# STUDIES IN FOREST PATHOLOGY

## I. DECAY IN BALSAM FIR (*Abies balsamea*, Mill.)

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DOMINION EXPERIMENTAL FARMS
E. S. ARCHIBALD, Director

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# DIVISION OF BOTANY

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### PLANT PATHOLOGY

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## INTRODUCTION

The field studies upon which the present bulletin is based were carried on in Quebec on the limits of Price Brothers and Company. At the time when this work was undertaken the company was gathering information with the object of placing a portion of their holdings under forest management and, knowing that in balsam fir—the principal species in the district under consideration—decay was very prevalent, and realizing the intimate relation which decay bears to management, they desired to secure definite data regarding the pathology of this species, especially in connection with decay. Such knowledge would be of value in furnishing data for the correction of cruise estimates—in other words, in providing a cull factor based on scientific study and not arbitrarily arrived at,—and would be essential in the preparation of working plans as influencing the choice of rotation, since it is evident that, without some knowledge of the probable condition of the growing stock at various ages, it would be impossible to determine the felling age rationally.

It is only within recent years in this country that fungous diseases of forest trees have been given much attention. As was natural, the principal work at first was to study these troubles from a mycological viewpoint, becoming familiar with the fungi affecting each tree species. Such work is of primary importance—it is basic to all subsequent studies in forest pathology. The limited amount of investigation of this character which has been accomplished has been confined almost exclusively to Ontario and Quebec, leaving the maritime and western provinces practically a virgin field for scientific exploration.

The methods used in these studies are essentially those which were developed by Dr. E. P. Meinecke of the United States Office of Forest Pathology, to whom the writer is indebted for valuable assistance and advice, not only in planning the field work, but also in the interpretation of data and criticism of manuscript. Mr. R. D. Craig of the Dominion Forest Service assisted greatly, especially in the solution of the problems in mensuration which arose in working up the statistical data. Mr. R. H. Nisbet of Price Brothers and Company afforded every facility for carrying out these studies upon the company's limits. To Mr. Otto Schierbeck and Mr. Angus Graham, both foresters formerly in the employ of Price Brothers, acknowledgment is due for assistance and advice given during the course of the field work. Mr. H. T. Güssow, Dominion Botanist, suggested the presentation in bulletin form of the results secured from the investigation, and also assisted in the criticism of manuscript. Dr. F. C. Craighead of the United States Bureau of Entomology aided through discussion of certain phases of budworm injury. The Director of the Meteorological Service, Sir Frederic Stupart, kindly supplied data from which the figures for temperature and precipitation were obtained.

## NATURE OF FOREST PATHOLOGY

In the broadest sense forest pathology may be defined as that branch of the science of forestry which is concerned with loss in forest trees but, as the term is usually used and understood, it refers principally to the study of those diseases of forest trees which are caused by fungi. Of all the causes of loss in the forest, fire is undoubtedly the most obvious and therefore the most familiar. Because of this, and also because all but a small percentage of fires, being of human origin, are preventable, the chief activity of forest organizations in this country, as far, at least, as protection is concerned, is directed towards the suppression of this source of damage. In recent years, with the growing realization that the present rate of depletion of our forests cannot be maintained indefinitely, some attention has been paid to the other two major causes of loss in forest trees, i.e. fungi and insects. The immense amount of timber which has to be discarded annually on account of decay and the recent widespread damage in eastern Canada brought about by the budworm have served to emphasize the economic importance of these forms of loss. Though there are no definite figures available, it is generally agreed that the losses due to fungi and insects over a period of years are about equal, and that together such damage approximates that caused by fire. However, in attempting to estimate the relative importance of these three destructive agencies, it must be remembered that, while fungi and insects are not only non-injurious to the soil but are actually beneficial in reducing brush and the general debris of the forest floor to litter, repeated fires, in addition to destroying the growth, also destroy the soil; and, where this is thin, the damage may be irreparable. On this account fire is undoubtedly the most serious single agent of destruction operating in our forests at present.

Timber supplies are unfavourably influenced by fungi in two ways: first, by a decrease in increment which affects the future stock, and, second, by decay which reduces the present stand. In the first instance the fungi concerned attack the living parts of the tree, diminishing the amount of food elaborated and thus lessening the growth. In balsam fir rusts are the principal fungi which cause such damage. As Meinecke (16) has pointed out, this form of injury, though negligible for short periods, must over long cutting cycles cause a considerable loss, and further, such damage may suppress a tree with the same results that lack of light produces. In addition to fungi, leaf-destroying insects and mistletoes must be included here as causing this type of injury. Perhaps the most striking example of loss and suppression of this kind is shown by a study of diameter increment in balsam fir and spruce, which have been attacked by the budworm, but which have recovered. According, to Craighead (23), during the first year of feeding in trees which will recover ultimately, the current annual ring at the base of the tree is abnormally wide. Successive annual rings show a marked decrease in size down to a minimum which, in balsam fir, is reached five years after the first feeding occurred. Commonly, the rings are almost totally suppressed on the lower part of the trunk, and as much as three years' growth may be lacking on some parts of the stem. For a tree to recover the rate of increment, which prevailed before the injury, requires from twelve to fifteen years; and it is estimated that, in general, there is a loss of from three to five years' growth as a result of defoliation by the budworm. Over large areas of forest such as were affected by this insect there must have been a very great loss in increment in the trees which did not succumb.

Standing timber is subject to serious loss from certain forms included in that group of fungi which cause decay in wood, usually referred to as the wood-destroying fungi. Those species which infect living trees are generally confined to the heartwood and are rarely directly responsible for the death of their hosts. Decays of this kind are distinguished as butt rots and heart rots, the former being restricted principally to the roots and lower part of the trunk while the latter are usually found in the upper part of the stem. In both cases, however, they inhabit the heartwood. Butt rots are seldom the cause of much cull in trees, it ordinarily being sufficient to butt the first log about four feet from the stump to avoid the decay. They are, however, very important as a contributory cause of windthrow of affected trees. In this way not only is the tree destroyed but the fire hazard is greatly increased by the resulting debris. While trees affected by heart rot are also occasionally broken off by wind at some distance from the ground, this is not nearly as common. The importance of heart rots lies in the amount of wood destroyed by the decaying action of the causal fungi; in mature and over-mature stands this loss is very heavy.

Since these decays only affect the heartwood, it is evident that young trees in which such wood has not yet been formed are immune. Even after this time unwounded trees are safe from infection, because these fungi can only gain access to the heartwood through a wound or break in the bark. However, under forest conditions the protective covering of a tree does not long remain perfect. If it is not wounded in one way or another, whether by fire, lightning, snow, ice, or frost, the lower side branches soon die from lack of light, and, although they then persist for some time, are finally broken off. Upon those branch stubs which contain heartwood, fungous spores germinate under favourable condition and grow in to the heartwood of the tree. As a matter of fact the fungi which cause heart rots enter the tree in the great majority of cases by this means. In the case of butt rots the point of infection is usually the tap-root.

It is known that decay is the cause of much loss in virgin forests, and that managed forests are by no means free from such damage. It is also apparent that, until a certain age, trees are immune from decay; but, concerning this age, and also the age at which decay becomes the cause of cull of economic importance, very little is known. In the life of a tree species much subject to rot, there comes a time when the gain in volume is more than offset by the loss from decay. Obviously, from a silvicultural point of view, no tree should be allowed to remain uncut after this time, as this can be done only at the sacrifice of sound timber. It is clear, then, that in forest management generally, and especially in the management of a short-lived species very susceptible to decay, the relation of age to decay should have an important influence upon the choice of rotation. In the case of long-lived species it is equally apparent that the age at which decay becomes economically important will probably lie far beyond the age at which the species will be utilized under a system of management.

## STATUS OF BALSAM FIR AS A PULPWOOD

Until about thirty years ago very little balsam fir was cut either for pulpwood or lumber but, from that time onward, as the available supplies of pine and spruce became scarcer or more inaccessible, this species was utilized in gradually increasing quantities until, during the ten-year period ending in 1922, there was approximately half as much balsam fir as spruce used for pulpwood in Quebec. Since, during this period spruce constituted about two-thirds of the total amount of timber utilized for pulp, it is evident that balsam fir formed about one-third of the total cut for this purpose. There is no reason to believe that the latter species will become of less importance in the pulpwood industry,—rather the indications are that in the future it will be used to a much greater extent than is the case at present.

For several reasons there has always been a prejudice against the use of balsam fir for pulpwood, the principal objections raised being (1) inferior fibre as compared with spruce, (2) occurrence of more resin in this species than in spruce, (3) low yield per cord, and (4) tendency to decay. As far as actual length of tracheids or fibres of balsam fir is concerned, the wood seems to compare very favourably with spruce. Thus, the average length of tracheids in the former is 3·10 millimetres while in white spruce, red spruce, and black spruce the average lengths are 3·53, 2·97, and 3·48 millimetres respectively. However, there is no doubt that the tracheids of balsam fir are weaker than those of spruce and, as the wood is used at present, yield a lower quality of pulp than does spruce. The reason for the second objection is difficult to understand on account of the fact that neither resin cells nor resin canals occur normally in balsam fir as they do in spruce. When resin canals do occur in the former it is as the result of injury or wounding, and it would not be at all likely that much resin would be produced in this way as occurs naturally in spruce. The bark of balsam fir, however, is very rich in resin and it is possible that the resin complained of may be due either to the wood having been imperfectly rossed, or to the accidental transference in some way of resin from the bark to the surface of the wood. In any case it is not due to the inherent quality of the wood, but rather to faulty processes of treatment.

