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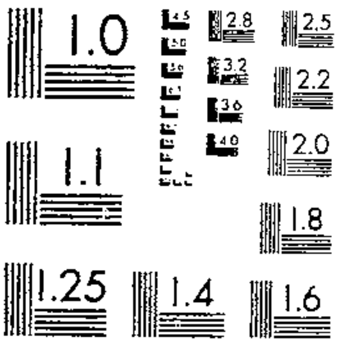

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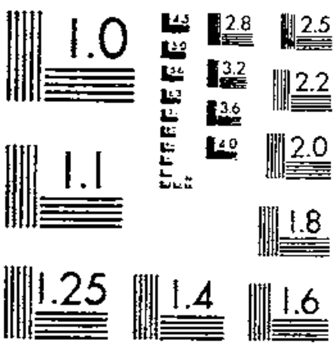

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Decay in Balsam Fir in New England and New York[1, 2]

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SUMMARY

In an investigation of decay and resultant cull of merchantable timber in balsam fir (*Abies balsamea* (L.) Mill.) from eastern Maine, northern New Hampshire, and the Adirondacks in New York, more than 1,100 trees 40 years of age and upward were dissected and the data analyzed to show the relation of cull to age, diameter, site factors, and growth rates. Decay severe enough to cause cull affected half

[1] Submitted for publication October 1943.

[2] This study was carried on in cooperation with the Allegheny (formerly Northeastern) Forest Experiment Station and Yale University, New Haven, Conn. The writers wish to acknowledge their cooperation and also that of the following organizations and individuals, who generously permitted the felling and study of balsam fir on their holdings: The Finch, Pruyn & Co., Inc., Glens Falls, N. Y.; the Whitney Realty Co., Sabattis, N. Y.; the Maine Forest Service, Augusta, Maine; the White Mountain National Forest, Laconia, N. H.; the Gale River Experimental Forest, Bethlehem, N. H.; and J. R. Jackson, Colebrook, N. H.; and of the Civilian Conservation Corps, for furnishing the labor necessary for the dissection of trees on some of the study areas.

In addition, the writers are particularly indebted to M. Westveld, of the Northeastern Forest Experiment Station, and to E. S. Bryant, of Bolton, Vt., for their advice and criticism; to L. H. Reineke, of the Northeastern Forest Experiment Station, for assistance in the preparation of the graphic illustrations and in the statistical analyses of data; to the U. S. Forest Service, Division of Forest Management Research, Washington, D. C., for assistance in computing the correlation analyses; and to H. J. MacAloney, of the Division of Forest Insects, Bureau of Entomology and Plant Quarantine, and to G. H. Hepting, R. W. Davidson, and H. G. Eno, of the Division of Forest Pathology, for their direct participation in the investigative work upon which this publication is based.

the trees at 72 years and all at 165. About one-fourth of the total volume of all trees was culled.

Most of the cull was due to three decays: Top rot, caused by *Stereum sanguinolentum* Alb. and Sch. ex Fr.; brown butt rot, by *Polyporus balsameus* Pk.; and white stringy butt rot, by *Poria subacida* (Pk.) Sacc. The first caused 54 percent of the total cull, the second 13 percent, and the third 28 percent, the remainder being due to miscellaneous fungi and form defects.

The butt rots appeared at about 40 years, were present in half the trees at 72, and caused some cull in half the trees at 105. Top rot began at 40 years, was present in one-fifth of the trees at 90, and usually caused much more cull than the butt rots. Butt rot severe enough to cause cull weakens the trees and makes them liable to windfall. This becomes so serious a matter that at about 70 years it appears to be the decisive factor in determining the proper rotation for this species.

On a volume basis, cull losses in the trees studied were almost identical on good and poor sites. On a percentage basis, however, the losses were higher on poor sites. Comparing slow-grown and fast-grown trees, on a volume basis cull was less in the former, while on a percentage basis it was much more nearly equal. The net periodic growth of fast-grown trees, after deducting decay cull, exceeded that of the slow-grown ones by a ratio of 4 to 1 up to 70 years, when the difference dropped gradually. The development of cull appears to be dependent on age, and insofar as diameter can be correlated with age, it may be used as an indicator of cull. Correlation analyses, however, show that diameter, because of its variability in reference to age, is a poor index and that height, age, and volume are better but lack complete correlation.

Extreme suppression, resulting in flat-top form for a number of years, favors attack by the top rot fungus, even though normal growth is resumed afterwards. No reliable external indications of decay were found. Figures are given for making cull corrections of gross-volume cruise estimates, but no sanitation measures are recommended under present conditions in the forest.

In the management of balsam fir for pulpwood the following measures are recommended. Present merchantable stands, which are largely overmature and highly defective, should be harvested to prevent further heavy loss. Considering losses from decay and windfall, the best cutting age appears to be about 70 years, with 80 years as a maximum. At these ages an average diameter of 8 to 9 inches is attained in unmanaged stands such as those investigated. These diameters may be considerably increased by silvicultural measures favoring the maintenance of a good and uniform rate of growth, and apparently without any increase in cull loss on a percentage basis. A rotation of about 70 years will keep cull losses at a relatively low figure, and at the same time produce trees of economical size for pulpwood. To avoid excessive losses between cuts the maximum cutting cycle should be about 20 years. In young stands, weeding and the girdling of dominant worthless hardwoods, to prevent severe suppression and induce a uniform rate of growth, should result in a minimum of cull up to 70 years.

The application of these conclusions will make available large quantities of balsam fir during the present extreme wartime shortage of pulpwood, and the detailed information should be made available to foresters as soon as possible.

PAST AND PRESENT FOREST PRACTICES

Softwood lumbering in the Northeast has consisted until rather recently in harvesting the choice species and leaving all others, which at the time were of little value. At first the best eastern white pines (*Pinus strobus* L.) were taken, but only the choicest logs. As demands increased and markets became more accessible, however, entire stands of this species were cut. This process went on in ever-widening belts along the seacoast and rivers until the commercial supply was almost exhausted. Fox (*8*)[3] has given an excellent account of the early lumber industry in the State of New York. The same sequence of events took place in New England. Springer (*35*) also gave an account of lumbering in Maine in earlier days.

As pine became depleted, spruce, mostly red spruce (*Picea rubens* Sarg.), went through the same selective process. As long as saw timber was its main use the huge northern stands of this species satisfied demands. This resulted from the fact that only the larger trees were taken, leaving the smaller and usually younger ones to grow for future crops. The paper pulp industry, however, began its tremendous inroads on the forests about 1880 (*3*, *8*). Spruce was soon found to be the best available species for this purpose, and by 1900 this industry was operating on a large scale. The type of logging changed to practically clear-cutting of spruce, as much smaller material than that required for saw timber could be used.

At about this time the process of pulp manufacture was modified so that hemlock (*Tsuga canadensis* (L.) Carr.), pine, and balsam fir (*Abies balsamea* (L.) Mill.), and other conifers could be used. Thus, conditions tended to accentuate the clear-cutting of all conifers in a stand, leaving large openings for young seedlings to become established in great numbers.

In early days balsam fir, a relatively small-sized tree in comparison with spruce and pine, was commonly very defective in the larger sizes and was usually not a very important component of the forests then accessible. Some of the best and largest trees may have been taken, but the species appears to have been largely left standing. A statement of lumber cut in New York in 1900 shows spruce, hemlock, and pine but no balsam fir (*9*). Its value was small or nil in contrast with eastern white pine and spruce. With its acceptance as a pulpwood it became of value, although not equal to spruce (*3*, *38*) until more recently (*12*). The advent of clear-cutting greatly favored the increase of balsam fir in softwood regeneration because of its prolific, continuous seeding and its aggressiveness in reseeding openings in the forest (*36*, *37*, *38*). Consequently balsam fir is becoming more abundant in the northern forests. Whether it is really wanted or not, it is now an important component of these forests and cannot be neglected. This increase in value and relative importance has drawn attention sharply to decay in the living tree, a well-known feature of balsam fir. The present study was initiated a number of years ago to help determine the forest practices that would be most efficient in

[3] Italic numbers in parentheses refer to Literature Cited, p. 28.

reducing cull losses. Now, at the time when there is an extreme wartime shortage of pulpwood, these practices can be utilized to the fullest extent.

PATHOLOGY OF BALSAM FIR

From colonial days, balsam fir has been condemned because of its excessive susceptibility to various wood rots. This would lead one to expect that the other parts of the tree might be especially subject to attack by fungi. As a matter of fact, the records and collections of the Division of Forest Pathology show that about 270 different fungi are known to grow on various parts of the tree. This situation is practically duplicated with the eastern white pine and red spruce, which are considered to be two of the best of the eastern timber species. So it does not seem that balsam fir, as a species, is abnormally susceptible to fungus attack. Aside from rots of the wood in living trees, balsam fir has shown no more conspicuous outbreaks of destructive endemic disease than the pine and the spruce.

In considering susceptibility to decay of living trees of balsam fir, the fact has been almost entirely overlooked that it is a short-lived tree as compared with red spruce and eastern white pine, both of which have a normal life span double that of balsam fir (*28, v. 11 and 12*). In other words, balsam fir of a certain stage of maturity—for instance, trees 100 years old—should be compared with red spruce or eastern white pine of the same stage of maturity, or 200 years old. As a rule, decay in living trees of all species increases with maturity, and overmaturity is accompanied by heavy losses from decay. It is reasonable to expect relatively heavier losses from decay in mature balsam firs than in the less mature trees of the other two species of the same age. It is conceded that balsam fir probably is more susceptible to these decays, but it is much less so than appears to be the case without making allowance for age at maturity.

Although decay is common in the living trees, fruiting bodies of the fungi causing decay are scarce. In most cases culturing the decayed wood is the only way to determine the identity of the fungus causing the damage. Such cultural checking of the common decays of balsam fir has been done extensively by a number of investigators, who have agreed that there are three types of rot commonly present in living trees. A white stringy butt rot, caused by *Poria subacida* (Pk.) Sacc. (*4, 5, 16, 20*); a brown cubical butt rot, largely caused by *Polyporus balsameus* Pk. (*15, 16, 20*); and a red heart rot in the middle or upper part of the trunk, caused by *Stereum sanguinolentum* Alb. and Schw. ex Fr. (*4, 5, 6, 7, 16, 20*). There is some uncertainty concerning the brown butt rot, as in some localities it is definitely known to be caused by *Polyporus schweinitzii* Fr. Most of that found by McCallum (*18, 19, 20*), Kaufert (*16*), and the writers, however, is attributed to *P. balsameus*, which appears to be more common than *P. schweinitzii* in balsam fir.

The culture work of various investigators shows that occasionally more than one fungus may be implicated in any one of the three common balsam fir decays. In the present study, cultures have shown the following fungi definitely associated with decay of living balsam fir trees: *Coniophora puteana* (Schum. ex. Fr.) Karst., *Polyporus balsameus*, *P. schweinitzii*, *Poria subacida*, and *Stereum sanguinolentum*.

Fruiting bodies of the following wood-decaying fungi have been collected on living trees: *Armillaria mellea* Vahl. ex Fr., *Fomes pini* (Brot. ex Fr.) Karst., *Hymenochaete tabacina* (Sow. ex Fr.) Lév., *Lenzites saepiaria* Wulf. ex Fr., *Polyporus abietinus* Dicks. ex Fr., *P. balsameus*, *P. circinatus* Fr., *P. schweinitzii*, and *Trametes heterc-morpha* (Fr.) Bres.

REVIEW OF PREVIOUS INVESTIGATIONS

When this investigation was being planned, no intensive dissection study of decay in any eastern tree species had been made and little was known concerning the fungi causing decay in living balsam fir. This situation has changed rapidly within a few years.

In 1900 Von Schrenk (*31*) published an account of the wood-rotting fungi that he found attacking living conifers in Maine. He described the following on balsam fir: *Polyporus schweinitzii*, causing a brown butt rot; *Fomes* (*Trametes*) *pini abietis* Karst., causing a trunk rot with small white pockets; *Poria subacida*, causing a stringy butt rot; and *Fomes annosus* (Fr.) Cke., causing a root and butt rot with small white pockets with black centers.

In 1907 Moore and Rogers (*23, p. 42*) examined standing balsam fir in central Maine by chopping into the trees. This would give information on the butt rots but nothing on the heart rot of the upper part of the tree. Their remarks apply therefore to butt rot only. They said, "* * * on the flats the fir dies out of the stand * * * approximately 50–60 years, whereas on the slopes and upper slopes it is found perfectly sound at 72 years, and even at 118 years it is only very slightly injured by rot at the centre. This applies to fir in a mixed stand. In a pure stand of even-aged fir, * * * the trees begin to be attacked by rot as soon as they are 8 inches in diameter and between 50 and 60 years old. But the stand may safely be allowed to grow for 10 to 20 years longer. * * * If they are left any longer than this the trees will be broken off by the wind * * *."

