volume of rot per tree	Net sound volume per tree	Net increment	Basis
yrs.	cu. ft.	cu. ft.	per cent	cu. ft.	cu. ft.	trees
10	0.08	0.0	0.0	0.08	0.08	6
20	0.22	0.0	0.0	0.22	0.14	68
30	0.74	0.0	0.0	0.74	0.52	103
40	1.47	0.0	0.0	1.47	0.73	121
50	2.50	0.05	0.2	2.45	0.98	32
60	3.76	0.20	5.3	3.56	1.11	139
70	5.25	0.40	7.6	4.85	1.29	237
80	6.82	0.73	10.7	6.09	1.24	171
90	8.27	1.12	13.6	7.15	1.06	121
100	9.38	1.58	16.9	7.80	0.65	103
110	10.08	2.12	21.1	7.96	0.16	43
120	10.40	2.67	25.6	7.73	—0.23	22
130	10.57	3.22	30.2	7.35	—0.38	6
140	10.68	3.82	35.8	6.86	—0.49	3
150	10.78	4.41	41.0	6.37	—0.49	1
Total						1,176

* Volume includes stump, stem, top, without bark.
Data read from curves.

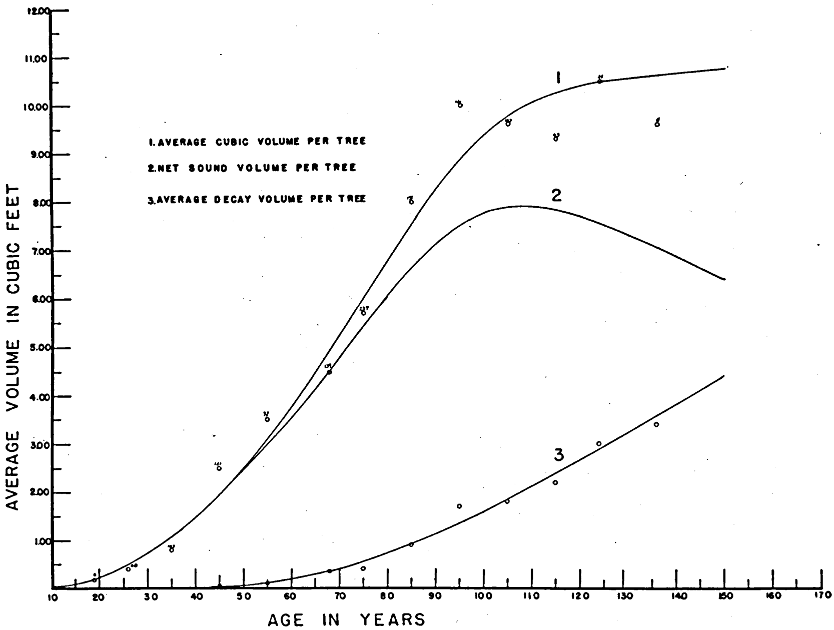

Fig. 4. Gross and Net Cubic Volume of Balsam Fir Trees, by Age Classes

is of minor importance. From 60 to 150 years it gradually increases, until at 150 years it is equal to 41 per cent of the total volume of the tree. The net sound volume reaches a maximum at 110 years. After this age the rate of decay increases more rapidly than the periodic annual increment. Altho the net increment reaches a maximum at 70 years, it is still considerable at 90 years, falling gradually to a minus quantity at 120 years.

The Volume of Cull in Trees of Different Ages

The data on merchantable volume and cull losses are shown in Table 3 and Figure 5. The curve for merchantable volume, which naturally has the same trend as the total cubic volume curve, flattens out gradually after 100 years. Actual cull, or cull according to commercial culling practices, is small up to 60 years, after which it increases rapidly until at 160 years the entire volume of the tree is cull. Actual net increment is highest at 70 years, decreasing gradually until at 100 years the volume of cull more than offsets periodic growth. Obviously,