The third objection to balsam fir is, of course, a valid one, as the weight of bone dry wood of this species is about 21·50 pounds and that of spruce is about 26·40 pounds per cubic foot. It is evident, then, that a cord of the latter, containing as it does about 20 per cent more wood substance by weight than the former, will give a much higher yield of pulp. Actually, this difference works out at approximately the figure for the difference in density of the two woods, i.e. about 20 per cent. As the lower yield of balsam fir is well known, it would seem reasonable to make allowance for it in fixing the stumpage price as is done in Ontario. At present in Quebec the same price is charged for the two species and, under these conditions, the utilization of balsam fir is naturally not so profitable as that of spruce.

In regard to rot it has been found that wood in the early stages of decay at least can be successfully used in making pulp, especially in mills where pulp is further converted into newsprint. The amount of such wood which is utilized by the different companies varies greatly. It is possible in the future that even more decayed wood may be used than at present, but in handling logs in an advanced state of decay the difficulties of transportation would probably be considerable. While balsam fir as it is used at present is regarded as an "inferior" species, yet this is, in large measure, not due to the inherent qualities of the wood itself, but to the lack of rational forest management. There will always, apparently, be a ready demand for sound balsam fir.

In some ways from a silvicultural point of view it is not a desirable species as it is subject to attack by many different fungi, of which those destroying the wood are the most important. On the other hand, this tree possesses decided silvicultural advantages. Good seed years occur frequently, sometimes as often as every second year, and seed is produced prolifically. Natural reproduction occurs freely almost to the total exclusion of spruce on every opening in the forest, whether made by cutting or otherwise. (Pl. I, fig. 1 and 2.) In fact, so dense is the representation of young balsam fir in any opening, that artificial thinning in early life may become a necessary part of the management of this species, even though there would probably be no sale for such material. The cost of this treatment would likely be justified by the increased rate of growth which would occur as a result of it and, consequently, by the shorter rotation which could then be used. Under similar conditions balsam fir grows more rapidly than spruce but it is a shorter-lived tree. The long life and sustained growth of spruce enables it to attain much greater dimensions than balsam fir. In regard to light requirements, while it can endure a good deal of shade, especially when young, it is not as tolerant as spruce. After release from long periods of suppression, however, it is capable of recovery and rapid growth.

There is an additional reason for prejudice against this species on account of its extreme susceptibility to the budworm in the past and on account of the possibility of future epidemics. On these grounds there have been those who have advocated the elimination of this tree from our forests, but such suggestions have probably been made without serious consideration of the question. As has been shown, balsam fir is an aggresive species, and it would be a manifest impossibility to get rid of it even were that desirable. Both Greeley (10) and Meinecke (16) have pointed out the probable dangers of such an attempt in connection with other species. It is evident, therefore, that whatever steps should be taken to anticipate possible future outbreaks of the budworm the elimination of balsam fir is not one of them.

## PATHOLOGY OF BALSAM FIR

Balsam fir is subject to attack by many different fungi and, under present forest conditions, much damage results from this cause. Of the fungi which infect living parts of the tree the rusts are probably the most important. Considerable investigation upon this group has been done in Ontario by Faull and his associates, and the following species have been reported by him (6) as occurring in northern Ontario:—

Blueberry rust—*Calyptospora columnaris,* (Alb. and Schw.) Kühn.
Fireweed rust—*Pucciniastrum pustulatum,* (Pers.) Dietl.
Fern rusts
*Uredinopsis Osmundae,* Magn.
*Uredinopsis mirabilis,* (Peck) Magn.
*Uredinopsis Struthiopteridis,* Störmer.
*Uredinopsis Phegopteridis,* Arthur.
*Uredinopsis Atkinsonii,* Magn.
*Uredinopsis polypodophila,* Bell.
*Hyalopsora Aspidiotus,* (Peck) Magn.
Chickweed rust—*Melampsorella elatina,* (Alb. and Schw.) Arthur.

These are all heteroecious forms and are a most interesting group.

The foliage of balsam fir is also parasitized by *Lophodermium nervisequum,* (D.C.) Rehm, and in small trees this causes some damage. The outstanding cause of loss, however, is that brought about by wood-destroying fungi. In the course of this investigation three rots of importance were encountered, one being a heart rot, and the other two butt rots. The former, termed red heart rot, is undoubtedly the most serious decay affecting balsam fir, and its distribution is apparently co-extensive with that of its host, although it is much more common in some districts than in others. Red rot is usually confined to the upper part of the trunk extending upward from about the end of the first log, though in several instances it was found continuing down to ground level.

In appearance the affected wood is reddish brown in colour, water soaked, and firm. In the most characteristic form of this decay, when viewed in transverse section, there are rays extending out from the main body of rotted wood. (Pl. II.) These rays may be as much as two inches in length and half an inch in width and, as they project out into the sound, light-coloured wood, they are a prominent feature of the rot. In most cases, however, the decay simply occurs as a solid, circular mass, or it may be present in irregular patches. (Pl. III, fig. 1.) At quite an early stage white, mycelial sheets are often found in the rotted wood and these persist until the later stages of decay. (Pl. III, fig. 2.) In advanced decay the wood becomes light brown in colour, light in weight, dry, and friable.

In a recent paper (8) Faull and Mounce have ascribed the cause of this rot to *Stereum sanguinolentum,* Alb. and Schw., and, during the course of the present investigation, much field evidence has been secured in support of this finding. (Pl. IV, fig. 1.) The fruiting bodies of this fungus do not seem to occur in connection with the decay in living trees, though occasionally they are to be found upon dead branches of such trees. It fruits in profusion upon dead wood, however, and in the Lac Epinette area few dead standing trees, stubs, or windfalls could be found which did not bear an abundance of these sporophores. In all cases examined the fungus was found to occur in connection with the characteristic type of decay which has been described.

Incipient decay of feather rot, the first type of butt rot encountered, is yellowish buff in colour, becoming lighter as the decay develops. (Pl. V, fig. 1.) Minute, longitudinal holes occurring in concentric rings soon appear in the affected wood, causing the annual layers of growth to separate from each other. Small, black spots usually are found in wood in the later stages of decay. In extreme decay the centre of the stem becomes hollow and the surrounding wood is reduced to a mass of water-soaked shreds. (Pl. V, fig. 2.) When a handful of this pulp is removed from the trunk it has a feathery appearance. In this stage, especially in trees which have been windthrown, dense layers of white mycelium are found lining the irregular cavities in the trunk.

While feather rot is usually confined to the roots, stump, and lower end of the first log, and, in general, is not the cause of much cull, it occasionally extends up the tree for long distances. Thus, in one instance, a continuous column of this decay was found reaching from ground level to a point in the third log which was 33·5 feet above the ground. In this particular case it was responsible for the cull of the first two logs or 65 per cent of the total merchantable volume of the tree.

The importance of feather rot, however, does not lie in the amount of loss which it causes directly as a result of its action in decaying wood, but rather in its role as a contributory cause to windthrow of affected trees. Some observations in this connection are of interest. On a representative area of $2\frac{3}{8}$ acres there were 37 balsam firs which had first been weakened by feather rot and then broken off by wind. At this rate, in a square mile of similar forest there would be 9,970 such trees, or about 7 per cent of the total stand of this species.

The identity of the causal fungus of this type of decay has not been proved by scientific methods but the indications are that it is *Poria subacida,* Peck. (Pl. IV, fig. 2 and 3.) Only in a few cases was a fungus noted in connection with this rot and then in fallen trees. In these instances it was always *Poria subacida.* Cultural work with this decay and with red rot has yielded no positive results as far as the production of fruiting bodies is concerned.

It is of interest, to note in passing that, in several, well-defined cases, red rot and feather rot were found growing together in the same trunk with no line of demarcation being noticeable between them. Generally it has been believed that decays caused by different fungi do not intermingle, but Boyce (3) has previously noted such merging in incense cedar between the decays of *Polyporus amarus,* Hedgc. and *Trametes Pini,* (Thore) Fr., and in Douglas fir between the decays of *Fomes officinalis,* (Vill.) Faull and *Trametes Pini.*

The second type of butt rot found is one which has long been familiar to pathologists, foresters, and lumbermen. In the early stages of decay the wood becomes light brown in colour, dry, and light in weight. (Pl. VI, fig. 1.) Later the wood darkens and checks into irregular cubical blocks. In this stage it can be easily powdered between the fingers. (Pl. VI, fig. 2.) In advanced decay thin, white, mycelial sheets appear between the blocks. Such a butt rot has usually been ascribed to *Polyporus Schweinitzii,* Fries, but in the present instance the field evidence and cultural characteristics indicate that *Polyporus balsameus,* Peck is the causal fungus. (Pl. VIII, fig. 1 and 2.) This rot rarely extends more than a few feet from ground level and so does not cause much direct loss. As is the case with butt rots generally, it is of greater importance in weakening affected trees and so rendering them more susceptible to damage by wind. (Pl. VII, fig. 1.) Curiously enough, this decay was not observed in the Lac Epinette area but was very common at Lake Metis.