In 1914 Zon (*38*) gave some general statements on unsoundness of balsam fir. In "wet swamps" it grows slowly and is free from "ground rot." In "dry swamps" (flats) it grows faster but has much more ground rot. On hardwood slopes it makes its best individual growth but is very defective. Top rot is especially noted in suppressed trees under hardwoods.

In 1918 Faull (*4*) began a careful investigation of the rots of living trees of pine, spruce, and balsam fir in Ontario. This continued until 1923 with special emphasis on balsam fir decays. Cultures of the various rots were made and studied intensively by Fritz (*10*). It was learned that "sapin rouge," or red heart decay, is caused by *Stereum sanguinolentum* (*7*); that the brown cubical butt rot is caused commonly by *Polyporus balsameus* instead of *P. schweinitzii*, as had been supposed previously (*5*); and that the white stringy butt rot is caused by *Poria subacida* (*4, 5*).

Rankin (*24*) in 1919 made a brief observational survey of butt rots of balsam fir in Quebec forests and concluded that many different fungi are causative agents. The most common and destructive one he attributed provisionally to *Fomes pinicola* (Sw. ex Fr.) Cke., but says that butt rot by *Polyporus schweinitzii* also is common. The early stages of these rots could not be distinguished with certainty. Infection by both is said to take place largely through the roots. He reports a definite relation between rate of growth of the tree and destructiveness of these butt rots, the more rapidly grown trees having less butt rot and a smaller proportion of affected trees. No correlation was found between butt rot and a previous attack by the spruce budworm (*Archips fumiferana* (Clem.)).

In 1922 Schierbeck (*29*) published an account of the causes of the dying of balsam fir in eastern Canada. In the order of their importance in the death and decay of trees previously attacked by the spruce budworm he lists the following fungi: *Armillaria mellea*, *Fomes pinicola*, *Polyporus abietinus*, *Stereum sanguinolentum*, *P. balsameus*, *Poria subacida*, and *Lenzites saepiaria*. In addition he says that *Polyporus schweinitzii* occurs on living balsam fir but does not in his opinion contribute to the high mortality of the species.

In 1923 McCallum (*18, 19*) began intensive field work on the rots of balsam fir, with a detailed dissection of trees on definite plots (*20*), the first study of its type in eastern forests. It was carried on in the Province of Quebec in two areas, one south of the St. Lawrence River, at Lake Metis, and the other in the Lake St. John region, on the Shipshaw River. The forest in these areas was quite similar, and the site was considered to be II (moderately good) for balsam fir. Quarter-acre plots were cut clear of balsam fir down to 3 inches d. b. h.[4] Identification of the fungi causing decays was made by means of pure cultures from the rotten wood. His data show that in Quebec cull losses become heavy in balsam fir at an age somewhere between 70 and 100 years and at an average diameter of 5 to 7 inches; that in the same age classes the percentage of volume culled is slightly higher in fast-grown trees than in slow-grown ones; and that there is no correlation between the percentage of cull and previous spruce budworm injury. He found only three important decays, those caused by *Stereum sanguinolentum*, *Poria subacida*, and *Polyporus balsameus*. The first gained entrance almost exclusively through branch stubs and the other two through the roots.

In 1932 in a preliminary report[5] covering part of the investigations now completely discussed in this bulletin, the results, anonymously reviewed (*1*), were that cull losses and windfall were common at 70 years, that the same three fungi reported by McCallum were important in living trees, and that there was no correlation between percentage of cull and rate of growth.

In 1935 Kaufert (*16*) published the results of an investigation of decay of living balsam fir in Minnesota and Wisconsin. His conclusions were that in the Lake States region balsam fir is highly defective and largely overmature; that cull increases rapidly after 70 years of age and an average diameter of 8 to 9 inches; that balsam fir should not be held longer than 80 years, or to an average diameter greater than 9 inches; that fast-grown trees have a slightly higher percentage of rot than slow-grown trees, but the difference is so little as to be insignificant; and that ridge trees are more susceptible to butt rot than swamp trees. His findings on the fungi causing decay and their importance are identical with those given by McCallum.

In 1940 Heimburger and McCallum (*14*) presented data to show that in Quebec the two butt rots of balsam fir caused by *Poria subacida* and *Polyporus balsameus* occurred more frequently and were more serious on mixed-wood slopes (ridges) than in softwood flats (swamps).

Faull (*4*), McCallum (*20*), and Kaufert (*16*) have described and illustrated the three important heartwood decays of balsam fir, and for this reason such treatment is not included in this publication.

PURPOSE OF THE STUDY

In planning the management of balsam fir stands, it is essential to have information on the relations of age and size of trees to cull losses. The primary object of this investigation was to obtain this information. Data pertaining to the following specific subjects were taken:

1. Age at which cull losses begin and rate of increase.
2. Relation of diameter to cull losses.
3. Felling age so far as determined by cull losses.
4. Relation of cull losses to quality and character of site and to rate of growth.
5. Cull-causing fungi and their prevalence under various conditions.
6. External indications of decay.
7. Avenues of entrance of cull-causing fungi.

FIELD METHODS

All data presented in this study are based upon the dissection of 1,127 trees on 15 plots in New Hampshire, New York, and Maine—5 plots on the Gale River Experimental Forest, near Bethlehem, N. H.; 3 at Cherry Mountain, Carroll, N. H.; 1 in Columbia, N. H.; 1 in Indian Township, Maine; 2 at Newcomb, N. Y.; and 3 at Sabattis,

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[4] The term d. b. h. means the tree diameter, including the bark, at 4.5 feet from the ground (breast height).

[5] SPAULDING, P., HEPTING, G. H., and MACALONEY, H. J. INVESTIGATIONS IN DECAYS OF BALSAM FIR. I. GALE RIVER EXPERIMENTAL FOREST, NEW HAMPSHIRE. U. S. Forest Serv., Northeastern Forest Expt. Sta. Tech. Note 11, 3 pp. 1932. [Processed.]

N. Y. Different ages and types of stands were included—upland and lowland, pure and mixed with hardwoods and spruce, on good sites and on poor sites. The plots were well scattered over the range of the balsam fir in New England and New York. The soil in all cases was glaciated—sandy loam with interspersed pebbles, stones, and boulders.

In the earlier cuttings quarter-acre plots were used and all balsam firs down to 1 inch d. b. h. were felled and examined. No decay or cull was found below 40 years; on later cuttings, therefore, only trees 40 years of age and older were examined. The later cuttings were on various-sized plots, usually of about a quarter acre, selected to represent average conditions for their districts and taken together to be representative of the region covered. General data on all plots are given in table 1.

For each plot the soil type, moisture relations, topography, elevation, density, associated species, and other minor details were noted and complete data were taken on the condition and physical characteristics of each tree studied. When decays of questionable identity were found, samples were submitted [6] for culturing and determination of the causal organism.

TABLE 1.—*General data on 1,127 balsam fir trees in study areas*

Plot No.	Locality	Trees	Stand age [1]		Balsam fir in stand	Soil moisture condition	Site index [2]
			Average	Range			
		Number	*Years*	*Years*	*Percent*		
1	Bethlehem, N. H	129	70	55–121	53	Upland	59
2	do	63	60	56–70	51	Intermediate	62
3	do	58	61	34–72	58	do	66
4	do	179	66	50–75	60	Upland	58
5	do	139	69	63–71	47	Lowland	58
6	Carroll, N. H	72	102	73–140	67	Upland	60
7	do	14	136	115–164	10	Lowland	70
8	do	51	121	61–176	44	Intermediate	60
9	Newcomb, N. Y	24	119	90–141	55	Upland	65
10	do	26	116	92–138	65	Lowland	61
11	Sabattis, N. Y	22	106	67–154	20	Intermediate	63
12	do	56	103	75–163	50	Lowland	49
13	do	69	82	45–167	50	Upland	58
14	Indian Township, Maine	124	66	58–77	65	do	56
15	Columbia, N. H	101	50	48–117	99	Lowland	59

[1] The age of a stand is taken as the average age of the dominant and codominant trees.
[2] 7 poor sites, 49 to 59; 8 good sites, 60 to 70. Indexes used in preparation of table 8 (p. 18).

CULLING PRACTICES

As stated by Kaufert (*16*), the problem of deciding what culling practice to follow in a study of this type is rather difficult. In any region the utilization of any one species varies from operator to operator and from State to State. In New England and New York the principal use of balsam fir is for pulp, and yet the closeness of utilization varies greatly. To obtain uniformity, the writers adopted the following culling rules, which are a composite of the woods practices observed throughout the region.

Butt off at base until sound wood equals two-thirds of cross-section area.
Cut into 4-foot bolts up to 3 inches top diameter.

[6] To R. W. Davidson, associate mycologist, Division of Forest Pathology.

Cull all bolts 6 inches in diameter and under at small end if they contain any rot.

Cull all bolts over 6 inches in diameter at the small end if more than one-third of their diameter is center rot, more than one-eighth of it is rim rot, or more than one-quarter of their cross-section area is scattered rot.

Application of these rules was made on the basis of ocular estimates. The resulting cull may be termed "commercial cull." Inasmuch as such a culling practice allows for close utilization, it was decided that no modification was necessary to allow for even closer future utilization. The cull in this bulletin approximates the theoretical cull of Kaufert.

METHOD OF COMPILATION

All volumes were computed by plotting the dimensions of each tree on the United States Forest Service tree measurement form (No. 558a). The area representing each tree was measured with a planimeter, and the volume in cubic feet was derived by multiplying with known converting factors. Cull volumes were computed in the same way.

Both total and gross merchantable volume were determined. Total volume includes all wood, inside bark, from ground to top; gross merchantable volume includes only that wood between a 1-foot stump and a top diameter of 3 inches inside bark; cull volume is the volume of merchantable material culled according to the rules stated under Culling Practices; net merchantable volume is the gross merchantable volume minus cull volume. Throughout this report, unless stated otherwise, the volumes referred to are merchantable.

Corrections for total age were made on the basis of height growth of trees in the vicinity. Young trees were cut and their age determined at the ground and at 1-foot intervals up to 17 feet. The correction for age was added to each tree, depending on the height of the age count above the ground.

CULL IN RELATION TO AGE

The first and in many respects the principal relation determined in this study was that between the age of the dissected tree and the cull volume. The data presented, though based upon individual trees, are applicable to the stands. In the lifetime of a balsam fir stand, individual trees are continually dropping out, largely from suppression and wind throw of those weakened by butt rot which is decay extending upward from the stump. Top rot is used to distinguish clearly decay in the trunk, which originates usually in the upper part. The principal rot thus designated is that caused by *Stereum sanguinolentum* and commonly known as red heart. The analyses that follow are based on the trees present in a stand at the time of cutting, and no consideration is given to mortality losses up to that time. The culmination of net growth in a stand will be attained earlier than these figures show.

Percentage of Trees With Decay and With Cull

The variation in percentage of trees with decay and cull with tree age is shown in figure 1. The eight curves are largely self-explanatory, but a few points should be stressed. No decay was found at stump height in any trees under 40 years of age, but by 45 years 20 percent had some decay, by 65 more than 50 percent had decay, and by 145 all were partially decayed. The figures for butt decay only are slightly lower. Butt decay appears at 40 years, 20 percent of the trees are affected by 47 years, 50 percent by 72, and 100 percent by 165. Top decay begins at the same time but builds up much more slowly. It is present in 20 percent of the trees by 90 years and in 50 percent by 150 years.