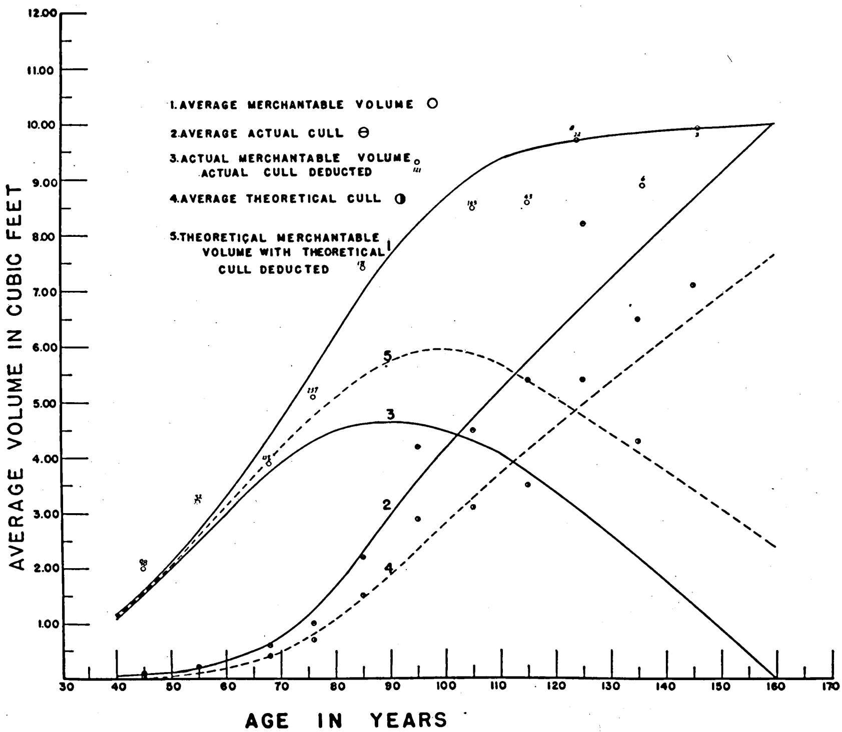

Fig. 5. Gross and Net Merchantable Volume of Balsam Fir Trees, by Age Classes

Both actual and theoretical merchantable volume are shown. The merchantable volume curve was obtained by expressing merchantable volume as a percentage of total volume and applying the curved percentages to the curved total volumes.

Table 3.—Average Gross and Net Merchantable Volume of Balsam Fir Trees by Age Classes*

Age	Merchantable volume per tree†	Cull per tree under present culling practices—actual cull		Present net merchantable volume per tree	Actual net increment	Theoretical or probable cull per tree		Theoretical net merchantable volume per tree	Theoretical net increment	Basis
yrs.	cu. ft.	cu. ft.	per cent	cu. ft.	cu. ft.	cu. ft.	per cent	cu. ft.	cu. ft.	trees
40	1.16	0.05	0.4	1.11	...	0.0	0.0	1.16	...	98
50	2.12	0.12	5.7	2.00	0.89	0.04	0.2	2.08	0.92	32
60	3.28	0.30	9.1	2.98	0.98	0.17	5.2	3.11	1.03	139
70	4.67	0.74	15.8	3.93	0.95	0.47	10.0	4.20	1.09	237
80	6.20	1.67	26.9	4.43	0.50	1.08	17.4	5.12	0.92	171
90	7.62	2.96	38.8	4.66	0.23	1.88	24.7	5.74	0.62	121
100	8.68	4.17	48.0	4.51	—0.15	2.82	32.5	5.86	0.12	103
110	9.35	5.23	55.9	4.12	—0.39	3.71	39.7	5.64	—0.22	43
120	9.63	6.23	64.7	3.40	—0.72	4.57	47.5	5.06	—0.58	22
130	9.78	7.21	73.7	2.57	—0.83	5.36	54.8	4.42	—0.64	6
140	9.88	8.17	82.7	1.71	—0.86	6.16	62.3	3.72	—0.70	3
150	9.94	9.10	91.5	0.84	—0.87	6.92	69.6	3.02	—0.70	1
160	10.00	10.00	100.0	0.0	—0.84	7.67	76.7	2.33	—0.69	0
Total										976

* Data read from curves.

† Volume includes the volume of the stem above a 1-foot stump to a 3-inch top diameter inside bark.

the trends of both actual and theoretical cull are almost identical. These data show that the culmination of growth takes place earlier when cull rather than the volume of decay alone is considered.

Pathologic Rotation of Balsam Fir

When considering the percentage of trees infected with butt rot, the percentage of decay, and the percentage of cull for the various age classes, it will be seen that there is general agreement as to the pathologic age or rotation. Net periodic increment is greatest at about 70 years, after which it decreases gradually until at approximately 100 years decay and cull losses offset growth. Since net increment is still appreciable at 90 years, stands probably could be left to that age without severe decay losses. After 80 years, however, damage from wind-breakage no doubt would be considerable. Altho the probable amount of wind-breakage cannot be estimated, field observations and the evidence presented indicate that the damage increases with increasing age, because of increase in the number of trees infected with butt rot.

When all the factors influencing the establishment of a pathologic rotation for balsam fir are considered, it appears that 80 years is about the maximum age that stands should be allowed to attain before logging.

These data show that much of the balsam fir in the Lake States is overmature. Of the 970 merchantable trees, over 400, or 41 per cent, are more than 80 years of age. As the older stands have so high a percentage of decay and cull, it is easy to see why balsam fir is considered a defective species in this region.

DECAY AND CULL OF BALSAM FIR IN RELATION TO DIAMETER

Balsam fir usually grows in uneven-aged stands in mixtures with other species. Because the age of individual trees is difficult to determine and pure even-aged stands seldom occur, the forester must work with diameter rather than with age. For this reason the relationship between cull and diameter has greater utility than the relationship between cull and age.