One other decay was met with in the course of the field work and, while it is not of economic importance in the region under consideration, it seems worth while to mention it. This was the decay, sometimes called partridge rot, caused by *Trametes Pini.* It is of very frequent occurrence in spruce and white pine in Quebec, but fortunately rare in balsam fir, though apparently common enough in this species in the New England States. Only one tree of the total number analyzed was decayed by this fungus.

Two other fungi should be noted here—*Fomes pinicola,* (Sw.) Cooke and *Armillaria mellea,* Vahl. The former is the commonest polypore to be found in the forests of Ontario and Quebec, fruiting abundantly upon dead stubs, fallen trees and stumps, but always, as far as observed, living as a saprophyte. This finding is not in accordance with the experience of others, since it has often been reported as the cause of a decay of living trees. Thus, von Schrenk (20), Atkinson (1), Hedgcock (11), Meinecke (15), and Rankin (19) have so recorded it, and in the western United States it is generally regarded by pathologists as an enemy of living timber. While it is quite possible that it does occasionally infect living trees in the two provinces mentioned, yet it must be considered as of little importance as far as being a cause of cull in either spruce or balsam fir when used for pulpwood.

Similarly, the other form—*Armillaria mellea,* one of the mushrooms—is, both in Europe and America, generally considered to be a destructive parasite of many species of coniferous and deciduous trees. It affects the roots causing a yellowish, wet rot of the sapwood, and occasionally the heartwood may be involved. On the outer surface of roots and of the bark of the trunk just below ground level its black rhizomorphs can be readily found. Beneath the bark the fungus may be present either in the form of mycelium or rhizomorphs. If the latter, they are usually flattened, brown in colour, and may extend upwards on the stem for several feet. The mycelium is white and often fan-shaped. These sheets of mycelium, the rhizomorphs, and the freshly decayed wood are luminescent, giving off a glowing, whitish light which, at times, especially in badly decayed wood, is very bright.

*Armillaria mellea,* or the honey fungus as it is called, is one of the commonest mushrooms occurring in the forest, but field observations over a period of years do not lend support to the opinion that it is a serious parasite. To be sure, it can easily be found on the roots of dead and dying trees, but there is grave doubt that it has been the primary cause in producing these conditions. It can almost invariably be found on the roots and at the base of balsam firs which have been injured by the budworm, but to account for the subsequent death of such trees there are other more important factors than the presence of this fungus (23). In many cases, too, such trees recover their former degree of health. There is, perhaps, no other form of injury in which it is more difficult to establish the cause than root damage. The grubbing up of trees and the examination of root systems is an arduous and often unsatisfactory task, as everyone who has attempted it well knows. While a few cases have been observed in which it seemed probable that this fungus was killing its host, yet, in general, it would be difficult indeed to produce convincing evidence that it is of importance as an enemy of either spruce or balsam fir in Ontario or Quebec.

Cultural work was carried on in connection with all these decays, and it was found to be of much assistance in differentiating between the rots, in identification, and in deciding in difficult cases whether or not decay was present. In this regard a paper by Fritz (9), in which a key, based on cultural characteristics, for the identification of some of the common wood-destroying forms is given, has been found of great value.

## FIELD METHODS

### LOCATION AND DESCRIPTION OF AREAS

Two separate areas were studied to secure the data presented herewith—one located on the north shore of the St. Lawrence river and the other on the south shore. The former is in the Lake St. John district on lac Epinette, an expansion of the Shipshaw river about 35 miles north of the Saguenay into which it flows between Chicoutimi and Kenogami.

The elevation of lac Epinette is 877·2 feet above sea level and it is surrounded by the Laurentian mountains which in the immediate neighbourhood rise about 800 feet above the lake, although a little farther east altitudes of over 2,000 feet are reached. Long winter seasons with low temperatures—down to 50° F. with a mean of 10·5°—and heavy snowfall are characteristic of this region. The growing season is short and fairly cool, the mean temperature for the summer months being about 48° F. The annual precipitation is approximately 32 inches, included in which is an average snowfall of about 70 inches.

The soil is fine sand having an average depth of 3 feet in the valleys and 9 inches on the ridges. Black peat is frequently found in the former. The humus varies in depth from 6 inches to 1 foot. Throughout the area are deposits of glacial boulders.

The principal species represented in the ground cover are *Osmunda regalis, L., Lycopodium complanatum, L., Clintonia borealis,* (Ait.) Raf., *Oxalis acetosella, L., Aralia nudicaulis, L., Cornus canadensis, L.,* and various species of mosses. The underbrush is, in general, dense and composed chiefly of *Acer spicatum, Lam.* and *Taxus canadensis,* Marsh. The former attains a height of about 12 feet and is an important factor in the early suppression of balsam fir seedlings.

The stand is of one type—the spruce-balsam—the present approximate proportions of the species being as follows: balsam fir, 63 per cent, birch, 30 per cent, and spruce 7 per cent. The two species of birch—*Betula lutea,* Michx. and *B. alba* var. *papyrifera* (Marsh) Spach.—are present in nearly equal quantities. Although balsam fir is the predominant species in the present composition of the stand spruce formerly formed a much greater proportion than it does now, for the area has been logged over and the best spruce removed. In addition, spruce lives much longer than balsam fir, and so, as the age of the stand increases, the proportion of spruce is increasing while that of balsam fir is decreasing.

The forest may best be described as two-storied, the upper storey composed of an even-aged stand of birch, and the lower of a many-aged stand of balsam fir and spruce. While some of the more vigorous individuals among the conifers now tower above the birches, in general the latter occupy by far the greater part of the crown space. Numerically the greatest number of balsam fir lie between the age limits 81 and 120, while the average age of the birches, from rather insufficient data, is 169 years. It is apparent that for the greater part of its life, and especially during that period when it should have been making its most rapid growth, balsam fir is suppressed by the birches. The latter ultimately begin to drop out commencing at the top where large branches are killed by the bronze birch borer (*Agrilus anxius*, Gory), which is followed by infection and decay due to *Fomes fomentarius,* Fr.

In passing, it is of interest to note the condition of these birches in regard to decay. Twenty-five average trees were selected, felled, and examined for rot. The heartwood of every tree was badly decayed and in nearly all cases the rot extended throughout most of the trunk. Decay caused by *Fomes fomentarius* alone was present in 71 per cent of the trees examined, that due only to *Fomes igniarius,* Fr. was found in 8 per cent, while in the remaining 21 per cent both types of rot occurred. Decay caused by the former fungus was found to have originated almost exclusively in dead branches and branch stubs in the crown, while that due to the latter usually began in side branch stubs or cracks in the trunk.

The second area chosen was in the Metis Seigneurie bordering on lake Metis about 60 miles south of the St. Lawrence river. This lake has an elevation above sea level of approximately 850 feet and is situated in the eastern end of the Notre Dame mountains which rise about 700 feet above the lake. The winter seasons are long with fairly even temperatures and heavy snowfall. The mean winter and summer temperatures are 12·6° and 49° respectively. The annual precipitation is about 32 inches, included in which is an average snowfall of 100 inches.

The mineral soil varies from clay to sandy loam and averages 6 inches in depth. On the surface and throughout the soil are scattered what are apparently glacial boulders. The humus is usually about 6 inches deep. The ground cover is composed chiefly of *Cornus canadensis* and *Aralia nudicaulis,* while the underbrush, which is moderately dense, is principally *Acer spicatum.* The forest type is the same as in the lac Epinette area, though there is, in addition to the species found there, a small admixture of cedar (*Thuja occidentalis, L.*). The proportions of the various species are approximately as follows: balsam fir, 57 per cent; spruce, 13 per cent; cedar, 11 per cent; birch, 19 per cent. This stand has not been burnt over in recent times, but has been logged intermittently for the best spruce and cedar.

The site classification for both areas is Site II which is the intermediate class of this system used by the Dominion Forest Service.

## FIELD NOTES (Shipshaw River)

Since the principal purpose of this work is to determine the age at which decay becomes of economic importance, trees of all ages must be considered. The plan adopted was to clear cut average quarter-acre plots taking all trees down to 3 inches D.B.H. and, as the younger age classes were not well represented on these plots, it was necessary to cut young trees wherever they could be found. The stump height was kept as nearly as possible to 12 inches, and the trees, after being limbed, were cut into 12-foot logs down to a top diameter of 3 inches, taking a 4-foot piece in the top if possible. The following data were recorded for each tree: height of stump, length of each section, width of bark in each section, length above last cut, diameters at stump, breast height, and at each cut. From the diameters, which were taken outside the bark and were averaged, the average width of the bark was deducted to secure the diameters inside the bark.