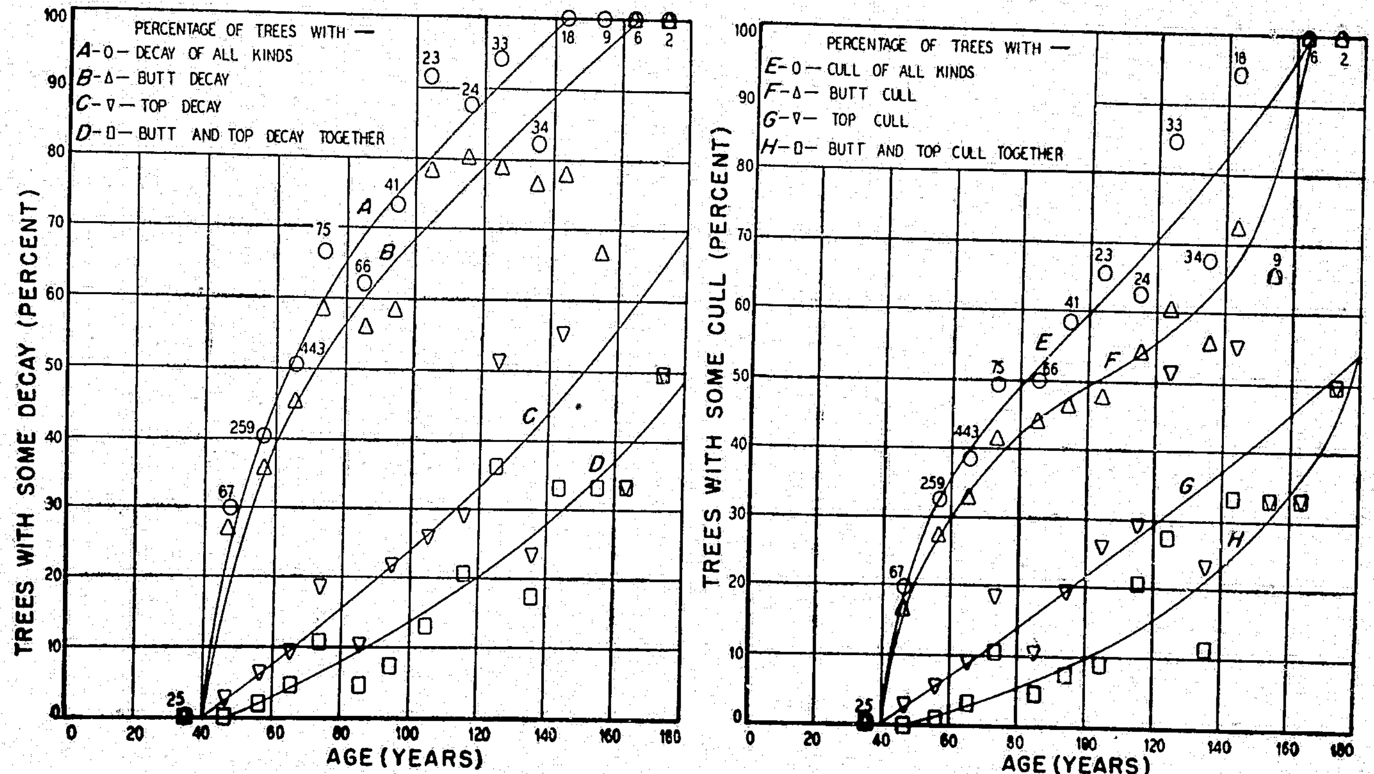

FIGURE 1.—Percentage of the total number of balsam fir trees with decay and with cull, by age classes.

Naturally cull lags behind decay. The relatively small size of the average balsam fir means that there are few trees in which decay does not result in cull. By 49 years 20 percent of all trees had some cull, by 84 years 50 percent had some cull, and by 165 years all had some cull. Butt cull lags only slightly behind total cull, i. e., 20 percent of all the trees at 50 years had butt cull, 50 percent at 105 years, and 100 percent at 165. The worst feature of the butt cull is that by the time a tree has enough butt decay to necessitate cull, the tree is greatly weakened and is predisposed to windfall.

TABLE 2.—*Association between butt rot and top rot in 1,125 balsam fir trees, 592 without and 533 with butt rot*

Age class (years)	Nonbutt-rotted trees		Butt-rotted trees		Age class (years)	Nonbutt-rotted trees		Butt-rotted trees	
	Number	With top rot	Number	With top rot		Number	With top rot	Number	With top rot
		Percent		*Percent*			*Percent*		*Percent*
31–40	25	----	----	----	111–120	5	40.0	19	26.3
41–50	49	4.1	18	----	121–130	7	71.4	26	46.2
51–60	167	7.2	92	5.4	131–140	8	25.0	26	23.1
61–70	242	9.5	201	10.0	141–150	4	100.0	14	42.9
71–80	31	19.4	44	15.9	151–160	3	100.0	6	50.0
81–90	29	13.8	37	8.1	161–170	----	----	6	33.3
91–100	17	29.4	24	8.3	171–180	----	----	2	50.0
101–110	5	60.0	18	16.7					

A comparison of the association of butt and top rot in balsam fir by age classes is given in table 2. Within each age class all trees were put in two groups, those with and those without butt rot. Then for each group the percentage of trees with top rot was computed. If some trees were more susceptible to decay than others, then the percentage of butt-rotted trees with top rot should be higher than the percentage of nonbutt-rotted trees with top rot. Reference to the data shows that the reverse is true. The percentage of nonbutt-rotted trees with top rot is consistently higher than that of the butt-rotted trees with top rot, with the exception of the 61- to 70-year age class, when it is approximately the same. This may be taken as an indication that there are no important differences in general decay susceptibility between individual trees and that the factor or factors determining decay infection in balsam fir are largely external or environmental.

MERCHANTABLE VOLUME AND CULL LOSSES

Data on merchantable volume and cull losses by age classes are shown in figure 2 and table 3. In figure 2, curve *A* shows the average gross merchantable volume of all trees; curve *B* shows the average cull volume per tree; and curve *C* shows the net merchantable volume per tree. Balsam fir in the Northeastern States attains merchantable size just before it reaches 40 years of age, and has an average gross merchantable volume of 5 cubic feet at about 60 years, 10 cubic feet at about 80 years, and 16 cubic feet at about 100. Cull is negligible up to 60 years, and reaches a volume of 1.7 cubic feet (17 percent) at 80 years, and 3.6 cubic feet (approximately 22½ percent) at 100. Periodic net increment of merchantable wood is highest from 60 to 80 years and then decreases gradually until at 150 the volume of cull more than offsets the periodic growth or increment. The mean annual net increment of individual trees does not reach its maximum until 110 years. This, of course, applies to the survivors in the stand and is not indicative of the culmination of mean annual net increment for the stand. Mortality becomes heavy after 70 years of age and the loss of large numbers of trees will hasten the culmination of growth for the stand as a whole. Since, however, the trees so lost usually have the highest proportion of cull, the decrease in net volume will not be so marked and culmination of net annual stand increment will be correspondingly deferred.

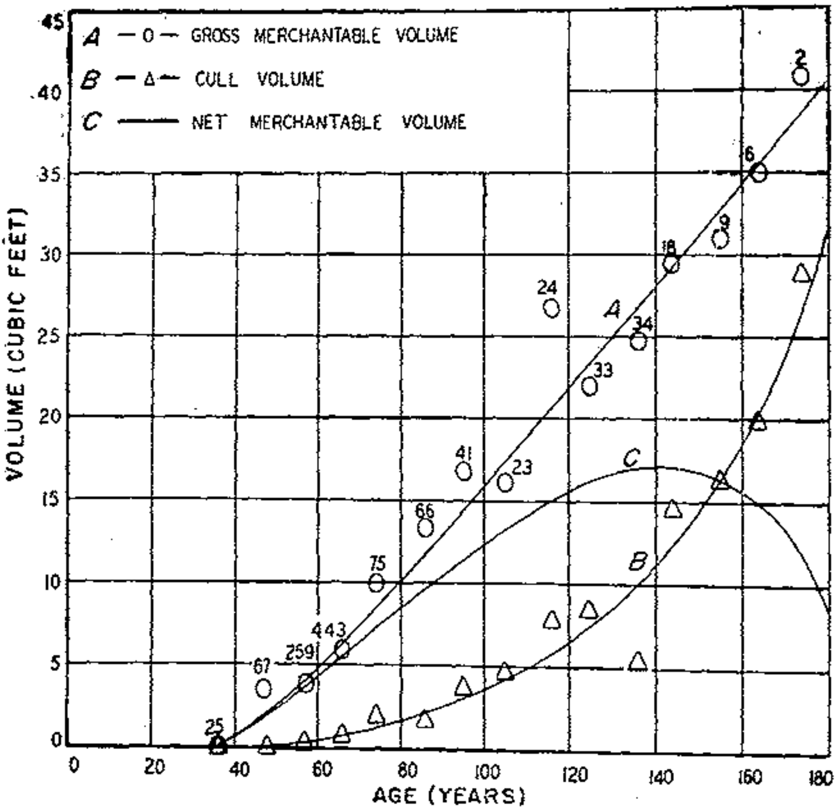

FIGURE 2.—Gross and net merchantable volume in cubic feet of balsam fir, by age classes.

TABLE 3.—*Gross, cull, and net merchantable volume and net increment of 1,125 balsam fir trees, by age classes*[1]

Age (years)	Trees	Total height	D. b. h.	Volume: Gross merchantable	Volume: Cull	Volume: Cull	Volume: Net merchantable	Net increment: Mean annual	Net increment: Periodic
	Number	*Feet*	*Inches*	*Cubic feet*	*Cubic feet*	*Percent*	*Cubic feet*	*Cubic feet*	*Cubic feet*
40	25	17	3.3	0.6	0	1.8	0.6	0.015	------
50	67	31	4.7	2.5	.2	6.3	2.3	.046	1.7
60	259	41	5.9	4.8	.5	10.3	4.3	.072	2.0
70	443	48	7.1	7.4	1.0	13.8	6.4	.091	2.1
80	75	54	8.3	10.2	1.7	17.0	8.5	.106	2.1
90	66	59	9.4	13.0	2.6	20.0	10.4	.116	1.9
100	41	62	10.5	15.9	3.6	22.6	12.3	.123	1.9
110	23	65	11.4	19.0	4.9	26.0	14.1	.128	1.8
120	24	67	12.2	22.0	6.6	30.0	15.4	.128	1.3
130	33	69	13.0	25.1	8.5	34.0	16.6	.128	1.2
140	34	71	13.7	28.2	11.2	39.6	17.1	.122	.5
150	18	72	14.4	31.2	14.5	46.4	16.7	.111	-.4
160	9	73	15.1	34.3	18.6	54.2	15.7	.098	-1.0
170	6	74	15.7	37.5	24.1	64.3	13.4	.079	-2.3
180	2	75	16.3	40.8	31.5	77.2	9.3	.052	-4.1

[1] Data read from curves.

PERCENTAGE OF MERCHANTABLE VOLUME CULLED

All the data in the preceding section were used in a comparison of cull and gross merchantable volume on the basis of the average tree in each class. The pulpwood operator may find the same data more useful expressed in percentages, particularly if he has information on the predominant age and estimated volume of his timber.

The percentage of the merchantable volume culled, in relation to age, is shown in figure 3, curve *A*. By 60 years 10 percent of this volume is cull, and

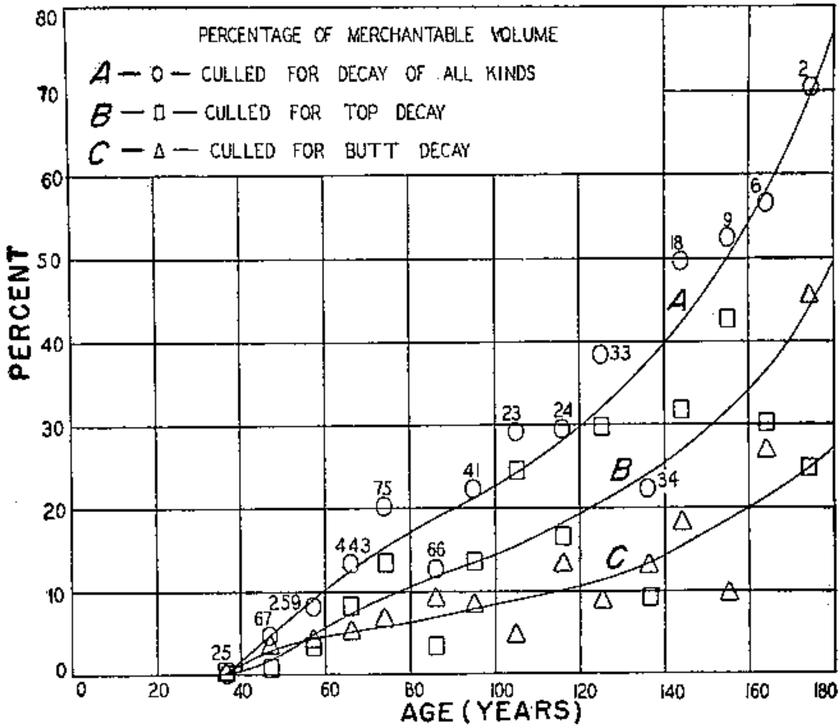

FIGURE 3.—Percentage of merchantable volume of balsam fir culled for butt and top decays, by age classes.

by 90 years 20 percent, after which there is a decided acceleration in the rate of increase until at 180 years more than 75 percent of the merchantable volume is cull. Every operator probably has his own idea as to the highest cull percentage he can allow with profit. Furthermore, this figure will vary according to whether he is buying stumpage or cutting from his own holdings.