The figures for decay and cull were therefore classified by diameter as well as age classes. The relationship between decay, cull, and diameter is shown in Table 4 and Figures 6 and 7. These figures show that the percentages of rot and the percentages of cull increase with diameter. The highest periodic increment is reached, however, at a diameter of between 9 and 10 inches. This is apparently true for net cubic increment, actual net merchantable increment, and theoretical net merchantable increment. The age of 9- or 10-inch trees is about 90

Table 4.—Gross and Net Volume by Diameter Classes*

DBH	Age	Total height	Total volume without bark	Decay in per cent of total volume	Net sound volume	Average merchantable volume	Actual cull in per cent of merchantable volume	Actual net merchantable volume	Actual net increment	Theoretical cull in per cent of merchantable volume	Theoretical net merchantable volume	Theoretical net increment	Basis
in.	yrs.	ft.	cu. ft	per cent	cu. ft.	cu. ft.	per cent	cu. ft.	cu. ft.	per cent	per cent	cu. ft.	trees
3	62	30	0.8	0.0	0.0	0.7	2.0	0.7	...	0.0	0.7	...	21
4	67	33	1.7	5.9	1.7	1.3	9.9	1.2	0.5	7.7	1.2	0.5	
5	72	39	2.8	7.2	2.6	2.3	14.3	1.9	0.7	12.0	2.0	0.8	241
6	76	44	4.3	9.3	3.9	3.7	22.0	2.8	0.9	18.9	3.0	1.0	
7	81	48	5.6	10.7	5.0	5.2	28.0	3.7	0.9	21.2	4.1	1.1	356
8	86	52	7.7	11.7	6.8	7.3	30.1	5.1	1.4	23.4	5.6	1.5	
9	90	56	10.4	13.5	9.0	9.8	33.8	6.5	1.4	25.0	7.4	1.8	201
10	94	59	13.7	16.1	11.5	12.8	38.7	7.7	1.2	29.5	9.0	1.6	
11	97	62	17.0	17.6	14.0	16.0	49.0	8.1	0.4	34.4	10.4	1.4	78
12	100	65	20.8	20.6	16.5	19.5	59.0	7.9	—0.1	40.0	11.7	1.3	
13	103	67	24.8	24.2	18.8	23.3	66.8	7.7	—0.2	45.8	12.6	0.9	25
14	106	68	28.7	25.4	21.4	27.3	73.0	7.3	—0.4	52.4	13.0	0.4	
15	108	69	32.4	27.8	23.4	31.3	81.0	5.9	—1.4	57.2	13.4	0.4	6
	Total												928

* Data read from curves.

years. These data thus show a close agreement with those obtained when the data were plotted over age. The diameter at which the greatest returns can be realized for individual balsam fir trees, therefore, appears to be in the neighborhood of 9 or 10 inches. To reduce probable losses from wind-breakage, the diameter limit should perhaps be reduced to 8 or 9 inches, which corresponds approximately to the 80-year pathologic rotation suggested earlier.

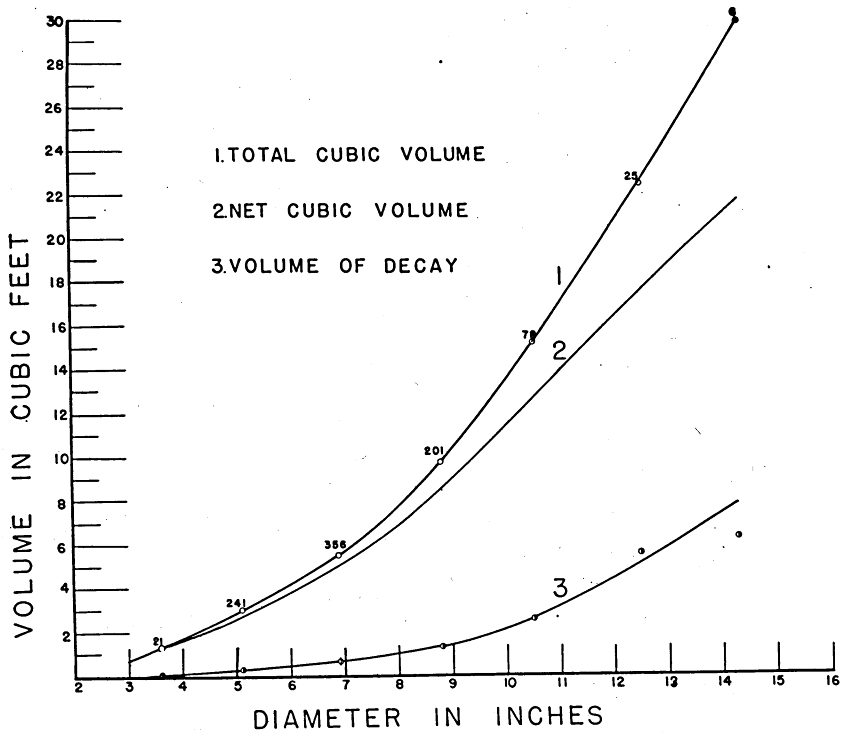

Fig. 6. Gross and Net Cubic Volume of Balsam Fir Trees, by Diameter Classes

As in the case of age, the percentage of rot and cull increases rapidly with diameter; but this increase is more than offset by the rapid increase in volume from one diameter class to another. Decay and cull losses become limiting factors and begin to reduce net periodic increment sharply only after a diameter of 9 or 10 inches has been reached. Table 4 shows that a tree with a diameter breast high of 9 inches averages 56 feet in height and has a gross merchantable volume of 9.8 cubic feet.

The cull percentages for the smaller diameters appear high, but a glance at the average age of trees in each diameter class shows the reason for this. The age of 5-inch trees is 72 years. The fact that a considerable number of very old suppressed trees of small diameter are included in each average perhaps accounts for this.