The age at stump was secured wherever possible but in about 10 per cent of the trees cut in the lac Epinette area this could not be done on account of decay. In order to ascertain the ages of such trees, the ages of sound trees at stump, first, and second sections were taken, and these figures plotted for each age class. In this way a final curve was constructed from which the ages of the decayed trees at stump height could be read. While these figures are not to be regarded as exact they are probably close enough to include in 10-year age classes. In the Lake Metis study in over 20 per cent of the trees cut it was impossible to count the rings at stump height. In this case the difficulty was overcome by determining, from a large number of sound trees, the average number of years taken to grow to the first section—12 feet above the stump —and adding this to the age at that point. In order to secure the total ages of the trees a count was made of the ages of seedlings of different heights, and the average number of years required to attain a height corresponding to the stump height was added to the age at stump. The degree of suppression to which balsam fir is subjected in early life is shown by the fact that it requires sixteen years in the lac Epinette area and fifteen years in the lake Metis area for a seedling to attain a height growth of 1 foot. In addition to the above, notes were taken on the crown class of trees, injuries, and entrance of decay.

For each tree in which there was decay the amount of cull was estimated. In this regard the present practice of the company was followed as closely as possible and was, therefore, not based on an exact determination of what might or might not be converted into pulp. In accepting or rejecting logs at present much is left to the scaler's own judgment. Under this system a great deal of wood in the very early stages of decay is accepted and gives quite satisfactory results when used for the manufacture of newsprint. In analyzing decayed trees each log showing signs of rot was split at least once so that the extent of decay and the means of entrance could be determined.

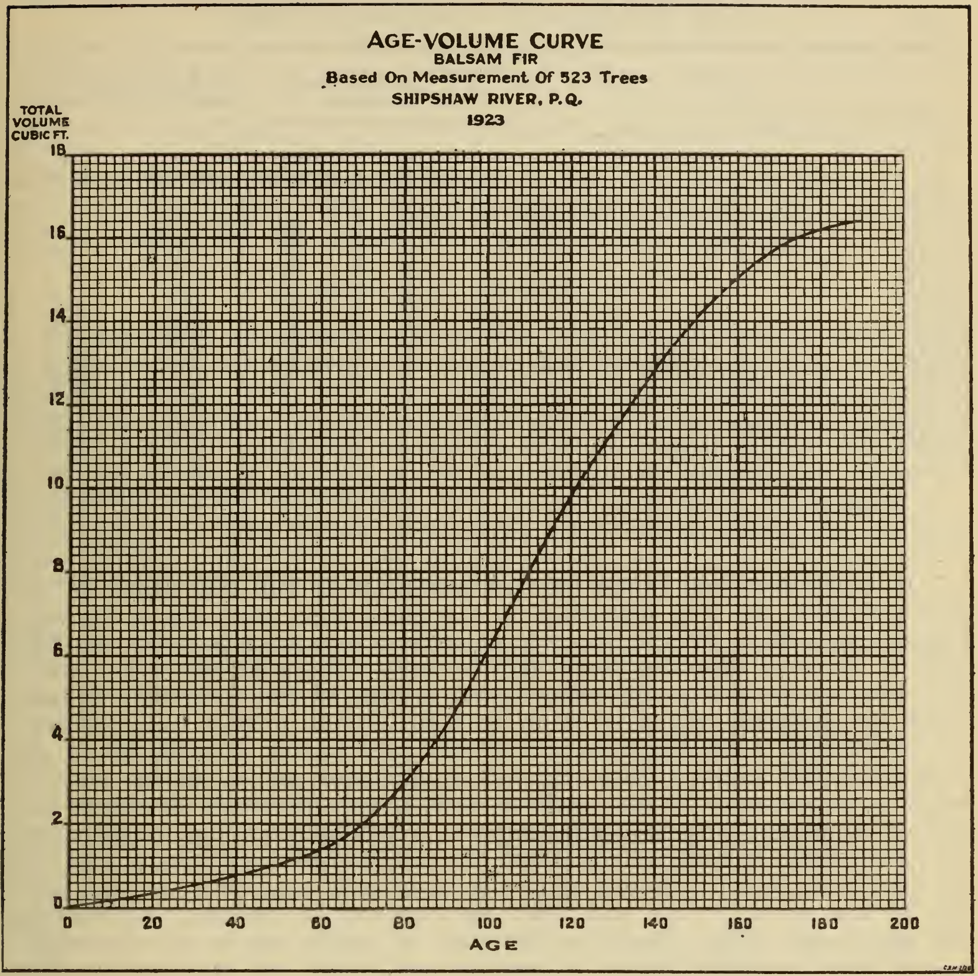
A total of 1,157 trees was analyzed, 523 at lac Epinette and 634 at lake Metis.

## INTERPRETATION

Since the present paper is really a report on two separate and distinct, though similar studies, it will be necessary to treat the results separately. Commencing with the lac Epinette study the first step in working up the field data was to calculate the total volume and the merchantable volume of each tree inside the bark. To secure these figures the paraboloid formula was used for the logs, and the formulae for the volume of a cylinder and for the volume of a cone for the stump and top above 3 inches respectively.

### RELATION OF DECAY TO RATE OF GROWTH

Having obtained the total, merchantable, and cull volume for each tree, the trees were then divided into age classes. In this study the youngest tree cut was thirty-seven years old and the oldest 190 years. The upper age classes were weakly represented, however, and in order to bring out the influence of age upon volume and cull most clearly, ten-year age classes were used. For each age class the average total tree volume and the average age were secured in order to construct a normal volume curve for the stand. When these points were plotted they exhibited such irregularity that a satisfactory curve could not be made with them as a basis. Instead of using age classes the total volume and age of each tree was then plotted. In this way the position of the desired curve was indicated, corrected, and finally drawn. The object in constructing this age-volume curve was to enable a comparison to be made of the actual total volumes of individual trees with the total volume of a tree of the same age as read off from the curve, and to substitute the relation thus obtained for the usual one of height growth in classifying the trees as to dominance and suppression.




Using this curve (fig. I) the trees were divided into two classes—those having volumes greater and those having volumes less than the average for the same age. These two classes may be referred to as dominant and suppressed. In cases in which the actual volume of a tree coincided with the value as read from the curve it was usually not difficult to decide into which class to put it after consulting the field notes taken upon that tree. From opinions and actual work of other investigators it was to be expected that rate of growth would have an influence upon the amount of cull, i.e. that in trees which had grown slowly there would be more cull than in trees which had grown quickly. Actually, however, the reverse was found to be the case as is shown in table I.

TABLE I.—AMOUNT OF CULL OCCURRING IN FAST GROWING TREES COMPARED WITH THAT FOUND IN SLOW GROWING TREES

| Age class | Number of trees (basis) | | Percentage of cull (based on total volume) | |
|---|---|---|---|---|
| | Fast growing | Slow growing | Fast growing | Slow growing |
| 41– 50 | 7 | 7 | 0 | 0 |
| 51– 60 | 15 | 46 | 0 | 0 |
| 61– 70 | 19 | 35 | 3·9 | 2·3 |
| 71– 80 | 14 | 21 | 5·6 | 14·1 |
| 81– 90 | 21 | 37 | 13·6 | 7·5 |
| 91–100 | 49 | 50 | 18·1 | 11·5 |
| 101–110 | 36 | 41 | 14·8 | 10·5 |
| 111–120 | 22 | 24 | 21·6 | 15·8 |
| 121–130 | 8 | 20 | 30·8 | 19·4 |
| 131–140 | 8 | 8 | 46·1 | 22·3 |
| 141–150 | 2 | 10 | 50·2 | 36·5 |
| 151–160 | 4 | 7 | 11·1 | 26·8 |
| 161–170 | 1 | 3 | 45·9 | 24·0 |
| 171–180 | 2 | 3 | 50·5 | 39·9 |
| 181–190 | 2 | 0 | 28·5 | 0·0 |
| Total | 210 | 312 | 20·9 | 16·5 |

In every age class except one the percentage of cull was higher in the dominant trees, the total percentage in this group being 20·9 and in the suppressed group 16·5. If it is true that suppression is favourable to the development of decay in trees this result may be accounted for in one of two ways. Meinecke has found that differences in the amount of cull occur only in trees which are decidedly above or below normal. In the present case, however, no intermediate class was adopted, all the trees having volumes above the values indicated in fig. I being regarded as dominant, and all having volumes below as suppressed. It may well be that, if only decidedly dominant and severely suppressed trees had been compared, a greater percentage of cull would have been found to occur in the latter. As an alternative solution, a study of fig. I indicates that the present stand has been badly suppressed, at least during the first seventy years, and while the trees can be classified as dominant and suppressed within themselves they are in reality nearly all suppressed. It was only occasionally that a tree was cut which had made consistently good growth throughout its life.