Comparison of the butt- and top-decay and cull data in figures 1 and 3 is essential to an understanding of balsam fir pathology. In figure 1, curves *B* and *C* show that in number of trees infected butt decay is far more common than top decay throughout the life of the species. Yet in spite of this, in figure 3, curves *B* and *C* show that in percentage of merchantable volume culled, top rot greatly exceeds butt rot after 55 years of age.

This situation arises from two entirely distinct but supplementary circumstances. First, and most evident, is the fact that *Stereum sanguinolentum*, which causes most of the top decay, grows very rapidly both upward and downward from the point of infection. On the other hand the fungi causing butt decay can spread only upward, and they also grow at a slower rate than the top rot fungus. This means that in most cases each top rot cull case accounts for a much higher percentage of the total volume than does each butt rot cull case. The other reason for this condition is that butt decay predisposes infected trees to windfall, whereas top decay apparently does little, if anything, to increase the rate of mortality of the species.

Thus, top rot is cumulative throughout the life of a stand, whereas butt rot tends to remove itself by causing many infected trees to break over and disappear. Of course, some trees with top rot will also have butt rot and thus be lost through windfall, but the proportion of trees thus removed is not nearly so high as for trees with butt rot. In figure 1, curves *D* and *H* show the percentage of trees with both butt and top decay and butt and top cull, respectively. In general, not more than one-fourth of the trees with butt rot also have top rot.

FELLING AGE AS DETERMINED BY CULL VOLUME AND MORTALITY LOSSES

The principal factor that should govern the choice of the rotation age, from the standpoint of wood production, is net increment. This is determined by the relations of gross volume and cull volume to stand age. These relations are presented, on an individual-tree basis, in figure 2 and table 3. In addition, information on mortality losses in fully stocked stands of merchantable size is essential, particularly if, as in balsam fir, the species being considered is relatively short-lived.

On the basis of mean annual increment, it would seem most profitable to hold balsam fir up to an age of 110 to 130 years. The mean annual net increment increases from a low of 0.015 cubic foot at 40 years of age up to 0.128 at 110 years, at which point it remains stationary for 20 years before decreasing. On the basis of the periodic net increment, balsam fir is growing most rapidly between 60 and 80 years of age, and not until 110 years is passed does the periodic increment become less than it was between 40 and 50 years.

The field data on which table 3 is based do not include any mortality losses—from supression, windfall, insect and disease attack, and fire. Balsam fir is subject in varying degree to all these injurious agencies, but particularly to windfall, as it approaches maturity. General observations throughout the balsam fir region of the Northeast have convinced the writers that this species becomes highly susceptible to windfall at the age of about 70 years. As an example, on 2 quarter-acre plots on the Gale River Experimental Forest in a stand approximately 60 to 70 years old there were 384 trees, of which 63 (16½ percent) had been wind-thrown within a 3-year period. Of the 63 down trees only 12 (19 percent) were sound at the butt. This is an indication that about 80 percent of the windfall losses in balsam fir are in butt-rotted trees. Curves *B* and *F*, figure 1, show that at 75 years 53 percent of the trees will have butt decay and 40 percent will have butt cull. Obviously, when butt decay has progressed far enough to cause cull a high incidence of wind breakage may be expected.

Even though the mean annual net increment figures on a tree, rather than a stand, basis indicate a maximum age of 130 years and the net periodic figures indicate a maximum of 80 years, the writers conclude that the increased incidence of windfall mortality in balsam fir stands after the age of 70 years is reached makes it imperative that a felling age of 70 years be set for maximum returns. Up to this age losses of trees of merchantable size from windfall are not severe. To set the felling age of balsam fir in the northeastern forest region at 70 years, with an outside maximum of 80 years, will assure the harvesting of the probable maximum wood volume.

CULL IN RELATION TO DIAMETER

Balsam fir frequently occurs in uneven-aged stands mixed in varying degree with other species, particularly red spruce. As the age of individual trees is difficult to obtain in such stands, it is a common practice to classify stands for cutting by diameter rather than by age. For this reason, the relation between diameter and cull has greater practical utility than that between age and cull. Data on the relation of cull to diameter are shown in figure 4 and table 4.

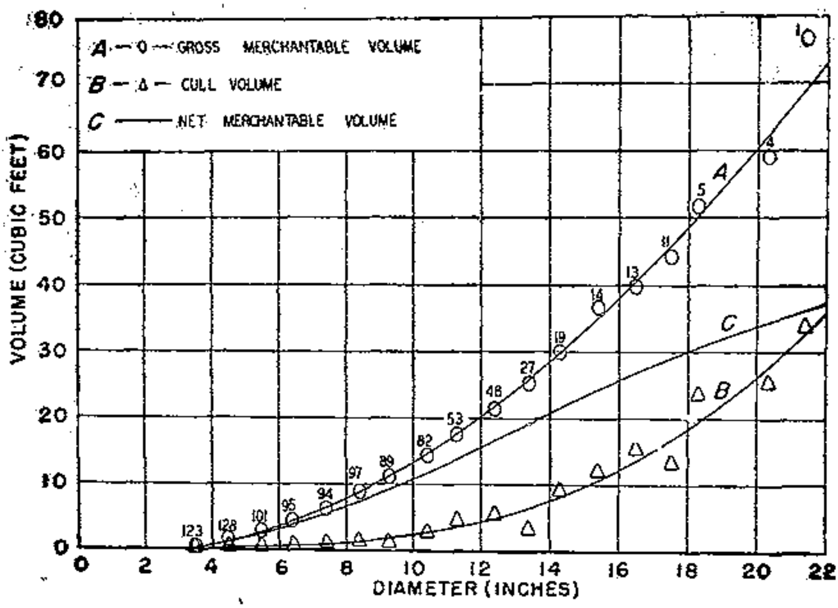

FIGURE 4.—Gross and net merchantable volume of balsam fir, by diameter classes.

TABLE 4.—*Gross and net merchantable volume of 1,004 balsam fir trees, by diameter classes* [1]

Class (d. b. h.)	Trees	Height	Average age	Gross merchantable volume	Gross [2] merchantable increment	Cull volume		Cull [2] increment	Current gross increment culled	Net merchantable volume	Net [2] increment
Inches	*Number*	*Feet*	*Years*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Percent*	*Cubic feet*	*Percent*	*Cubic feet*	*Cubic feet*
4	123	35	62	0.6		0.07	12.4			0.53	
5	128	41	65	1.8	1.2	.21	11.8	0.14	11.7	1.6	1.1
6	101	40	68	3.5	1.7	.42	11.9	.21	12.4	3.1	1.5
7	95	50	72	5.4	1.9	.68	12.6	.26	13.7	4.7	1.6
8	94	53	76	7.6	2.2	1.0	13.6	.32	14.5	6.6	1.9
9	97	56	80	10.2	2.6	1.5	15.0	.50	19.2	8.7	2.1
10	89	59	84	13.1	2.9	2.2	16.9	.68	23.4	10.9	2.2
11	82	62	89	16.4	3.3	3.2	19.3	.96	29.1	13.2	2.3
12	53	65	93	20.1	3.7	4.4	21.9	1.2	33.2	15.7	2.5
13	48	68	98	24.2	4.1	5.9	24.3	1.5	36.1	18.3	2.6
14	27	70	104	28.6	4.4	7.7	26.8	1.8	40.5	20.9	2.6
15	19	72	110	33.1	4.5	9.8	29.6	2.1	47.6	23.3	2.4
16	14	74	116	37.9	4.8	12.2	32.2	2.4	50.0	25.7	2.4
17	13	76	122	43.0	5.1	15.0	34.9	2.8	55.1	28.0	2.3
18	11	78	128	48.4	5.4	18.3	37.8	3.3	60.9	30.1	2.1
19	5	80	134	54.1	5.7	22.0	40.6	3.7	64.2	32.1	2.0
20		82	140	60.1	6.0	26.1	43.4	4.1	68.7	34.0	1.9
21	4	84	145	66.4	6.3	30.7	46.3	4.7	74.0	35.7	1.6
22	1	86	160	73.0	6.6	35.9	49.2	5.2	78.5	37.1	1.4

[1] Data read from curves.
[2] Increment is used here in the sense of the increase in volume from one diameter class to the next larger class.

Up to 8 inches in diameter, cull increases rather slowly, but above that size it mounts rapidly. On the basis of cull increase by diameter classes there is no indication of the maximum size at which balsam fir in the residual stand will produce the greatest net increment. There is a gradual decrease in the net increment after 14 inches, but up to the highest diameter, 22 inches, the net increment still remains at a rate higher than in small trees up to 5 inches. It must be realized, however, that this net increase does not offset the loss through wind throw or decay of whole trees of the smaller sizes from which the larger trees would have grown.

In the absence of a complete history of stands, it seems profitable to consider the situation if the frequencies shown by curving and weighting the data in the number-of-trees column of table 4 approximated the course of growth and mortality in all-aged balsam fir stands. Following this assumption, 138 4-inch trees will grow into 135 5-inch trees, which in turn will develop into 132 6-inch trees, and so on.

The aggregate gross and net volume that would still be standing when the survivors of the original 138 4-inch trees attain various larger diameters are shown in table 5. Aggregate gross volume reaches its peak at 10 to 12 inches, aggregate net volume at 10 to 11 inches, and aggregate cull volume not until 12 to 15 inches. If the original assumption is conceded as approximating correctly the average conditions in balsam fir stands in the Northeastern States, it would follow logically from table 5 that for maximum returns this species should not be held to average diameters greater than 11 inches.

TABLE 5.—*Hypothetical course of gross, net, and cull volumes with increasing size, of the survivors of an original group of 138 4-inch balsam fir trees, assuming that the growth and mortality followed the course indicated by the study plots*

Class (inches d. b. h.)	Trees [1]	Gross merchantable volume		Net merchantable volume		Cull volume
	Number	*Average cubic feet*	*Aggregate cubic feet*	*Average cubic feet*	*Aggregate cubic feet*	*Aggregate cubic feet*
4	138	0.6	83	0.53	73	10
5	135	1.8	243	1.59	215	28
6	132	3.5	462	3.08	407	55
9	128	5.4	691	4.72	604	87
8	123	7.6	935	6.6	812	123
9	117	10.2	1,193	8.7	1,018	176
10	109	13.1	1,428	10.9	1,188	240
11	96	16.4	1,574	13.2	1,267	307
12	73	20.1	1,467	15.7	1,146	321
13	54	24.2	1,307	18.3	988	319
14	41	28.6	1,173	20.9	857	316
15	33	33.1	1,092	23.3	769	323
16	25	37.9	948	25.7	643	305
17	19	43.0	817	28.0	532	285
18	14	48.4	678	30.1	421	256
19	10	54.1	541	32.1	321	220
20	7	60.1	421	34.0	238	183
21	4	66.4	266	35.7	143	123
22	2	73.0	176	37.1	74	102

[1] Frequencies in column 2, table 4, weighted to give equal representation to the 3 age groups considered in table 6, and then curved. There were 7 plots in the young stands and 4 each in the other 2 age groups. The raw data were weighted to indicate the populations as if there had been 7 plots in each age group.

Further backing for this recommendation is given by reference to the column of table 4 on current gross increment culled, which indicates that of the gross increase in volume as the trees grow from 4 to 5 inches in diameter, 11.7 percent is culled. From 9 to 10 inches cull has increased to 23.4 percent, and from 14 to 15 inches it has doubled, to 47.6 percent. Obviously with increasing tree size the current cull losses mount very rapidly—so rapidly that any plan to utilize most of the growth of balsam fir must call for relatively small average upper diameter limits.

An entirely different type of analysis of the relation of cull to diameter is that shown in table 6. The average stand ages for all the study areas are given in table 1. On the basis of average age the plots were divided into three groups: Young stands, plots 1, 2, 3, 4, 5, 14, and 15, varying from 59 to 70 years; intermediate stands, plots 6, 11, 12, and 13, varying from 82 to 106 years; and old stands, plots 7, 8, 9, and 10, varying from 116 to 136 years. Within each group the relation of cull to diameter was computed and expressed as a percentage of the gross merchantable volume in each diameter class.