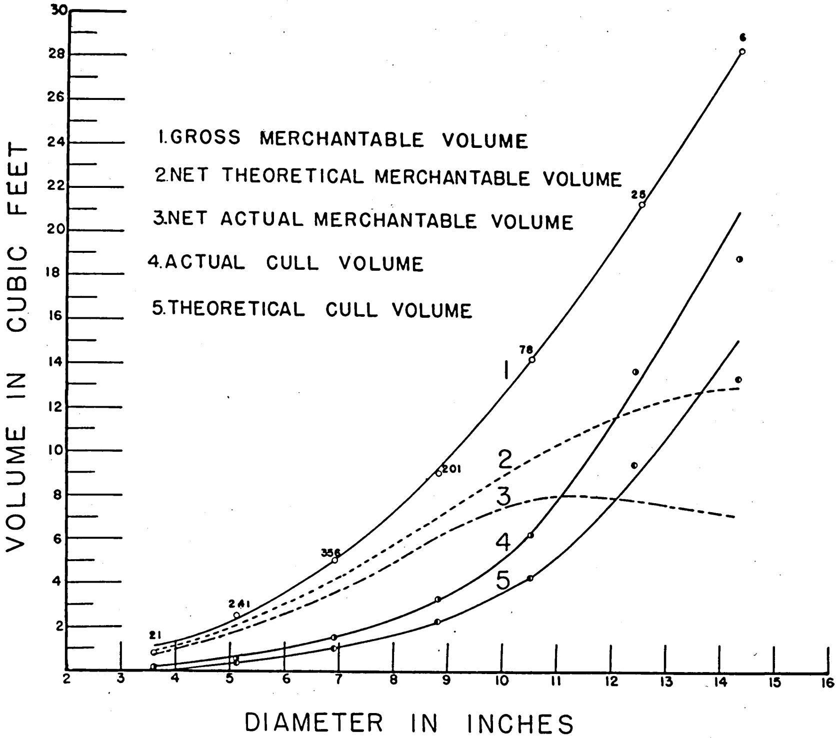

Fig. 7. Gross and Net Merchantable Volume of Balsam Fir Trees, by Diameter Classes Both actual and theoretical merchantable volume are shown.

THE RELATION BETWEEN RATE OF GROWTH, ROT, AND CULL

The relation between rate of growth or vigor of trees and the amount of decay or cull has received considerable attention from a number of workers. Vigorous, fast-growing trees usually are considered more resistant to decay than suppressed or slow-growing trees. Meinecke (6) found that trees decidedly above average were decayed less than those considerably below normal. McCallum (5) found the reverse to be true of balsam fir in the East. However, this disagreement may be due, as McCallum states, to the fact that he used only two classes within each age class, those trees having a volume greater than the average and those with a volume smaller than the average, whereas Meinecke divided his trees into three classes. Schmitz and Jackon (7) likewise found more decay in fast-growing aspen trees than in those that grew more slowly.

To determine whether there is a relationship between rate of growth and decay losses, McCallum's method of subdividing the data was used. Those below the average were considered slow-growing trees and those above the average fast-growing trees. The results are summarized in Table 5. Only the results for total cubic volume of merchantable trees and amount of decay are shown. These results show practically no difference in decay in fast- and slow-growing trees. The net periodic increment for both classes culminates at about the same point, 80 years.

The figures for average height, diameter breast high, and volume of fast-growing trees are of particular interest in connection with predictions for probable growth in managed stands of the future. Since managed stands should contain a high percentage of fast-growing trees, the results given in Table 5 for the fast-growing trees should apply more nearly to future stands than does the average of all trees.

Table 5.—The Amount of Decay in Merchantable Fast- and Slow-Growing Balsam Fir Trees of the Same Age*

Total age	Average height		Average diameter breast high		Average total cubic volume per tree		Average volume of rot per tree		Average volume of rot per tree		Basis	
	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
years	feet		inches		cubic feet		cubic feet		per cent		trees	
40	43	33	6.6	4.6	4.6	1.6	0.0	0.0	0.0	0.0	30	23
50	48	36	7.1	4.8	5.6	1.8	0.12	0.04	0.2	0.2	16	15
60	53	39	7.8	5.2	7.0	2.6	0.35	0.14	5.0	5.5	53	86
70	57	42	8.6	5.8	9.2	3.5	0.66	0.28	7.2	8.0	101	136
80	61	46	9.5	6.4	12.0	4.4	1.21	0.42	10.1	9.6	66	104
90	63	48	10.2	7.0	14.9	5.1	1.75	0.65	11.7	12.7	47	74
100	64	49	10.7	7.4	15.8	5.5	2.50	0.87	15.8	15.6	42	60
110	65	49	11.0	7.6	16.2	5.7	3.50	1.30	21.3	22.5	17	26
120	65	48	11.3	7.7	16.5	5.7	4.20	1.45	25.2	25.4	8	14
130	65	47	11.5	7.8	16.8	5.7	4.90	1.75	29.1	30.8	2	4
Total											382	542

* Data read from curves.

THE PREVALENCE OF DECAY AND CULL IN DIFFERENT FOREST TYPES

There is difference of opinion among foresters and loggers with respect to the defectiveness of balsam fir growing on different land types. Some maintain that trees growing in swamps or lowland are more defective than upland trees, whereas others argue that the reverse is true. Some maintain that butt rot is most prevalent on ridges and that trees in swamps have more red top rot. Judging from the prevalence of windthrown trees on ridges, it would appear that butt rot is more prevalent on uplands. To determine this, the trees were divided into two classes, those from ridges and those from swamps. These were then divided into age classes.