TABLE II.—COMPARISON OF DIAMETER GROWTH IN NEW YORK AND QUEBEC BASED ON AGE.

| New York | | Metis Lake | | Quebec Shipshaw River | |
|---|---|---|---|---|---|
| Age | Diameter | Age | Diameter | Age | Diameter |
| 55 | 6·0 | 55 | 5·6 | 56 | 4·0 |
| 65 | 7·0 | 64 | 5·3 | 64 | 4·4 |
| 75 | 7·8 | 77 | 5·7 | 75 | 5·0 |
| 85 | 8·5 | 87 | 6·7 | 86 | 6·8 |
| 95 | 9·2 | 96 | 7·3 | 96 | 7·6 |
| 105 | 9·8 | 105 | 7·9 | 106 | 8·1 |
| 115 | 10·4 | 115 | 8·89 | 116 | 9·1 |
| 125 | 11·0 | 124 | 8·86 | 124 | 8·7 |
| 135 | 11·6 | 136 | 9·3 | 135 | 10·5 |
| 145 | 12·2 | 145 | 9·5 | 144 | 9·7 |

In table II a comparison is made between the diameter growth of balsam fir in New York State and in Quebec. The figures for the former are taken from Zon (25), and for the latter are those secured from the trees cut during the present investigation. In both cases the types are similar. The diameters shown for the trees used in these studies are secured by taking the average diameter at breast height of the trees included in each age class, and the age corresponding to these diameters in the average age of each class. It will be noted that the growth is decidedly better in New York than in either of the two localities in Quebec. The figures in this table tend to support the view that the trees in the two Quebec areas are as a class suppressed.

### RELATION OF DECAY TO AGE

As expected a very definite relation was found to exist between decay and age. This is but natural when it is recalled that the particular types of decay met with invariably have their origin in heartwood which is not present in very young trees. Consequently, these are immune for a time at least, but from the period of heartwood formation onward the trees are subject to ever increasing risk as the number of possible points of infection becomes greater. Once a tree becomes infected the resulting decay spreads until, under favourable conditions and given time enough, most of the heartwood is destroyed. In old trees, therefore, it is evident that the probabilities are strong that there will be much more decay and, as a result, more cull than in young trees.

TABLE III.—NUMBER OF INFECTED TREES ARRANGED BY AGE CLASSES. (F.R.—FEATHER ROT, R.R.—RED ROT, AND S.R.—SECONDARY ROT).

| Age class | Number of trees (basis) | F.R. | R.R. | S.R. | F.R. and R.R. | F.R. and S.R. | Per cent cull cases | Per cent of infected trees |
|---|---|---|---|---|---|---|---|---|
| 41- 50 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51- 60 | 61 | 0 | 2 | 1 | 0 | 0 | 0 | 5 |
| 61- 70 | 54 | 2 | 3 | 0 | 0 | 0 | 7 | 9 |
| 71- 80 | 35 | 11 | 2 | 0 | 0 | 0 | 23 | 37 |
| 81- 90 | 59 | 6 | 10 | 0 | 5 | 1 | 19 | 37 |
| 91-100 | 99 | 27 | 18 | 1 | 12 | 0 | 40 | 59 |
| 101-110 | 77 | 23 | 19 | 0 | 11 | 0 | 47 | 69 |
| 111-120 | 46 | 14 | 8 | 0 | 11 | 0 | 63 | 71 |
| 121-130 | 28 | 7 | 10 | 0 | 4 | 0 | 57 | 75 |
| 131-140 | 16 | 4 | 4 | 0 | 7 | 0 | 75 | 94 |
| 141-150 | 12 | 2 | 3 | 0 | 7 | 0 | 83 | 100 |
| 151-160 | 11 | 4 | 0 | 0 | 6 | 0 | 64 | 91 |
| 161-170 | 4 | 0 | 0 | 0 | 3 | 0 | 75 | 75 |
| 171-180 | 5 | 3 | 0 | 0 | 2 | 0 | 100 | 100 |
| 181-190 | 2 | 0 | 0 | 0 | 1 | 0 | 50 | 50 |

In table III the percentage of infected trees—those showing incipient decay—and of cull cases—those in which decay has progressed far enough to cause a certain amount of loss—arranged by age classes is presented. This table illustrates very clearly how with increasing age the trees are subject to increasing infection and decay. In the upper age classes the results are not reliable owing to the low numerical representation, but there is a very definite trend to the figures, and it is apparent that the percentage of infected trees increases fairly regularly up to the age class 141-150, while the percentage of cull cases mounts up in the same way to the same age class, but is always lower than the former. This is so because every infection is not a cause of loss. It is only when the resulting decay becomes serious enough to cause a part of the tree to be discarded that an infection becomes a cull case.

TABLE IV.—RELATION BETWEEN AGE CLASSES AND AMOUNT OF CULL BASED ON MERCHANTABLE VOLUME.

| Age class | Percentage of cull. (curved) | Age class | Percentage of cull. (curved) |
|---|---|---|---|
| 41– 50 | 0 | 121–130 | 29 |
| 51– 60 | 0 | 131–140 | 31 |
| 61– 70 | 6 | 141–150 | 34 |
| 71– 80 | 10 | 151–160 | 36 |
| 81– 90 | 14 | 161–170 | 38 |
| 91–100 | 18 | 171–180 | 40 |
| 101–110 | 22 | 181–190 | 41 |
| 111–120 | 25 | ........ | ........ |

However, it is neither the mere number of infected trees nor the actual amount of decay which is of special interest, but it is the amount of cull or loss caused by decay. For each age class the percentage of cull based on merchantable volume was secured and from these figures a graph was then constructed. In table IV the values for each age class as indicated by the curve are given. Owing to the lack of sufficient numbers of trees in the upper age classes the results beyond the 121 to 130 year class are not very reliable. The most striking features of the table is the steady increase from age class to age class of the amount of cull. From zero in the 51 to 60 year class it reaches 18 per cent in the 91 to 100 year class.

### RELATION OF DECAY TO DIAMETER

The relation between decay and diameter at breast height which might be of more immediate practical use than the relation between decay and age was studied. The trees were divided into one inch diameter classes and the amount of cull calculated for each class. On account of the fact that diameter growth is largely a function of age, a similar relation to that existing between decay and age was found. The results are presented in table V.

TABLE V.—RELATION BETWEEN DIAMETER AND CULL COMBINED WITH RELATED DATA.

| Diameter class | Number of trees (basis) | Average diameter (B.H.) inches | Average height feet | Average vol. (merchantable) cubic feet | Percentage of cull based on merchantable volume (curved) |
|---|---|---|---|---|---|
| 2 | 3 | 2·4 | 19·8 | 0·17 | 0 |
| 3 | 25 | 3·2 | 24·6 | 0·23 | 0 |
| 4 | 110 | 4·1 | 31·0 | 0·68 | 3 |
| 5 | 60 | 5·0 | 39·2 | 1·37 | 8 |
| 6 | 61 | 6·0 | 45·7 | 2·43 | 12 |
| 7 | 50 | 7·1 | 53·4 | 3·96 | 16 |
| 8 | 65 | 8·1 | 56·4 | 5·75 | 19 |
| 9 | 50 | 9·0 | 60·0 | 7·44 | 22 |
| 10 | 34 | 10·1 | 62·4 | 9·49 | 25 |
| 11 | 29 | 11·0 | 65·4 | 11·65 | 28 |
| 12 | 20 | 12·0 | 67·2 | 13·80 | 31 |
| 13 | 7 | 13·0 | 65·5 | 15·91 | 34 |
| 14 | 5 | 13·8 | 74·5 | 20·03 | 37 |
| 15 | 2 | 14·9 | 70·8 | 23·65 | ........ |
| 16 | 2 | 16·0 | 81·2 | 25·06 | ........ |

## FIELD NOTES (Lake Metis)

Although such operations as have already been carried on at lake Metis have been for saw timber, it was assumed that, when the forests of the Seigneurie are placed under management, it will be for the purpose of pulpwood production, and the deductions for cull have been made on this basis. The methods adopted in this study were much the same as those used in the previous work and similar notes were taken for each tree. In all there were 12 quarter-acre plots cut over and, in addition, a number of trees in the younger age classes were taken from outside the plots.

### RELATION OF DECAY TO RATE OF GROWTH

In computing the volume of trees used in this study the Smalian formula was used, but in all other respects procedure was similar. The trees were divided into ten-year age classes and for each age class the average total tree volume and the average age were secured. After plotting these an age-volume curve for the stand was drawn. Using this graph the trees were then divided into two classes as previously, and the percentages of cull, arranged by ten-year classes, occurring in each of these two groups was calculated. The results appear in table VI. Also in this table are shown the percentages of the total number of trees in each of the two groups in which there is actual loss by decay, as it was thought that such figures might help to explain the irregularities in the precentages of cull.