TABLE 6.—*Comparison of the percentage of merchantable volume culled in 676 young, 213 intermediate, and 115 old trees in stands of balsam fir* [1]

Class (inches d. b. h.)	Young stands				Intermediate stands				Old stands			
	Trees	Age	Height	Cull	Trees	Age	Height	Cull	Trees	Age	Height	Cull
	Number	*Years*	*Feet*	*Percent*	*Number*	*Years*	*Feet*	*Percent*	*Number*	*Years*	*Feet*	*Percent*
4	118	60	35	11.2	5	76	39	85.0				
5	116	61	38	10.0	12	78	42	38.0				
6	90	62	42	10.1	8	80	45	5.0	3	110	57	62.0
7	89	63	46	10.6	3	82	48	2.6	3	111	59	32.5
8	80	64	49	11.4	9	84	51	8.4	5	112	61	23.1
9	54	64	52	12.0	31	87	54	11.7	12	113	63	20.0
10	54	65	56	12.8	27	89	57	17.7	8	114	65	19.7
11	34	65	59	13.0	32	92	60	23.2	16	115	67	20.9
12	16	66	62	13.4	26	94	62	28.3	11	116	69	22.7
13	10	66	64	13.7	27	97	65	33.4	10	117	71	24.7
14	7	67	67	14.0	12	100	68	37.8	9	118	73	26.8
15	4	67	69	14.3	9	103	71	41.6	8	119	75	29.0
16	1	67	71	14.6	6	107	73	45.2	7	121	76	31.2
17	1	68	73	14.7	2	111	75	48.5	10	123	78	33.3
18	2	69	74	14.8	2	116	77	51.6	7	120	80	35.5
19					2	121	79	54.4	3	131	82	37.4
20										137	84	39.3
21									4	144	87	41.0
22									1	153	90	42.6

[1] Data read from curves.

The high cull values at the lowest diameters are due to the culling rules, under which the presence of any decay in the smallest diameters causes complete cull, whereas in the larger trees the cull depends on the volume of infection. Within the same diameter class, except in classes with an insufficient numerical basis, the cull was almost always higher in the intermediate and old stands than in the young stands. In the largest diameter classes the old stands showed a lower cull percentage than the intermediate stands; this was probably due to the insufficient numerical basis in these classes and to the fact that in overmature stands badly rotted trees tend to drop out before those that are sound. It is true that within each of the three age groups there appears to be a relation of cull percentage to diameter, but this is believed to be due primarily to the fact that the age groupings were rather broad, and within each age group age increased with diameter. In the young group the increase in age with diameter is slight, and the increase of cull percentage is correspondingly slight. In the other groups the more rapid increase of cull with diameter goes with a rapid increase of age with diameter. This analysis indicates quite strongly that cull percentage is related to age rather than to size.

The discussion introducing the section on the percentage of cull in relation to age is equally applicable here. The data are shown in figure 5. Butt decay is the principal cause of cull up to 6 inches, but after that top decay rapidly becomes most important until above 8 inches it accounts for approximately two-thirds of all cull.

The high percentage values for all cull and for cull from butt decay only at the smallest diameters is due to the culling rules, as explained in the preceding section, and not to any greater volume of decay.

FELLING DIAMETER AS DETERMINED BY CULL VOLUME AND MORTALITY LOSSES

The preceding discussion suggests the difficulties encountered in attempting to set up diameter limits for balsam fir management. The principal deterrent lies largely in the fact that the rate of increase in cull is a function of time or age rather than of size or diameter; and that the correlation between diameter and age in the present unmanaged and often overstocked stands of balsam fir is very poor. Table 7 gives the frequency distribution of diameter by age of all the trees dissected in this study. The wide dispersion is characteristic of the species and reflects its tolerance to high stand density and overtopping. At the same time it reveals the pitfalls confronting anyone who attempts to use diameter as an indicator of age or a measure of maturity.

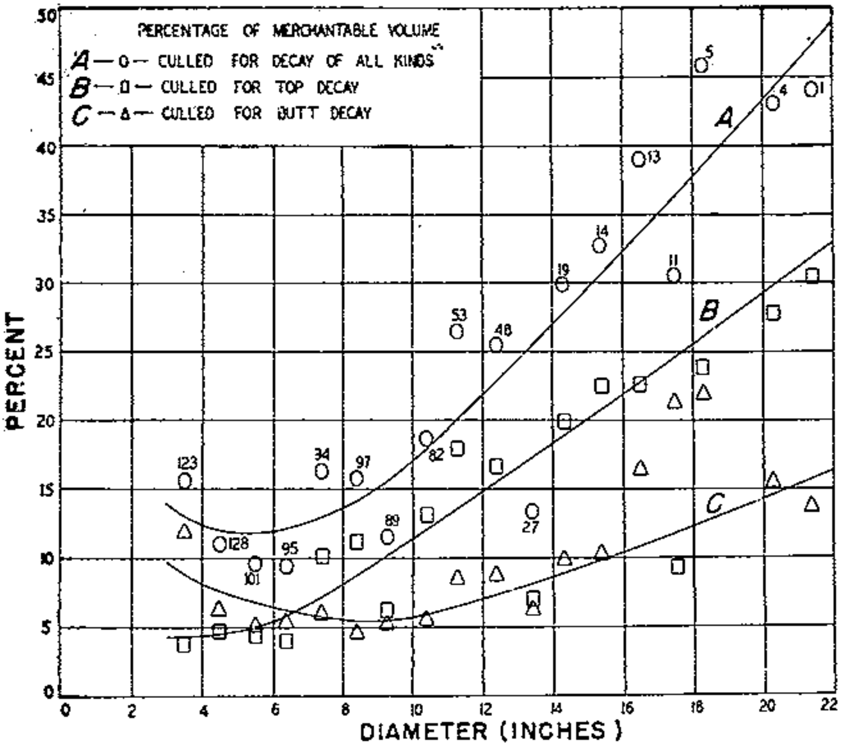

Figure 5.—Percentage of merchantable volume of balsam fir culled for butt and top decays, by diameter classes.

The use of two criteria—age and size—for establishing rotation requires that the relationship between them be examined critically, since one criterion may have priority under certain conditions and the other may rule under other conditions. In this particular study the difficulty is magnified by lack of stand figures and the necessity of applying findings for individual trees under varying site conditions to stands as a whole.

Table 7.—*Frequency distribution of diameter by age in 1,127 balsam fir trees*

Age class (years) [1]	Diameter class (inches) [2]											Total
	1.0	3.0	5.0	7.0	9.0	11.0	13.0	15.0	17.0	19.0	21.0	
10												
30	18	6	1									25
50	31	92	56	53	35	22	6					295
70	8	88	161	121	91	43	22	7	3			544
90		3	8	9	36	28	19	6	1	1		111
110				3	9	18	7	6	3		1	47
130			3	3	12	17	9	10	9	2	1	66
150					3	7	9	4	5	1	2	31
170							3		3	1	1	8
Total	57	189	229	189	186	135	75	33	24	5	5	1,127

[1] Midpoints of age classes 0–19, 20–39, etc.
[2] Midpoints of diameter classes 0–1.9, 2.0–3.9, etc.

The average diameter of 70-year-old trees is 7.1 inches and of 80-year-old trees 8.3 inches (see table 3), and the average age of 7- to 9-inch-diameter trees is between 72 and 80 years (see table 4). From this it may be inferred that the average felling diameter for maximum returns should be somewhere between 7 and 9 inches. This does not agree with the conclusion from table 5, that balsam fir may be held safely up to an average diameter of 11 inches, but this disparity is not unexpected. The felling age of 70 to 80 years, when the diameter is 7 to 9 inches, was set in an attempt to avoid serious losses from decay and windfall, but the maximum average diameter of 11 inches was based upon survivor trees, and no allowance was made for serious losses of the trees that did not survive to the large diameters. From this viewpoint the two diameter limits are not incompatible but may be considered supplementary to each other.

Assuming that 70 years is the maximum age and 9 inches the maximum average diameter allowable for highest net volume stand returns, and further assuming that these values are independent of site variations, it is obvious that stands on poor sites will reach the 70-year age before they reach the 9-inch average diameter and that stands on good sites will reach the 9-inch average diameter well in advance of 70 years. Inasmuch as age is the real factor determining the proportion of cull, it seems clear that on poor sites balsam fir will have to be harvested at average diameters less than 9 inches but that on good sites it may safely be allowed to grow to larger sizes.

RELATION OF CULL TO SITE QUALITY

The site index of each cutting area, based upon the average height of the dominant and codominant trees, was determined according to the method described by Meyer (22). Site index figures for the 15 plots are given in table 1; for 7 poorer sites these range from 49 to 59, and for 8 better sites, from 60 to 70. Using these two groups as representative of the poorer and the better sites, the data in table 8 were obtained.

TABLE 8.—*Comparison of gross and net merchantable volume of 795 balsam fir trees from poor and 328 from good sites*[1]

Age (years)	Trees		Average volume						Net periodic increment	
			Gross merchantable		Cull		Net merchantable			
	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Poor	Good
	Number	*Number*	*Cubic feet*	*Cubic feet*	*Percent*	*Percent*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
40	18	7	0.6	0.7			0.6	0.7		
50	60	7	2.3	3.9	8.7	5.1	2.1	3.7	1.5	3.0
60	189	70	4.2	7.2	11.9	6.9	3.7	6.7	1.6	3.0
70	397	48	6.7	10.3	14.9	9.7	5.7	9.3	2.0	2.6
80	38	37	9.6	13.1	17.7	13.0	7.9	11.4	2.2	2.1
90	30	36	12.6	16.0	20.6	16.3	10.0	13.4	2.1	2.0
100	21	20	15.2	18.8	23.7	19.1	11.6	15.2	1.6	1.8
110	13	10	17.4	21.6	28.2	22.7	12.5	16.7	.9	1.5
120	7	17	18.9	24.4	34.9	27.0	12.3	17.8	−.2	1.1
130	7	26	20.2	27.2	42.1	31.3	11.7	18.7	−.6	.9
140	4	30	21.2	30.0	52.8	37.3	10.0	18.8	−1.7	.1
150	5	13	22.0	32.7	65.0	44.3	7.5	18.2	−2.5	−.6
160	3	6	22.7	35.5	81.9	52.4	4.1	16.9	−3.4	−1.3
170	3	3	23.3	38.2	100.0	63.1		14.1	−4.1	−2.8

[1] Data read from curves.

For trees from the better sites the average gross merchantable volume at a given age is considerably and consistently greater than for trees from the poorer sites. At the same age, however, the average cull volume of trees in both classes is almost identical. Therefore the same cull figures were used for both groups. These figures are given in the cull volume (cubic feet) column of table 3. The percentage of cull is appreciably greater on the poorer than on the better sites, varying on poor sites at 50 and 170 years from 8.7 to 100 percent and on good sites from 5.1 to 63.1 percent.

The net periodic increment of merchantable wood of trees on the better sites is greatest from 40 to 60 years, but on the poorer sites it is delayed to 70 to 80 years. Moreover, the maximum for the better sites is 3.0 cubic feet per 10-year interval, whereas it is only 2.2 cubic feet for the poorer sites. The conclusions drawn from these data are that balsam fir on the better sites in the Northeast will yield highest returns if handled on a 60-year rotation, with only slightly less production if held to 70 years, and that on the poorer sites the slower growth rate delays peak production until 80 years, with only a slight reduction up to 90 years. These figures indicate that any silvicultural practices that will improve site quality will increase returns in two ways—by stepping up the production of merchantable wood, and at the same time by reducing the time interval between rotations.

RELATION OF CULL TO SOIL MOISTURE CONDITIONS

At the time the field data were taken, the cutting areas were classified according to soil moisture conditions—if distinctly wet or swampy as lowland, if distinctly well drained as upland, and if between these two as intermediate. Reference to table 1 shows that of the 15 plots 6 were upland and 5 lowland. The site index ratings of the upland plots varied from 56 to 65 with an average of 59, and the site index ratings of the lowland plots varied from 49 to 70 with an average of 59 also. Table 9 gives all the comparative data on these 11 plots. The 4 intermediate plots were disregarded in this analysis.

Of the trees from upland sites, 45 percent had butt rot with 9 percent of the gross merchantable volume culled, and 13 percent had top rot with 15 percent of the gross merchantable volume culled. On lowland sites the conditions were almost identical: 51 percent of the trees had butt rot with 9 percent of the gross merchantable volume culled, and 13 percent had top rot with 14 percent of the gross merchantable volume culled. In general, therefore, the prevalence of butt and top rot is independent of character of site and is approximately equal in both dry and wet situations.

The data in table 9 show that on the uplands balsam fir grows more rapidly than in lowlands and has a higher net volume up to 80 years. Even though on a percentage basis cull is higher throughout most of the life of the species on uplands than in lowlands, the increased growth rate on the uplands compensates for the greater cull losses until after 70 years.