Table 6.—Gross and Net Merchantable Volume of Trees from Ridges and Lowland*

Age	Average gross merchantable volume		Theoretical cull in per cent of gross merchantable volume		Theoretical net merchantable volume		Basis	
	Ridge	Lowland	Ridge	Lowland	Ridge	Lowland	Ridge	Lowland
years	cubic feet		per cent		cubic feet		trees	
40	1.50	1.41	2	2	1.41	1.27	31	22
50	2.55	2.06	5	5	2.43	1.95	19	13
60	4.06	3.07	8	7	3.71	2.83	86	53
70	5.46	4.31	12	11	4.76	3.80	121	116
80	6.77	5.64	18	16	5.49	4.69	92	79
90	7.97	6.83	26	22	5.87	5.27	71	50
100	8.96	7.76	34	29	5.89	5.50	61	42
110	9.74	8.45	43	36	5.53	5.35	19	24
120	10.34	8.88	52	45	4.95	4.88	11	11
130	10.76	9.17	59	53	4.42	4.31	5	1
140	11.04	9.46	64	60	3.92	3.73	1	2
150	11.27	9.75	69	66	3.43	3.26	1	0
Total							518	413

* Data read from curves.

Of the trees from ridges, 66 per cent had butt rot, whereas 51 per cent of those from swamps and lowlands had this type of rot. The number of trees from highland and lowland with top rot did not differ appreciably, 28 per cent from the highland having rot and 31 per cent from the lowland. The data on theoretical cull of trees from these two land types are shown in Table 6. The raw data did not show any appreciable or regular difference in cull in trees from these land types. The curved data show a slightly higher cull figure for the ridge type, altho the differences are not appreciable.

PREVALENCE OF DIFFERENT TYPES OF DECAY

As mentioned previously, three distinct types of decay are found in balsam fir. There are two butt rots and a top rot which is limited largely to the upper part of the bole. The two butt rots are quite easily distinguishable. One is a yellow stringy rot said to be caused by *Poria subacida* (5), the other is a brown cubical rot said to be caused by *Polyporus balsameus* (4) (Figs. 8 and 9). The characteristic red top rot has been shown to be caused by *Stereum sanguinolentum* (Fig. 10).

The type and location of rot was recorded for each tree and is summarized by diameter classes in Figure 3. Out of a total of 1,170 trees, 690 or 59 per cent had rot of some type. Of the 690 trees with rot, 70 per cent had butt rot alone, 23 per cent had both butt and top rot, and 7 per cent had only top rot. As shown in Figure 3, butt rot attacks trees as young as 40 years of age. The number of trees with butt rot increases rapidly until at an age of 90 to 100 years 80 per cent of the trees are infected. Top rot, however, does not attack trees until they are somewhat older, and, as shown above, it never occurs in a very high percentage of trees.

Fig. 8. Butt Rott, Caused by *Polyporus balsameus,* Weakened This Tree in a 75-Year-Old Stand of Balsam Fir at Big Fork, Minnesota

Note the large amount of brown cubical rot near the ground line and the thin shell of sound wood that is left.

Judging from the number of trees with butt rot as compared to the number with top rot, it would appear as if the greater part of the cull losses were caused by butt rot. An analysis of the data, however, shows that this is not true. The average percentage of decay in all the trees amounted to 16.5 per cent of the total volume. Of this, 8.7 per cent was caused by butt rot and 7.8 per cent by top rot. The figures for theoretical cull show a similar relationship. An average of all the trees shows that 38.1 per cent of the merchantable volume was culled due to rot. Of this total, 17.7 per cent was caused by butt rot and 20.4 per cent by top rot. Altho butt rot occurs in a far greater number of trees than top rot, apparently it does not cause as much cull. This is partly due to the fact that butt rot is confined to the lower part of the bole, whereas top rot usually occupies a high percentage of the upper bole in the trees attacked.