TABLE VI.—AMOUNT OF CULL OCCURRING IN FAST GROWING TREES COMPARED WITH THAT FOUND IN SLOW GROWING TREES.

| Age class | Number of trees | | Percentage of cull (based on total volume) | | Percentage of cull cases | |
|---|---|---|---|---|---|---|
| | Fast growing | Slow growing | Fast growing | Slow growing | Fast growing | Slow growing |
| 31- 40 | 2 | 4 | 0 | 0 | 0 | 0 |
| 41- 50 | 11 | 5 | 0 | 0 | 0 | 0 |
| 51- 60 | 8 | 10 | 0 | 0 | 0 | 0 |
| 61- 70 | 8 | 12 | 0 | 0 | 0 | 0 |
| 71- 80 | 4 | 12 | 3·5 | 0 | 25 | 0 |
| 81- 90 | 28 | 37 | 0·3 | 2·2 | 4 | 5 |
| 91-100 | 64 | 85 | 9·5 | 4·4 | 20 | 14 |
| 101-110 | 47 | 67 | 9·1 | 8·8 | 34 | 27 |
| 111-120 | 40 | 50 | 7·2 | 16·3 | 47 | 30 |
| 121-130 | 10 | 26 | 4·7 | 6·8 | 33 | 22 |
| 131-140 | 8 | 13 | 7·7 | 6·4 | 33 | 42 |
| 141-150 | 7 | 7 | 8·2 | 1·5 | 17 | 25 |
| 151-160 | 11 | 14 | 12·2 | 32·0 | 77 | 62 |
| 161-170 | 11 | 10 | 22·5 | 23·2 | 64 | 80 |
| 171-180 | 6 | 6 | 32·9 | 25·8 | 67 | 83 |
| 181-190 | 5 | 3 | 53·2 | 27·6 | 83 | 100 |
| 191-200 | 0 | 1 | 0 | 89·9 | 0 | 100 |
| 201-210 | 0 | 2 | 0 | 82·7 | 0 | 100 |
| Total | 270 | 364 | 11·7 | 10·6 | | |

It is apparent from a study of this table that there is no definite trend in the percentage of decay, i.e. from age class to age class neither the fast growing group nor the slow growing group predominates consistently in the amount of cull. The trees were then arranged in 50-year age classes, so that any minor irregularities due to the smallness of the ten-year age classes would be eliminated, but the results were similar. For the total number of trees cut it was found that in the fast growing group there was 11·7 per cent cull and in the slow growing group 10·6 per cent.

RELATION OF DECAY TO AGE

In table VII are presented the most important data obtained from this work. These show the percentage of cull based on merchantable volume for each of the ten-year age classes, and a study of these figures indicates the part, if any, which decay should play in fixing the rotation to be used in the management of these forests. The most significant feature of this table is that it is apparent that in this region balsam fir may be safely left to grow for 100 years without incurring any very serious loss from decay and, since it is not probable that a longer rotation than this will ever be used for this species, it is evident that decay will not have any influence in fixing the rotation.

TABLE VII.—RELATIONS BETWEEN AGE CLASSES AND AMOUNT OF CULL BASED ON MERCHANTABLE VOLUME.

| Age class | Percentage of cull (curved) | Age class | Percentage of cull (curved) |
|---|---|---|---|
| 31- 40 | 0 | 121–130 | 14 |
| 41- 50 | 0 | 131–140 | 16 |
| 51- 60 | 0 | 141–150 | 18 |
| 61- 70 | 0 | 151–160 | 21 |
| 71- 80 | 2 | 161–170 | 25 |
| 81- 90 | 3 | 171–180 | 30 |
| 91–100 | 6 | 181–190 | 54·0 |
| 101–110 | 10 | 191–200 | 100·0 |
| 111–120 | 12 | 201–210 | 89·1 |

It is interesting to compare this table with the corresponding one derived from the lac Epinette study. In the latter it will be noted that the cull percentages are much higher throughout. This is due to the fact that, for some unknown reason, the fungus causing red rot, which is responsible for most of the cull, was far more abundant at lac Epinette than at lake Metis. In the former locality it was very common, fruiting in profusion upon practically every balsam fir stub and upon many fallen trees, but at lake Metis it was rarely observed. This discrepancy cannot be accounted for by differences in the type of stand, soil, conditions of growth, or climate, since these are all quite similar. Of the total number of trees cut at lac Epinette 15 per cent of the merchantable volume was classed as cull while at lake Metis the corresponding figure was 10·3 per cent.

RELATION OF DECAY TO DIAMETER

In table VIII the trees have been arranged so as to show the percentage of cull by one inch diameter classes. Since the stand here is much freer from decay than that at lac Epinette the percentages are considerably lower than the corresponding figures in the latter area.

TABLE VIII.—RELATION BETWEEN DIAMETER CLASSES AND AMOUNT OF CULL BASED ON MERCHANTABLE VOLUME.

| Diameter class | Percentage of cull (curved) | Diameter class | Percentage of cull (curved) |
|---|---|---|---|
| 4 | 3 | 11 | 23 |
| 5 | 5 | 12 | 26 |
| 6 | 8 | 13 | 29 |
| 7 | 11 | 14 | 21 |
| 8 | 14 | 15 | 12 |
| 9 | 17 | 16 | 2 |
| 10 | 20 | | |

ENTRANCE OF DECAY

In the course of the work at lac Epinette care was taken to determine as accurately as possible how the fungi causing the two principal types of decay met with, gained entrance to their hosts. The results are shown in tables IX and X.

TABLE IX.—METHODS OF ENTRANCE OF FEATHER ROT.

| Number of infections | Entrance of infection—percentage | | |
| --- | --- | --- | --- |
| | Roots | Wounds | Blazes |
| 181 | 95 | 4 | 1 |

In the case of feather rot it will be seen that practically the only means of entrance is by way of the roots from which point the decay progresses upward into the lower part of the trunk. Balsam fir is a shallow-rooted species and the roots are often exposed for some distance about the base of the tree. They are thus subject to injury and undoubtedly feather rot in some cases enters the tree in this way. Wounds on the lower part of the stem just above ground level account for a small percentage of infections by this decay. The principal point of entrance, however, is the tap root. Zon (25) states that " taproots, if developed at all, soon die and rot away, especially in soils lacking in abundance of moisture, and often become points of entrance for destructive ground rot." It is an extremely difficult matter to examine the root system of large trees; but, in the few cases in which this was done, the decay seemed to have originated in the tap root, spread upward into the base of the stem, from here outward into the lateral roots, and on up into the stem above ground. In any event, feather rot enters principally by way of the root system and spreads upwards into the trunk of the tree.

TABLE X.—METHODS OF ENTRANCE OF RED ROT.

| Number of infections | Entrance of infections—percentage | | |
| --- | --- | --- | --- |
| | Branch stubs | Dead tops | Miscellaneous |
| 157 | 90 | 8 | 2 |

As in the case of feather rot so with red rot there was found to be but one important means of entrance. In this instance it was by way of branch stubs. In a close stand the side branches in the lower part of the crown are soon killed due to lack of light, but they persist for a long time. Ultimately, however, they are broken off and it is by means of these broken branches that the fungus causing red rot gains entrance to its host. From table X it will be seen that 90 per cent of the infections occur in this manner, 8 per cent come in by way of dead tops, and 2 per cent are classed as miscellaneous.

RELATION OF DECAY TO THE BUDWORM

It was realized from the beginning that such studies as the present one would be somewhat complicated on account of the fact that the budworm outbreak had recently affected most of the forest areas of Eastern Canada. Excepting Nova Scotia and the Gaspé peninsula in Quebec there is probably no considerable tract of balsam fir and spruce in the East which has escaped the ravages of this insect. In order to avoid to as great an extent as possible this disturbing factor, the districts chosen to work in were localities in which mortality percentages following budworm injury was comparatively low; on the Shipshaw river from 15 to 20 per cent of the balsam fir was killed and in the Métis Seigneurie about 10 per cent.

When the budworm epidemic occurred it was the slower growing, suppressed trees, which were killed outright, directly due to the effects of defoliation; the faster growing, dominant trees, while likewise injured, were better able to withstand the damage. During a period of from five to ten years following defoliation all trees made very slow growth, and those which before the injury occurred were suppressed generally failed to recover, gradually dying off during the next ten years. The dominant trees for the most part recovered after the period of suppression and, due to the thinning out of the stand, grew more rapidly than they had done previous to the outbreak.

Briefly, this was the effect which the budworm had upon the forests under consideration. First, there was a general retardation of the growth of all injured trees, followed by a weeding out of the less resistant individuals and a consequent stimulation of the remaining members of the stand; more or less pronounced according to the mortality percentage. Thus, it would seem that the effect of thinning out and the correspondingly increased growth would tend to reduce the seriousness of budworm attack, to that degree at least. However, in attempting to judge the possible influence of these effects upon the present studies, care must be taken not to overestimate them. Scarcely sufficient time—ten to thirteen years—had elapsed between the inception of the outbreak and the analyses of the trees for the purposes of this work to permit of any marked change in growth conditions. Moreover, trees killed by the budworm are not uniformly distributed throughout the stand and usually care was taken to select plots as free from budworm injury as possible. On the other hand, two plots were laid out where killed trees were most numerous. It is interesting to note that in these plots the trees were exceptionally free from decay; the conclusion may be drawn that the trees which succumbed were the least vigorous and sound.