TABLE 9.—*Comparison of gross and net merchantable volume of 595 balsam fir trees from upland and 336 from lowland sites*[1]

Age (years)	Trees		Average volume						Periodic net increment	
			Gross merchantable		Cull		Net merchantable			
	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland
	Number	*Number*	*Cubic feet*	*Cubic feet*	*Percent*	*Percent*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
40	18	------	0.4	0.3	2.5	3.3	0.4	0.3	------	------
50	39	21	1.8	1.3	6.7	7.7	1.7	1.2	1.3	0.9
60	120	70	4.1	3.2	12.0	9.1	3.6	2.9	1.9	1.7
70	266	138	7.1	5.7	17.3	9.5	5.9	5.2	2.3	2.3
80	54	12	10.4	8.4	22.4	10.0	8.1	7.6	2.2	2.4
90	34	20	13.4	11.5	27.1	10.1	9.8	10.3	1.7	2.7
100	11	23	15.9	14.6	31.8	11.2	10.8	13.0	1.0	2.7
110	11	10	17.9	17.9	36.0	13.6	11.5	15.5	.7	2.5
120	13	4	19.5	21.2	39.8	19.0	11.7	17.2	.2	1.7
130	12	12	20.7	24.6	43.0	28.3	11.8	17.6	.1	.4
140	10	14	21.7	28.1	45.6	41.0	11.8	16.6	0	−1.0
150	5	6	22.6	31.5	47.9	56.0	11.8	13.9	0	−2.7
160	1	2	23.3	35.0	49.9	73.0	11.7	9.5	−.1	−4.4
170	1	4	24.0	38.5	51.8	91.4	11.6	3.3	−.1	−6.2

[1] Data read from curves.

RELATION OF CULL TO RATE OF GROWTH OF INDIVIDUAL TREES

The data presented previously might be interpreted as indicating that the progress of decay on a volume basis is fairly constant, regardless of the size of individual trees. The fact that the average cull loss on a volume basis at a given age is the same on poor sites as on good sites supports this interpretation. So many other variables enter into the comparison on a site-quality basis, however, that such an interpretation is not warranted. On a poor site, because of optimum spacing, individual trees may grow just as rapidly and be just as vigorous as individual trees in a denser stand on a far better site. For this reason all trees were considered as individuals regardless of site and were classified as fast- or slow-grown according to their relation to the average gross merchantable volume for all trees of the same age. This method of dividing the trees into two groups is the same as that used by McCallum (*20*) and Kaufert (*16*).

Curve *A* in figure 2 shows the average gross merchantable volume by age for all the trees dissected in this study. The actual volume of each tree was compared with the average volume of all trees of the same age read from this curve. If the volume of a tree exceeded the average, it was classified as fast-grown; if it was exactly the same as the average, it was discarded; and if the volume was less than the average, it was classified as slow-grown. The average volume and cull by ages for both groups are given in table 10.

The average gross and net merchantable volume of slow-grown trees is always much less than in fast-grown trees of the same age, varying from a ratio of 1 to 10 at 40 years to 1 to 2 at 170 years. The reason for the greater disparity in size of balsam fir at the younger ages is found in its extreme tolerance. Under severe suppression it will survive for years, with almost no increment. In the older age classes the effects of suppression tend to be equalized between the two groups through progressive mortality of the most severely suppressed trees.

The average cull volume in 50-year-old fast-grown trees exceeds by five times that of slow-grown trees of the same age, the ratio being gradually reduced with increasing age as the severely suppressed trees drop out, until at 170 years there is only twice as much cull in the fast-grown trees. The reasons for this difference are obscure, and little published information is available to support any of the various possible theories. It is not because the slow-growing trees escaped infection and probably not because the time of infection of such trees was delayed. Of the slow-grown trees, 50 percent were infected with decay organisms at the time they were cut, as were 60 percent of the fast-grown trees, but this difference is not sufficient to account for the much greater difference in cull volume. In some cases, particularly the most severely suppressed trees, it is probable that the rot soon occupies the entire cross-sectional area of the heartwood near the point of infection, but this presumably would not have any effect on the longitudinal extension of the decay.

The most plausible explanation, in the opinion of the writers, is that differences in the density (specific gravity) of the wood of fast- and slow-grown trees are largely responsible. Hale and Prince (*12*) have recently shown that in eastern Canada the density of spruce and balsam fir woods is dependent upon the growth rate—rapidly grown wood is light in weight and slow-grown wood is relatively heavy. Per unit of volume, therefore, there is more wood substance by weight in slow-grown than in fast-grown trees. If it is assumed that in a specified unit of time a wood-rotting fungus can digest a specified quantity of wood tissue by weight regardless of the volume it occupies, it is apparent that the progress of decay would be more rapid both longitudinally and radially in a fast-growing tree than in a slow-growing tree. In addition, it is possible that in a living tree the air-moisture relations are nearer the optimum for the progress of decay in a relatively light wood than in a dense wood. Snell (*32, 33, 34*) indicates this possibility when he states (*34, p. 379*): "Presupposing that a certain definite volume of air is necessary to support the growth of these wood destroyers, the moisture content favoring the maximum amount of decay or inhibiting decay entirely will vary inversely with the specific gravity." In a dense wood the lumina are small and the limited air available for fungus growth may be a factor in determining the slower rate of decay.

A comparison of the cull volume of slow- and fast-grown trees expressed as a percentage of the gross merchantable volume shows more clearly the relations between the two groups. The cull percentage is slightly higher in slow-grown trees up to 70 years of age, slightly lower from 80 to 120 years, and slightly

TABLE 10.—*Comparison of gross and net merchantable volume of 713 slow- and 407 fast-grown balsam fir trees* [1]

Age (years)	Trees		Diameter (average)		Height (average)		Gross merchantable volume (average)		Cull volume (average)				Net merchantable volume (average)		Increment			
															Net periodic		Mean annual	
	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow		Fast		Slow	Fast	Slow	Fast	Slow	Fast
	Number	*Number*	*Inches*	*Inches*	*Feet*	*Feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Percent*	*Cubic feet*	*Percent*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
40	20	5	1.9	4.2	15	39	0.3	2.9					0.3	2.9			0.008	0.073
50	44	23	2.7	7.1	24	46	1.1	7.2	0.10	9.1	0.5	6.9	1.0	6.7	0.7	3.8	.020	.134
60	162	97	4.1	9.1	33	55	2.2	11.5	.30	13.6	1.3	11.3	1.9	10.2	.9	3.5	.032	.170
70	304	139	5.3	10.4	43	61	3.8	15.8	.56	14.7	2.3	14.6	3.2	13.5	1.3	3.3	.046	.193
80	37	38	6.6	11.5	49	65	5.9	20.1	.94	15.9	3.7	18.4	5.0	16.4	1.8	2.9	.063	.205
90	38	27	7.7	12.4	53	68	8.3	24.3	1.4	16.9	5.1	21.0	6.9	19.2	1.9	2.8	.077	.213
100	18	21	8.6	13.3	57	70	10.7	28.7	2.1	19.6	6.7	23.3	8.6	22.0	1.7	2.8	.086	.220
110	18	5	9.4	14.1	60	72	13.0	32.9	3.1	23.8	8.8	26.7	9.9	24.1	1.3	2.1	.090	.219
120	11	13	10.1	14.8	62	74	15.3	37.1	4.6	30.1	11.2	30.2	10.7	25.9	.8	1.8	.089	.216
130	21	12	10.7	15.5	63	76	17.5	40.8	6.5	37.1	14.1	34.6	11.0	26.7	.3	.8	.085	.205
140	22	12	11.3	16.1	64	77	19.7	44.2	8.8	44.7	17.7	40.0	10.9	26.5	−.1	−.2	.078	.189
150	10	8	11.8	16.7	65	78	21.9	47.0	11.3	51.6	22.4	47.7	10.6	24.6	−.3	−1.9	.071	.164
160	5	4	12.2	17.3	66	79	24.1	49.3	13.3	59.3	28.3	57.4	9.8	21.0	−.8	−3.6	.061	.131
170	3	3	12.6	17.8	67	80	26.2	51.3	17.7	67.6	34.8	67.8	8.5	16.5	−1.3	−4.5	.050	.097

[1] Data read from curves.

higher again from 130 to 170 years. The differences are not statistically significant, however, and probably would be even less apparent on an actual rot-volume than on a cull-volume basis.

The analysis in table 10 includes many trees near the average volume. In order to contrast trees of distinctly slow and fast growth, another analysis was made on the basis of very slow grown trees, including only trees whose volume is less than 75 percent of the average volume for that age, and very fast grown trees, including only those whose volume exceeds the average volume by more than 25 percent. This disclosed that there is no essential difference between the results obtained by the two methods of comparison.

At 70 years the net merchantable volume of slow-grown trees is 3.2 cubic feet; of fast-grown trees, 13.5 cubic feet; and of very slow and very fast grown trees, 2.5 and 15.1 cubic feet, respectively. That this differential in volume per tree is also accompanied by an increase in wood production by weight is shown by the studies of Hale and Prince (*12, p. 40*) in eastern Canada, who found ". . . that although rapidly grown wood of spruce and balsam fir is light in weight and the slowly grown wood relatively heavy, the rate of wood-production of rapidly grown trees on a basis of total weight far exceeds the amount produced by slow-growing trees."

These data indicate that there is considerable argument in favor of careful management of balsam fir stands to increase the number of fast-grown trees. Up to 70 years of age such trees not only produce more wood than slow-grown trees but they are also at the same time subjected to somewhat smaller cull percentage losses.

ANALYSES OF CORRELATION OF CULL WITH AGE, DIAMETER, HEIGHT, AND VOLUME

The preceding analyses of the variation of cubic-foot volumes and percentage cull with age and by diameter show gross relations that are informative to a certain degree but do not reveal the net relation of diameter, age, and other variables to the development of cull. An attempt was made, by correlation analysis, to define the net relations between the incidence of cull in balsam fir and its contributing or associated tree characteristics.

First, cull volume, in cubic feet, was linearly correlated with gross merchantable volume, age, height, and diameter, yielding a correlation coefficient of 0.650 and a linear regression equation by which the expected deviation of cull volume of a tree from the mean cull volume for all trees is found to be—

$$C-\overline{C}=0.364\ (x_1-\overline{x_1})\ +0.060\ (x_2-\overline{x_2})-0.076\ (x_3-\overline{x_3})-0.143\ (x_4-\overline{x_4})$$

when for each tree, C=cull volume, in cubic feet; x_1=gross volume, in cubic feet; x_2=total age, in years; x_3=total height, in feet; x_4=diameter, breast high, in inches; and a bar above the symbol indicates the mean for all trees.

The regression coefficient of diameter was not significant. Omitting it as a variate, the correlation coefficient became 0.645 and the recomputed equation became—

$$C-\overline{C}=0.334\ (x_1-\overline{x_1})\ +0.060\ (x_2-\overline{x_2})-0.090\ (x_3-\overline{x_3})$$

Applying the extreme values in the basic data for each variate, the maximum change in cull ascribed to height was 5.2 cubic feet; to age, 8.5 cubic feet; and to volume, 13.4 cubic feet. Since tree volume is highly correlated with cull it is likely that if it had not been included in the equation, diameter would have had a significant coefficient because of the direct bearing of diameter upon volume. In other words, in trees of equal age and height, there might be found a definite correlation between diameter and cull.

With the possibility that the relation between cull and the above-mentioned variates might be more apparent on a relative basis, cull was expressed as a percentage of the gross merchantable volume and linearly correlated with diameter, height, age, and gross merchantable volume. The correlation coefficient, however, was 0.300, so low that the equation has little significance.

These correlation analyses were made, not only as a check upon the preceding simple analyses, but also to attempt to ascertain more exactly what characteristics of individual trees may be used safely as an index to their pathological condition. They were made on the assumption of straight-line relations, which as seen in figures 2 and 4 are far from the actual facts. The relatively high coefficient for volume is partly due to the fact that the volume graph has a shape somewhat like that of the cull graph. By an analysis in which curvilinearity was taken into account, more reliable and probably higher coefficients could presumably have been found for the other factors. The simpler analysis of the relation between cull percentage and age and diameter given in table 6 and accompanying text discussion is perhaps more enlightening.

In the order of the ease with which they may be obtained the variables considered in relation to cull are diameter, height, age, and volume. The value of diameter as an index of cull in balsam fir is doubtful, but because it is by far the easiest and quickest measurement to take, it probably will continue to be the principal gage of the practicing forester in inventorying his stock. The great variation of diameter with age makes it imperative that when diameter is used to determine the cutting age of balsam fir, it must be taken on a sample large enough to give a reliable average.