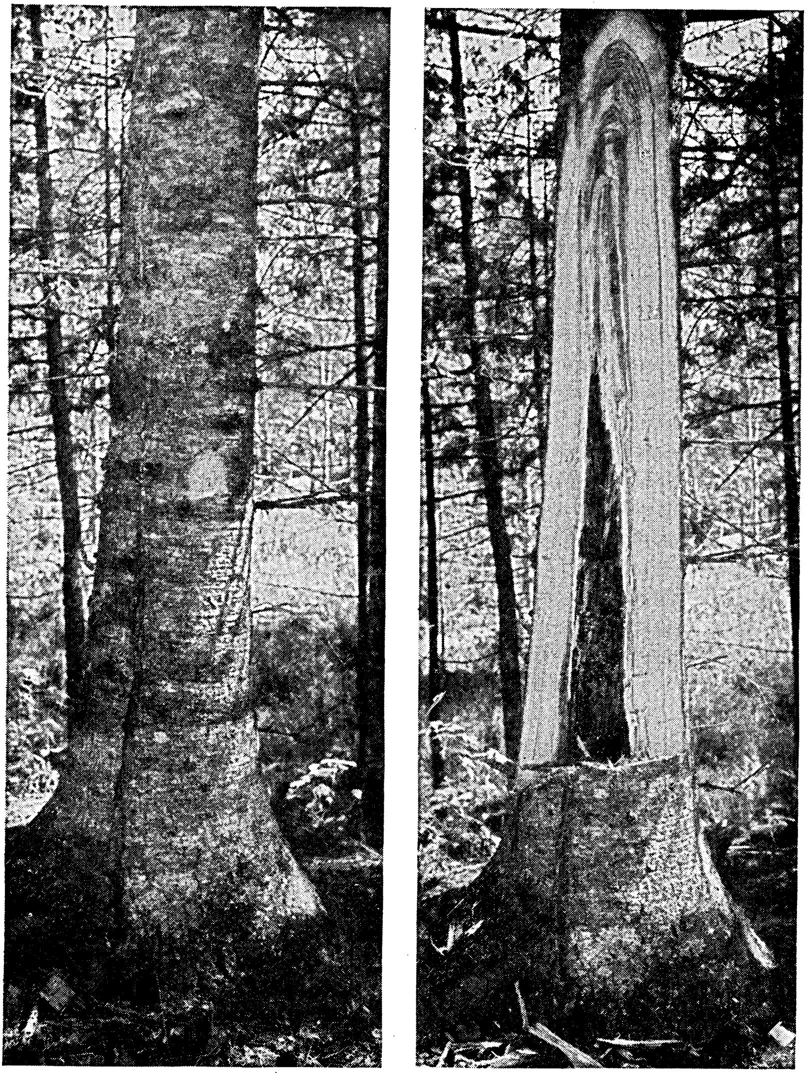

Fig. 9. (Left) Frost injury in an 11-inch, 69-year-old balsam fir on the Chequamegon National Forest, Wisconsin. The large crack runs approximately nine feet up the trunk. (Right) The same tree after it has been opened to show the presence of yellow butt rot caused by *Poria subacida*. The rot extends approximately eight feet from the base. Sound wood still remains around the rot. Altho this tree will remain in the stand for years, a section of the best part of the tree will be cull.

Of the 642 trees with butt rot, 471, or 73.4 per cent, had a yellow stringy rot; 110, or 17.1 per cent, had a brown cubical rot; 24, or 3.7 per cent, had both types of rot, and in 37, or 5.8 per cent, the red top rot extended down to the stump and caused a butt rot. Evidently, therefore, *Poria subacida* causes about three-fourths of the butt rot. Here again, the figures for number of trees infected do not indicate accurately the losses caused by the several fungi involved. When placed on a volume basis, *Poria subacida* causes 89.0 per cent, *Polyporus balsameus,* 5.7 per cent, the two when occurring together in the same tree, 4.7 per cent, and *Stereum sanguinolentum,* 0.6 per cent, of the rot and cull due to butt rot. *Poria subacida* is thus shown to be by far the most important organism in causing butt rot of balsam fir.

IDENTIFICATION OF THE CAUSAL ORGANISMS BY CULTURAL CHARACTERS

During the course of the field work, the type of decay present in each tree was recorded according to the macroscopic characteristics of the rot. Since several fungi may cause almost identical rots, isolations were made from numerous decayed trees to check these macroscopic identifications. The cultures were made on 2.5 per cent malt extract agar, the piece of inoculum being taken from near the top of the rot column. Two cultures were made from each tree. Decay specimens from 117 trees were cultured. A total of 58 cultures were made from trees affected with yellow stringy rot, 26 trees with red rot, 24 from trees with brown cubical rot, and 9 from trees with blue stain in the inner wood. In a few cultures there was no growth and some were contaminated with molds and bacteria, but the majority yielded pure cultures of wood-rotting fungi.

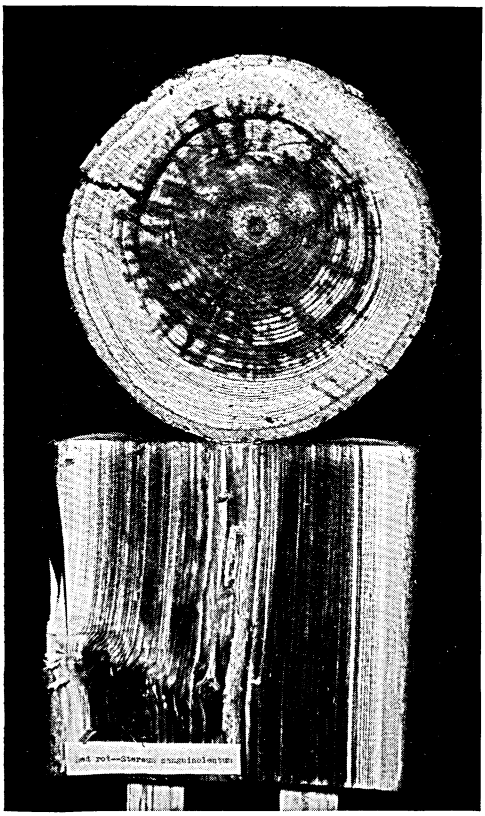

Fig. 10. Cross and Longitudinal Sections of an 8-Inch Balsam Fir, Showing Red Rot Caused by *Stereum sanguinolentum*

Note the very dark color of the wood and the large area of the section occupied by the rot. Specimen from Chequamegon National Forest, Wisconsin.