Since there seems to be a general impression that the present condition of balsam fir in regard to decay, especially to red rot, is due in large measure to the recent budworm outbreak it is worth while to consider briefly if such is the case and, if so, just how it has arisen. It has been stated that red rot is more prevalent in stands which have been subjected to the attack of the budworm; but, at best, this statement can only be regarded as speculative, since no studies of decay, made both before and after the epidemic, have been carried out, nor have comparative studies in damaged and undamaged stands been made.

It has also been stated that tops which have been killed by the budworm are a common means of entrance for the fungus causing red rot. Reference to table X indicates that this idea is not founded on fact, as, even if it is assumed that all dead tops are due to the work of this insect, it will be seen that only 8 per cent of the infections originated in killed leaders. Moreover, this percentage gives an exaggerated idea of the importance of this type of injury as a means of entrance since, in most cases, the resulting decay does not extend down to the merchantable portion of the stem, and when it does it causes but a small amount of cull, as it is then working in the upper and, consequently, smallest logs.

It has further been suggested that the budworm infestation has influenced the extent of decay in balsam fir by reducing the vitality and resistance of the trees which have been fed upon but which have recovered after a number of years. Since the heartwood of a tree is almost exclusively composed of dead elements any reduction in vitality which a tree might suffer would not affect the heartwood to any considerable extent, nor could it conceivably decrease the resistance of the heartwood to fungus infection. In any case, the susceptibility of a tree to the attacks of wood-destroying fungi is probably more a question of physics and chemistry of the wood than of vitality.

There is one indirect method by which the budworm outbreak might, and probably does, to a slight extent increase the chances of infection by red rot. This is by the greatly increased amount of dead material which is left as a result of the work of this insect. These killed trees, if not already infected by red rot—and other forms—soon become so, and thus act as centres of infection for the remaining trees in the stand. It is obvious that the more fruiting bodies, and consequently spores, a fungus produces the greater will be the chances for successful infection of neighbouring additional hosts. This, however, must be a slow process, since dead trees must first become infected, fruiting bodies must be produced, and the spores from these fruiting bodies must successfully infect new hosts and cause decay before any results are apparent.

On the Shipshaw river the budworm epidemic broke out about 1910 and in the Métis Seigneurie about 1913; in both cases the feeding lasted three or four years. During this time many trees were killed as a direct result of continued defoliation, and many more died from various other causes subsequent to the disappearance of the insect. It is apparent, then, that owing to the recent occurrence of the outbreak the great increase in debris in the forest cannot yet have influenced the amount of decay in living trees to any marked extent.

For these reasons it seems that the cause for the widespread occurrence of decay in balsam fir must be sought elsewhere than in the budworm epidemic. In fact, in plots laid out in areas where the damage from budworm attack seemed to be most extensive, some of the soundest balsam fir has been found, and, in the course of work extending over two seasons in forests which have been subjected to the attacks of this insect, no evidence has been met with which would make one regard the budworm as being more than a contributory cause in a small way to the condition of balsam fir in regard to decay. What probably has been an important factor in this connection is the fact that, until recently, balsam fir was not cut with the other more valuable species—especially spruce—and, in this way, the proportion of this species became much greater than in the original stand. The condition thus created could not be favourable to the spread of a fungus which is confined to balsam fir, as in many cases practically a pure stand of this species was left. In this connection it is interesting to note that Moore and Rogers (18) state that "the soundness of fir timber depends chiefly on the percentage of fir in the stand," and they go on to show that the greater the proportion of this species in the stand, the earlier decay occurs and the more loss it causes.

## DISCUSSION

From a perusal of the foregoing pages it is readily apparent that, from a pathological point of view, the most important factor to be considered in the treatment of these forests is the loss caused by the three decays which have been described, i.e. red rot, brown rot, and feather rot. While there are certain other forms of injury such as broken branches, dead tops, lightning scars, and frost cracks, yet these do not cause loss of pulpwood but are of importance as being the points of entrance of the fungi which cause these decays. The present stands in the areas studied, having never been subjected to fire, wounds due to this cause did not need to be considered. It is probably true, however, that, in stands which have been injured by fire, a considerable percentage of butt rot infections would enter the trees in this way.

As for the control of these decays one is quite safe in stating that neither at present nor for a very long period of time to come need anything in the nature of direct control measure be considered, since economic conditions are such that expenditures for this purpose would be prohibitive. Slash burning has been advocated as a method of control for red rot and, if we define control measure as " any means by which the incidence of a fungous disease is reduced to any extent whatever," it may be admitted that slash burning would be a method of control, since it would remove some of the material upon which this fungus grows. In this way the number of fruiting bodies would be reduced and, consequently, there would be less chance of sound trees becoming infected. It is very doubtful, however, if the results anticipated by those who hold such views would be realized if slash were burned or otherwise disposed of. For instance, Meinecke (16) states that " even in the best managed forests of Germany losses from decay are heavy," and quotes a forest authority to the effect that in the pine forests of the Prussian Government the annual loss caused by *Trametes Pini* alone is about $250,000. These forests have been under management for about 150 years; slash and other debris is disposed of down to the last twig, and from time to time improvement cuttings are made which remove suppressed and unthrifty trees that would otherwise have died and decayed. Yet there are still serious losses from wood-destroying fungi. How then can it be thought that, here in our practically virgin and unmanaged stands, slash disposal is going to reduce the loss from this source to any appreciable extent? However, it is hardly necessary to concern ourselves over this question, since there is no prospect that slash disposal for the control of decay in living trees is going to be adopted. The principal argument against slash disposal as a means of reducing the fire hazard is that based on the cost of the operation, but it may safely be assumed that, in time, this objection will be overcome and slash disposal will become an integral part of logging operations. When this is accomplished we shall then be in a position to judge as to whether or not any material reduction in decay occurs as a result. My personal opinion is that improvement cuttings which would remove dead and dying trees would do much more to prevent decay than the burning of logging slash.

The one certain method of avoiding such loss from decay, as is found in the present stand, is by taking into consideration in fixing the rotation, the percentages of loss which occur in the several age classes. Since the rotation to be used in the management of these limits will probably be based on maximum volume production, such figures would be especially valuable. If, for instance, it could be demonstrated that at the age of 100 years a stand would show a loss of 20 per cent of its merchantable volume, the forester in charge would then be in a position, having regard to the economic and silvicultural factors involved, to decide whether or not it would be profitable to allow the stand to grow until that age.

Working with balsam fir in Maine, Moore and Rogers (18) conclude that " in pure stands fir is subject to rot at the butt after the age of fifty years is reached, particularly in moist situations." The writers conclude, however, that such a stand may safely be left until approximately seventy years of age, when a diameter of 12 to 14 inches will have been attained. If diameter at breast height is meant, or even diameter at the stump, this would certainly be remarkable growth. Even at that age 27 per cent of the total volume is designated as unsound, though it is not clear if this percentage is to be regarded absolutely as cull or not. The authors further state that " in mixture with hardwoods the percentage of rot is smaller and the trees are usually sound up to an average age of 85 years." No particular decay is specified, the loss being spoken of as due to butt rot; nor are the methods described by which the ages mentioned are secured.

In regard to rotation Zon states that this should be fixed at 100 to 125 years, at which time a diameter of about 12 to 14 inches at breast height should be attained, but he also writes that " balsam fir at the age of 80 to 100 years is already old, and especially susceptible to rot of any kind." He mentions two species of fungi as the cause of decay—*Trametes Pini* causing heart rot and *Polyporus Schweinitzii* causing butt rot. In Quebec neither of these forms seem to be of economic importance. His figures for rotation are apparently based on growth and yield data.

While the percentages of cull derived from these studies for the different age classes may be accepted as approximately correct for the present stands under the conditions of utilization obtaining at present, and for any other similar stands grown under like conditions, yet, because of the fact that the trees have not made as rapid growth as is possible, it is doubtful if the cull figures can be used without modification as an aid in calculating rotation. This is because one of the fundamentals of forest management is that the crop must be so handled that the maximum volume of timber will be produced in the minimum space of time. If this is admitted, then at once suppressed and unhealthy individuals are eliminated from the final crop of the future. Perhaps, however, one errs on the side of optimism in taking such a view, since it is doubtful if improvement, according to European standards, can be expected over large areas of unsettled country under present economic conditions. One may reasonably expect, though, that, in the type of stand being considered, the birch will be utilized or thinned since it is of less value than the balsam fir—in fact, largely on account of present difficulties of transportation, it must be regarded as more of a liability than an asset—and the future crop in this way given an opportunity to grow as it should. Until this is done it is difficult to conceive of any silvicultural system which would give satisfactory results.

If, then, it is assumed that the future crop of balsam fir will be released from suppression by birch, it follows that it will attain merchantable size more rapidly and so can be cut at any earlier age. From tables IV and VII it is evident that the shorter the rotation used the less cull there will be, though it is to be borne in mind that a pure stand of balsam fir will be more subject to decay than a mixed stand.