IMPORTANCE OF FUNGI CAUSING DECAY

As previously stated, practically all cull from decay in balsam fir is attributable to three fungi. In order of importance they are the red heart rot fungus (*Stereum sanguinolentum*), the white stringy rot fungus (*Poria subacida*), and the brown cubical rot fungus (*Polyporus balsameus*). The first is an upper crown or top rot and the other two are butt rots. The characteristic decay of each has been described elsewhere (*4, 5, 7, 16, 20*).

The 1,127 trees dissected in this study had a total volume, including top and stump, of 10,707 cubic feet, of which almost one-fourth, or 2,536 cubic feet, was cull. Of this cull volume, 54 percent was caused by *Stereum sanguinolentum*, 28 percent by *Poria subacida*, 13 percent by *Polyporus balsameus*, and 5 percent by all other fungi, mechanical defects, and ants. Environmental variations had no appreciable effect upon the relative abundance of the three principal decays. In the percentages of cull and of trees affected by each fungus, differences were not significant between well-drained and wet areas, good and poor sites, and fast- and slow-grown trees.

In stands of different ages the importance of the different decay fungi will vary. In young stands the two butt-rot fungi account for more cull than does top rot. Furthermore, the number of trees infected with butt rot exceeds the number of those with top rot at all ages. Actually *Poria subacida* and *Polyporus balsameus* are more important and are the cause of higher losses than the above figures indicate, for the windfall losses in a stand are directly proportional to their frequency. It is reasonable to surmise that if the data here given included all losses from mortality throughout the life of the various stands sampled and if all windfall losses of butt-rotted trees were charged to the butt rots that predisposed the trees to that windfall, the relative losses attributed to butt rots would be far greater.

ENTRANCE OF FUNGI AND ANTS INTO LIVING TREES

Data on the avenues of entrance of cull-producing organisms into living balsam fir are given in table 11. In the 1,127 trees dissected there were 663 fungus infections and 47 infestations by carpenter ants (belonging to the genus *Camponotus*). Decay occurred in 584 trees, and ants in 47, including 26 that also had decay. Cull-producing organisms were present, therefore, in 605 (54 percent) of the 1,127 trees.

Of the 369 decay cases attributed to *Poria subacida*, the fungus entered through the roots in 342 (93 percent), through frost cracks in 18 (5 percent), and through basal branch stubs, basal forks, and mechanical wounds in 9 (2 percent).

Of the 116 decay cases attributed to *Polyporus balsameus*, the fungus entered through the roots in 106 (91 percent), through frost cracks and mechanical wounds in 4 each (3½ percent each), and through basal branch stubs and basal forks in the other 2 (2 percent).

Of the 144 decay cases attributed to *Stereum sanguinolentum*, the fungus entered through abnormally large dead branches and branch stubs in the crown in 113 (79 percent), through forks in 19 (13 percent), and through broken and dead tops, mechanical wounds, and frost cracks in the remaining 12 (8 percent).

Of the 34 decay cases attributed to other fungi, which include *Armillaria mellea*, *Coniophora puteana*, *Lenzites saepiaria*, *Polyporus abietinus*, *Trametes heteromorpha*, and a few others of uncertain identity, the fungus entered through the roots in 13 cases (38 percent), through mechanical wounds in 12 (35 percent), through branch stubs, frost cracks, and forks in 7 (21 percent), and through unknown avenues in the remaining 2 cases (6 percent).

TABLE 11.—*Avenues of entrance of fungi and ants into living balsam fir trees*

Entrance point	Frequency of causes of decay or cull					Total
	Poria subacida	*Polyporus balsameus*	*Stereum sanguinolentum*	Other fungi	Carpenter ants	
Roots	342	106	----------	13	41	502
Branch stubs	3	1	113	3	----------	120
Frost cracks	18	4	1	2	4	29
Mechanical wounds	4	4	5	12	2	27
Forks	2	1	19	2		24
Broken top	----------	----------	4	----------	----------	4
Dead top	----------	----------	2	----------	----------	2
Unknown	----------	----------	----------	2	----------	2
Total	369	116	144	34	47	710

Of the 47 infestations with carpenter ants, the insect entered through the roots in 41 cases (87 percent), and through frost cracks and mechanical wounds in the remaining 6 (13 percent).

Summarizing the data on avenues of entrance discloses that in 71 percent of the cases, the organism entered through the roots; in 17 percent, through branch stubs; in 4 percent, through frost cracks; in 4 percent, through mechanical wounds; in 3 percent, through forks; and in 1 percent through broken and dead tops and in unknown ways.

The absence of fire scars as an avenue of entrance is not a chance circumstance but represents the usual condition in the balsam fir forests of the Northeast. Fires occur frequently in such forests, but balsam fir, like other thin-barked species, usually is killed outright by even relatively light ground fires. Fire-scarred trees, therefore, seldom continue as a component of balsam fir stands and thus are of slight consequence as a decay hazard.

The exact relation between carpenter ant infestations and butt decays has been the source of much conjecture and discussion. Many foresters and woodsmen feel rather strongly that fungus infection nearly always precedes ant infestation. The data obtained in this study do not bear out this conclusion. Of 533 trees with butt rot, ant colonies were established in 26 (4.9 percent). Of 594 trees with no butt rot, ant colonies were established in 21 (3.5 percent). While this indicates that trees with butt rot may be slightly more susceptible to ant infestation than are those free of such rot, the difference is not sufficient to warrant the conclusion stated above. The fact that 3.5 percent of the rot-free trees were infested with ants indicates rather strongly that the presence of decayed wood is not an essential predisposing agent to the entrance of those insects. Furthermore, there is no evidence either way to indicate whether the fungi or the insects first attacked the 4.9 percent of the butt-rotted trees that harbored ants.

EXTERNAL INDICATIONS OF DECAY IN LIVING TREES

At the time of cutting, every tree was carefully examined and all abnormalities and defects were noted with the expectation that some external indications of decay might be found. Such information would be particularly useful in timber cruising. The results were almost entirely negative. Out of the total of 710 cases caused by fungi and ants, there were no external evidences before the tree was felled of the presence of cull-producing organisms in 622 cases (88 percent). Forty-nine trees with frost cracks were cut, but only 29 (slightly less than 60 percent) had decay. Of 32 trees with mechanical wounds, 27 (84 percent) had decay, as also did 24 of 37 trees with forks (65 percent), all 4 with tops broken out by wind, and 2 of the 3 trees with dead or spike tops.

Briefly summarized, it is found that if a balsam fir has a mechanical wound or a broken or dead top, it probably will have decay, but there is no way to tell how much unless the defect is obviously very old or severe. If a tree is forked or has a frost crack, it is slightly more subject to decay than otherwise. Finally, and most important, in almost 9 of every 10 trees with decay, there is no abnormality in growth to give any indication of the decay. There is no difference in the appearance of the exposed roots in decayed and in sound trees except in the relatively few cases where dead bark is present or where woodpeckers have entered in search of insects, nor is there any diagnostic difference in the appearance of most trees with and without top rot. Dead lateral branches or branch stubs more than 2 inches in diameter are likely infection entrances for top rot, but they are as common in rot-free trees as in decayed trees.

Excluding those trees with obvious crown injuries, there is only one characteristic that usually suggests the occurrence of top rot—the presence of a series of nodes separated by almost indistinguishable internodes at some point in the midcrown. This indicates that at that time the tree was subjected to suppression sufficiently severe to result in almost complete cessation of terminal height growth and that it was flat-topped in form. In many cases the top-rot fungus (*Stereum sanguinolentum*) gains entrance during or following such a period of low vigor. This fact suggests the futility of most attempts to release flat-topped balsam fir. Even though such trees respond satisfactorily to such release, they are likely to be subject to heavy cull when harvested.

APPLICATION TO FOREST MANAGEMENT PLANS

Throughout this bulletin simple and multiple correlation analyses of the relation of cull in balsam fir to those variables that are considered highly important in the silvicultural management of the species have been presented. In the following discussion the general practical applications of the analyses are indicated, with suggestions as to how the results of the investigation may be integrated into forest management plans.

Cultural Operations

Specific operations to improve either the quality or the quantity of balsam fir are rare today but should receive increasing attention in the near future. Westveld (*36*, *37*) has stressed the desirability of weeding and girdling to release spruce and balsam fir. The increased value of the product on treated areas is considered to be sufficient justification of such measures, and their use together with partial cutting should result in excellent yields.[7] Balsam fir appears to be especially responsive to such operations. The present study indicates that a further return from such management is available in that, as measured by cull percentage, balsam fir up to 70 years of age is slightly less susceptible to decay when growing rapidly than when suppressed. Furthermore, as noted earlier by Zon (*38*) and now confirmed by these investigations, the top rot fungus (*Stereum sanguinolentum*) gains entrance to many trees that have been suppressed long enough to assume a flat-topped form. Release of young trees before they have been subjected to long suppression removes one important cause of infection by this fungus.

General observations indicate that balsam fir is most likely to escape top rot infection if grown in stands sufficiently dense to keep the diameter of the lateral branches below 1½ inches but not dense enough to cause suppression or stand stagnation. In other words, proper management of balsam fir to minimize the chances of such infection during the course of the entire rotation would call for beginning with a fairly dense stand and then maintaining a uniformly fair rate of growth, not alternately very slow and very fast; this can be obtained

[7] Spaulding, P., Westveld, M., and Hansbrough, J. R. Balsam fir—use it, don't lose it. U. S. Forest Serv., Northeastern Forest Expt. Sta. Tech. Note 49, 2 pp. 1942. [Processed.]

by at least one girdling operation where overtopping hardwoods are present (unless the hardwoods are marketable, of course) and by one or two weedings and thinnings.

Rotation

A rotation of about 70 years is recommended for balsam fir in the Northeastern States as a measure to reduce losses from decay and windfall. Analysis of the individual-tree data on which this bulletin is based shows that the net periodic increment begins to decrease after the age of 80 years. These data, however, do not include any losses in the stand from wind throw and breakage but are based only on the trees present in the stand at the time of cutting; therefore, to avoid heavy loss from windfall, the recommended cutting age is fixed at 70 years. Individual operators for business reasons may cut on an 80-year or longer rotation but they must bear in mind that they are subjecting themselves to an additional risk of curtailed returns by so doing. At 70 years balsam fir is well above the minimum merchantable size, particularly if any operations have been performed to promote growth. Table 3 shows that the average diameter of 443 70-year-old trees is 7.1 inches and the height 48 feet, and table 10 shows that the average diameter of fast-grown trees at the same age is 10.4 inches and the height 61 feet. Data presented on balsam fir growth in the Adirondacks by Meagher and Recknagel (*21*) show that under forest management, diameters ranging from 2.6 to 8 inches will, in 36 years, increase to 6 and 14 inches, respectively. The same authors state that for economical handling, ". . . Finch, Pruyn & Co. have shown that the optimum diameters of spruce and fir for pulpwood are 9, 10, and 11 inches d. b. h." It is evident that balsam fir under good management can attain these sizes in 70 years.

Logging Operations

Most of the present unmanaged second-growth balsam fir stands of merchantable size in the Northeast are pathologically overmature and highly defective. Kaufert (*16*) found identical conditions existing in the Lake States. Much of this timber should be harvested as soon as possible before decay renders it unmerchantable. Balsam fir more than 80 years of age deteriorates rapidly through decay of standing trees and through losses from windfall and breakage. At the time of logging such stands the minimum diameter should be small enough to include as many small old trees as possible. Table 7 indicates their frequency. Then if sound silvicultural practices (weeding, releasing, and partial cutting), such as recommended by Westveld (*36*, *37*), are employed in the future, there will be a much better correlation between diameter and age at the time of the next cut. Growth studies in present stands are essential before minimum diameter limits are set.

Cull in balsam fir becomes an appreciable factor at 50 years of age and an economic limiting factor, along with windfall, at 70 years. From the pathological standpoint, the difference between these ages, 20 years, should be the maximum time allowable between cutting cycles, for if longer periods elapse, cull and windfall losses are liable to become very severe. The relatively frequent removal of dominant balsam firs will contribute to the prevention of severe budworm outbreaks (*11*).

Since balsam fir usually grows in mixture with spruce, it is assumed that the latter will be so managed that there will be available a light cut of spruce to help carry the costs of more frequent fellings on a given area, as was stated under Cultural Operations.