The occurrence of blue stain in about 10 per cent of the overmature tree is of considerable interest. The fact that many dead branch stubs and overgrown knots of overmature trees were found stained indicates that the organism causing the stain enters through dead branch stubs. The stain is usually limited to the inner part of the tree in what appears to be heartwood. The wood is stained a light blue and appears to be somewhat drier than the surrounding wood. In some cases the stain was found around the margins of heart rot caused by the fungi mentioned above. The fungus is easily isolated, produces a luxuriant grey-blue mycelium in culture, and forms numerous conidia. Its identity has not yet been established.

These cultures were transferred several times to eliminate bacterial contamination, and then grown in petri dishes on 2.5 per cent malt agar for comparison. The cultures were identified by comparing them with stock cultures of *Poria subacida, Polyporus balsameus,* and *Stereum sanguinolentum* obtained from the Forest Pathology Section of the Forest Products Laboratory, and by microscopic examination and comparison with the descriptions given for these fungi by Fritz (2). By following this procedure, practically all of the cultures could be identified. The results are summarized in Table 7.

Table 7.—The Identification of the Fungi Causing Heart Rot of Balsam Fir

No. of trees	Type of rot	Pure cultures obtained	Contaminations	No growth	*Poria subacida*	*Stereum sanguinolentum*	*Polyporus balsameus*	Blue stain	Unknown
58	Yellow stringy	46	12	0	46	..	..	..	..
26	Red	20	4	2	..	20	..	..	..
24	Brown cubical	14	6	4	..	..	7	..	7
9	Blue stain	7	2	0	..	..	..	7	..
117		87	24	6	46	20	7	7	7

It is evident that the yellow stringy rot *(Poria subacida)* and the red rot *(Stereum sanguinolentum)* can be identified readily by macroscopic characteristics alone. Almost every specimen of rot attributed to these fungi in the field yielded cultures that agreed with known cultures of the organisms. The results with the brown cubical rot caused by *Polyporus balsameus* did not, however, yield such clear-cut results. Of the 24 specimens attributed to *P. balsameus* in the field, 14 yielded pure cultures. Of these, 7 appeared to be *P. balsameus* and 7 could not be identified. Furthermore, the 7 cultures identified varied so much that their identity is not certain.

These cultures show conclusively that the volume of rot and cull attributed in this bulletin to *Poria subacida* and *Stereum sanguinolentum* was actually caused by these fungi, but that some correction may be necessary for the decay and cull figures given for *P. balsameus.* However, the brown cubical rot attributed entirely to *P. balsameus* was of little importance as a cause of heart rot and cull, and the error involved is therefore not serious.

THE POINTS OF ENTRANCE OF THE FUNGI CAUSING HEART ROT

The point of entrance of the fungus was determined as accurately as possible for each decayed tree cut. In some cases the decay had progressed so far that this could not be established with certainty. In 601, or 93.6 per cent of the 642 trees with butt rot, the fungus appeared to have entered through the roots; in 18 trees, or 2.8 per cent, it entered through wounds; and in 23 trees, or 3.6 per cent, it entered through branch stubs near the base. In 188, or 91.2 per cent of the 206 trees with top rot, the fungus entered through dead or broken branch stubs, and in 18 trees, or 8.8 per cent, it entered through wounds.

Since the butt rot fungi entered primarily through the roots, they must be commonly present in the soil of balsam fir stands. A number of young trees were dug up to determine the probable manner of infection by these fungi. Almost every tree more than 30 years old had some small broken and dead roots, due probably to frost heaving, strain caused by bending in wind storms, etc. These broken roots probably are the entrance points for the fungi, for several were found with incipient decay near the broken tip. The rot apparently works slowly up the tree from the broken side root or tap root. The writer ventures the opinion that if the root systems of 50-year-old trees were carefully examined, every tree would be found infected. The figures for the number of trees with butt rot are for the number of infections at stump height, which is probably too low for the actual number infected, for the fungi spread slowly.

Since balsam fir prunes itself slowly, there are numerous branch stubs through which top rot may enter. Whether *Stereum sanguinolentum* enters only through branch stubs with some heartwood, or whether every dead branch stub, regardless of its size, is a potential point of entrance is difficult to ascertain. To trace the top rot to any definite branch stub is usually very difficult.

THE OCCURRENCE OF WOUNDS AND OTHER EXTERNAL SIGNS OF DECAY

External signs of decay that furnish clues to the presence of interior defect are very helpful to foresters and timber cruisers alike. In silvicultural operations, if defective trees can be detected from external appearances, the non-profitable individuals can be eliminated. Knowledge of surface indications of interior defect is essential in timber cruising if the estimate is to be accurate.

To obtain information regarding external indications of decay, a record was made of all wounds or surface defects for each tree. Of the 1,170 trees, 210, or 17.8 per cent of the total, had wounds of some type. Of these wounded trees, 77.0 per cent had frost cracks; 12.4 per cent had mechanical wounds of some type, such as injury from falling trees, logging, etc.; 3.8 per cent had been injured by porcupines; 3.8 per cent had broken tops, and 2.8 per cent had been injured by woodpeckers. Frost cracks are thus by far the most important type of wound found on this species. Of the 210 wounded trees, 95 per cent were decayed. Altho wounds and decay are therefore very closely associated, this does not indicate that decay enters through wounds. For example, even tho frost cracks are the most common type of wound, very few cases of butt rot could be traced to them.