## SUMMARY

Three decays of importance—one heart rot and two butt rots—were found to occur in balsam fir in Quebec. The former called red rot is caused by *Stereum sanguinolentum* and the latter known as feather rot and brown rot are due to *Poria subacida* (probably) and *Polyporus balsameus* respectively.

In the case of red rot entrance to the heartwood is gained principally by way of branch stubs; while the butt rots enter their hosts chiefly through the roots.

No relation was found to exist between the recent budworm outbreak and the widespread occurrence of decay in balsam fir.

From a study of the statistical data presented herewith it will be possible to determine what cull factor should be used in making allowance for decay in the areas in question. Cull percentages are given both for age and diameter classes. In this connection it should be pointed out that, on account of the fact that the sample plots used in this work were clear cut, the results will naturally be somewhat higher than is the case in actual practice. This is so because, under the present system of logging by jobbers, a certain amount of selection is practiced. Obviously unsound trees are either not cut or are left in the woods, and in general the tendency is to take out only the best timber.

A direct relation was found to exist between age and decay. As an aid in determining the proper rotation to be used in these areas the values indicated in tables IV and VII may be used if no radical change in the composition of the stand is to take place, and if present methods of cutting are continued. Should the balsam fir, however, be released from suppression by the birch it will be possible to reduce the length of rotation considerably.

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Plate I.

Fig. 1.—Illustrating the dense reproduction of balsam fir which occurs on every opening in the stand. This photograph was taken in a small opening resulting from damage by the budworm.

Fig. 2.—The same. Photograph taken on the edge of a clearing made by cutting.

Plate I

Plate II.

Fig. 1.—Red heart rot of balsam fir. The type of decay shown by this specimen—a solid body of decay with a suggestion of radial extensions of this out into the sound wood—is fairly common. At the left is a branch stub—the usual means by which the causal fungus enters the tree.

Fig. 2.—The same. The extreme radiate type of decay occurring in this specimen is not common. (Photograph courtesy Dr. J. H. Faull).

Plate II

1

2

PLATE III.

Fig. 1.—Red heart rot of balsam fir. The occurrence of the decay as a solid, round mass, as in this specimen, is most frequent. (Photograph courtesy Mr. J. B. MacCurry).

Fig. 2.—The same. Longitudinal section showing white sheets of mycelium.

Plate III

1

2

## Plate IV.

Fig. 1.—*Stereum sanguinolentum* on a fallen balsam fir. This fungus causes red heart rot of balsam fir.

Fig. 2.—*Poria subacida*—the fungus which is found in connection with feather rot. As it always occurs on the lower sides of logs it could not be photographed *in situ,* so a short length of the log on which it was found was placed upright and the fungus then photographed.

Fig. 3.—*Poria subacida*—a closer view of the fruiting body shown in Fig. 2.

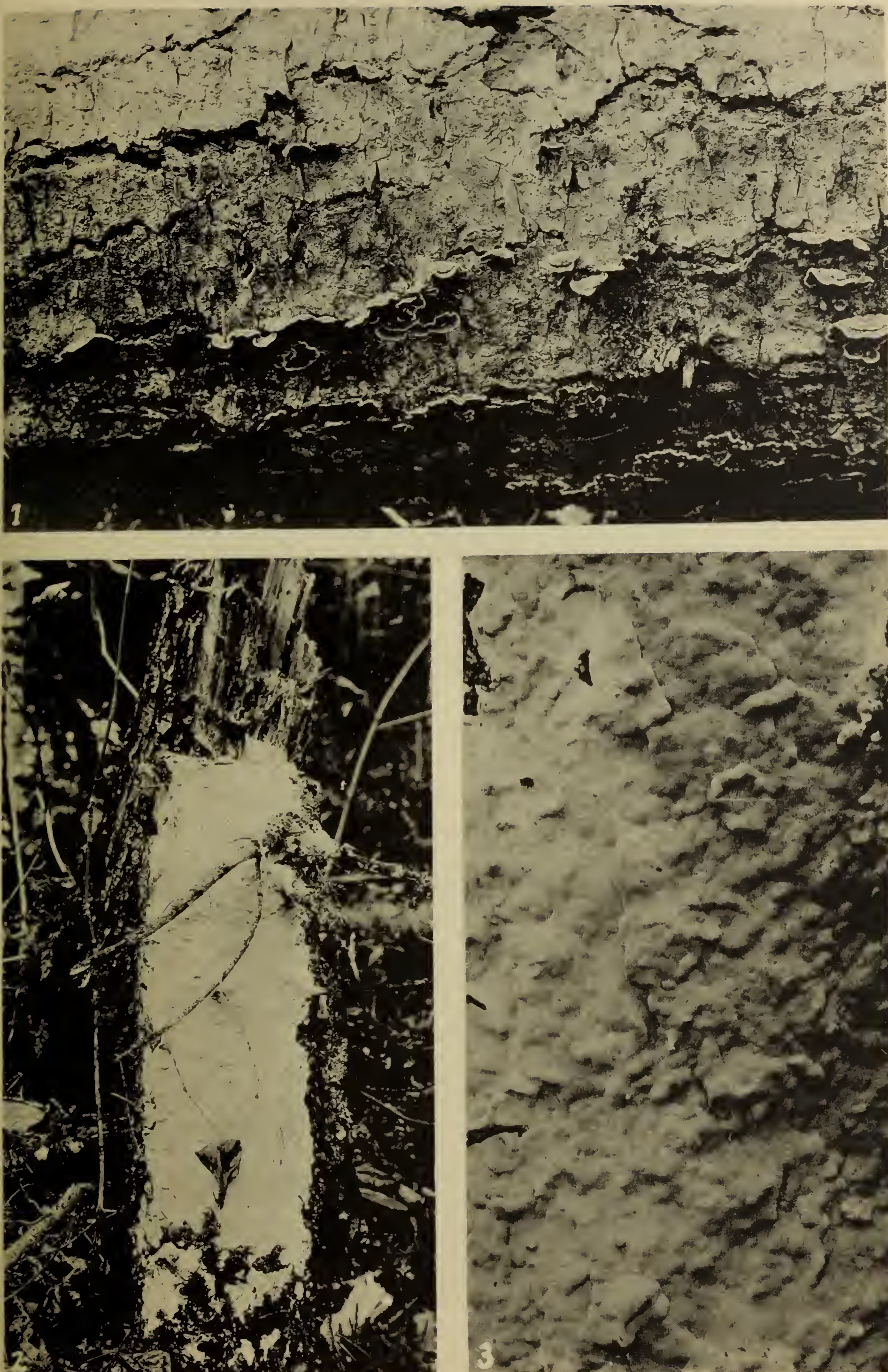
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PLATE V.

Fig. 1.—Feather rot of balsam fir—early stage.

Fig. 2.—The same—advanced state of decay. In extreme decay affected trees become hollow. (Photograph courtesy Mr. J. B. MacCurry).

Plate V

1

2

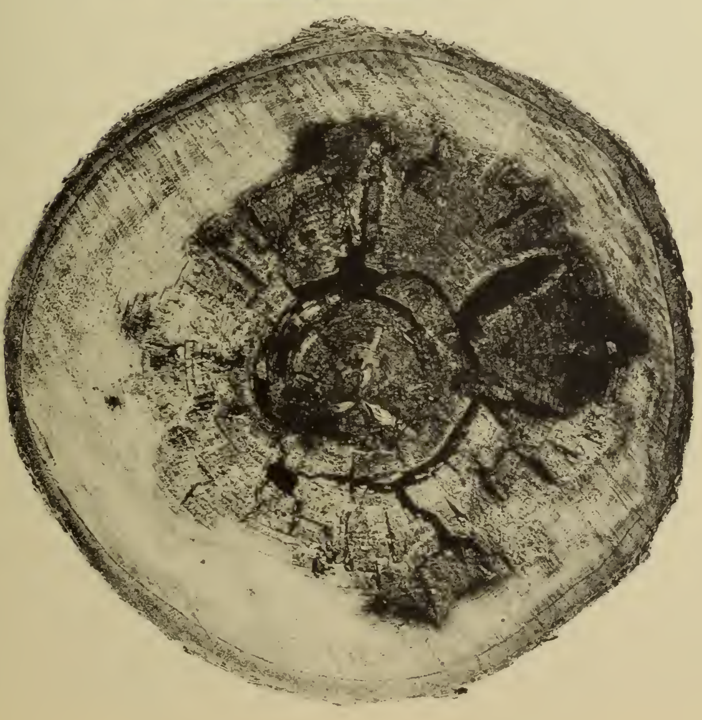
## Plate VI.

Fig. 1.—Brown butt rot of balsam fir—early stage.

Fig. 2.—The same—more advanced state of decay. The wood breaks up into cubical blocks which can be picked out of the rotten trunk.

Plate VI

1



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## Plate VII.

Fig. 1.—Windfall in balsam fir weakened by brown butt rot. About 7 per cent of the stand is affected in this way.

Fig. 2.—*Polyporus balsameus*—the causal organism of brown butt rot—fruiting at the base of a living balsam fir.

Fig. 3.—The same—growing on the stump of a balsam fir which has been broken off by wind.

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