Sanitation

No special and particular forest sanitation measures are recommended for balsam fir stands. The three principal fungi causing decay of living trees are widespread throughout the range of the species and are not limited to balsam fir. Two of them, *Stereum sanguinolentum* and *Poria subacida*, are present abundantly on logs and slash of several other conifers. No practicable sanitation measures would be sufficiently effective in reducing the supply of inoculum to justify the additional expense of application. Furthermore, if balsam fir is handled on a rotation not exceeding 70 to 80 years, losses caused by decay will be much lower than in the present stands, which contain many overmature trees.

Timber Cruising

This publication gives conversion factors (pp. 11, 14) by which total volume estimates of balsam fir may be corrected for cull. If a stand is predominantly of one age group or if the representation of various age groups is known, the gross volume estimates may be corrected for cull by applying the percentages in the cull volume column of table 3, or the actual cull volume per tree in cubic feet as shown in that table and by curve *B* of figure 2. Usually, however, cruise estimates are by diameters. In this case correction for cull may be obtained by applying the percentages in the cull volume column of table 4, or the actual cull volume per tree in cubic feet, as shown in that table, and by curve *B* of figure 4. The data upon which these tables and curves are based were taken over a wide range of conditions and cannot with accuracy be applied to single small stands.

Utilization

About 1920 many attempts were made, particularly in eastern Canada, to encourage the use of partly decayed wood of spruce and balsam fir for pulp. The preliminary results and discussions by Bates (*2*), Faull (*4*, *5*, *6*), Hawkings (*13*), Rue and Humphrey (*25*), Rue et al. (*26*, *27*), and Schierbeck (*30*) may be interpreted as indicating that, in general, the white rots do not render affected wood economically unfit for pulp except where the rot is so advanced that actual disintegration has taken place. Brown rots, however, reduce the fiber strength sufficiently to make affected wood unusable for pulp except in the very earliest stages. Of the butt rot caused by *Polyporus balsameus*, Faull (*5*, *p. 202*) says—

> Brown heart rot when developed to the friable stage is certainly of no value for pulp, and in earlier stages the affected fibres are weakened to a greater or less extent. * * * How much should be rejected would appear to depend in part on the floating capacity (of which no definite data are at hand) and in part on the relative amounts of sound and diseased wood. The latter is valueless.

Of red heart rot caused by *Stereum sanguinolentum* he says (*5, p. 201*)—

From the limited evidence at hand, it would appear that the action of the decay may have affected the *lignocellulose* without materially attacking the cellulose in the wood. It would also appear very possible that most of the wood which is normally discarded in the woods or diverted to the boiler-house as fuel might be economically pulped.

Of the white stringy rot caused by *Poria subacida* he says (*5, p. 203*)—

Feather rot, except in the later stages, is not marked by an excessive weakening of the fibres—apparently the cellulose is more resistant to the action of the causal fungus than is the lignin. The actual loss in ordinary cutting operations usually amounts to a short butt log; it is doubtful if even this is necessary.

In the case of balsam fir this means that wood decayed by *Polyporus balsameus* had better be rejected in the woods, but that wood with incipient and early typical decay by *Poria subacida* and *Stereum sanguinolentum* has possibilities for economical conversion into pulp.

Sound balsam fir can be pulped by all the standard commercial processes (*3, 17*), but for pulping wood in which decay has not advanced too far, only the sulfite process is recommended (*6, 17, 25, 26, 27*). Other methods yield seriously discolored pulp from decayed wood. Satisfactory pulps have been prepared experimentally by the sulfite process from balsam fir decayed by both *Stereum sanguinolentum* and *Poria subacida*. Kress et al. (*17, p. 49, note*) state that—

The value of decayed wood for sulphite pulp is closely associated with the chemical action of the wood-destroying organisms, and these organisms vary widely in their method of attack. Further investigations . . . indicate already that some types or rot tend to reduce the value of wood for sulphite pulp less than the superficial appearance of the wood might suggest.

Sulfite pulp mills utilizing all wood not too badly decayed by the white rot fungi are able materially to reduce their cull losses in balsam fir without unduly increasing their operating expenses.

Mills using decayed wood for pulp should take particular care that such wood is not kept in storage any longer than absolutely necessary and that it is segregated from sound wood in storage piles. Kress et al. (*17, p. 8*) say that—

Badly infected shipments should always be segregated in an allotted portion of the yard for quick utilization. *This precaution is important. Deterioration in such wood is proportionately much greater than in sound or slightly infected stock. If it is intermixed with sound wood it serves as a rapid and vigorous source of infection to the better material.*

The italics are theirs, but the writers cannot emphasize too strongly the need for heeding their warning. In particular, the decay caused by *Stereum sanguinolentum* will spread very rapidly in already infected bolts and to adjacent uninfected bolts. Under favorable conditions it will in a very short time make stored pulpwood unfit for use.

LITERATURE CITED

(1) ANONYMOUS.
1932. BUTT ROT IN BALSAM FIR ON GALE RIVER FOREST. U. S. Forest Serv. Forest Worker 8 (4): 12.

(2) BATES, J. S.
1923. HOW FAR CAN THE PULP-MILL GO IN UTILIZING DECAYED INSECT-KILLED OR OTHER INFERIOR WOOD IN THE MANUFACTURE OF PULP. Pulp and Paper Mag. Canada 21: 77–80.

(3) CLAPP, E. H., and BOYCE, C. W.
1924. HOW THE UNITED STATES CAN MEET ITS PRESENT AND FUTURE PULPWOOD REQUIREMENTS. U. S. Dept. Agr. Dept. Bul. 1241, 100 pp., illus.
(4) FAULL, J. H.
1923. FOREST PATHOLOGY. IV. Ontario Min. Lands and Forests Rpt., 1921–22: 245–254, illus.
(5) ———
1924. FOREST PATHOLOGY. IV. Ontario Min. Lands and Forests Rpt., 1922–23: 197–207.
(6) ———
1924. THE TREATMENT OF DECAYED WOOD IN AND OUTSIDE THE MILL. Pulp and Paper Mag. Canada 22: 255–257.
(7) ——— and MOUNCE, I.
1924. STEREUM SANGUINOLENTUM AS THE CAUSE OF "SAPIN ROUGE" OR RED HEART ROT OF BALSAM. (Abstract) Phytopathology 14: 349–350.
(8) FOX, W. F.
1901. HISTORY OF THE LUMBER INDUSTRY IN THE STATE OF NEW YORK. N. Y. Forest, Fish, and Game Comn. Ann. Rpt. (1900) 6: 237–305, illus.
(9) ———
1902. REPORT OF THE SUPERINTENDENT OF FORESTS. N. Y. Forest, Fish, and Game Comn. Ann. Rpt. (1901) 7: 19–41, illus.
(10) FRITZ, C. W.
1923. CULTURAL CRITERIA FOR THE DISTINCTION OF WOOD-DESTROYING FUNGI. Roy. Soc. Canada, Proc. and Trans., Ser. 3, 17 (5): 191–288, illus.
(11) GRAHAM, S. A., and ORR, L. W.
1940. THE SPRUCE BUDWORM IN MINNESOTA. Minn. Agr. Expt. Sta. Tech. Bul. 142, 27 pp., illus.
(12) HALE, J. D., and PRINCE, J. B.
1940. DENSITY AND RATE OF GROWTH IN THE SPRUCES AND BALSAM FIR OF EASTERN CANADA. Canada Dept. Mines and Resources, Lands, Parks, and Forests Branch Bul. 94, 43 pp., illus.
(13) HAWKINGS, C. S. V.
1923. ROTTEN WOOD IN PAPER MAKING. Pulp and Paper Mag. Canada 21: 287–289, illus.
(14) HEIMBURGER, C., and MCCALLUM, A. W.
1940. BALSAM FIR BUTT-ROT IN RELATION TO SOME SITE FACTORS. Pulp and Paper Mag. Canada 41: 301–303.
(15) HUBERT, E. E.
1929. A BUTT-ROT OF BALSAM FIR CAUSED BY POLYPORUS BALSAMEUS PK. Phytopathology 19: 725–732, illus.
(16) KAUFERT, F.
1935. HEART ROT OF BALSAM FIR IN THE LAKE STATES, WITH SPECIAL REFERENCE TO FOREST MANAGEMENT. Minn. Agr. Expt. Sta. Tech. Bul. 110, 27 pp., illus.
(17) KRESS, O., HUMPHREY, C. J., RICHARDS, C. A., and others.
1925. CONTROL OF DECAY IN PULP AND PULP WOOD. U. S. Dept. Agr. Dept. Bul. 1298, 80 pp., illus.
(18) MCCALLUM, A. W.
1924. INVESTIGATIONS ON DECAYS OF BALSAM FIR (ABIES BALSAMEA MILL.). Canada Dept. Agr., Dominion Bot. Rpt. (1923): 10–12, illus.
(19) ———
1926. INVESTIGATIONS ON DECAYS OF BALSAM FIR (ABIES BALSAMEA MILL.). Canada Dept. Agr., Dominion Bot. Rpt. (1925): 11–12.
(20) ———
1928. STUDIES IN FOREST PATHOLOGY. I. DECAY IN BALSAM FIR (ABIES BALSAMEA MILL.). Canada Expt. Farms, Div. Bot. Bul. 104 (n. s.), 25 pp., illus.
(21) MEAGHER, G. S., and RECKNAGEL, A. B.
1935. THE GROWTH OF SPRUCE AND FIR ON THE WHITNEY PARK IN THE ADIRONDACKS. Jour. Forestry 33: 499–502.
(22) MEYER, W. H.
1929. YIELDS OF SECOND-GROWTH SPRUCE AND FIR IN THE NORTHEAST. U. S. Dept. Agr. Tech. Bul. 142, 52 pp., illus.
(23) MOORE, B., and ROGERS, R. L.
1907. NOTES ON BALSAM FIR. Forestry Quart. 5: 41–50.

(24) RANKIN, W. H.
1920. BUTT ROTS OF THE BALSAM FIR IN QUEBEC PROVINCE. (Abstract) Phytopathology 10: 314-315.
(25) RUE, J. D., and HUMPHREY, C. J.
1924. DECAYED WOOD FOR PULP—AT A PROFIT. Amer. Paper and Pulp Assoc., Canad. Pulp and Paper Assoc., Newsprint Serv. Bur., [unnumb. pub.], 14 pp., illus.
(26) ——— MILLER, R. N., and HUMPHREY, C. J.
1924. DECAYED WOOD FOR SULPHITE PULP. Pulp and Paper Mag. Canada 22: 93-100, illus.
(27) ——— MILLER, R. N., and HUMPHREY, C. J.
1924. THE UTILIZATION OF DECAYED WOOD IN THE CHEMICAL PROCESSES. Paper Trade Jour. 78 (20): 44-48, illus.
(28) SARGENT, C. S.
1891-1902. THE SILVA OF NORTH AMERICA. 14 v. Boston and New York.
(29) SCHIERBECK, O.
1922. TREATISE ON THE SPRUCE BUD WORM, BARK BEETLE AND BORER. THE CAUSES OF THE DYING OF THE BALSAM IN QUEBEC AND SUGGESTIONS FOR PREVENTIVE MEASURES. Pp. 1-38, illus. Montreal.
(30) ———
1923. DISCUSSION ON USE OF ROTTEN WOOD. Pulp and Paper Mag. Canada 21: 262-264.
(31) SCHRENK, H. VON.
1900. SOME DISEASES OF NEW ENGLAND CONIFERS: A PRELIMINARY REPORT. U. S. Dept. Agr., Div. Veg. Physiol. and Path. Bul. 25, 54 pp., illus.
(32) SNELL, W. H.
1921. RELATION OF MOISTURE CONTENTS OF WOOD TO ITS DECAY. Paper 28 (9): 22-24, illus.
(33) ———
1929. THE RELATION OF THE MOISTURE CONTENTS OF WOOD TO ITS DECAY. III. Amer. Jour. Bot. 16: 543-546.
(34) ——— HOWARD, N. O., and LAMB, M. U.
1925. THE RELATION OF MOISTURE CONTENTS OF WOOD TO ITS DECAY. Science (n. s.) 62: 377-379.
(35) SPRINGER, J. S.
1851. FOREST LIFE AND FOREST TREES. 259 pp., illus. New York.
(36) WESTVELD, M.
1930. SUGGESTIONS FOR THE MANAGEMENT OF SPRUCE STANDS IN THE NORTHEAST. U. S. Dept. Agr. Cir. 134, 23 pp., illus.
(37) ———
1931. REPRODUCTION ON PULPWOOD LANDS IN THE NORTHEAST. U. S. Dept. Agr. Tech. Bul. 223, 52 pp., illus.
(38) ZON, R.
1914. BALSAM FIR. U. S. Dept. Agr. Dept. Bul. 55, 68 pp., illus.

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