Wounds therefore are good signs of decay, especially in the older classes. Unfortunately, however, only a small percentage of decayed trees have wounds, and these occur principally upon the overmature trees; hence, they are of little value in the selection of young healthy trees in silvicultural operations. In this investigation symptoms could not be found by means of which young infected trees can be distinguished from sound trees.

PRACTICAL APPLICATION OF RESULTS

Logging

Much of the balsam fir in northern Minnesota and Wisconsin is overmature and very defective. To prevent further damage from decay and wind-breakage, the merchantable trees should be logged in the near future. Since most of these stands are uneven-aged and contain many size classes, they should lend themselves well to selective logging.

Timber Estimating

A close correlation was found between diameter and decay or cull in balsam fir. By applying the cull data obtained in this study to the gross volume of timber estimates, the net sound or merchantable volume may be estimated. Since two sets of cull data are included, the gross volume may be corrected by applying the figures for cull according to the present heavy culling practices or by applying the figures for theoretical cull, which are somewhat lower because they are based on closer utilization. Because the sample on which these data are based was obtained from widely separated localities, the results are certain to be more applicable to averages of several stands from different localities than to individual stands.

Forest Management

A pathologic rotation of 80 years is proposed for Lake States balsam fir. The proposal is based on an average of data from individual sample trees. As pointed out by Schmitz (8), pathologic rotations arrived at in this way are usually too high because of mortality, and this is probably true for balsam fir. Altho decay and cull losses are not excessive at 80 years, many trees will drop out previous to this because of weakening by butt rot followed by wind-breakage. It is therefore necessary to shorten the pathologic rotation somewhat. That such a reduction in the length of rotation will have little effect upon the yields of balsam is shown in Table 5. It is shown that trees of pulpwood size can be grown in 60 to 70 years, for the managed stands of the future should contain a high percentage of fast-growing trees. Since it is probable that the rotation for stands under management will be reduced, decay and cull should be of less importance in the future.

SUMMARY AND CONCLUSIONS

1. Balsam fir is one of the most widely distributed and aggressive conifers in the Lake States. It is reproducing well, particularly under aspen stands protected from fire. Judging from conditions in the field at present, an increasing amount of balsam fir may be expected in the future.

2. The rapidly decreasing supply of spruce has focused attention on balsam fir as a pulpwood in the Lake States. All indications point to an increasing consumption of balsam in the future.

3. Some prejudice still exists against the use of balsam for pulp, but this is rapidly disappearing. A good deal of this prejudice is due to the large amount of rot in the present merchantable stands. Practically all of these cull losses are due to heart rot. Under present utilization practices little or no material containing heart rot is used by pulp mills.

4. This investigation, which is based on more than 1,100 trees cut from 19 sample plots in northern Minnesota and Wisconsin, shows the pathological condition of the present balsam stands and furnishes information necessary for determining decay and cull losses in present stands and the probable pathologic rotation.

5. The present stands are very defective, due largely to overmaturity. Over 40 per cent of the merchantable trees cut were more than 80 years old. The percentage of cull and rot increases rapidly after 70 years. For this reason, to avoid additional losses from rot and wind-breakage, many of the overmature stands should be logged in the near future.

6. When decay, cull, and liability to damage by wind-breakage are considered, the pathologic rotation should be set at not more than 80 years. Tree diameter and decay are closely correlated. The diameter limit in the present stands at which decay becomes an important factor is about 8 or 9 inches. The age of such trees is about 80 years.

7. These data show that trees of pulpwood or merchantable size may be grown in 60 to 70 years in stands under management. By shortening the rotation, decay and cull losses can be reduced to a minimum.

8. Fast-growing trees contain a slightly higher percentage of rot than slow-growing trees of the same age, but the difference is of no practical importance. A higher percentage of the trees from ridges were found to have butt rot than the trees from swamps. The difference in number of trees infected with butt rot on ridges probably has something to do with the larger amount of wind-breakage at present on the higher land.

9. Over 90 per cent of the butt rot is a yellow stringy rot, caused by *Poria subacida.* The remainder is a brown cubical rot, principally caused by *Polyporus balsameus.* Almost 100 per cent of the top rot, a red rot, was the result of infection by *Stereum sanguinolentum.* Altho a smaller percentage of trees have top rot than butt rot, top rot causes as much cull as butt rot, because it affects more of the merchantable volume of the infected trees.

10. Butt rot was found in rather young trees. Fifty per cent of the trees have some rot at stump height at 60 years. Top rot does not occur in many trees until they are 80 or 90 years old.

11. Wounds are common only on overmature trees. Frost cracks are the most common type of wound found. No reliable external signs were found by means of which young trees with decay can be distinguished from young sound trees.

12. The fungi causing butt rot usually enter the trees through broken side or tap roots. The fungus causing top rot enters through branch stubs.

13. A cultural study of the fungi causing the decay showed that the field identifications of the various rots was accurate for the yellow stringy and red rots. The presence of several fungi made identification difficult in the case of the brown cubical rot.

14. A blue stain fungus was found to be quite prevalent in the interior of overmature trees.

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